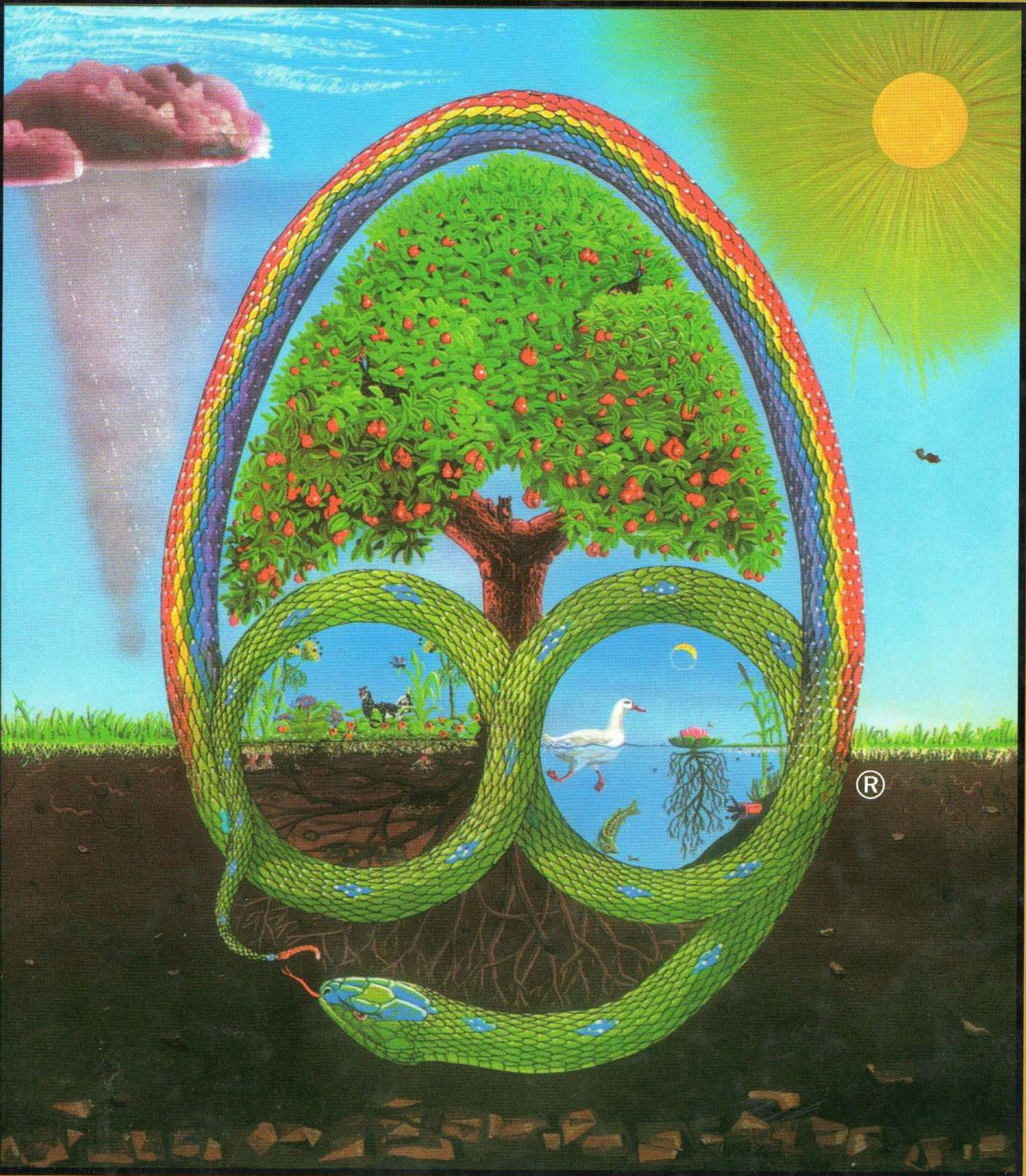
PERMACULTURE
A Designers' Manual

BILL MOLLISON



TAGARI

PERMACULTURE

A Designers' Manual

This book is about designing sustainable human settlements, and preserving and extending natural systems. It covers aspects of designing and maintaining a cultivated ecology in any climate: the principles of design; design methods; understanding patterns in nature; climatic factors; water; soils; earthworks; techniques and strategies in the different climatic types; aquaculture; and the social, legal, and economic design of human settlement.

It calls into question not only the current methods of agriculture but also the very need for a formal food agriculture if wastelands and the excessive lawn culture within towns and cities are devoted to food production and small livestock suited to local needs.

The world can no longer sustain the damage caused by modern agriculture, monocultural forestry, and thoughtless settlement design, and in the near future we will see the end of wasted energy, or the end of civilization as we know it, due to human-caused pollution and climate changes.

Strategies for the necessary changes in social investment policy, politics itself, and towards regional or village self-reliance are now desperately needed, and examples of these strategies are given. It is hoped that this manual will open the global debate that must never end, and so give a guide to the form of a future in which our children have at least a chance of a reasonable existence.

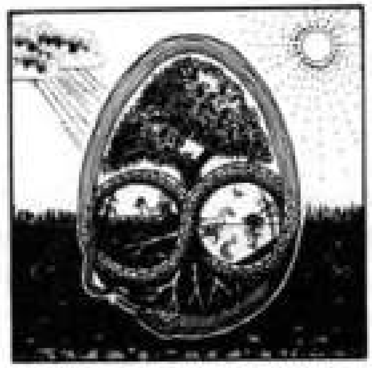
Born in 1928 in the small fishing village of Stanley, Tasmania, Bill Mollison left school at the age of 15 to help run the family bakery. He soon went to sea as a shark fisherman and seaman bringing vessels from post-war disposals to southern ports, and until 1954 filled a variety of jobs as a forester, mill-worker, trapper, snarer, tractor-driver, and naturalist.

Bill joined the CSIRO (Wildlife Survey Section) in 1954 and for the next nine years worked in many remote locations in Australia as a biologist, doing field work on rabbits, locusts, muttonbirds, and forest regeneration problems with marsupials. In 1963 he spent a year at the Tasmania Museum in curatorial duties, then returned to field work with the Inland Fisheries Commission surveying the macrofauna of inland waters and estuaries, recording food chains and water conditions in all the rivers and lagoons of Tasmania.

Returning to studies in 1966, he lived on his wits running cattle, bouncing at dances, shark fishing, and teaching part-time at an exclusive girls' school. Upon receiving his degree in bio-geography, he was appointed to the University of Tasmania where he later developed the unit of Environmental Psychology. During his university period (which lasted for 10 years), Bill independently researched and published a three-volume treatise on the history and genealogies of the descendants of the Tasmanian aborigines. In 1974, he and David Holmgren developed and refined the permaculture concept, leading to the publication of *Permaculture One* and *Permaculture Two*.

Since leaving the Unversity in 1978, Bill has devoted all his energies to furthering the system of permaculture and spreading the idea and principles worldwide. He has taught thousands of students, and has contributed many articles, curricula, reports, and recommendations for farm projects, urban clusters, and local government bodies. In 1981, Bill Mollison received the Right Livelihood Award (sometimes called the "Alternative Nobel Prize") for his work in environmental design. In recent years, he has established a "Trust in Aid" fund to enable permaculture teachers to reach groups in need, particularly in the poorer parts of the world, with the aim of leaving a core of teachers locally to continue appropriate educational work.

Bill Mollison is the Executive Director of the Permaculture Institute, which was established in 1979 to teach the practical design of sustainable soil, water, plant, and legal and economic systems to students worldwide.



PERMACULTURE
A Designers' Manual

by Bill Mollison

illustrated by Andrew Jeeves

manuscript and editing,
Reny Mia Slay

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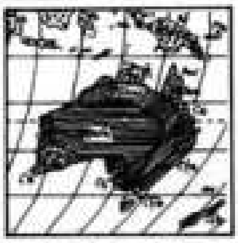

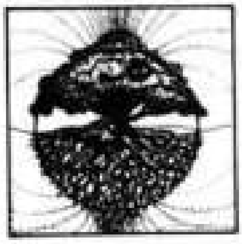

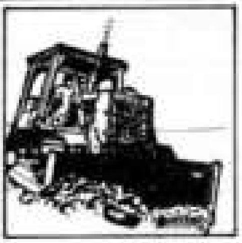

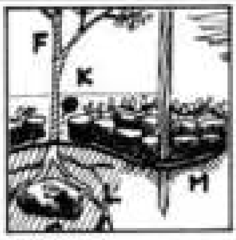
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PREFACE

To many of us who experienced the ferment of the late 1960's, there seemed to be no positive direction forward, although almost everybody could define those aspects of the global society that they rejected, and these include military adventurism, the bomb, ruthless land exploitation, the arrogance of polluters, and a general insensitivity to human and environmental needs.

From 1972-1974, I spent some time (latterly with David Holmgren) in developing an interdisciplinary earth science (permaculture) with a potential for positivistic, integrated, and global outreach. It was January 1981 before the concept of permaculture seemed to have matured sufficiently to be taught as an applied design system, when the first 26 students graduated from an intensive 140-hour lecture series. Today, we can count thousands of people who have attended permaculture design courses, workshops, lectures, and seminars. Graduates now form a loose global network, and are effectively acting in many countries. The permaculture movement has no central structure, but rather a strong sense of shared work. Everybody is free to act as an individual, to form a small group, or to work within any other organisation. We cooperate with many other groups with diverse beliefs and practices; our system includes good practices from many disciplines and systems, and offers them as an integrated whole.

Great changes are taking place. These are not as a result of any one group or teaching, but as a result of millions of people defining one or more ways in which they can conserve energy, aid local self-reliance, or provide for themselves. All of us would acknowledge our own work as modest; it is the totality of such modest work that is impressive. There is so much to do, and there will never be enough people to do it. We must all try to increase our skills, to model trials, and to pass on the results. If a job is not being done, we can form a small group and do it (when we criticise others, we usually point the finger at ourselves!) It doesn't matter if the work we do carries the "permaculture" label, just that we do it.

By 1984, it had become clear that many of the systems we had proposed a decade earlier did, in fact, constitute a sustainable earth care system. Almost all that we had proposed was tested and tried, and where the skills and capital existed, people could make a living from products derived from stable landscapes, although this is not a primary aim of permaculture, which seeks first to stabilise and care for land, then to serve household regional and local needs, and only thereafter to produce a surplus for sale or exchange.

In 1984, we held our first international permaculture conference, and awarded about 50 applied diplomas to those who had served two years of applied work since their design course. Those of us who belong to the permaculture family have cause to be proud, but not complacent. Work has scarcely begun, but we have a great team of people which increases in numbers daily. To empower the powerless and create "a million villages" to replace nation-states is the only safe future for the preservation of the biosphere. Let interdependence and personal responsibility be our aims.

AUTHOR'S NOTE

This volume was written for teachers, students, and designers; it follows on and greatly englarges on the initial introductory texts*Permaculture One* (1978) and *Permaculture Two* (1979), both of which are still in demand a decade after publication. Very little of the material in this book is reproduced from the foundation texts.

Each volume of this work carries a surcharge of 50¢ which will be paid by Tagari Publications to the Permaculture Institute. The Institute (a public trust) holds the funds so generated in trust for tree-planting, and from time to time releases monies to selected groups who are active in permanent reafforestation. In this way, both publisher and readers can have a clear conscience about the use of the paper in this volume, or in any book published by Tagari Publications. Our trust funds are open to receive any such levy from other ethical publishers.

PERMACULTURE DEFINED AND ITS USE

Permaculture is a word coined by the author. Its copyright is vested in the Permaculture Institutes and their College of Graduates, and is guarded by them for the purposes of consistent education.

Permaculture (**perma**nent agri**culture**) is the conscious design and maintenance of agriculturally productive ecosystems which have the diversity, stability, and resilience of natural ecosystems. It is the harmonious integration of landscape and people providing their food, energy, shelter, and other material and non-material needs in a sustainable way. Without permanent agriculture there is no possibility of a stable social order.

Permaculture design is a system of assembling conceptual, material, and strategic components in a pattern which functions to benefit life in all its forms.

The philosophy behind permaculture is one of working with, rather than against, nature; of protracted and thoughtful observation rather than protracted and thoughtless action; of looking at systems in all their functions, rather than asking only one yield of them; and of allowing systems to demonstrate their own evolutions.

The word "permaculture" can be used by anybody adhering to the ethics and principles expressed herein. The only restriction on use is that of teaching; only graduates of a Permaculture Institute can teach "permaculture", and they adhere to agreed-on curriculae developed by the College of Graduates of the Institutes of Permaculture.

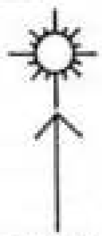
CONVENTIONS USED

References and Abbreviations: Minor references are given in the text, and those useful to chapter contents only are located at the close of those chapters. Key references are assembled at the close of the book, and are superscripted as numbers in the text.

Seasons and Directions: So that the text and figures are useful and readable in both hemispheres, I have used the words "sun-side" or "sunwards", and "shade-side" or "polewards" rather than south and north, and converted months to seasons as below:

Used Here		Northern Hemisphere	Southern Hemisphere
Summer	early	June	December
	mid	July	January
	late	August	February
Autumn	early	September	March
	mid	October	April
	late	November	May
Winter	early	December	June
	mid	January	July
	late	February	August
Spring	early	March	September
	mid	April	October
	late	May	November

These may be further refined by the use of "first week of...". For the same reason, the symbol below is used in figures to indicate the sun direction rather than the north or south symbol:



One hopes this prevents the problem of all those good North Americans wandering on the north face of their hills, looking for the sun, poised dangerously upside-down on the Earth as they are.

ACCESS TO INFORMATION

Material in this work can be fairly easily accessed in these ways: chapter and section contents are listed in the Table of Contents. Main subjects are listed in the Index. There is a list of the common and Latin names of plants used in the text located in the Appendix. Also located in the Appendix is a glossary of terms used; some few words are recently coined or (like "permaculture") are the conceit of the author.

To forestall needless correspondence, subscription to the *International Permaculture Journal* (113 Enmore Rd, Enmore, NSW 2042, Australia) gives information on permaculture themes, reviews recent publications, gives news of events, publishes a directory of permaculture centres, and has a host of other useful data. Further resources are also listed in the Appendix.

COVER STORY

The great oval of the design represents the egg of life; that quantity of life which cannot be created or destroyed, but from within which all things that live are expressed. Within the egg is coiled the rainbow snake, the Earth-shaper of Australian and American aboriginal peoples.

"We have a legend that explains the formation of the hills, the rivers, and all the shapes of the land. Everytime it rains and I see a beautiful rainbow I am reminded of the legend of the the Rainbow Serpent...

In the beginning the earth was flat, a vast grey plain. As the Rainbow Serpent wound his way across the land, the movement of his body heaped up the mountains and dug troughs for the rivers. With each thrust of his huge multi-coloured body a new land form was created.

At last, tired with the effort of shaping the earth, he crawled into a waterhole. The cool water washed over his vast body, cooling and soothing him... Each time the animals visited the waterhole, they were careful not to disturb the Rainbow Serpent, for although they could not see him they knew he was there. Then one day, after a huge rainstorm, they saw him. His huge coloured body was arching from the waterhole, over the tree tops, up through the clouds, across the plain to another waterhole.

To this day the Aborigines are careful not to disturb the Rainbow Serpent, as they see him, going across the sky from one waterhole to another."

(From Gulpilil's Stories of the Dreamtime, compiled by Hugh Rule and Stuart Goodman, published by William Collins, Sydney, 1979.)

Within the body of the Rainbow Serpent is contained the tree of life, which itself expresses the general pattern of life forms, as further elaborated in the chapter on pattern in this book. Its roots are in earth, and its crown in rain, sunlight and wind. Elemental forces and flows shown external to the oval represent the physical environment, the sun, and the matter of the universe; the materials from which life on earth is formed. The whole cycle and form is dedicated, as is this book, to the complexity of life on Earth.

Chapter 1

INTRODUCTION

1.1 PERMACULTURE DESIGN PHILOSOPHY

Although this book is about design, it is also about values and ethics, and above all about a sense of peronal responsibility for earth care. I have written at times in the first person, to indicate that it is not a detached, impersonal, or even unbiased document. Every book or publication has an author, and what that author chooses to write about is subjective, for that person alone determines the subject, content, and the values expressed or omitted. I am not detached from, but have been passionately involved with this earth, and so herein give a brief vision of what I think can be achieved by anyone.

The sad reality is that we are in danger of perishing from our own stupidity and lack of personal responsibility to life. If we become extinct because of factors beyond our control, then we can at least die with pride in ourselves, but to create a mess in which we perish by our own inaction makes nonsense of our claims to consciousness and morality.

There is too much contemporary evidence of ecological disaster which appals me, and it should frighten you, too. Our consumptive lifestyle has led us to the very brink of annihilation. We have expanded our right to live on the earth to an entitlement to conquer the earth, yet "conquerors" of nature always lose. To accumulate wealth, power, or land beyond one's needs in a limited world is to be truly immoral, be it as an individual, an institution, or a nation–state.

What we have done, we can undo. There is no longer time to waste nor any need to accumulate more evidence of disasters; the time for action is here. I deeply believe that people are the only critical resource needed by people. We ourselves, if we organise our talents, are sufficient to each other. What is more, we will either survive together, or none of us will survive. To fight between ourselves is as stupid and wasteful as it is to fight during times of natural disasters, when everyone's cooperation is vital.

A person of courage today is a person of peace. The courage we need is to refuse authority and to accept only personally responsible decisions. Like war, growth at any cost is an outmoded and discredited concept. It is *our* lives which are being laid to waste. What is worse, it is our children's world which is being destroyed. It is therefore our only possible decision to withhold all support for destructive systems, and to cease to invest our lives in our own annihilation.

<u>The Prime Directive of Permaculture.</u>
The only ethical decision is to take responsibility for our own existence and that of our children.
Make it now.

Most thinking people would agree that we have arrived at final and irrevocable decisions that will abolish or sustain life on this earth. We can either ignore the madness of uncontrolled industrial growth and defence spending that is in small bites, or large catastrophes, eroding life forms every day, or take the path to life and survival.

Information and humanity, science and understanding, are in transition. Long ago, we began by wondering mainly about what is most distant; astronomy and astrology were our ancient pre-occupations. We progressed, millenia by millenia, to enumerating the wonders of earth. First by naming things, then by categorising them, and more recently by deciding how they function and what work they do within and without themselves. This analysis has resulted in the development of different sciences, disciplines and technologies; a welter of names and the sundering of parts; a proliferation of specialists; and a consequent inability to foresee results or to design integrated systems.

The present great shift in emphasis is on how the parts interact, how they work together with each other, how dissonance or harmony in life systems or society is achieved. Life *is* cooperative rather than competitive, and life forms of very different qualities may interact beneficially with one another and with their physical environment. Even "the bacteria... live by collaboration, accommodation, exchange, and barter" (Lewis Thomas, 1974).

Principle of Cooperation.
Cooperation, not competition, is the very basis of existing life systems and of future survival.

There are many opportunities to *create* systems that work from the elements and technologies that exist. Perhaps we should do nothing else for the next century but apply our knowledge. We already know how to build, maintain, and inhabit sustainable systems. Every essential problem is solved, but in the everyday life of people this is hardly apparent. The wage–slave, peasant, landlord, and industrialist alike are deprived of the leisure and the life spirit that is possible in a cooperative society which applies its knowledge. Both warders and prisoners are equally captive in the society in which we live.

If we question why we are here and what life is, then we lead ourselves into both science and mysticism which are coming closer together as science itself approaches its conceptual limits. As for life, it is the most open of open systems, able to take from the energy resources in time and to re-express itself not only as a lifetime but as a descent and an evolution.

Lovelock (1979) has perhaps best expressed a philosophy, or insight, which links science and tribal beliefs: he sees the earth, and the universe, as a thought process, or as a self–regulating, self–constructed and reactive system, creating and preserving the conditions that make life possible, and actively adjusting to regulate disturbances. Humanity however, in its present mindlessness, may be the one disturbance that the earth cannot tolerate.

> The Gaia hypothesis is for those who like to walk or simply stand and stare, to wonder about the earth and the life it bears, and to speculate about the consequences of our own presence here. It is an alternative to that pessimistic view which sees nature as a primitive force to be subdued and conquered. It is also an alternative to that equally depressing picture of our planet as a demented spaceship, forever travelling, driverless and purposeless, around an inner circle of the sun.
>
> (J.E. Lovelock, 1979).

For every scientific statement articulated on energy, the Aboriginal tribespeople of Australia have an equivalent statement on life. Life, they say, is a totality neither created nor destroyed. It can be imagined as an egg from which all tribes (life forms) issue and to which all return. The ideal way in which to spend one's time is in the perfection of the expression of life, to lead the most evolved life possible, and to assist in and celebrate the existence of life forms other than humans, for all come from the same egg.

The totality of this outlook leads to a meaningful daily existence, in which one sees each quantum of life eternally trying to perfect an expression towards a future, and possibly transcendental, perfection. It is all the more horrific, therefore, that tribal peoples, whose aim was to develop a conceptual and spiritual existence, have encountered a crude scientific and material culture whose life aim is not only unstated, but which relies on pseudo–economic and technological systems for its existence.

The experience of the natural world and its laws has almost been abandoned for closed, artificial, and meaningless lives, perhaps best typified by the dreams of those who would live in space satellites and abandon a dying earth.

I believe that unless we adopt sophisticated aboriginal belief systems and learn respect for all life, then we lose our own, not only as lifetime but also as any future opportunity to evolve our potential. Whether we continue, without an ethic or a philosophy, like abandoned and orphaned children, or whether we create opportunities to achieve maturity, balance, and harmony is the only real question that faces the present generation. This is the debate that must never stop.

A young woman once came to me after a lecture in which I wondered at the various concepts of afterlife; the plethora of "heavens" offered by various groups. Her view was,"This is heaven, right here. This is it. *Give it all you've got.*"

I couldn't better that advice. The heaven, or hell, we live in is of our own making. An afterlife, if such exists, can be no different for each of us.

1.2 ETHICS

In earlier days, several of us researched community ethics, as adopted by older religious and cooperative groups, seeking for universal principles to guide our own actions. Although many of these guidelines contained as many as 18 principles, most of these can be included in the three below (and even the second and third arise from the first):

The Ethical Basis of Permaculture
1. CARE OF THE EARTH: Provision for all life systems to continue and multiply.
2. CARE OF PEOPLE: Provision for people to access those resources necessary to their existence.
3. SETTING LIMITS TO POPULATION AND CONSUMPTION: By governing our own needs, we can set resources aside to further the above principles.

This ethic is a very simple statement of guidance, and serves well to illuminate everyday endeavours. It can be coupled to a determination to make our own way: to be neither employers nor employees, landlords nor tenants, but to be self-reliant as individuals and to cooperate as groups.

For the sake of the earth itself, I evolved a philosophy close to Taoism from my experiences with natural systems. As it was stated in *Permaculture Two*, it is a philosophy of working with rather than against nature; of protracted and thoughtful observation rather than protracted and thoughtless action; of looking at systems and people in all their functions, rather than asking only one yield of them; and of allowing systems to demonstrate their own evolutions. A basic question that can be asked in two ways is:

"What can I get from this land, or person?" or

"What does this person, or land, have to give if I cooperate with them?"

Of these two approaches, the former leads to war and waste, the latter to peace and plenty.

Most conflicts, I find, lay in how such questions are asked, and not in the answers to any question. Or, to put it another way, we are clearly looking for the right questions rather than for answers. We should be alert to rephrase or refuse the "wrong" question.

It has become evident that unity in people comes from a common adherence to a set of ethical principles, each of us perhaps going our own way, at our own pace, and within the limits of our resources, yet all leading to the same goals, which in our own case is that of a living, complex, and sustainable earth. Those who agree on such ethics, philosophies, and goals form a global nation.

How do a people evolve an ethic, and why should we bother to do so?

Humans are thinking beings, with long memories, oral and written records, and the ability to investigate the distant past by applying a variety of techniques from dendrochronology to archaeology, pollen analysis to the geological sciences. It is therefore evident that behaviours in the natural world which we thought appropriate at one time later prove to be damaging to our own society in the long-term (e.g. the effects of biocidal pest controls on soils and water).

Thus, we are led by information, reflection, and careful investigation to moderate, abandon, or forbid certain behaviours and substances that in the long-term threaten our own survival; *we act to survive*. Conservative and cautious rules of behaviour are evolved. This is a rational and sensible process, responsible for many taboos in tribal societies.

From a great many case histories we can list some rules of use, for example the RULE OF NECESSITOUS USE—that we leave any natural system alone until we are, of strict necessity, forced to use it. We may then follow up with RULES OF CONSERVATIVE USE—having found it necessary to use a natural resource, we may insist on every attempt to:

- Reduce waste, hence pollution;
- Thoroughly replace lost minerals;
- Do a careful energy accounting; and
- Make an assessment of the long-term, negative, biosocial effects on society, and act to buffer or eliminate these.

In practice, we evolve over time to various forms of *accounting for our actions*. Such accounts are fiscal, social, environmental, aesthetic, or energetic in nature, and all are appropriate to our own survival.

Consideration of these rules of necessitous and conservative use may lead us, step by step, to the basic realisation of our interconnectedness with nature; that we depend on good health in all systems for our survival. Thus, we widen the self-interested idea of human survival (on the basis of past famine and environmental disaster) to include the idea of "the survival of natural systems", and can see, for example, that when we lose plant and animal species due to our actions, we lose many survival opportunities. Our fates are intertwined. This process, or something like it, is common to every group of people who evolve a general earthcare ethic.

Having developed an earthcare ethic by assessing our best course for survival, we then turn to our relationships with others. Here, we observe a general rule of nature: that cooperative species and associations of self-supporting species (like mycorrhiza on tree roots) make healthy communities. Such lessons lead us to a sensible resolve to cooperate and take support roles in society, to foster an interdependence which values the individual's contributions rather than forms of opposition or competition.

Although initially we can see how helping our family and friends assists us in our own survival, we may evolve the mature ethic that sees all humankind as family, and all life as allied associations. Thus, we expand *people care* to *species care*, for all life has common origins. All are "our family".

We see how enlightened self-interest leads us to evolve ethics of sustainable and sensible behaviour. These then, are the ethics expressed in permaculture. Having evolved *ethics*, we can then devise *ways to apply them* to our lives, economies, gardens, land, and nature. This is what this book is about: the mechanisms of mature ethical behaviour, or how to act to sustain the earth.

There is more than one way to achieve permanence and stability in land or society. The peasant approach is well described by King[6] for old China. Here people hauled nutrients from canals, cesspits, pathways and forests to an annual grain culture. We could describe this as "feudal permanence" for its methods, period and politics. People were bound to the landscape by unremitting toil, and in service to a state or landlord. This leads eventually to famine and revolution.

A second approach is on permanent pasture of prairie, pampas, and modern western farms, where large holdings and few people create vast grazing leases, usually for a single species of animal. This is best described as "baronial permanence" with

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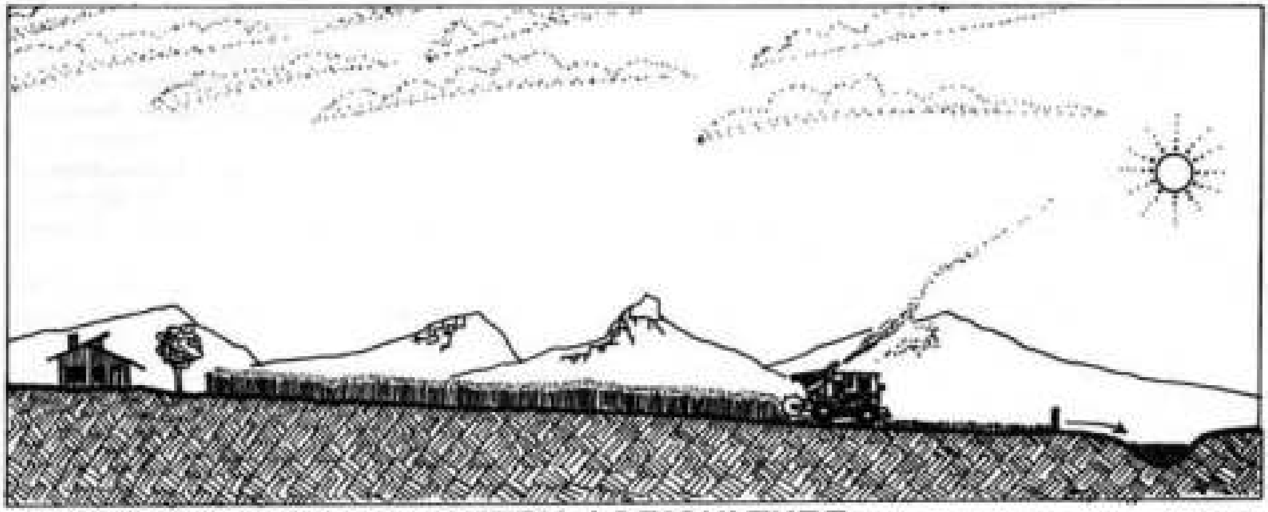
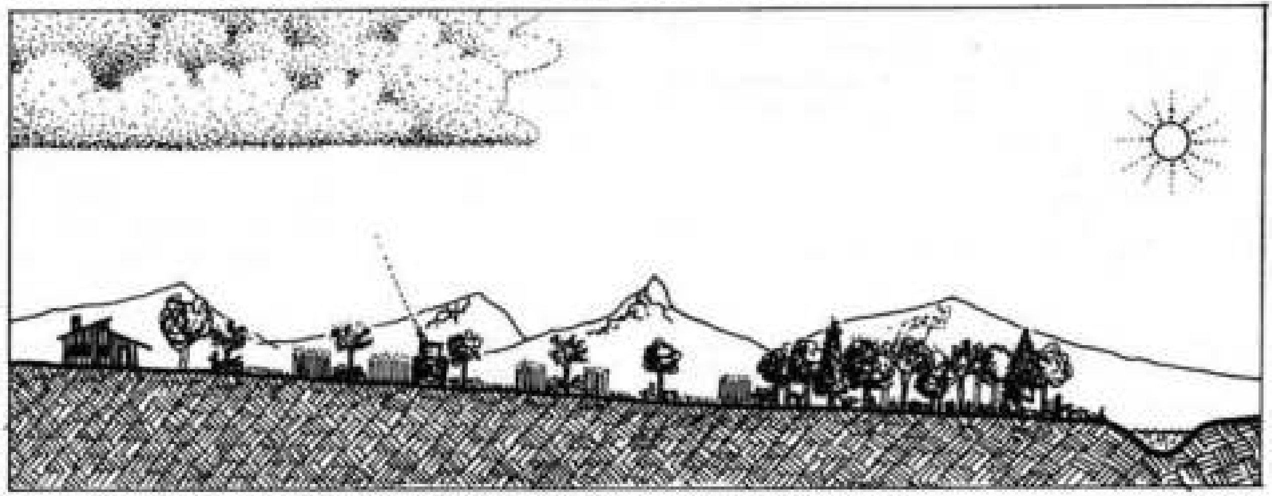
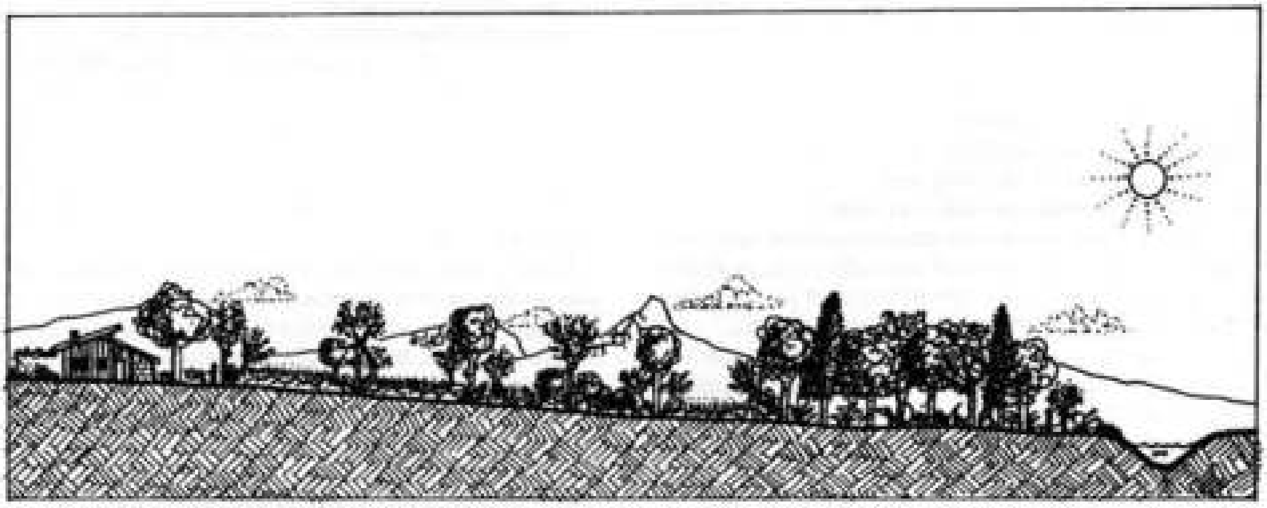


A. CONTEMPORARY/WESTERN AGRICULTURE **YEAR 1**

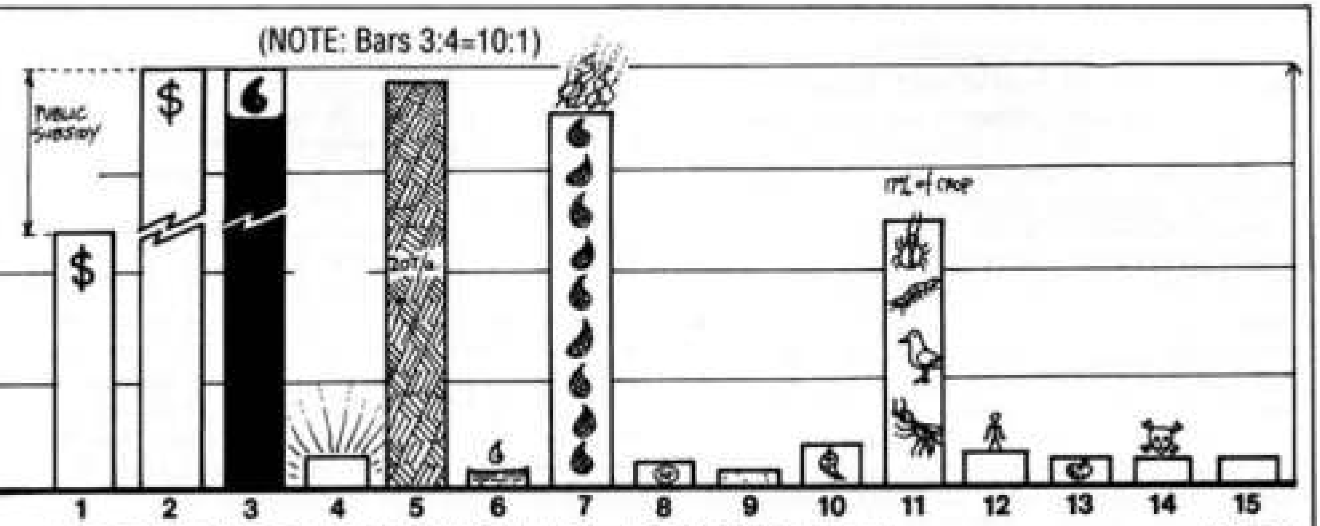


B. TRANSITIONAL AND CONSERVATION FARMING **YEAR 4**



C. PERMACULTURE; 70% cropland devoted to forage farming **YEAR 8**

FIGURE 1.1.
EVOLUTION FROM CONTEMPORY AGRICULTURE TO A PERMACULTURE.
I have attempted to cost contempory agriculture against a changeover to permaculture over a period of 3 8 years *(the transition period)*. Basic changes involve replacing animal forage grains with tree crop, increasing forest cover, adopting low to no tillage on remaining croplands, retrofitting the house for energy conservation, and producing some (if not all) fuel on the farm.



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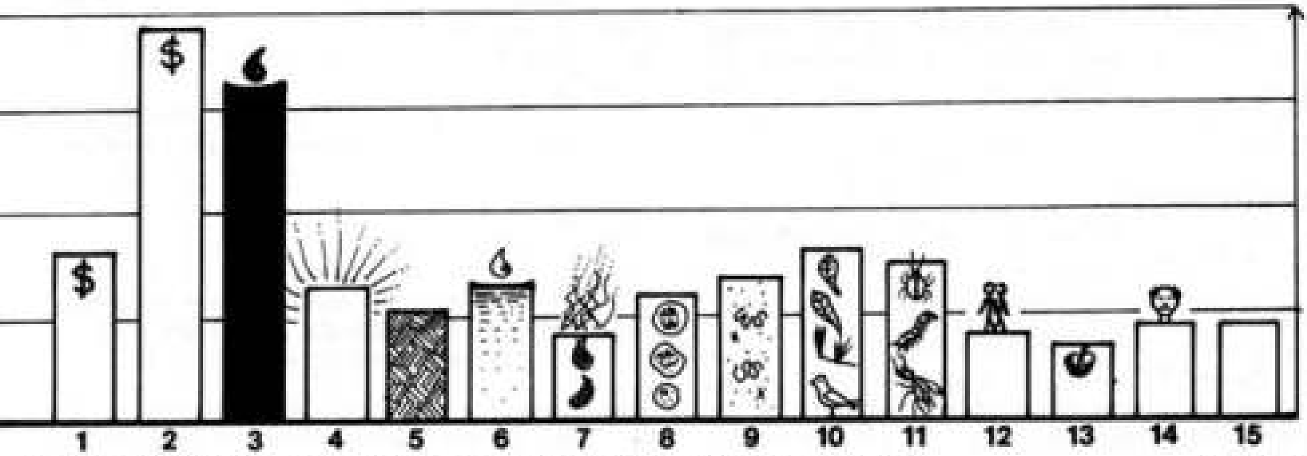
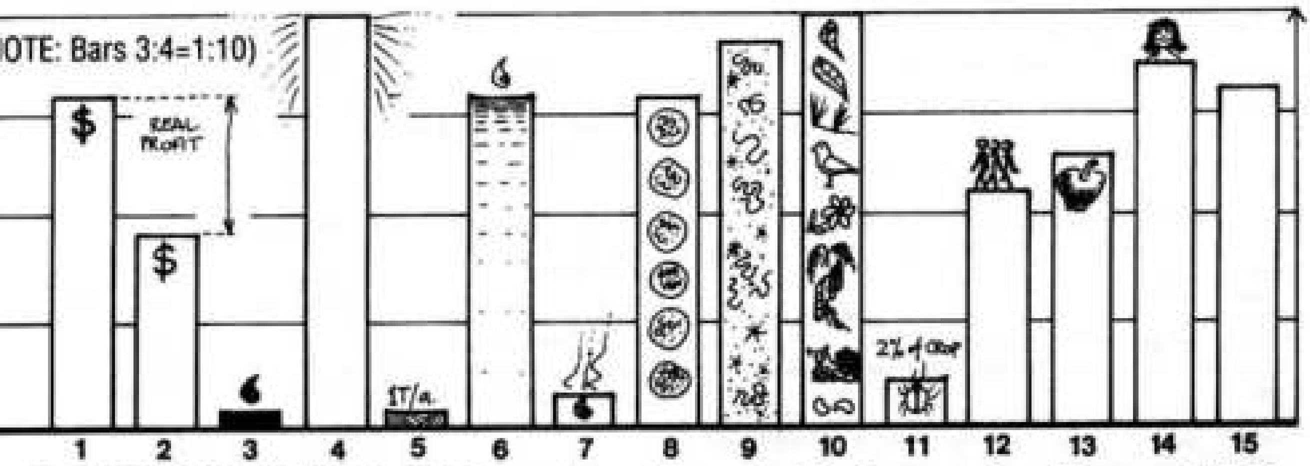


B. TRANSITIONAL AND CONSERVATION FARMING **YEAR 4**



C. PERMACULTURE; 70% cropland devoted to forage farming **YEAR 8**

FIGURE 1.1 (Continued)
ANNOTATIONS TO THE BAR DIAGRAM; ACCOUNTING THE COSTS OF FARMING.
The accounting is in sections as follows:

I Cash (Dollar) Accounting.
Bar 1: Income from total product on the farm.

(continued next page....)

[...from page 3]

near-regal properties of immense extent, working at the lowest possible level of land use (pasture or cropland is the least productive use of land we can devise). Such systems, once mechanised, destroy whole landscapes and soil complexes. They can then best be typified as agricultural deserts.

Forests, not seen by industrial man as anything but wood, are another permanent agriculture. But they need generations of care and knowledge, and hence a tribal or communal reverence only found in stable communities. This then, is the communal permanence many of us seek: to be able to plant a pecan or citrus when we are old, and to know it will not be cut down by our children's children.

The further we depart from communal permanence, the greater the risk of tyranny, feudalism, and revolution and the more work for less yield. Any error or disturbance can then bring disaster, as can a drought year in a desert grain crop or a distant political decision on tariffs.

The real risk is that the needs of those people working "on the ground", the inhabitants, are overthrown by the needs (or greeds) of commerce and centralised power; that the forest is cut for warships or newspaper and we are reduced to serfs in a barren landscape. This has been the fate of peasant Europe, Ireland, and much of the third world.

The characteristic that typifies all permanent agricultures is that the needs of the system for energy are provided by that system. Modern crop agriculture is totally dependent on external energies—hence the oil problem and its associated pollution.

Figure 1.1 is a very simple but sufficient illustration of the case I am making. Selected forests not only yield more than annual crops, but provide a diverse nutrient and fuel resource for such crops.

Without permanent agriculture there is no possibility of a stable social order. Thus, the move from productive permanent systems (where the land is held in common), to annual, commercial agricultures where land is regarded as a commodity, involves a departure from a low- to a high-energy society, the use of land in an exploitative way, and a demand for external energy resources, mainly provided by the third world. People think I am slightly crazy when I tell them to go home and garden, or *not* to involve themselves in broadscale mechanised agriculture; but a little thought and reading will convince them that this is, in fact, the solution to many world problems.

What is now possible is a totally new synthesis of plant and animal systems, using a post-industrial or even computerised approach to system design, applying the principles of whole-system energy flows as devised by Odum (1971), and the principles of ecology as enunciated by Watt[13] and others. It is, in the vernacular, a whole new ball game to devise permaculture systems for local, regional, and personal needs.

Had we taught this approach from the beginning, we would all be in a stable and functional landscape, but our grandparents failed us, and (perhaps for lack of time or information) set up the present, and continuing, mis-designed households, towns, and cities. The concept of "free" energy put the final nail in the coffin of commonsense community, and enabled materialistic societies to rob distant peoples, oblivious of the inevitable accounting to come.

1.3
PERMACULTURE IN LANDSCAPE AND SOCIETY

As the basis of permaculture is beneficial design, it can be added to all other ethical training and skills, and has the potential of taking a place in all human endeavours. In the broad landscape, however, permaculture concentrates on already-settled areas and agricultural lands. Almost all of these need drastic rehabilitation and re-thinking. One certain result of using our skills to integrate food supply and

[...FIGURE 1.1 CAPTION CONTINUED]

Bar 2: Cost of producing that income in real terms (excess cost over income represents subsidies. Note that any farm "profits" are achieved by subsidy; the dollar costs do not balance until organic farming is achieved. Farm income is achieved by reducing production costs).

II Energy Accounting.

Bar 3: Oil (or calories) as machinery, fuels, fertilisers, biocides. Starts at 10:1 *against* (loss) in conventional farming, and can reach a 1:120 *gain* in conservation farming/permaculture with firewood and fuels.

Bar 4: Energy produced on farm; includes fuel oils from crop, firewood, calories in food produced (solar energy is a constant, but it contributes most energy in conservation farming/permaculture).

III Environmental Accounting.

Bar 5: Soil loss; includes humus loss and mineral nutrient loss.

Bar 6: Efficiency of water use and soil water storage.

Bar 7: Pollution produced (poisoning of atmosphere, soils, water) by fuels, biocides, and fertilisers. Soils are created in conservation farming/permaculture, water conserved, and pollutants removed.

IV Conservation Accounting; Life Form Richness.

Bar 8: Genetic richness in crops and livestock.

Bar 9: Soil life (biomass).

Bar 10: Forest biomass and wildlife richness.

Bar 11: Loss to pests.

V Social Accounting

Bar 12: Employment on farm (human design and/or skills replace most machine systems).

Bar 13: Food quality produced.

Bar 14: Human and environmental health.

Bar 15: Life quality, as "right livelihood".

Thus, it can be seen that a transition from contempory western agriculture to conservation farming and permaculture has most benefits for people and to other life forms; farming can become energy productive; and farms can produce real income without public subsidy, in particular if farm products are already matched to local or regional demand.

settlement, to catch water from our roof areas, and to place nearby a zone of fuel forest which receives wastes and supplies energy, will be to free most of the area of the globe for the rehabilitation of natural systems. These need never be looked upon as "of use to people", except in the very broad sense of global health.

The real difference between a cultivated (designed) ecosystem, and a natural system is that the great majority of species (and biomass) in the *cultivated* ecology is intended for the use of humans or their livestock. We are only a small part of the total primeval or natural species assembly, and only a small part of its yields are directly available to us. But in our own gardens, almost every plant is selected to provide or support some direct yield for people. Household design relates principally to the needs of people; it is thus human-centred (anthropocentric).

This is a valid aim for *settlement design*, but we also need a nature-centred ethic for wilderness conservation. We cannot, however, do much for nature if we do not govern our greed, and if we do not supply our needs from our existing settlements. If we can achieve this aim, we can withdraw from much of the agricultural landscape, and allow natural systems to flourish.

Recycling of nutrients and energy in nature is a function of many species. In our gardens, it is our own responsibility to return wastes (via compost or mulch) to the soil and plants. We actively create soil in our gardens, whereas in nature many other species carry out that function. Around our homes we can catch water for garden use, but we rely on natural forested landscapes to provide the condenser leaves and clouds to keep rivers running with clean water, to maintain the global atmosphere, and to lock up our gaseous pollutants. Thus, even anthropocentric people would be well-advised to pay close attention to, and to assist in, the conservation of existing forests and the rehabilitation of degraded lands. Our own survival demands that we preserve all existing species, and allow them a place to live.

We have abused the land and laid waste to systems we need never have disturbed had we attended to our home gardens and settlements. If we need to state a set of ethics on natural systems, then let it be thus:

- Implacable and uncompromising opposition to further disturbance of any remaining natural forests, where most species are still in balance;
- Vigorous rehabilitation of degraded and damaged natural systems to stable states;
- Establishment of plant systems for our own use on the *least* amount of land we can use for our existence; and
- Establishment of plant and animal refuges for rare or threatened species.

Permaculture as a design system deals primarily with the third statement above, but all people who act responsibly in fact subscribe to the first and second statements. That said, I believe we should use all the species we need or can find to use in our own settlement designs, *providing they are not locally rampant and invasive*.

Whether we approve of it or not, the world about us continually changes. Some would want to keep everything the same, but history, palaeontology, and commonsense tells us that all has changed, is changing, will change. In a world where we are losing forests, species, and whole ecosystems, there are three concurrent and parallel responses to the environment:

1. CARE FOR SURVIVING NATURAL ASSEMBLIES, to leave the wilderness to heal itself.
2. REHABILITATE DEGRADED OR ERODED LAND using complex pioneer species and long-term plant assemblies (trees, shrubs, ground covers).
3. CREATE OUR OWN COMPLEX LIVING ENVIRONMENT with as many species as we can save, or have need for, from wherever on earth they come.

We are fast approaching the point where we need refuges for *all* global life forms, as well as regional, national, or state parks for indigenous forms of plants and animals. While we see our local flora and fauna as "native", we may also logically see all life as "native to earth". While we try to preserve systems that are still local and diverse, we should also build new or recombinant ecologies from global resources, especially in order to stabilise degraded lands.

In your own garden, there are likely to be plants, animals, and soil organisms from every major landmass and many islands. Jet travel has merely accelerated a process already well-established by continental drift, bird migration, wind transport, and the rafting of debris by water. Everything will, in time, either become extinct, spread more widely, or evolve to new forms. Each of these processes is happening at once, but the rate of extinction and exchange is accelerating. Rather than new species, adapted hybrids are arising for example as palms, sea grasses, and snails, and micro-organisms from many continents meet, mix, and produce new accommodations to their "new" environments.

The very chemistry of the air, soil, and water is in flux. Metals, chemicals, isotopes, gases, and plastics are loose on earth that have never before been present, or never present in such form and quantity before we made it so.

It is my belief that we have two responsibilities to pursue:

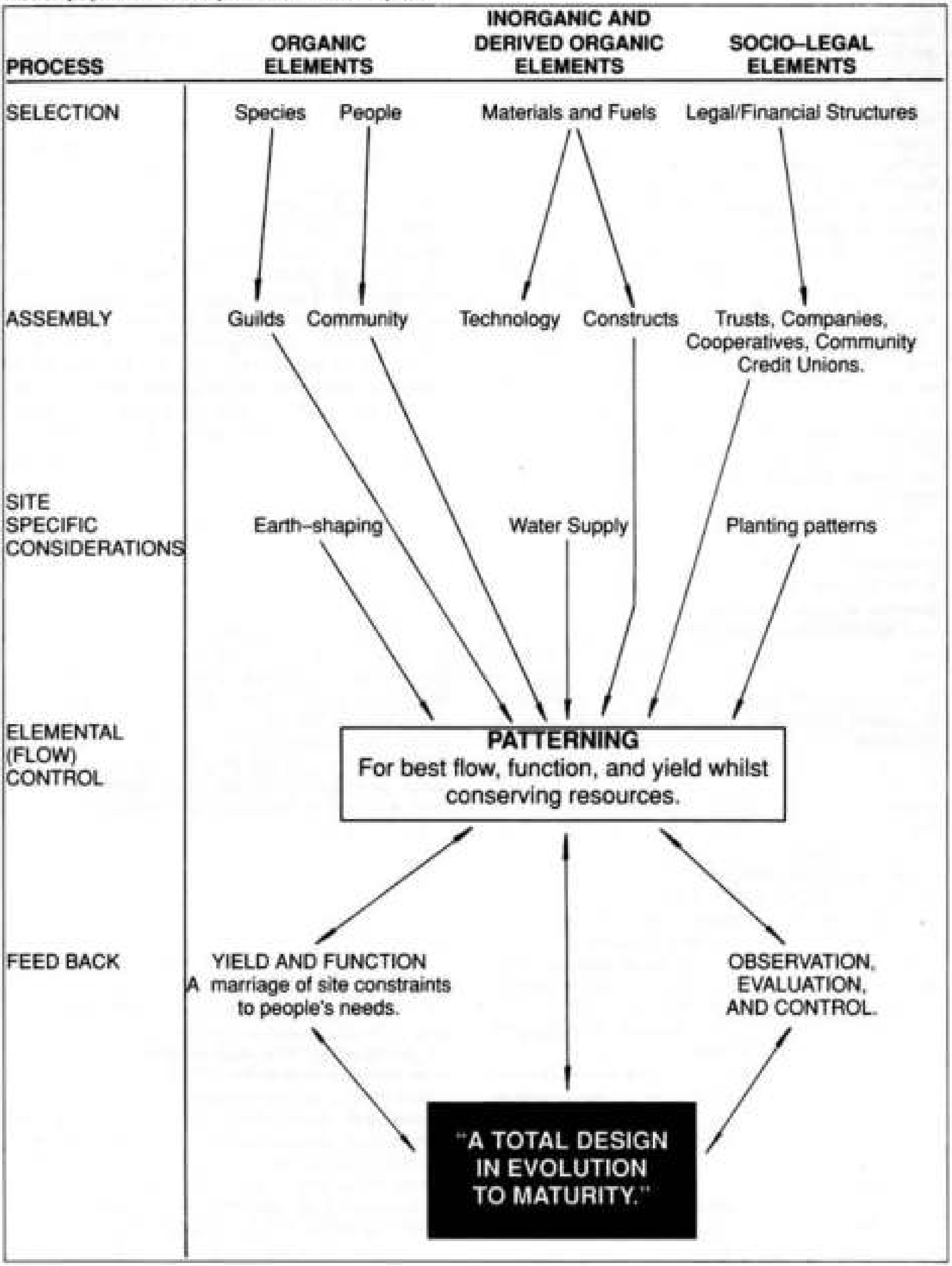
- Primarily, it is to get our house and garden, our place of living, in order, so that it supports us.
- Secondarily, it is to limit our population on earth, or we ourselves become the final plague.

Both these duties are intimately connected, as stable regions create stable populations. If we do not get our cities, homes, and gardens in order, so that they feed and shelter us, we must lay waste to all other natural systems. Thus, truly responsible conservationists have gardens which support their food needs, and are working to reduce their own energy needs to a modest consumption, or to that which can be supplied by local

TABLE 1.1

PERMACULTURE DESIGN

The result of a unique assembly of constructs, species, and social systems into a unique pattern suited to a specific site and set of occupants.



wind, water, forest, or solar power resources. We can work on providing biomass for our essential energy needs on a household and regional scale.

It is hypocrisy to pretend to save forests, yet to buy daily newspapers and packaged food; to preserve native plants, yet rely on agrochemical production for food; and to adopt a diet which calls for broadscale food production.

Philosopher-gardeners, or farmer-poets, are distinguished by their sense of wonder and real feeling for the environment. When religions cease to obliterate trees in order to build temples or human artefacts, and instead generalise love and respect to all living systems as a witness to the potential of creation, they too will join the many of us now deeply appreciating the complexity and self-sustaining properties of natural systems, from whole universes to simple molecules. Gardener, scientist, philosopher, poet, and adherent of religions all can conspire in admiration of, and reverence for, this earth. We create our own life conditions, now and for the future.

In permaculture, this means that all of us have some part in identifying, supporting, recommending, investing in, or creating wilderness habitats and species refuges. the practical way to proceed (outside the home garden) is to form or subscribe to institutes or organisations whose aims under their legal charter are to carry out conservation activities. While the costs are low, in sum total the effects are profound. Even the smallest garden can reserve off a few square metres of insect, lizard, frog, or butterfly habitat, while larger gardens and farms can fence off forest and wetland areas of critical value to local species. Such areas should be *only* for the conservation of local species.

Permaculture as a design system contains nothing new. It arranges what was always there in a different way, so that it works to conserve energy or to generate more energy than it consumes. What is novel, and often overlooked, is that *any* system of total common-sense design for human communities is revolutionary!

Design is the keyword of this book: design in landscape, social, and conceptual systems; and design in space and time. I have attempted a treatment on the difficult subject of patterning, and have tried to order some complex subjects so as to make them accessible. The text is positivistic, without either the pretended innocence or the belief that everything will turn out right. Only if we make it so will this happen.

As will be clear in other chapters of this book, the end result of the adoption of permaculture strategies in *any* country or region will be to dramatically reduce the area of the agricultural environment needed by the households and the settlements of people, and to release much of the landscape for the sole use of wildlife and for re-occupation by endemic flora. Respect for all life forms is a basic, and in fact essential, ethic for all people.

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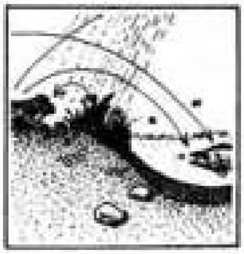


Chapter 2

CONCEPTS AND THEMES IN DESIGN

The world teeters on the threshold of revolution. If it is a bloody revolution it is all over. The alternative is a design science revolution... Design science produces so much performance per unit of resource invested as to take care of all human needs.

(Buckminster Fuller)

All living organisms... are 'open systems'; that is to say, they maintain their complex forms and functions through continuous exchanges of energies and materials with their environment. Instead of 'running down' like a mechanical clock that dissipates its energy through friction, the living organism is constantly 'building up' more complex substances from the substance it feeds on, more complex forms of energies from the energies it absorbs, and more complex patterns of information... perceptions, feelings, thoughts... form the input of its receptor organs.

(Arthur Koestler, 1967, *The Ghost in the Machine*)

Most **thermodynamic** problems concern 'closed' systems, where the reactions take place in confinement, and can be reversed; an example is the expansion and compression of gas in a cylinder. But in an open system, energy is gained or lost irreversibly, and the system, its environment, or both are changed by the interaction... the second law of thermodynamics [states that] energy tends to dissipate and organized systems drift inevitably towards **entropy**, or chaos. In seeming violation of that law, biological systems tend to become increasingly complex and efficient.

(*Newsweek*, October 24, 1977, on the Nobel Prize awarded to Ilya Prigogine.)

Lovelock shows that the biosphere, or Gaia as he calls it, actually created those conditions that are required for its support... and systematically builds up the stock of materials that it requires to move... towards increasng complexity, diversity, and stability.

(Edward Goldsmith, 1981, "Thermodynamics or Ecodynamics", *The Ecologist*.)

Man did not weave the web of life, he is merely a strand in it. Whatever he does to the web, he does to himself... to harm the earth is to heap contempt upon the creator... contaminate your bed, and you will one night suffocate in your own waste.

(Chief Seattle, 1854, responding to a U. S. government offer to buy Indian land.)

2.1 INTRODUCTION

It is alarming that in western society no popular body of directives has arisen to replace the injunctions of tribal taboo and myth. When we left tribal life we left with it all guides to sensible behaviour in the natural world, of which we are part and in which we live and die. More to the point, by never having the time or commonsense to evolve new or current guiding directives, we have forgotten how to evolve self-regulating systems. Hence, the call for a society in which we are all designers, based on an ethical and applied education, with a clear concept of life ethics.

The Gaia hypothesis, as formulated by James Lovelock, is that the earth less and less appears to behave like a material assembly, and more and more appears to act as a thought process. Even in the inanimate world we are dealing with a life force, and our acts are of great effect. The reaction of the earth is to restore equilibrium and balance. If we maltreat, overload, deform, or deflect natural systems and processes, then we will get a reaction, and this reaction may have long-term consequences. Don't do anything unless you've thought out all its consequences and advantages.

Aboriginal cultures used *myth* to show how unnecessary acts and unthinking destruction of elements brings about catastrophe and suffering. The usual structure of myth has these sequences:

1. A willful act of an individual or group.
2. A transmutation (animate to inanimate or the reverse, e.g. Lot's wife turns into a pillar of salt). This is by way of a warning.
3. Invocation of an elemental force (fire, storm, earthquake, flood, tidal wave, plague) as a result of any set of willful acts.
4. Necessary atonement by suffering, isolation, migration, or death.

So the act of a child or individual is given a meaning which relates to the whole of nature, and rebounds on the society. Reared on such myths, we go carefully in the world, aware that every unthinking act can have awful consequences.

Because we have replaced nature-based myth with a set of fixed prohibitions relating only to other people, and unrelated to nature, we have developed destructive and people-centred civilisations and religions.

In life and in design, we must accept that *immutable rules will not apply*, and instead be prepared to be guided on our continuing exploration by *flexible principles and directives*.

Thus, this book emphasises self-reliance, responsibility, and the functions of living things. Within a self-regulated system on earth, energy from the sun can be trapped and stored in any number of ways. While the sun burns, we are in an open system. If we don't destroy the earth, open-system energy saving will see us evolve as conscious beings in a conscious universe.

A Policy of Responsibility (to relinquish power)
The role of beneficial authority is to return function and responsibility to life and to people; if successful, no further authority is needed. The role of successful design is to create a self-managed system.

2.2 SCIENCE AND THE THOUSAND NAMES OF GOD

Although we can observe nature, living systems do not lend themselves to strict scientific definition for two reasons. Firstly, life is always in process of change, and secondly, life systems *react* to investigation or experiments. We must always accept, therefore, that there will never be "laws" in the area of biology.

"Hard" science, such as we apply to material systems (physics, mathematics, inorganic chemistry), studiously avoids life systems, regarding as not quite respectable those sciences (botany, zoology, psychology) which try to deal with life. Rigorous scientific method deals with the necessity of rigorous control of variables, and in a life system (or indeed any system), this presumes two things that are impossible:

1. That you know all variables (in order to control some of them and measure others) before you start; or
2. That you can in fact control all or indeed any variables without creating disorder in the life system.

Every experiment is carried out by people, and the results are imparted to people. Thus living things conduct and impart knowledge. To ignore life in the system studied, one has to ignore oneself. Life exists in conditions of flux, not imposed control, and responds to any form of control in a new fashion. Living things respond to strict control (either by removal of stimuli or by constant input of stimuli) by becoming *uncontrolled*, or (in the case of people and rats at least) by dysfunction, or by going mad.

Experiments, therefore, are not decisive, rigid, or true findings but an eternal search for the variables that have *not* been accounted for previously. This is the equivalent of true believers, in their empirical approach to the knowledge of God's name. They simply keep chanting variables of all possible names until (perhaps) they hit on the right one. Thus does science proceed in biological experiments.

Scientists who "know" and observe, don't usually apply their knowledge in the world. Those who "act", often don't know or observe. This has resulted in several tragic conditions, where productive natural ecosystems have been destroyed to create unproductive cultivated systems, breaking every sane environmental principle to do so. Energy-efficient animals (deer, kangaroo, fish) have been displaced by inefficient animal systems (sheep, cattle). Every widespread modern agricultural system needs great energy inputs; most agriculture destroys basic resources and denies future yields.

As Edward Goldsmith makes clear ("Thermodynamics or Ecodynamics", *The Ecologist*, 1981), many scientists refuse to consider the function of life in such systems. Natural systems disintegrate and decay, producing more and more helpless plants, animals, and people, and the State or the farmer takes over the function of natural processes. (The State becomes the father of the orphaned child, the farmer the father of the orphaned chicken.) It is only by returning self-regulating function and responsibility to living things (such as people) that a stable life system can evolve.

Scientific method is one of the ways to know about the real world, the world we are part of and live in. Observation and contemplative understanding is another. We can find out about many things, both living and inorganic, by timing, measuring, and observing them; enough to make calendars, computers, clocks, meters, and rulers, but not ever enough to understand the complex actions in even a simple living system. You can hit a nail on the head, or cause a machine to do so, and get a fairly predictable result. Hit a dog on the head, and it will either dodge, bite back, or die, but it will never again react in the same way. We can predict only those things we set up to be predictable, not what we encounter in the real world of living and reactive processes.

Ecologists and "whole systems" people struggle to understand open and complex systems, even though they realise that they too are a part of the system they study. In fact, given enough limnologists (those who study freshwater lakes and lake organisms), these become the most important factor in the spread of lake organisms via their boats, boots, and nets! (It is also time, I feel, for students of communities to form a *community* of students of communities and keep out of everybody else's hair!)

Overseas aid is perilously close to being a very good reason for overseas aid to be necessary, as spies need counterspies. I shudder to think that if we train more brain surgeons, they must cut open more brains in order to support themselves... imagine! I think it fair to say that if you submit to poverty, you equip yourself to know about poverty, and the same goes for lobotomy.

There are several ways not to face life: by taking drugs, watching television, becoming a fakir in a cave, or reading in pure science. All are an abdication of personal responsibility for life on earth (including, of course, one's own life). Value- and ethic-free lifestyles are as aberrant in science as in society.

> It is the quantifiability of many... scientific concepts that have led to their adoption by scientists often regardless of the fact that, as they are defined, they correspond to nothing whatsoever in the world of living things.
>
> (E. Goldsmith, 1981 "Thermodynamics or Ecodynamics", *The Ecologist*.)

Perverse planning is everywhere obvious: houses face not the sun, but rather the road, lawns replace gardens, and trees are planted to be pruned and tended. Make-work is the rule, and I suspect that most theoretical scientists inhabit demented domestic environments, just as many psychiatrists are inhabitants of mental institutions.

Scientific (and non-scientific) groups or individuals can make progress in finding solutions to specific problems. The following approaches do very well (designers please note):

1. IMPROVING TOOLS, or inventing new tools for specific jobs.
2. COLLECTING A LARGE SET OF OBSERVATIONS on occurrences, or samples of a set of phenomena, and sorting them on the basis of likeness-unlikeness (by establishing systems and system boundaries, categories, and keys to systems). This process often reveals common characteristics of diverse elements, and leads to an understanding of common traits, suggesting (by analogy) strategies in design.
3. INSIGHT : the "Aha!" or "Eureka!" response to observation. This, as is well recorded, comes to the individual as though by special gift or providence. In fact, it is quite probably the end point of 2.
4. TRIALS: "give it a try and see if it works". This empirical approach simply eliminates those things that don't work. It does not necessarily establish how or why something works, or even if it works in the long run.
5. GUESSING: the best guesses are based on trials that are already known to work.
6. OBSERVING UNIQUE EVENTS and taking note of them (the "discovery" of penicillin).
7. ACCIDENT: trials set up for one reason work in a way not predicted or foreseen; compounds made for one purpose are applied to another.
8. IMITATION: by testing already-known effects (discovered by others).
9. PATTERNING: by seeing a pattern to events of often very different natures, and thus producing insights into underlying effects. Often preceded by 2 above, but rare in science.
10. COMMONSENSE: often called "management" in business and natural systems control. This consists of staying with and steering a system or enterprise through constant adjustment to a successful conclusion or result. It also suits evolving systems, and is the basis of continuous change and adjustment.

2.3
APPLYING LAWS AND PRINCIPLES TO DESIGN

Principles differ from dogmas in that there are no penalties for error, but only learning from error, which leads to a new evolution. Dogmas are rules which are intended to force centralised control (often by guilt), and it is obvious that every such rule or law represents a failure of the social system. It is too late to fail, but never too late to adopt sensible principles for our guidance, and to throw away the rule book.

Life Intervention Principle
In chaos lies unparalleled opportunity for imposing creative order.

Just join with one or two friends to make your way in the confusion. Others will follow and learn.

There is only one law that is offered to us by such education as we derive from nature, and that is the law of return, which can be stated in many ways:

Law of Return
"Whatever we take, we must return", or

"Nature demands a return for every gift received," or "The user must pay."

We should examine, and act on, the forms of this law. It is the reason why this book carries a tree tax: that we may be able to continue in the use of books. It is why we must never buy books or newspapers that do *not* tax, nor goods where the manufacturer does not recycle or replant the materials of the manufacture. It is why we must carefully study how to use our wastes, and this includes our body wastes. Put in the form of a directive or policy statement, this law would read:

Every object must responsibly provide for its replacement; society must, *as a condition of use*, replace an equal or greater resource than that used.

Inherent in such a law are the concepts of replanting, recycling, durability, and the correct or beneficial disposal of wastes. Nature has extreme penalties for those who break such laws, and for their descendants and neighbours.

Nor can we deny immanence; if a landscape delights us, we should not insult it with castles on peaks, roadways, and clear-cuts. We should return the pleasure we get from natural prospects, and maintain their integrity. It would be pleasant indeed were the land around us always to appear welcoming or non-threatening. This effect, too, can be created or destroyed. There is no reason not to bury our necessary constructs in earth, or clothe them with vegetation. If we want pleasure in life, then we should preserve the life around us.

Energies enter a system, and either remain or escape. Our work as permaculture designers is to prevent energy leaving before the basic needs of the whole system are satisfied, so that growth, reproduction, and maintenance continue in our living components.

All permaculture designers should be aware of the fundamental principles that govern natural systems. These are not immutable rules, but can be used as a set of directives, taking each case as unique but gaining confidence and inspiration from a set of findings and solutions in other places and other times. We can use the guiding principles and laws of natural systems, as formulated by such people as Watt, Odum, and Birch, and apply some of them to our consciously-designed ecologies.

One such law is the basic law of thermodynamics, as restated by Watt[13]:

> All energy entering an organism, population or ecosystem can be accounted for as energy which is stored or leaves. Energy can be transferred from one form to another, but it cannot disappear, or be destroyed, or created. No energy conversion system is ever completely efficient.

As stated by Asimov (1970):

> The total energy of the universe is constant and the total entropy is increasing.

Entropy is bound or dissipated energy; it becomes unavailable for work, or not useful to the system. It is the waters of a mountain stream that have reached the sea. It is the heat, noise, and exhaust smoke that an automobile emits while travelling. It is the energy of food used to keep an animal warm, alive, and mobile. Thus, ambient and useful energy storages are degraded into less useful forms until they are no longer of any use to our system.

The question for the designer becomes, "How can I best use energy before it passes from my site, or system?" Our strategy is to set up an interception net from "source to sink". This net is a compound web of life and technologies, and is designed to catch and store as much energy as possible on its way to increasing entropy (as in **Figure 2.1**).

Therefore, we design to catch and store as much water as possible from the hills before it ends up at its "sink" in the quiet valley lake. If we made no attempt to store or use it as it passes through our system, we would suffer drought, have to import it from outside our system, or use energy to pump it back uphill.

Although the material world can perhaps be predictably measured (at least over a wide range of phenomena), by applications of the laws of thermodynamics, these relate mainly to non-living or experimentally "closed systems". The concept of entropy is not necessarily applicable to those living, open earth systems with which we are involved and in which we are immersed. Such laws are more useful in finding an effective path through material technologies than through a life-complexed world. The key word in open systems is "exchange". For example, on the local level, cities *appear* to be "open", but as they return little energy to the systems that supply them, and pass on their wastes as pollutants to the sea, they are *not* in exchange but in a localised one-way trade with respect to their food resource. All cities break the basic "law of return".

Life systems constantly organise and create complex storages from diffuse energy and materials, accumulating, decomposing, building, and transforming them for further use. We can use these effects in the design process by finding pathways or routes by which life systems convert diffuse materials into those of most use. For example, if we have a "waste" such as manure, we can leave it on a field. Although this is of productive use, we have only achieved one function. Alternatively, we can route it through a series of transformations that give us a variety of resources.

First we can ferment it, and distill it to alcohol, and secondly route the waste through a biogas digester, where anaerobic organisms convert it to methane, of use as a cooking or heating gas, or as fuel for vehicles. Thirdly, the liquid effluent can be sent to fields, and the

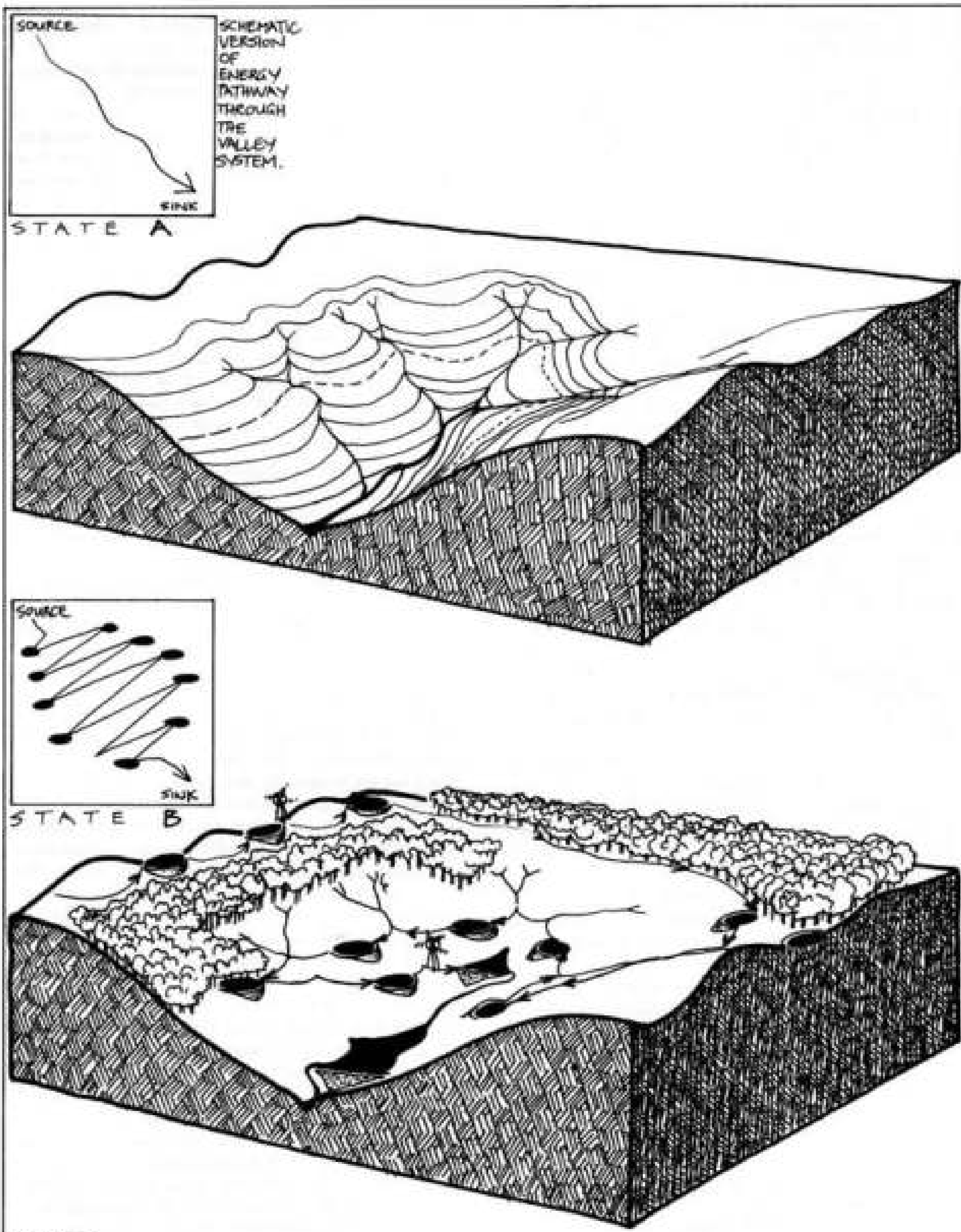


FIGURE 2.1
DESIGNING TO CATCH AND STORE ENERGY.
The designer's work is to set up useful energy storages in a landscape or building (proceeding from State A to State B). Such storages, available for increasing yields, are called resources.

solid sludge fed to worms, which convert it to rich horticultural soil. Fourthly, the worms themselves can be used to feed fish or poultry.

Birch states six principles of natural systems:

1. "Nothing in nature grows forever."
   (There is a constant cycle of decay and rebirth.)
2. "Continuation of life depends on the maintenance of the global bio-geochemical cycles of essential elements, in particular carbon, oxygen, nitrogen, sulphur, and phosphorus."
   (Thus, we need to cycle these and other minor nutrients to stimulate growth, and to keep the atmosphere and waters of earth unpolluted.)
3. "The probability of extinction of populations or a species is greatest when the density is very high or very low."
   (Both crowding and too few individuals of a species may result in reaching thresholds of extinction.)
4. "The chance that species have to survive and reproduce is dependent primarily upon one or two key factors in the complex web of relations of the organism to its environment."
   (If we can determine what these critical factors are, we can exclude, by design, some limiting factors, e.g. frost, and increase others, e.g. shelter, nest sites).
5. "Our ability to change the face of the earth increases at a faster rate than our ability to foresee the consequence of such change."
   (Hence the folly of destroying life systems for short-term profit.)
6. "Living organisms are not only means but ends. In addition to their instrumental value to humans and other living organisms, they have an intrinsic worth."
   (This is the *life ethic* thesis so often missing from otherwise ethical systems.)

Although these principles are basic and inescapable, what we as designers have to deal with is survival on a particular site, here and now. Thus, we must study whether the resources and energy consumed can be derived from renewable or non-renewable resources, and how non-renewable resources can best be used to conserve and generate energy in living (renewable) systems. Fortunately for us, the long-term energy derived from the sun is available on earth, and can be used to renew our resources if life systems are carefully constructed and preserved.

There are thus several practical design considerations to observe:

- The systems we construct should last as long as possible, and take least maintenance.
- These systems, fueled by the sun, should produce not only their own needs, but the needs of the people creating or controlling them. Thus, they are sustainable, as they sustain both themselves and those who construct them.
- We can use energy to construct these systems, providing that in their lifetime, they store or conserve more energy than we use to construct them or to maintain them.

The following are some design principles that have been distilled for use in permaculture:

1. WORK WITH NATURE, RATHER THAN AGAINST IT. We can assist rather than impede natural elements, forces, pressures, processes, agencies, and evolutions. In natural successions, grasses slowly give way to shrubs, which eventually give way to trees. We can actively assist this natural succession not by slashing out weeds and pioneers, but by using them to provide microclimate, nutrients, and wind protection for the exotic or native species we want to establish.

"If we throw nature out the window, she comes back in the door with a pitchfork" (Masanobu Fukuoka). For example, if we spray for pest infestations, we end up destroying both pests and the predators that feed on them, so the following year we get an explosion of pests because there are no predators to control them. Consequently, we spray more heavily, putting things further out of balance. Unfortunately, all the pests are never killed, and the survivors breed more resistent progeny (nature's pitchfork!)

2. THE PROBLEM IS THE SOLUTION. Everything works both ways. It is only how we see things that makes them advantageous or not. If the wind blows cold, let us use both its strength and its coolness to advantage (for example, funneling wind to a wind generator, or directing cold winter wind to a cool cupboard in a heated house). A corollary of this principle is that everything is a positive resource; it is up to us to work out *how* we may use it as such. A designer may recognise a specific site characteristic as either a problem or as a unique feature capable of several uses, e.g. jagged rock outcrops. Such features can only become "problems" when we have already decided on imposing a specific site pattern that the rock outcrop interferes with. It is not a problem, and may be an asset if we accept it for the many values it possesses. "The problem is the solution" is a Mollisonism implying that only our fixed attitudes are problems when dealing with things like rock outcrops! A friend has included several natural boulders in her home, with excellent physical, aesthetic, and economic benefit; the builder would have removed them as "problems", at great expense.

3. MAKE THE LEAST CHANGE FOR THE GREATEST POSSIBLE EFFECT. For example, when choosing a dam site, select the area where you get the most water for the least amount of earth moved.

4. THE YIELD OF A SYSTEM IS THEORETICALLY UNLIMITED. The only limit on the number of uses of a resource possible within a system is in the limit of the information and the imagination of the designer. If you think you have fully planted an area, almost any other innovative designer can see ways to add a vine, a fungus, a beneficial insect, or can see a yield potential that has been ignored. Gahan Gilfedder at the Garden of Eden in Australia found an unsuspected market for cherimoya seed, required by nurseries as seed stock for

grafting. This made a resource from a "waste" product derived from damaged fruit.

5. EVERYTHING GARDENS. A Mollisonian principle is that "everything makes it own garden", or everything has an effect on its environment. Rabbits make burrows and defecation mounds, scratch out roots, create short swards or lawns, and also creates the conditions favourable for weeds such as thistles. People build houses, dispose of sewage, dig up soils for gardens, and maintain annual vegetable patches. We can "use" the rabbit directly as food, to help in fire control, to prepare soil for "thistles" (cardoons and globe artichokes), and to shelter many native animal species in their abandoned burrows. Rabbits maintain species-rich moorland swards suited to many orchids and other small plants. It is a matter of careful consideration as to where this rabbit, and ourselves, belong in any system, and if we should control or manage their effects or tolerate them. When we examine how plants and animals change ecosystems, we may find many allies in our efforts to sustain ourselves and other species. (See **Figure 2.2**).

2.4 RESOURCES

The energies coming into our system are such natural forces as sun, wind, and rain. Living components and some technological or non-living units built into the system translate the incoming energies into useful reserves, which we can call *resources*. Some of these resources have to be used by the system for its own purposes (stocks of fish must be maintained to produce more fish). An ideal technology should at the very least fuel itself.

The surplus, over and above these system needs, is our *yield*. Yield, then, is any useful resource surplus to the needs of the local system and thus available for use, export or trade. The way to obtain yield is to be conservative in resource use, for energy, like money, is much more easily saved than generated. Resource saving involves recycling waste, insulating against heat loss, etc. Then, we can work out paths or routes to send resources on to their next "use point".

If the aim of functional design is to obtain yields, or to provide a surplus of resources, it is as well to be clear about just what it is that we call a resource, and what categories of resource there are, as these latter may affect our strategies of use. In short, we cannot use all resources in the same way and to the same ends. Ethics of resource use are evolved by knowing about the results of resource exploitation. Forests, soils, air, water, sunlight, and seeds are resources that we all regard as part of a common heritage.

A second category of resource is that which belong to us as group, family, or person: those fabricated, ordered, or otherwise developed resources that people create by their work, and of which a presence or absence does not apparently affect the common resource. What we create, however, is *always made from the common resource*, so that it is impossible to draw a line between these categories.

What other ways can we look at resources? Let us try a use-and-results approach. What happens if we use some resources, if we look upon them as a yield? We then find that a response or result follows. Resources are:

1. THOSE WHICH INCREASE BY MODEST USE. Green browse is an example: if deer do not browse shrubs, the latter may become woody and unpalatable. Also, a browsed biennial, unable to flower, may tiller out and become perennial (e.g. the fireweed *Erechthites* nibbled by wallaby in Tasmania). Seedling trees can be maintained at browse height, but if ungrazed, "escape" to unbrowsable height and shade out other palatable plants. *Overgrazing* may (by damage) cause extinction of palatable selected browse and browsers, but underbrowsing may cause similar effects. *Information* is another resource that can increase with use. It withers or is outdated if not used. Too little impoverishes a system, but when freely used and exchanged, it flourishes and increases.

2. THOSE UNAFFECTED BY USE. In impalpable terms, a view or a good climate is unaffected by use. In palpable terms the diversion of a part of a river to hydroelectric generation or irrigation (the water returned to the stream after use), is also unaffected, as is a stone pile as mulch, heat store, or water run-off collector. A well-managed ecosystem is an example of resources unaffected by use.

3. THOSE WHICH DISAPPEAR OR DEGRADE IF NOT USED. For example an unharvested crop of an annual, or a grass which could be stored for the winter, irruptions of oceanic fish, swarms of bees or grasshoppers, ripe fruit, and water run-off during rains.

4. THOSE REDUCED BY USE. For example a fish or game stock unwisely used, clay deposits, mature forests, and coal and oil.

5. THOSE WHICH POLLUTE OR DESTROY OTHER RESOURCES IF USED. Such as residual poisons in an ecosystem, radioactives, super-highways, large buildings or areas of concrete, and sewers running pollutants to the sea.

Categories 1 to 3 are those most commonly produced in natural systems and rural living situations, and are the only sustainable basis of society. Categories 4 and 5 are as a result of urban and industrial development, and if not used to produce permanent beneficial changes to the ecosystem, become pollutants (some are permanent pollutants in terms of the lifetimes of people).

It follows that a sane society manages resources categories 1 to 4 wisely, bans the use of resource category 5, and regulates all uses to produce sustainable yield. This is called resource management, and has been successfully applied to some fish and animal populations, but seldom to our own lives. Investment priorities can be decided on the same criteria, at both the national and household level.

<u>Policy of Resource Management</u>
A responsible human society bans the use of resources which permanently reduce yields of sustainable resources, e.g. pollutants, persistent poisons, radioactives, large areas of concrete and highways, sewers from city to sea.

Failure to do this will cause the society itself to fail, so that programmes of highway building and city expansion, the release of persistent biocides, and loss of soil will bring any society down more surely and permanently than war itself. Immoral governments tolerate desertification and land salting, concreted highways and city sprawl, which take more good land permanently out of life production than the loss of territory to a conqueror. Immorality of this nature is termed "progress" and "growth" to confuse the ignorant and to supplant local self-reliance for the temporary ends of centralised power.

The key principle to wise resource use is the principle of "enough". This is basic to understanding

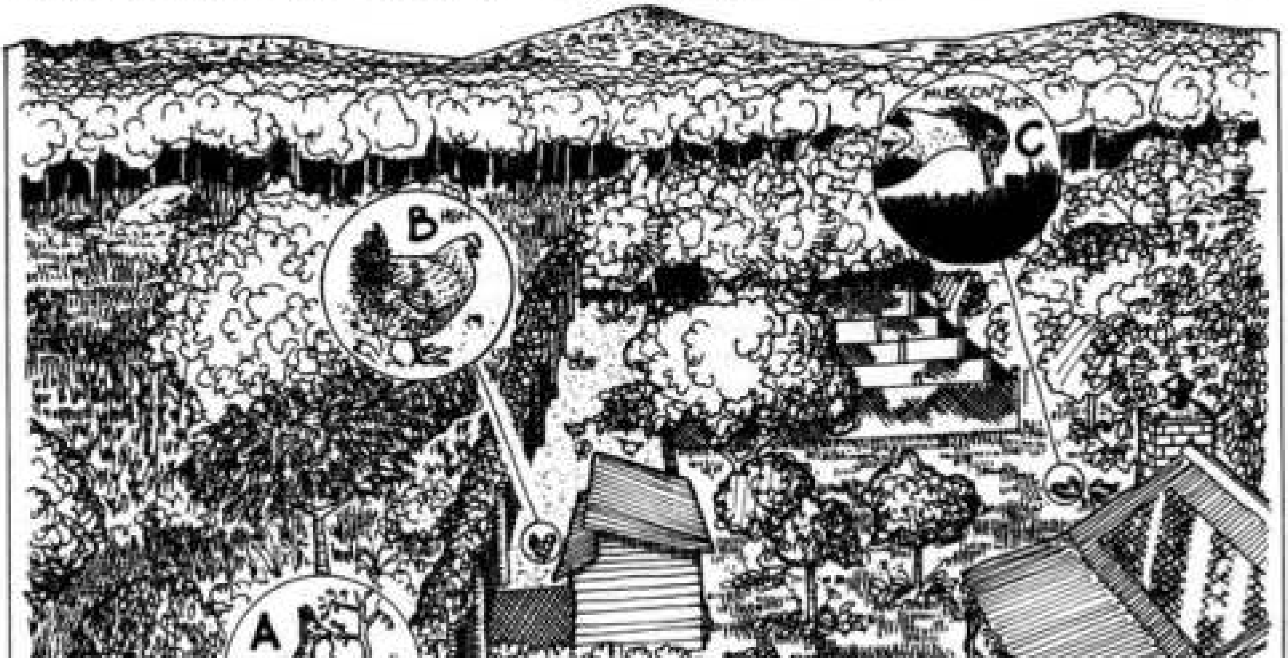


FIGURE 2.2
EVERYTHING GARDENS.
A – Pruning, B – Digging, C – Mowing, D – Typical plant assembly for species. Some species (*Oryctolagus, Cuniculus, Macropus, Gallus, Cairina*, and *Homo sapiens*) at work in their fields. Plants developed by each species are maintained in similar deflection states as lawns, pruned trees, flat weeds, and characteristic herbage around dwellings.

societies in chaos or systems in disorder. Today superhighways and overpasses in Massachusetts alone need some 400 billion dollars to repair, and the collapsing sewer systems of London and New York some 80 billions. Neither Massachusetts, London, nor New York can raise this money, which shows that an unthinking historical development strategy can cripple a future society. Today's luxuries are tomorrow's disasters.

Principle of Disorder
Any system or organism can accept only that quantity of a resource which can be used productively. Any resource input beyond that point throws the system or organism into disorder; oversupply of a resource is a form of chronic pollution.

Both an over- and undersupply of resources have much the same effect, except that oversupply has more grotesque results in life systems than undersupply. To a degree, undersupply can be coped with by reduced growth and a wider spacing or dispersal of organisms, but oversupply of a resource can cause inflated growth, crowding, and sociopathy in social organisms. In people, both gross over- and under-nutrition are common. Ethical resource management is needed to balance out the pathologies of famine and obesity.

2.5 YIELDS

Yields can be thought of in immediate, palpable, and material ways, and are fairly easily measured as:

1. PRODUCT YIELD: The sum of primary and derived products available from, or surplus to, the system. Some of these are intrinsic (or precede design), others are created by design.

2. ENERGY YIELD: The sum of conserved, stored, and generated energy surplus to the system, again both intrinsic and those created by design.

Impalpable yields are those related to health and nutrition, security, and a satisfactory social context and lifestyle. Not surprisingly, it is the search for these invisible yields that most often drives people to seek good design or to take up life on the land, for "what does it benefit a man if he gains the whole world and loses his soul?" Thus, we see the invisible yields in terms of values and ethics. This governs our concept of needs and sets the limits of "enough". Here, we see an ethical basis as a vital component of yield.

Although all systems have a natural or base yield depending on their productivity, our concern in permaculture is that this essential base yield is sustainable. Several factors now operate to reduce the yield of natural systems. In the simplest form, this is the overuse of energy in degenerative systems due to the unwise application of fossil fuel energy. "Poisoning by unproductive use" is observable and widespread.

Thus we must concentrate on productive use, which implies that the energy used is turned into biological growth and held as basic living material in the global ecosystem. Unused, wasted, or frivolously used resources are energies running wild, which creates chaos, destroys basic resources, and eventually abolishes all yield or surplus.

In design terms, we can find yields from those living populations or resources which are the stocks of the biologist (the so-called standing crop) or from non-living systems such as the climatic elements, chemical energy, and machine technology. There is energy stored by extinct life as coal, oil, and gas; energy left over from the formation of the earth as geothermal energy; tides; and electromagnetic and gravitational forces. Cosmic and solar energies impinge on the earth, and life intercepts these flows to make them available for life forms.

In our small part of the system (the design site) our work is to store, direct, conserve, and convert to useful forms those energies that exist on, or pass through, the site. The total sum of our strategy, in terms of surplus energy usefully stored, is the *system yield* of design.

Definition of System Yield
System yield is the sum total of surplus energy produced by, stored, conserved, reused, or converted by the design. Energy is in surplus once the system itself has available all its needs for growth, reproduction, and maintenance.

Some biologists may define yield or production in more narrow terms, accepting that a forest, lake, or crop has a finite upper limit of surplus due to substrate conditions and available energy. We do not have to accept this, as it is a passive approach, inapplicable to active and conscious design or active management using, for example, fertilisers, windbreaks, or selected species.

Even more narrowly defined is the yield of agricultural economists, who regard a single product (peaches/ha) as the yield. It may be this approach itself itself which is the true limit to yield!

A true accounting of yield takes into consideration both upstream costs (energy) and downstream costs (health). The "product yield" may create problems of pollution and soil mineral loss, and cost more than it can replace.

The very concept of surplus yield supposes either flow through or growth within our system. Coal and rock do not have yield in this sense; they have a finite or limited product. Only life and flow can yield continually, or as long as they persist. Thus the energy stocks of any system are the flows and lives within it. The flow may exist without life (as on the moon), where only technology can intervene to obtain a yield, but on earth at least, life is the intervening strategy for capturing flow and producing yield. And technology depends on the continuation of life, not the opposite.

The Role of Life in Yield

Living things, including people, are the only effective intervening systems to capture resources on this planet, and to produce a yield. Thus, it is the sum and capacity of life forms which decide total system yield and surplus.

We have long been devising houses, farms, and cities which are energy-demanding, despite a known set of strategies and techniques (all well tried) which could make these systems energy-producing. It has long been apparent that this condition is deliberately and artificially maintained by utilities, bureaucracies, and governments who are composed of those so dependent on the consumption and sale of energy resources that without this continuing exploitation they themselves would perish.

In permaculture, we have abundant strategies under the following broad categories which can create yields instead of incurring costly inputs or energy supply.

STRATEGIES THAT CREATE YIELDS.

Physical-Environmental:

- The creation of a niche in space; the provision of a critical resource.
- The rehabilitation and creation of soils.
- The diversion of water, and water recycling.
- The integration of structures and landscape.

Biological:

- The selection of low-maintenance cultivars and species for a particular site.
- Investigation of other species for usable yields.
- Supplying key nutrients; biological waste recycling (mulch, manure).
- The assembly of beneficial and cooperative **guilds** of plants and animals.

Spatial and Configurational:

- **Annidation** of units, functions, and species (annidation is a design or pattern strategy of "nesting" or stacking one thing within another, like a bowl in a bowl, or a vine in a tree).
- **Tessellation** of units, functions, and species (tessellation is the forming or arranging of a mosaic of parts).
- Innovative spatial geometry of designs as **edge** and **harmonics**.
- Routing of materials or energy to next best use.
- Zone, sector, slope, orientation, and site strategies (Chapter 3).
- Use of special patterns to suit irrigation, crop systems, or energy conservation.

Temporal:

- Sequential annidation (interplant, intercrop).
- Increasing cyclic frequency.
- Tessellation of cycles and successions, as in browsing sequences.

Technical:

- Use of appropriate and rehabilitative technology.
- Design of energy-efficient structures.

Conservation:

- Routing of resources to next best use.
- Recycling at the highest level.
- Safe storage of food product.
- **No-tillage** or low-tillage cropping.
- Creation of very durable systems and objects.
- Storage of run-off water for extended use.

Cultural:

- Removing cultural barriers to resource use.
- Making unusual resources acceptable.
- Expanding choices in a culture.

Legal/Administrative:

- Removing socio-legal impediments to resource use.
- Creating effective structures to aid resource management.
- Costing and adjusting systems for *all* energy inputs and outputs.

Social:

- Cooperative endeavours, pooling of resources, sharing.
- Financial recycling within the community.
- Positive action to remove and replace impeding systems.

Design:

- Making harmonious connections between components and sub-systems.
- Making choices as to where we place things or how we live.
- Observing, managing, and directing systems.
- Applying information.

This approach to potential production is beyond that of product yield alone. It is theoretically unlimited in its potential, for system yield results from the number of strategies applied, what connections are made, and what information is applied to a particular design.

Now we see that yield in design is not some external, fixed, immutable quantity limited by circumstances that previously existed, but results from our behaviour, knowledge, and the application of our intellect, skill, and comprehension. These can either limit or liberate the concept of yield. Thus, the profound difference between permaculture design and nature, is that in permaculture we actively intervene to supply missing elements and to guide system evolution.

Limits to Yield

Yield is not a fixed sum in any design system. It is the measure of the comprehension, understanding, and ability of the designers and managers of that design.

Defined in this way, yield has no known limits, as we cannot know all ways to conserve, store, and save energy, nor can we fail to improve any system we build and observe. There is always room for another plant, another cycle, another route, another arrangement, another technique or structure. We can thus continually shrink the area we need to survive. The critical yield strategy is in governing our own appetites!

Just as we can increase yield, so we can decrease it. The perverse aims of some politicians, developers, and even religious dogmatists limit yield by disallowing certain products as a yield. Just as one's neighbours may refuse the snail and eat the lettuce, refuse the blackbird and eat the strawberry, so we may only "allow" certain types of toilets, or certain plants in gardens or parks. And thus people are the main impediment to using their potential yields.

FARM STRATEGIES:
CATEGORIES AND EXAMPLES.

If we take as a condition the "fencepost-to-fencepost" grasslands or crops now developing in the western world, and apply the strategies given, then yields will increase. How these systems interact raises yield even more, but on their own they are sufficiently impressive.

Water Storage:
(12–20% of landscape).

1. Product increase, e.g. animal protein production (water is more productive per unit area than land; fish more efficient at food conversion than cattle).

2. Product increase on land remaining due to:
   - irrigation; and
   - water nutrient quality from, e.g. fish manure.

3. Interaction, e.g. ducks on water to increase yields in and around ponds (e.g. pest and weed control, manure).

4. **Microclimatic** buffering due to water bodies (see Chapter 5, Climatic Factors).

Land Forming:

1. Product increase due to even irrigation (no dry areas or waterlogging).

2. Land stability due to reduction of soil loss from water run-off or salting.

3. Gravity flow replaces pumped water (depends on site).

4. Recycling of water possible.

Soil Reconditioning:

1. Product increase due to deeper root penetration.

2. Water infiltration (zero run-off) due to absorption.

3. Buffering of soil microclimate (see Chapter 8, Soils).

4. Supply of essential nutrients.

Establishing of Windbreak and Forage Forest:
(20–30% of landscape)

1. Shelter effects, e.g. increase in plant yields, animal protein, and microclimate buffering both above and below ground.

2. Increase in carrying capacity due to shrub and tree forage.

3. Savings on nutrients recycled via legumes and trees.

4. Intrinsic products of the forest, e.g. nectar for honey, seeds, firewood from fallen timber).

5. Insect and bird escapement, and **pest predator** habitat.

6. **Wildlife corridors**.

Selective Farm Reafforestation:
(*not* industrial forestry)

1. Increase precipitation due to night condensation, water penetration (see Chapter 6, Trees and Their Energy Transactions).

2. Product increase due to superiority of perennials over annuals in bulk, energy savings, and length of yield (**Figure: 1.1**).

3. Increase in rainfall due to trees cross-wind (see Chapter 6).

4. Reduced cost and increased capacity due to selected self-forage browse, e.g. drought-proof stockfeed, medicinal qualities of some perennial plants.

5. Reduced cost due to on-farm durable timber, e.g. fence posts, construction material.

6. Reduced carcass loss due to shivering, sweating, exposure.

7. Increased crop production in sheltered areas.

8. Increased carcass weight due to increased food intake in sheltered conditions (not the same as 6. above), i.e. on hot days cattle will graze all day when they are on shaded pasture, instead of sheltering from the sun.

9. Reduced evaporation from ponds due to less wind over water surfaces (see Chapter 5).

Market and Process Strategies:

1. Selected crop for specialty market for price/ha increase, e.g. fresh herbs near a concentration of restaurants.

2. Marketing by self-pick, mail order, direct dispatch, way-side sale.

3. Processing to a higher order of product (e.g. seed to oil).

4. Processing to refined order (e.g. crude eucalyptus oil to fractions).

5. Money saved by processing fuels on farm; plus sale of surplus fuel.

Social/Financial:

1. Market stability gained by farm-link strategy, where an urban group contracts to buy specific produce from the farmer.

2. Income from field days and educational courses.

3. Rental or income from urban visitors e.g. a guest house or holiday farm.

4. Direct investment by city people in a particular farm.

5. Formation of a local credit union and bank for the district, thus recycling money locally.

6. Vehicle and implement pool with neighbours; schedules of sowing and reaping worked out (capital saved 90%).

7. Labour exchange with neighbours.

8. Produce and marketing cooperatives.

Crop techniques:

1. Low or no-tillage farming saves:
   - energy in reduced tillage;
   - soil;
   - water and reduces evaporation; and
   - time between crops.

To put these into practical terms, I have culled from an interview with a farmer (Norm Sims, *Weekly Times*, 5 Jan. 1983) statements on savings due to some site strategies applied. On land-forming: "We expect to double production over the next few years, using half the irrigation waters" (4 times benefit); "Salinity is reduced". In severe drought: "Pasture production has never looked better and water is available". "It took us six days to irrigate what we now do in two..." and, "Rather than restricting watering intervals we are restricting the area" (aiming to milk 185 cows on 24 ha. On grazing rotation and electric fencing: "26 paddocks are grazed in a 21 day rotation" (average field of 1.6 ha each with a trough water-point for cattle).

Here, there are these specific strategies in use:

- laser levelling of fields for even irrigation;
- water reticulation;
- water storage and recycling;
- grazing rotation of 21 days;
- central access road;
- crop for concentrated rations grown; and
- pasture area reduced to give best watering regime.

It seems obvious from the foregoing that the *primary* and *certain* increases in crop yield do not just come from varietal selections (a fiction promulgated by agricultural companies, seed patent holders, agricultural researchers, or extension officers), but from attention to site design and development, followed by wise enterprise selection to suit the (modified) site, concurrently with a marketing and processing strategy.

As these are often permanent or durable strategies, it is not in the commercial interest to encourage them, as the continuous benefit is to the farmer alone, and the role of middlemen and traders is reduced. But, in the western world, the 4-6% of us in essential production are in fact enslaved, while the remaining 96% are deriving secondary or tertiary benefits without adequate return to the primary producers. This can only result in a weak economy, waste, and irresponsibility for life existence based on the expectation that the world owes politicians, students, and middlemen a living.

Benefits, like wastes, must be *returned* or recycled to keep any system going. Accumulations of unused benefits are predictive of a collapse at production level; thence, throughout all tiers of the system.

EXTENDING YIELDS

The concentration of yields into one short period is a fiscal, not an environmental or subsistence strategy, and has resulted in a "feast and famine" regime in markets and fields, and consequent high storage costs. Our aim should be to disperse food yield over time, so that many products are available at any season. This aim is achieved, in permaculture, in a variety of ways:

- By selection of early, mid and late season varieties.
- By planting the same variety in early or late-ripening situations.
- By selection of varieties that yield over a long season.
- By a general increase in diversity in the system, so that:
- Leaf, fruit, seed and root are all product yields.
- By using self-storing species such as tubers, hard seeds, fuelwood, or rhizomes which can be cropped on demand.
- By techniques such as preserving, drying, pitting, and cool storage.
- By regional trade between communities, or by the utilisation of land at different altitudes or latitudes.

YIELDS AND STORAGE

How yields endure is important, for there are unlimited opportunities to use durable yields in terms of season or lifetime.

By a series of preservation strategies, food can be stored for days, weeks, or years. Water not open to evaporation and pollution, or with natural cleansing organisms, will keep indefinitely. Shelters may outlast the forests that build them, or can be made of living or durable materials such as ivy, concrete, or stone. Energy alone (like the food which is part of energy) is difficult to store. Batteries leak or decay, heat escapes, and insulation breaks down. Only living things, like forests, increase their energy store.

Because of seasonal or diurnal cycles, we should pay close attention to storage strategies. Very little famine would occur could grains, fish, and fruit available in good times be stored for lean times. The strategies of food storage are critical. I believe that people should therefore mulch their recipe books, which often specify out-of-season or not-in-garden foods, and replace them with books that stress either low-energy methods of food preservation, or how to live easily from your garden in season.

CULTURAL IMPEDIMENTS TO YIELD.

I confess to a rare problem—gynekinetophobia, or the fear of women falling on me—but this is a rather mild illness compared with many affluent suburbanites, who have developed an almost total zoophobia, or fear of anything that moves. It is, as any traveller can confirm, a complaint best developed in the affluent North American, and seems to be part of blue toilet dyes, air fresheners, lots of paper tissues, and two showers a day.

It is very difficult, almost taboo, to talk of using rabbits, quail, pigs, poultry, or cows in city farms or urban gardens in the United States. They are commonplace city farm animals in England, and are ordinary village animals in Asia. Australians feel no repulsion towards them, and the edible guinea-pig lives comfortably in the homes of South Americans. But in the USA, no!

Useful animals are effectively abolished from American cities, leaving the field wide open for a host of others: pigeons forage the streets, thousands of gulls defecate in New York City reservoirs (fresh from the garbage piles); gigantic garbage bins are tipped over by large, flea-ridden dogs in Los Angeles; rats half the size of dogs (and also flea-ridden) are waiting for the garbage left by the dogs, and have tunnelled under the bus stops in their millions in Washington, D.C. (not far from the White House). They in turn are stalked by mangy cats, who also keep a desultory eye on the billions of cockroaches crawling in most houses. Not to mention the flies.

We will omit the legendary albino alligators of the sewers, and the rejected boa constrictors that pop up in the blue-rinse toilets. So much wasted food breeds its own population of pests. A sensible re-routing of edible garbage through a herd of pigs or a legion of guinea-pigs would abolish much of this nuisance, and a few good Asian restaurants could deal with the cats and dogs. The gulls would starve if chickens were fed on household wastes, and the besieged American might add a very large range of foods to those now available in cities. I mention this only to show that cultural prejudices can grossly reduce the available food resources, and that if we refuse to take sensible actions, some gross results can follow, with the biomass of useful foragers such as domesticated animals replaced by an equivalent biomass of pests.

MAXIMUM PRODUCT YIELD CONCEPT: THE "BIG PUMPKIN" FALLACY.

In a fluctuating climatic and market environment, the concept of forcing a *maximum product yield* is courting disaster. This is, however, the whole impetus of selling (e.g., the "big pumpkin" and "giant new variety" advertisements in seed catalogues), or in prizes awarded at agricultural shows. Better by far are more crop mixes and fail-safe systems that can produce in most conditions (wet or dry, cold or hot), or that hold constant value as subsistence (potato, taro, arrowroot) or have special value (vanilla, quinine, bamboo), or high food value per volume (fish, chicken).

The factors which can increase product yield are these:

- Genetic selection;
- Increased fertiliser (to a limited extent);
- Increased water (to a limited extent);
- Decreased competition from other non-beneficial species; and
- Better management in utilisation of yield and of harvest, timing, and integration.

They are the same factors which cause imbalance, as the selection of types for a particular yield need not be the factor that enables it to produce consistently in field field conditions (whether it be feathering to a "standard" in a chicken, redness in a rose, or weight in a fish). High-producing hens need biennial replacement (thus a constant breeding program) and may not even set their own eggs, thus needing artificial aids. A water and fertiliser-dependent crop is liable to collapse when it is water or nutrient stressed, or becomes too expensive to maintain in any market downturn. To go for one such crop, and so decrease diversity, is to decrease insurance for yield if one species or variety fails or is susceptible to change. Peasant farmers rightly reject advice based on maximum yield fallacies, and even more so if they share crops with a landlord, for they also value their spare time.

In the case of livestock, forced production is eventually limited by insoluble or intractable illnesses, so that in high-producing New Zealand herds, veterinary costs reach $120 per stock unit (for chronic illnesses such as facial eczema and white muscle disease). On less stressed pastures and farms, veterinary costs drop away to $20 or so per unit, top-dressing of pasture is reduced, and healthier herds give healthier yields. In the end, the forcing of product yields creates unique and inflexible health problems in plants, soils, and animals. Such yields become economically and ecologically unsustainable, and a danger to public health. 93% of chickens in battery cages develop cancers. If we eat cancer, we must risk cancer, for "we are what we eat" in a very real sense.

Insurance of some yield on a sustainable basis is better than expensive "feast and famine" regimes. The home garden is one such secure approach, where it is rare for all crops to fail, because of the innate diversity of such a mixed system. In fact, it is commonplace for gardeners to find a garden plant or some varieties fail in any one season, but no great harm results, as many other crops or varieties are available. Thus, species and and variety diversity are what people really need. Plant Variety Rights legislation, plant patenting, and multinational seed resource ownership has had a disastrous effect on the availability of hardy, adapted local varieties of plants, especially in Europe, where some 85% of locally-adapted seed crops have become "illegal", or have disappeared from seed company catalogues.

There are several paths open to us in design, and the least energy path is the one we seek, or evolve towards. There are two ways of producing an egg: the first has become the normal way in the western world (**Figure 2.3**), and the second is the way proposed by permaculture systems (**Figure 2.4**).

Some ridiculous systems have been evolved in which people, machines, time, and energy are expended in vast quantities on the chicken, perhaps with the aim of maximum product yield, regardless of costs. We can short-cut these systems with great gains in personal and planetary health, and with a far greater variety of yields available for local ecologies. These illustrations also bring home the commonsense nature of self-regulated systems.

2.6

CYCLES: A NICHE IN TIME

Cycles are any recurring events or phenomena. They have another implication, which is one of diversion. A cycle is, if you like, an interruption or eddy in the straight-line progression towards entropy. It is the special provenance of life to cycle materials. So efficiently does this happen that in a tropical forest almost all material nutrients are in cycle in life forms. It is this very complex cycling in the tropics which opened up so many opportunities for yield that thousands of species have evolved to take advantage of these.

If NICHES are opportunities in space, CYCLES are opportunities in time (a time-slot) and both together give harbour to many events and species. Geese eat grass, digest it, moult, produce waste products, add parasites, digestive enzymes, acids and alkalis, and defecate. The ground receives the rejecta, the sun shines, and rain may fall. Fungi, bacteria, grass roots and foliage work on feathers and faeces, and re-metabolise them into life. If we reorganise and encourage such cycles, our opportunities to obtain yields multiply. Every peasant farmer who keeps pigeons (as they still do in the Mediterranean borders) knows this truth. Here, every thinking farmer builds his own phosphate factory, as a pigeon loft.

Each such cycle is *a unique event*; diet, choice, selection, season, weather, digestion, decomposition, and regeneration differ each time it happens. Thus, it is the number of such cycles, great and small, that decide the potential for diversity. We should feel ourselves privileged to be part of such eternal renewal. Just by living we have achieved immortality—as grass, grasshoppers, gulls, geese, and other people. We are *of* the diversity we experience in every real sense.

If, as physical scientists assure us, we all contain a few molecules of Einstein, and if the atomic particles of our physical body reach to the outermost bounds of the universe, then we are all *de facto* components of all things. There is nowhere left for us to go if we are already everywhere, and this is, in truth, all we will ever have or need. If we love ourselves at all, we should respect all things equally, and not claim any superiority over what are, in effect, our other parts. Is the hand superior to the eye? The bishop to the goose? The son to the mother?

<u>Principle of Cyclic Opportunity</u>
Every cyclic event increases the opportunity for yield. To increase cycling is to increase yield.

People are built up molecule by molecule, cycling through themselves the materials of their environment: its air, soils, foods, minerals, and pathogens. Over time, people create their own local ecology (as do wombats and all sedentary animals); their wastes, exudae, and rejecta eventually create the very soils in which they garden. "Garbage in, garbage out" applies equally to computers and people. We gardeners are constantly cycling ourselves, and by a generational pattern of adjustment become "eco-compatible" with our landscape and climate. We are not the end point of evolution but a step on the way, and part of a whole sequence of cycles.

It is the number of such degenerative-regenerative cycles, unknowable to us, which determine the number of *opportunities* in the system, and its potential to change, mutate, diversify, and reintegrate. Not only can we never cross the same river twice, we can never see the same view twice, nor know the same system twice. Every cycle is a new opportunity. In nature, it is our right to die and make way for our successors, who are ourselves re-expressed in different forms.

It is our tolerance of the proliferation of life which permits such cycles. Deprived systems, like those blasted by biocides, lose most or all opportunity to transcend their prior state, and the egg of life is broken, degrades, and assumes a lower potential.

Tribal peoples are very much aware of, and tied to, their soil and landscapes, so that their mental and physical health depend on these ties being maintained. The rest of us have suffered forcible, historic dislocations from home sites, and many no longer know where home is, although there are new and conscious moves to reinhabit the earth and to identify with a **bioregion** as "home."

Travel itself causes stress and morbidity. Travellers both carry and acquire pathogens and spread them to other cultures. New settlers bring new species, new timetables, and new concepts. Local systems have to readjust, or fail. These processes are analagous to the disturbance of old ecosystems by new ecological or climatic forces. The post-invasion evolution contains part of the old and part of the new system, so is itself a new assembly with new potentials. Too often, however, we have destroyed very productive local ecologies, only to replace them with energy-consuming "improvements" of our own making. We have assumed the role of the creator, and destroyed the creation to do so.

Cycling of nutrients is continuous in the tropics, but is interrupted wherever drought, cold, or low nutrient status reduces the "base opportunity", just as the killing of fish stocks reduces the yield. Such cycles are slowed or even stopped by climatic factors or by our interference.

Cycles in nature are diversion routes away from entropic ends—life itself cycles nutrients—giving opportunities for yield, and thus opportunities for species to occupy time niches.

Cycles, like comets, have schedules or times to occur. Some are frequent and obvious like day and night, others long-term like sunspot cycles. Both short and long cycles are used in phenomenological reckoning by aborigines, who use cycle-indicators as time maps.

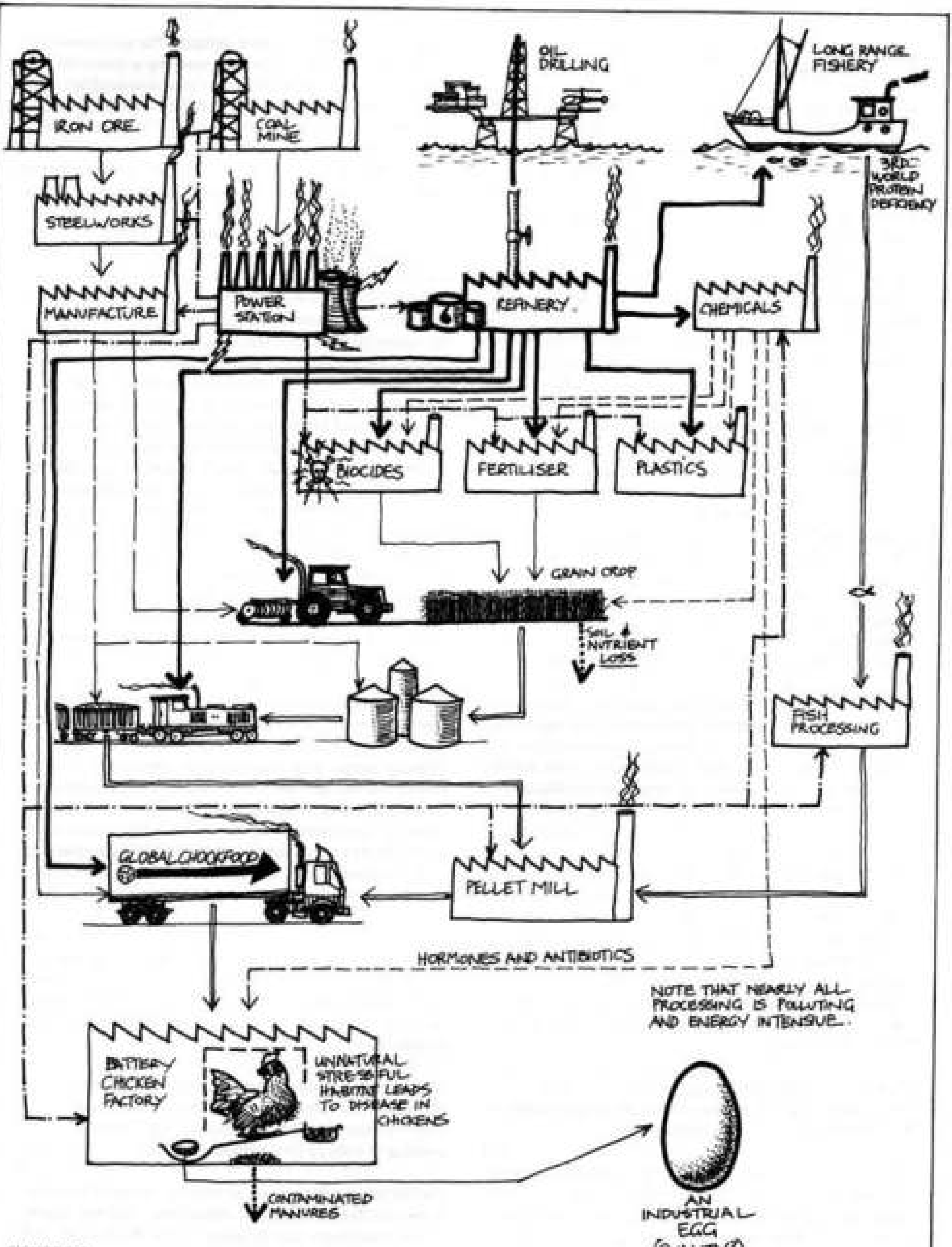


FIGURE 2.3
INDUSTRIAL METHODS OF PRODUCING AN EGG.

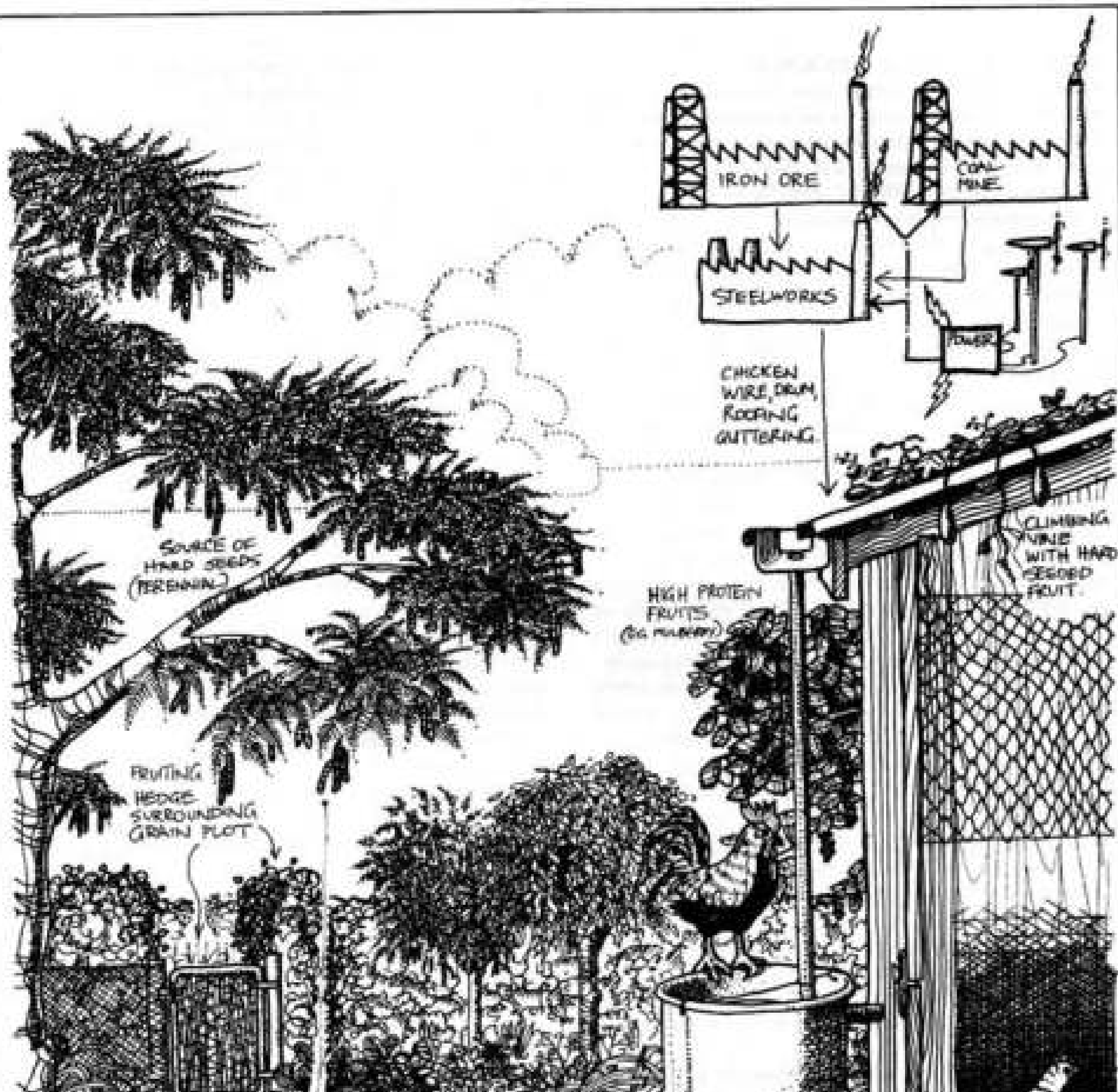


FIGURE 2.4
PERMACULTURE METHODS OF PRODUCING AN EGG.

ASPECTS OF THE TIME RESOURCE.

Time is a resource which can accumulate in ecosystems. It can be "lost" to an evolving or evolved system by setback (adverse disturbance), just about the same way as we can set back the hands of a clock. Such setbacks are termed *deflection states* by ecologists.

Ecosystems, especially those we are in process of constructing or destroying, are always proceding to some other state of evolution. Left alone, they may evolve at their own pace to some unknowable (or imaginary) endpoint, which we once called a climax state. However, forest climax states are temporary events in the long span of geological time.

Australian studies show that old dune forests lose the battle to mobilise nutrients, and begin to show a net nutrient loss, aided by rainfall and occasional fire, until they begin to recede to a less vigorous shrubbery system. Most other (disturbed) forests appear to be building, but (if disturbed too often) never reach the previous vigour, height, or yield. This is obvious to many of us who have seen original, regrowth, and second regrowth tree stands. These show signs of decay at progressively lower heights, and no doubt these too are losing vitality with age. I can sympathise.

Time can work as a rehabilitative resource, for active intervention in such successions enables us to analyse and to supply key nutrients and soil treatments, if needed, to assist maximum forest rejuvenation .

A second time concept is that of life-time, or the "quality time" that we have to enjoy, examine, and understand our world. To the interested observer, it would seem that life-time is very short indeed for those mobile, power-using, bombarded, employed, make-work, and busy humans who make up non-tribal societies, while many tribal peoples still manage to preserve a high quota of the celebrations, discussions, contemplations, mutual preening, and creative artwork on which many of us "wish we had time to spend..."

This erosion of the lifetimes of people, exacerbated by the media and messages of the consumer society, is perhaps the most serious effect of that society.

> Life is too much with us, late and soon
> Getting and gaining, we lay waste our years...
> (W. B. Yeats)

People so harried that they have "no time for anything else", may find that time has run out to save themselves, their lives, or those of their children.

A NICHE IN TIME AND SPACE.

Niche is a place to be, to fit in and find food, shelter, and room to operate. Many such niches are unfilled due to chance factors. Many are wiped out by agriculture or urban sprawl. Many can be created. But in pursuit of a simple food product, most farmers give no place for wildlife, no nesting sites or unbrowsed grass for quail or pheasant (both industrious insect eaters), and often no time for any intelligent assessment of the potential benefits of other species.

Existence is not only a matter of product yield, but a question of appreciating variety in landscape. Evolving plant systems and existing animals provide niches for new species: the cattle egret follows cattle; the burrows of rabbits are occupied by possum, bandicoot, snakes, frogs, and feral cats; and the growing tree becomes a trellis, shade spot, and a host to fungus and epiphytes.

Every large tree is a universe in itself. A tree offers many specialty-forage niches to bird, mammal, and invertebrate species. For instance, yellow-throated honeyeaters (in Tasmania) search the knot-holes for insects, treecreepers the bark fissures, strongbilled honeyeaters the rolls of branch bark and hanging strips of bark, and blackheaded honeyeaters the foliage, where pardalotes specify the scale insects as *their* field. As for time-sharing, the yellow-throats are permanent and territory-holding residents, the treecreepers migrants, the strongbills and blackheads roving flock species, and all of them scatter as breeding pairs in the spring and summer, so that it is rare to find any one tree fully occupied at any one time. There is also a pronounced post-breeding tendency for several bird species to form **consociations** for foraging and travelling in autumn and winter. Five to eight species travel together, some (e.g. fly-catchers) gathering insects disturbed by the others, with all species reacting to the alarm calls of any one species, but some species (mynahs for example) acting as sentinels for the whole mixed company.

Here, we see time, space, and functions all used in a complex and non-competitive way, and glimpse something of the potential for designers to enrich human societies *providing that no individual or group claims a right to sole use at all times* for an area. The failure of a monoculture to produce, sustain, or persist is thus easily explained, as many species are invading or trying to use more efficiently the complex resources of time and space.

A combined space-time factor is called a **schedule**: a time to be in that place. Any observer of public park use sees the usage change hour by hour. Morning joggers give way to lunch-time office workers, who are succeeded by older, retired people playing draughts, later displaced by evening entertainment crowds, and late at night, the people on the edge of time: the semi-legal, the unemployed, and the lonely. Towards dawn, only the lame and isolated strollers, often with dogs for companions, remain on the streets.

Many mammals, forced to develop tracks and resting places, do not control "areas", but rather time-slots in space. My own studies of wild wallaby, urban people, and possum show this to be the case. Fighting occurs when one is *out of schedule*, and ceases when that place is vacated for use.

Schedules may run on long cycles, tuned to the level of browse or succession of vegetation, e.g. a sequence of grazing has been observed for African herds, so that

FIGURE 2.5
NICHES IN SPACE AND TIME; SCHEDULES.

Not only can we fit species into various levels of plant structure, and broad ecotones of vegetation and soils, but also season, time of day, migration, and scheduling of SPACE–TIME relationships allows a complex use of vegetative resources by a great variety of animal species, such as we see in the natural world.

In this landscape, plant and animal species can find innumerable niches:

a) In the vertical structure of vegetation (I – IV) including a root zone;
b) Across the aspects, zones, or soil catena variations with slope, and with soil water depth;
c) In the different orders of flow in streams;
d) Within the different species that occupy specific sites or assemblies;
e) At the edges or boundaries of any system.

All of the above are independent 'dimensions' of the total SPATIAL system. As well:

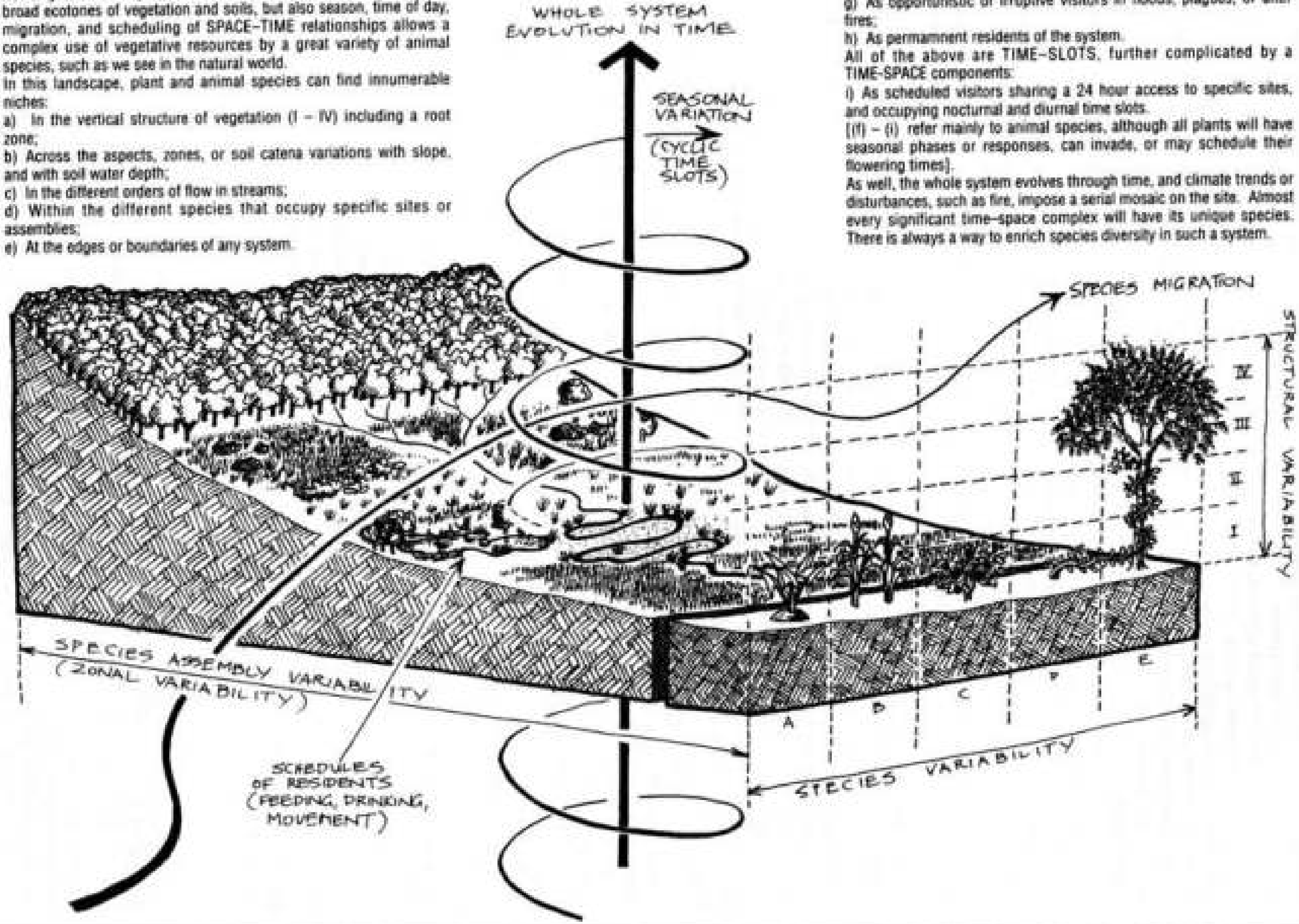
f) As seasonal migrants through the system;
g) As opportunistic or irruptive visitors in floods, plagues, or after fires;
h) As permamnent residents of the system.

All of the above are TIME–SLOTS, further complicated by a TIME-SPACE components:

i) As scheduled visitors sharing a 24 hour access to specific sites, and occupying nocturnal and diurnal time slots.

[(f) – (i) refer mainly to animal species, although all plants will have seasonal phases or responses, can invade, or may schedule their flowering times].

As well, the whole system evolves through time, and climate trends or disturbances, such as fire, impose a serial mosaic on the site. Almost every significant time–space complex will have its unique species. There is always a way to enrich species diversity in such a system.



antelope follow wildebeest follow elephant (or some such sequence) for many herd species.

This suggests that informed graziers, knowing the preferences of different species (sheep follow cattle follow horses follow goats) can make much better use of the basic browse resource by scheduling rotation (not to keep one level of browse constant, but to dynamically balance levels by species succession).

Scheduling (the "right" to use a particular space at a specific time) occurs within species, where dominant animals use prime grazing land at prime time, and sub-dominants are pushed to the edge of time and space, or between species, so that sequences of different species use the same area of vegetation at different seasons or stages of growth. No individual "owns" the area, just a time-space slot (like a chair in a family kitchen at dinnertime). In Tasmania, there are two prime time activity peaks for wallaby over 24 hours, both at night: the main one is crepuscular (just after sundown), and the secondary one is auroral (just before dawn). This permits digestive and recuperative rest periods, denied to weaker animals who cannot compete for preferred periods. Within this framework, any possum can, by aggression, displace a wallaby at a feeding-place. Any individual holds a place only for a short time, moving on to contest another area until satiated. Thus, the sharing of resources is a complex dynamic, but no species or individual has sole rights. A human analogy would be that of a sports-ground used by different sports groups at times, by gulls or rodents whenever sports are not being played, and by worms at all times.

To summarise, we have:

- Niche in space, or "territory" (nest and forage sites);
- Niche in time (cycles of opportunity); and
- Niche in space-time (schedules).

Between these, there is always space or time available to increase turnover. Niches enable better utilisation and greater diversity, hence more yield. Of all of these niches, schedules are the best strategy for fitting in new species of mammals, providing these are not territorial species (which try to hold their own space at all times), but are chosen from cooperative species which yield space when the time is right (see **Figure 2.5**). There are lessons here for people: those who try to hold on to all things at all times prevent their use by others.

2.7
PYRAMIDS, FOOD WEBS, GROWTH, AND VEGETARIANISM

A figure often used to explain how much of a food or forage is needed to grow another animal is the *trophic pyramid*. While the pyramid is a useful concept, it is very simplistic, and in all but laboratory conditions or feed-lot situations, it is unrelated to field reality, and may only apply where we actually provide simple food to captive species. The field condition is very different (**Figure 2.6**).

The pyramid is often used to support claims that we should all become vegetarians, or herbivores. This is perhaps not so far from the truth, but there are real-world factors to consider. I have shown the pyramid and also a direct path (herbage to human) to illustrate how we would support more people if we ate vegetation. But we need to re-examine this concept for people who return their wastes to gardens. There are the following factors to consider:

1. NATURE IS MUCH MORE COMPLEX than is shown in a pyramid. Instead of simple "trophic levels", we have a complex interaction of the same species, largely governed not by food habits, but by pasture management practices. Such a complex diagram is called a *food web*, and is the normality in field conditions.

2. PYRAMIDS IGNORE FEEDBACK. In a very real sense vegetation eventually "eats" grasshoppers, frogs, fish, and people. Not only that, but as an animal grows, it returns nutrient to the soil via excreted, moulted, or discarded body wastes, and even if the frog eats 10 kg of grasshoppers to make one kilo of frog, it doesn't (obviously) keep the 10 kg in a bag, but excretes 9 kg or more back to earth as manures. This causes more vegetation to grow, thus producing more grasshoppers. The manure from insect "pests" may be the basis of a regenerative future evolution.

With these obvious feedbacks, the web itself becomes much more complex, and it starts to resemble less of a one-way staircase (the pyramid) than a series of cyclic events; less of a ziggurat and more like a spider's web. So that the real position is that waste recycling to herbage is the main producer of that herbage.

3. WHAT OF MATURITY? If our fish (level 4) was a carp, and that carp was more than a year or two old, then it would probably have reached full size, although it may then continue to live for another 80-100 years.

So now, the carp (at 80 years old and 10 kg weight) has eaten 100 x 10 kg = 1000 kg of frogs and insects, and has returned 990 kg of digested material per year to the pond, to grow more herbage. Thus, in order to keep the system in growth, we must be able to efficiently crop *any* level just before maturity is reached. We can see that old or mature systems no longer use food for growth, but for *maintenance*. So it is with mature fish, frogs, forests, and people.

Old organisms thus become constant recyclers (food in, waste out) and cease to grow, or they even begin to lose weight. This is why we try to use only young and growing plants and animals for food, if food is scarce. An exception is a fruit or nut tree, where we consume seed or fruit (seed is an immature tree).

4. ARE FOOD CHAINS SO SIMPLE? We know that people normally eat vegetation, and that many people eat grasshoppers, frogs, fish, and (at times) other people. Even a cow eats grasshoppers as it eats grass, and of course every eater ingests large quantities of

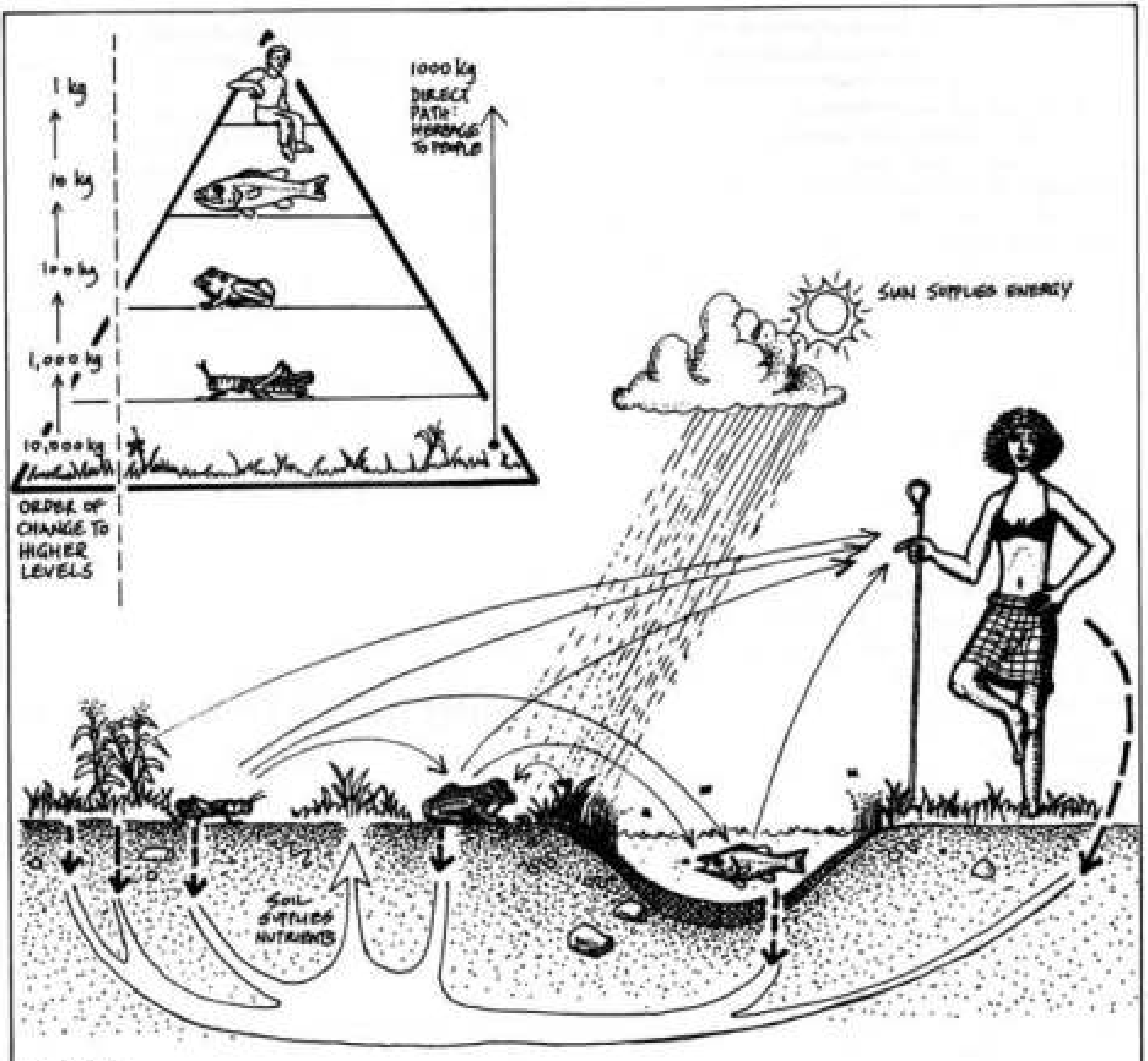


FIGURE 2.6
TROPHIC PYRAMID.
Life systems are rarely strictly hierachical as in the pyramid structure. Most species are omnivorous and *all* species recycle valuable waste products to lower levels of the trophic ladder. Thus, life systems are a web or cyclic systems rather than a pyramid.

bacteria and small animals living on vegetation. "Man cannot live by bread alone", unless in a sterile laboratory condition!

As our one-way pyramid is very suspect, so is the argument that we should become vegetarians to ameliorate the world food shortage problem. Only in home gardens is most of the vegetation edible for people; much of the earth is occupied by inedible vegetation. Deer, rabbits, sheep, and herbivorous fish are very useful to us, in that they convert this otherwise unusable herbage to acceptable human food. Animals represent a valid method of storing inedible vegetation as food. If we convert all vegetation to edible species, we assume a human priority that is unsustainable, and must destroy other plants and animals to do so.

In the urban western world, vegetarianism relies heavily on grains and grain legumes (e.g. the soya bean). Even to cook these foods, we need to use up very large quantities of wood and fossil fuels. Worse, soya beans are one of the foods owned (100% of patent rights) by a few multinationals. They are grown on rich bottomland soils, in large monocultural operations, and in 1980–82 caused more deforestation in the USA and Brazil than any other crop. Worse still, about 70% of the beans were either fed to pigs, or used in industry as a base for paint used on motor vehicles!

Much worse again, grains and grain legumes account for most of the erosion of soils in every agricultural region, and moreover, very few home gardeners in the developed world ever grow grains or grain legumes, so that much of what is eaten in the West is grown in areas where real famine threatens (mung beans from India, chick peas from Ethiopia, soya beans from Africa and India).

Old farmers and my own great-grandfather had a saying that bears some consideration. This was: "We will sell nothing from our farm that will not walk or fly off." In effect, the farmer was concerned to sell *only* animals, never crops or vegetation, because if the farm was to survive without massive energy inputs, animals were the only traditional recycling strategy for a sustainable export market.

What does all this mean to concerned and responsible people in terms of their diet and food habits, with respect to a sustainable natural system?

1. Vegetarian diets *are* very efficient, providing:
   - They are based on easily cooked or easily processed crop grown in *home gardens*;
   - That wastes, especially body wastes, are returned to the soil of that garden; and
   - That we eat from where we live, and do not exploit others or incur large transport costs.
2. Omnivorous diets (any sort of food) make the best use of *complex natural systems*; that we should eat from what is edible, at any level (except for other people in most circumstances, and under most laws!)
3. Primarily carnivorous diets have a valid place in special ecologies, such as areas of cold, where gardening cannot be a sufficient food base; in areas where people gather from the sea; where harsh conditions mean reliance on animals as gatherers; and where animals can use otherwise-waste products, such as vegetable trimmings, scraps, or rejected or spoilt vegetation.
4. We should always do our energy budgets. Whatever we eat, if we do not grow any of our own food, and over-use a flush toilet (sending our wastes to sea) we have lost the essential soil and nutrients needed for a sustainable life cycle.

While a tropical gardener can be very efficient and responsible by developing fruit and vegetable crop which needs very little cooking, sensible omnivorism is a good choice for those with access to semi-natural systems. City people using sewers would be better advised to adopt a free-range meat diet than to eat grain and grain legumes. Better still, all city waste should be returned to the soils of their supply farms.

Even in our garden, we need to concentrate on cycles and routes rather than think in pyramids. Simplistic analysis of trophic levels fails to note that some food resources are unusable by people, either because the energy needed in processing is too much (since some products of nature are poisonous or unpalatable foods), or because the resources are too scattered to repay our collection. Such resources are often harvested into useful packages by other species. Herons, themselves edible, eat poisonous toadfish, and goats will browse thorny and bitter shrubs. Thus we can specify these useful conversions before blindly eliminating a life element *of any type* from our diets.

While it is manifestly immoral to feed edible Peruvian fish to hogs in the USA, it may be of great value to convert forest acorns (unharvested in the USA) to hogs, and let the pilchards and anchovies feed the hungry of Peru (which includes the pelicans!)

The trophic pyramid is valid enough as a conceptual model, for we can see that poisons at the base concentrate at the top. In fact, the highest level of some radioactives and DDT measured are found in mothers' milk. We can see that the generalised or omnivorous (non-selective) feeder is buffered from catastrophic famine by a complex web of trophic connections, so that some losses and some gains accrue to people, being generally omnivorous.

In short, people need to discard fixed ideas, examine their kitchen cupboards, and try to reduce food imports, waste, and energy loss. A responsible diet is not easy to achieve, but the solutions lie very close to home. Viva the home gardener!

2.8
COMPLEXITY AND CONNECTIONS

There are ecologies on very flat and somewhat invariant sites that in the end simplify, or are originally simple because that condition itself is not typical of the earth's crust, just as a field, levelled, drained, and fertilised for a specific crop will not support the species that it once did when it varied in micro-elevation, drainage, and plant complexities. Other simple natural ecologies occur where rapid change can occur (sea coasts), or where we deliberately fire or plough on a regular basis, so that there is never enough time for a diverse system to establish.

Marshes, swamps, tidal flats, salt-pans, and level deserts support less diversity than adjoining hill and valley systems, but nevertheless in sum (if species are assembled from global environments or from similar climatic areas) are still very rich, and, in the case of mangrove and tidal marsh, extremely productive ecologies.

It is not that a single stand of one mangrove species is itself so diverse, it is the mobile species working at different stages of decomposition of the mangrove leaf. Each of these species in turn feeds others.

Thus, very simple plant associations may support very productive and complex animal associations. Mobile species are capable of occupying a great variety of niches in one mangrove tree or swamp stand, from underground to canopy, and of schedules from low to high tide. Time and space are needed for tree species to evolve a complex stand in such situations, and as they are often obliterated and re-established by a world-wide change due to a sea level fluctuation, relatively little time can be allowed for mangrove species to themselves develop and colonise the new, and potentially short–term, shoreline.

Old deserts, like that of Central Australia, may exhibit some 3000 species of woody plants, while recently desertified areas, like those of southwest Asia, may have as few as 150 plants surviving the recent changes from forest. We can, in these cases, act as the agents of constructive change, bringing species to assist local re-colonisation from the world's arid lands. Such species will assist in pioneering natural reafforestation. This has not generally been our aim, and we annually destroy such invaluable species complexes to grow a single crop such as wheat, thus laying waste to the future.

The number of elements in an aggregate or system certainly affects its potential complexity, if complexity is taken to be the number of functional connections between elements. In fact, as Waddington (1977) points out, in the case of a single interaction (a conversation) between elements, complexity goes up roughly as the square of the number of elements: "Two's company, three's a crowd"...and five or six is getting to be a shambles!

This is bad enough, but if we consider the number of possible connections to and from an element such as a chicken (**Figure 3.1**), we can see that these potential connections depend on the information we have about the chicken, so that the complexity of a system depends on the information we have about its components, always providing that such information is used in design. As we cannot know everything, or even know more than the approximate categories and quantity of things which are (for example) eaten by chickens, thus in permaculture we always suppose that the chicken is busy *making connections itself*, about which we could not know and, of course, for which we could not design. We must simply trust the chicken.

Thus, in commonsense, we can design for what we believe to be essentials, and let the chicken attend to all the details, checking at later stages to see that yields (our ultimate products) are satisfactory, the chickens healthy and happy, and the system holding up fairly well.

It is important to concentrate on the nature or value of *connections between elements*. In nature, we can rarely connect components as easily as a wire or piece of pipe can be fixed into place. We do not "connect" the legume to the orange tree, the chicken to the seed, or the hedgerow to the wind; we have to understand how they function, and then place them where we trust they will work. They then proceed to do additional tasks and to provide other connections themselves. They do not confine their functions to our design concepts!

Evolving complex species assemblies in isolated sites, like the Galapagos Islands, may depend more on a species–swarm arising from pioneer or survivor species than on invaders adapting from borderlands. Only when many niches are empty is a species able to differentiate and survive without competition; so the dodo and Darwin's finches arose. Having arisen, they may then well prove to be very useful to other systems. Unique island species often have functions not easily found in continental and crowded ecologies; frequently, hardy travelers like reptiles and crustaceans take up those niches that, on continents, are occupied by species of mammals and birds.

It is not enough to merely specify the *number* of connections, and not note their value in the system as a whole; it may be possible that complex social situations and cultivated or chance complexity may occur in natural systems by introductions or migrations. These new events, although increasing complexity, may reduce stability with respect to a desirable local yield. Thus, where the *benign* complexity of cooperative organisms is useful, competitive or inharmonious complexity is potentially destructive. Again, it is a question of matching needs with products, and of the values given to connections.

2.9
ORDER OR CHAOS

It follows that order and disorder arise not from some remote and abstract energy theory but from actual ground conditions or contexts, both in natural and designed systems. Entropy is the result of the framework, not the complexity. A jumble of diverse elements is disordered. An element running wild or in an active destructive mode (bull in a china shop) is disordered, and too few or too many forced connections lead to disorder.

Order is found in things *working beneficially together*. It is not the forced condition of neatness, tidiness, and straightness all of which are, in design or energy terms, disordered. True order may lie in apparent confusion; it is the acid test of entropic order to test the system for yield. If it consumes energy beyond product, it is in disorder. If it produces energy to or beyond consumption, it is ordered.

Thus the seemingly–wild and naturally–functioning garden of a New Guinea villager is beautifully ordered and in harmony, while the clipped lawns and pruned roses of the pseudo–aristocrat are nature in wild disarray.

Principle of Disorder

Order and harmony produce energy for other uses. Disorder consumes energy to no useful end.

Neatness, tidiness, uniformity, and straightness signify an energy–maintained disorder in natural systems.

2.10
PERMITTED AND FORCED FUNCTIONS

All key living elements may supply many functions in a system, but if we try to force too many work functions on an element, it collapses. One cannot reasonably expect a cow to give milk, raise a calf, forage its own food, plough, haul water, and tread a corn mill. *Forcing* an element to function, however, is a very different proposition from putting it in position where its natural or everyday behaviours permit benefits to other parts of the system.

Placed correctly, a tree or chicken experiences no stress not common to all trees and chickens about their daily business. Further, if we place any of the other elements needed close by, the tree or chicken has less stress than normal. It is the design approach itself that permits components to provide many functions without forcing functions (that are not in any case inherent) upon that element. The chicken may be busy, but not overworked.

People, too, like to be where their very different and complementary capabilities are used rather than being forced to either a single function (like a 300–egg–a–year chicken or a typist confined to a computer operation in an office), or so many functions that they suffer deprivation or overload (like our cow above).

Principle of Stress and Harmony

Stress here may be defined as either prevention of natural function, or of forced function. Harmony may be defined as the integration of chosen and natural functions, and the supply of essential needs.

2.11 DIVERSITY

Diversity is the number of different components or constructs in the system; an enumeration of elements and of parts. It has no relationship to connections between components, and little to the function or the self–regulating capacity of any real system (within the boundaries of too few or too many components). Thus diversity either of components or assemblies does not of itself guarantee either stability or yield. Where we *maintain* such diversity, as in our gardens, then this may guarantee yield, but if we leave our gardens, they will simplify, or simply be obliterated by non–maintained and hardy species adapted to that site (as is evident in any abandoned garden).

Thus, our own efforts are an integral part of maintaining diversity in a permaculture system. Few species grown by people persist beyond the lifetime of those species if we leave the situation alone. Australia is a country where towns may arise and be abandoned to serve a mining or port operation. Where these were built in forested areas, they are obliterated by forest in 30–80 years, with perhaps a few trees such as dates, mulberries, and figs persisting in savannah or isolated dryland locations. These "survivor" trees are important to note in planning longer–term stability for that region.

Great diversity may create chaos or confusion, whereas multiple function brings order and develops resources. I believe that a happy medium is to include as much diversity in a cultivated ecosystem as it can maintain itself, and to let it simplify or complicate further if that is its nature.

Very diverse things, especially such abstract systems as competing beliefs, are difficult to make compatible with any natural system, or knowledge, so that some sorts of dogmatic diversity are as incompatible as a chicken and a fox. Although true incompatibility may be rare, one should be prepared for it to exist, and an intervening neutral component can be introduced, as is the case when growing those "bad neighbours" apples and walnuts, where it is necessary to intervene with a mulberry, which gets along with them both.

Principle of Stability

It is not the number of diverse things in a design that leads to stabilty, it is the number of beneficial connections between these components.

It follows that adding in a technology or living species "just to have it there" has no sense to it. Adding it in to supply a need or consume an otherwise wasted resource—*to do something useful*—makes a great deal of sense. Often, however, we lack functional information on components and may therefore leave out technologies or species in designs which would have been useful had we known. Thus,

Information is the critical potential resource. It becomes a resource only when obtained and acted upon.

In the real world, resources are energy storages; in the abstract world, useful information or time. Watt[13], in his categories of resources, includes time and diversity. Diversity *of itself* is now not seen as a resource, but a diversity *of beneficial functional connections* certainly is a resource. *Complexity*, in the sense of some powerful interconnections between species, is what we are really seeking in food systems. Such complexity has its own rules, and we are slowly evolving those rules as recommendations for polycultures (dealt with elsewhere in this book under their climatic characteristics), or as "guilds" of plants and animals that assist each other.

Peter Moon (*New Sientist*, 28 Feb. '85) differentiates between *richness* (the number of species per unit area), *diversity* (the relative abundance of species), and *evenness* (how species contribute to the biomass total). He notes that richness may decrease in plants as systems age, when shade and competition reduce annuals or weaker species, but that richness may then increase in animals such as decomposers, due to the development of a greater range of niches and microclimate (more animals live in ungrazed or uncut grasslands, but less plant species survive).

Richness of tree species has very recently been correlated to the energy use of that plant community, as measured by evapotranspiration (*New Scientist*, 22

Oct '87) . Thus species-rich regions are not so much correlated to latitude, allied to richness in birds and mammals, or as result of prior events such as glaciation or fire, but are essentially linked to the basic productivity of the region. Within this broader framework, local niches or a range of altitudes can create more diversity; such measures refer to present, not past, climate.

Some disturbance or "moderate stress" such as we achieve in gardens provides the richest environment. We can actively design to allow some undisturbed (low stress) islands of vegetation, while mowing or digging in other areas (high stress), thus getting the best of both worlds in terms of a stress **mosaic**. We can also be active in plant and animal maintenance, increasing or decreasing grazing pressures, thus managing species abundance locally.

2.12 STABILITY

The short meaning of stability in an ecosystem is *self-regulation* rather than a climax (end-point) stability. Nothing in nature remains forever, not soil or hills or forests. For our foreseeable future we can have dynamic life-support systems, as tribal people have demonstrated to us all over the world, sometimes for thousands of years of constructive regulation.

Thus, stability in ecosystems or gardens is not the stability of a concrete pylon; it is the process of constant feedback and response that characterises such endeavours as riding a bike. We are also in an area of uncertainty about the concept of end states or climax in systems—the state to which they tend to evolve. It is doubtful if any such state ever existed, as inexorable climatic change, fire, nutrient leaching, and invasion deflect systems from their apparent endpoints.

Moreover, it is probable that very old systems are also fragile, having been long in a state of maintenance, and we may see sudden or slow collapse in such evolved states. John Seymour (*Ecos*, Summer '81-82), notes the slow loss of nutrients in an old stable dune system at Cooloola in Australia. Here, climax is a passing phase as the virgin dunes lose nutrient status to fire and water filtration to great depths, where nutrients become unavailable to trees. Thus, the study of very old systems shows a retreat from the "most evolved" (greatest biomas) condition unless some new factor is introduced (ash from a volcano, fertiliser applied by people).

Daniel Goodman [*Quarterly Review Biology*, 50(3)] notes that "wild fluctuations" may occur in tropical forests, or in savannah grasslands. Epidemics of pathogens may affect a plant or animal species and sadly decrease its numbers. Although these natural fluctuations pale beside our own effects on ecosystems, such disturbances, providing they affect only a few species, are not as severe as persistent nutrient loss (or acid rain).

All these effects are under some human control in a developed ecosystem. Protection from fire, positive nutrient supply to plants, and long-term evolutions are possible *in terms of human occupancy*. In the longer term, however, we too will be gone, and other species will arise to replace us (unless we take the earth with us, as megalomaniacs would do if we give them that chance: "If I can't take it with me, I'm not going....!") Just as it was the habit of kings to be buried with their riches, horses, and slaves, so modern warlords threaten to bury all humanity as they depart.

2.13 TIME AND YIELD

Old systems store up their energy in bulky unproductive forms, e.g. an old forest has large trunks, roots and limbs, and old fish are "on maintenance". Such ancient systems composed of large individuals (trees or animals) need energy just to maintain their health, and thus they can use less of the available sun energy, so that flow of energy *through* the system is less. Therefore the yield, or turnover of matter, is less. This too is a function of time (ageing). Matter is used up in system maintenance, and is not available as yield, or as increasing size or weight in life components.

Against this factor, species diversity (richness) works to make the most of incoming energy.

> Carlander has shown that the standing crop of fish in different reservoirs is an increasing function of the number of species present.
>
> (Watt[13])

This is also true of studies in most "wild" systems, where the complexity and standing crop are both much more than the simple cultivated ecology which replaces them. Thus, the clearing of an African veld or an Australian savannah of their web of species, and their replacement with a few perennial pasture plants and beef cattle, or with a single-species pine forest not only takes enormous energy but also grossly decreases total yields.

We would do better to try to understand how to manage natural yields, and modify such systems by management than to replace them with "economic" (here economic means monetary rather than energy return) systems which impoverish the yield and encourage disaster via pests and soil loss. Economics in future will inevitably be tied to yield judged on energy rather than on monetary return. In the present economy, we waste energy to make money. But in the very near future, any system which wastes energy must fail.

Pond and hedgerows both slowly gain species as they age, probably as a function of natural dispersal plus new niche evolution created by other species. This continues until the system begins to be overshadowed by a few large dominants or hyper-predators whose biomass represents an end storage of energy, and a decreasing yield in the total system.

Only local disturbance (fire, flood, death) renews the flow of energy through old systems. The time of cycling of natural systems may be a very long period, but in annual cropping it may be reduced to just one season or less. Permaculture thus uses the time resource much better than does annual gardening alone, and so uses sun energy to better effect. The mixed ecology of annuals and perennials maximises not only product yield, but also the resourcefulness of the men and women who establish, control, and harvest, it. It is only in a thoughtless, monetary, and doomed economy that we can evolve the concept of unemployed and unwanted human beings.

Death in over-mature systems is thus seen as the essential renewal of life, not in the negativistic sense of the fatalist, but in a positivistic and natural way. It is better that elements die, and are renewed by other species, than the system simplifies to extinction. It is better for the tribe if its components change than if it turns in on itself, ages, and decays as a whole. Life is then seen as a preparation for succession and renewal, rather than a journey to extinction.

Time as Watt notes is a resource. Like all resources, too much of it becomes counterproductive, and a system in which too much time is accumulated becomes chronically polluted, as a system in which not enough time has accumulated is below peak yield. A strawberry seedling and an old strawberry bush are equally unproductive, as are the very young and the very old in society. As there are age-specific diseases in people (whooping cough, prostate hypertrophy) so there are age-specific diseases in whole systems, and a mixed-age stand is the best insurance against complete failure or epidemic disease of this nature. As individuals, we have a right to live a responsible life, and a right to die. If our efforts to prevent ageing succeed, we may produce a crowded, unstable, and unproductive society subject to gerontocratic peevishness!

2.14 PRINCIPLE SUMMARY

The Prime Directive of Permaculture: The only ethical decision is to take responsibility for our own existence and that of our children's.

Principle of Cooperation: Cooperation, not competition, is the very basis of future survival and of existing life systems.

The Ethical Basis of Permaculture:

1. CARE OF THE EARTH: Provision for all life systems to continue and increase.

2. CARE OF PEOPLE: Provision for people to access those resources necessary to their existence.

3. SETTING LIMITS TO POPULATION AND CONSUMPTION: By governing our own needs, we can set resources aside to further the above principles.

Rules of Use of Natural Resources:

- Reduce waste, hence pollution;
- Thoroughly replace lost minerals;
- Do a careful energy accounting; and
- Make a biosocial impact assessment for long term effects on society, and act to buffer or eliminate any negative impacts.

Life Intervention Principle: In chaos lies unparalleled opportunity for imposing creative order.

Law of Return: Whatever we take, we must return, or

Nature demands a return for every gift received, or

The user must pay.

Directive of Return: Every object must responsibly provide for its replacement. Society must, *as a conditions of use*, replace an equal or greater resource than that used.

Set of Ethics on Natural Systems:

- Implacable and uncompromising opposition to further disturbance of any remaining natural forests;
- Vigorous rehabilitation of degraded and damaged natural systems to a stable state;
- Establishment of plant systems for our own use on the *least* amount of land we can use for our existence; and
- Establishment of plant and animal refuges for rare or threatened species.

The Basic Law of Thermodynamics [as restated by Watt[13]]:

"All energy entering an organism, population or ecosystem can be accounted for as energy which is stored or leaves. Energy can be transferred from one form to another, but it cannot disappear, or be destroyed, or created. No energy conversion system is ever completely efficient."

[As stated by Asimov (1970)]: "The total energy of the universe is constant and the total entropy is increasing."

Birch's Six Principles of Natural Systems:

1. Nothing in nature grows forever. There is a constant cycle of decay and rebirth.

2. Continuation of life depends on the maintenance of the global bio-geochemical cycles of essential elements, in particular carbon, oxygen, nitrogen, sulphur, and phosphorus.

3. The probability of extinction of populations or a species is greatest when the density is very high or very low. Both crowding and too few individuals of a species may reach thresholds of extinction.

4. The chance that a species has to survive and reproduce is dependent primarily upon one or two key factors in the complex web of relations of the organism to its environment.

5. Our ability to change the face of the earth increases at a faster rate than our ability to foresee the consequence of change.

6. Living organisms are not only means but ends. In addition to their instrumental value to humans and other living organisms, they have an intrinsic worth.

Practical Design Considerations:

• The systems we construct should last as long as possible, and take least maintenance.

• These systems, fueled by the sun, should produce not only their own needs, but the needs of the people creating or controlling them. Thus, they are sustainable, as they sustain both themselves and those who construct them.

• We can use energy to construct these systems, providing that in their lifetime, they store or conserve more energy than we use to construct them or to maintain them.

Mollisonian Permaculture Principles:

1. Work with nature, rather than against the natural elements, forces, pressures, processes, agencies, and evolutions, so that we assist rather than impede natural developments.

2. The problem is the solution; everything works both ways. It is only how we see things that makes them advantageous or not (if the wind blows cold, let us use both its strength and its coolness to advantage). A corollary of this principle is that everything is a positive resource; it is just up to us to work out *how* we may use it as such.

3. Make the least change for the greatest possible effect.

4. The yield of a system is theoretically unlimited. The only limit on the number of uses of a resource possible within a system is in the limit of the information and the imagination of the designer.

5. Everything gardens, or has an effect on its environment.

A Policy of Responsibility (to relinquish power): The role of beneficial authority is to return function and responsibility to life and to people; if successful, no further authority is needed. The role of successful design is to create a self-managed system.

Categories of Resources:

1. Those which increase by modest use.
2. Those unaffected by use.
3. Those which disappear or degrade if not used.
4. Those reduced by use.
5. Those which pollute or destroy other resources if used.

Policy of Resource Management: A responsible human society bans the use of resources which permanently reduce yields of sustainable resources, e.g. pollutants, persistent poisons, radioactives, large areas of concrete and highways, sewers from city to sea.

Principle of Disorder: Any system or organism can accept only that quantity of a resource which can be used productively. Any resource input beyond that point throws the system or organism into disorder; oversupply of a resource is a form of chronic pollution.

Definition of System Yield: System yield is the sum total of surplus energy produced by, stored, conserved, reused, or converted by the design. Energy is in surplus once the system itself has available all its needs for growth, reproduction, and maintenance.

The Role of Life in Yield: Living things, including people, are the only effective intervening systems to capture resources on this planet, and to produce a yield. Thus, it is the sum and capacity of life forms which decide total system yield and surplus.

Limits to Yield: Yield is not a fixed sum in any design system. It is the measure of the comprehension, understanding, and ability of the designers and managers of that design.

Dispersal of Food Yield Over Time:

• By selection of early, mid and late season varieties.

• By planting the same variety in early or late-ripening situations.

• By selection of long-yielding varieties.

• By a general increase in diversity in the system, so that:

• Leaf, fruit, seed and root are all product yields.

• By using self-storing species such as tubers, hard seeds, fuelwood, or rhizomes which can be "cropped on demand".

• By techniques such as preserving, drying, pitting, and cool storage.

• By regional trade between communities, or by the utilisation of land at different altitudes or latitudes.

Principle of Cyclic Opportunity: Every cyclic event increases the opportunity for yield. To increase cycling is to increase yield.

Cycles in nature are diversion routes away from entropic ends—life itself cycles nutrients—giving opportunities for yield, and thus opportunities for species to occupy time niches.

Types of Niches:

• Niche in space, or "territory" (nest and forage sites).

• Niche in time (cycles of opportunity).

• Niche in space-time (schedules)

Principle of Disorder: Order and harmony produce energy for other uses. Disorder consumes energy to no useful end.

Neatness, tidiness, uniformity, and straightness signify an energy-maintained disorder in natural systems.

Principle of Stress and Harmony

Stress may be defined as either prevention of natural function, or of forced function; and (conversely) harmony as the permission of chosen and natural functions and the supply of essential needs.

Principle of Stability: It is not the number of diverse things in a design that leads to stability, it is the number of beneficial connections between these components.

Information as a Resource: Information is *the* critical potential resource. It *becomes* a resource only when obtained and acted upon.

2.15

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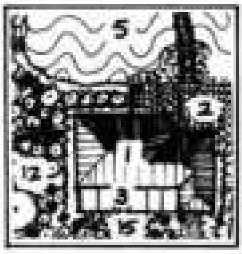


Chapter 3

METHODS OF DESIGN

3.1
INTRODUCTION

Any design is composed of concepts, materials, techniques, and strategies, as our bodies are composed of brain, bone, blood, muscles, and organs, and when completed functions as a whole assembly, with a unified purpose. As in the body, the parts function *in relation to each other*. Permaculture, as a design system, attempts to integrate fabricated, natural, spatial, temporal, social, and ethical parts (components) to achieve a whole. To do so, it concentrates not on the components themselves, but on the *relationships between them*, and on how they function to assist each other. For example, we can arrange any set of parts and design a system which may be self-destructive or which needs energy support. But by using the same parts in a different way, we can equally well create an harmonious system which nourishes life. It is in the *arrangement of parts* that design has its being and function, and it is the adoption of a purpose which decides the direction of the design.

<u>Definition of Permaculture Design</u>
Permaculture design is a system of assembling conceptual, material, and strategic components in a pattern which functions to benefit life in all its forms. It seeks to provide a sustainable and secure place for living things on this earth.

Functional design sets out to achieve specific ends, and the prime directive for function is:

Every component of a design should function in many ways. Every essential function should be supported by many components.

A flexible and conceptual design can accept progressive contributions from any direction, and be modified in the light of experience. Design is a continuous process, guided in its evolution by information and skills derived from earlier observations of that process. All designs that contain or involve life forms undergo a long-term process of change.

To understand design, we must differentiate it from its component parts, which are techniques, strategies, materials and assemblies:

- TECHNIQUE is "one-dimensional" in concept; a technique is *how* we do something. Almost all gardening and farming books (until 1950) were books on technique alone; design was largely overlooked.
- STRATEGIES, on the other hand, add the dimension of *time* to technique, thus expanding the conceptual dimensions. Any planting calendar is a "strategic" guide. Strategy is the use of technique to achieve a future goal, and is therefore more directly value-oriented.
- MATERIALS are those of, for instance, glass, mud, and wood. ASSEMBLIES are the putting together of technologies, buildings, and plants and animals.

There are many ways to develop a design on a particular site, some of them relying on observation, some on traditional skills usually learned in universities. I have outlined some methods as follows:

ANALYSIS: Design by listing the characteristics of components (3.2).

OBSERVATION: Design by expanding on direct observation of a site (3.3).

DEDUCTION FROM NATURE: Design by adopting the lessons learnt from nature (3.4).

OPTIONS AND DECISIONS: Design as a selection of options or pathways based on decisions (3.5).

DATA OVERLAY: Design by map overlays (3.6).

RANDOM ASSEMBLY: Design by assessing the results of random assemblies (3.7).

FLOW DIAGRAMS: Design for workplaces (3.8).

ZONE AND SECTOR ANALYSIS: Design by the application of a master pattern (3.9).

All these methods can be used to start on sensible and realistic design, with innovative characteristics. Each method is described below.

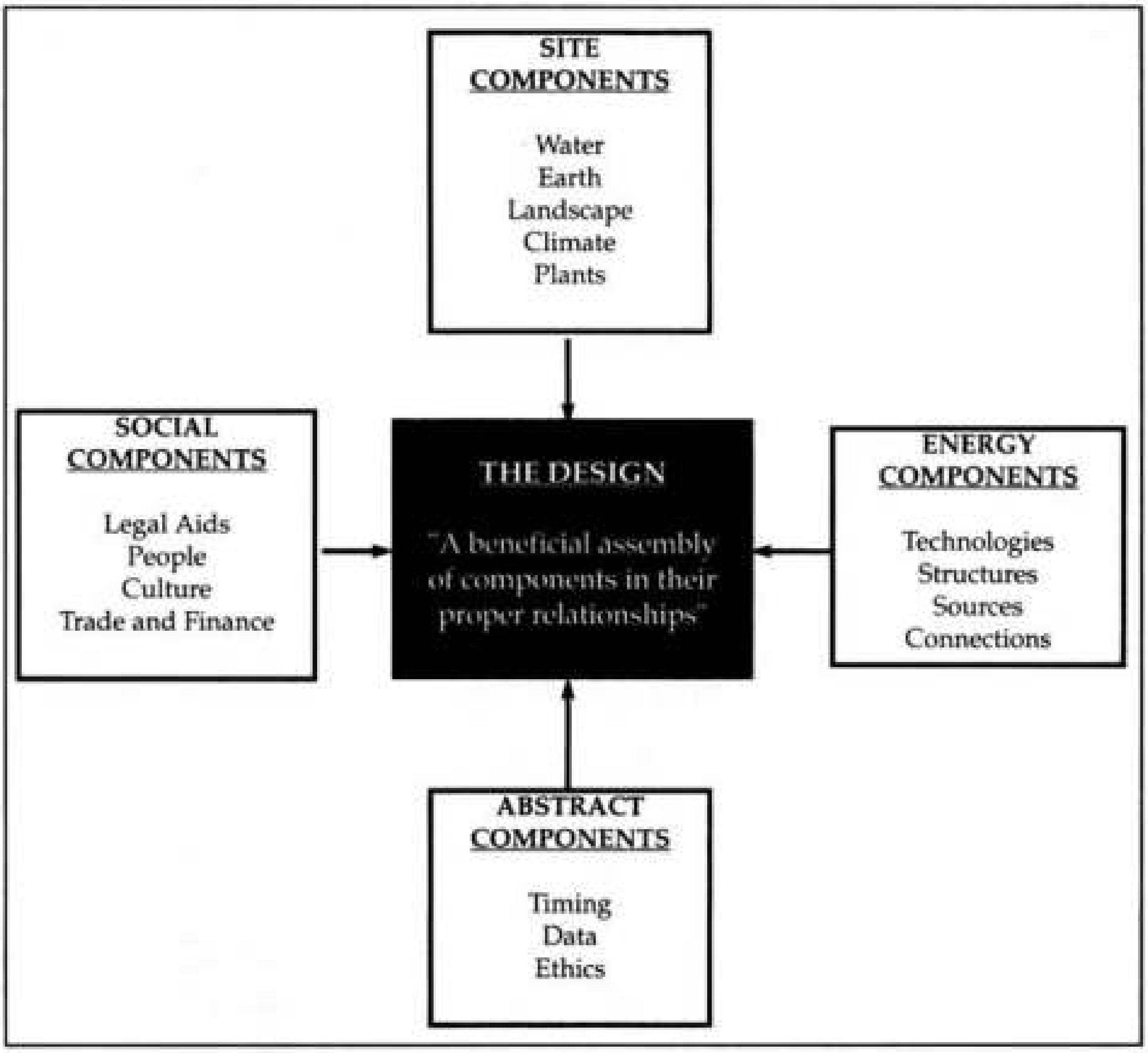
3.2
ANALYSIS
DESIGN BY LISTING THE CHARACTERISTICS OF COMPONENTS

The components of a total design for a site may range from simple technological elements to more complex economic and legal systems. How are we to make decisions about the patterning and placement of our components (systems, elements, or assemblies)? We can list what we know about the characteristics of any one component, and see where this leads us in terms of beneficial connections.

Principle of Self-Regulation
The purpose of a functional and self-regulating design is to place elements or components in such a way that each serves the needs, and accepts the products, of other elements.

To illustrate, we could select a homely and universally-known component, a chicken. What do we know about this hen? We can list its PRODUCTS (materials, behaviours, derived products), NEEDS (what the

TABLE 3.1
ELEMENTS OF A TOTAL DESIGN



chicken requires to lead a full life), and BREED CHARACTERISTICS (the characteristics of this special kind of chicken, whether it be a Rhode Island Red, Leghorn, Hamburg, etc). See **Figure 3.1**.

A broader classification would have only two categories: "outputs" and "inputs". Outputs are the yields of a chicken, inputs are its requirements in order to give those yields. Before we list either, we should reflect on these latter categories:

OUTPUTS, YIELDS or PRODUCTS are RESOURCES if they are used productively, or can become POLLUTANTS if not used in a constructive way by some other part of the system.

INPUTS, NEEDS, or DEMANDS have to be supplied, and if not supplied by other parts of the system, then EXTERNAL ENERGY or EXTRA WORK must be found to satisfy these demands. Thus:

A POLLUTANT is an output of any system component that is not being used productively by any other component of the system. EXTRA WORK is the result of an input not automatically provided by another component of the system.

As pollution and extra work are both unneccessary results of an incompletely designed or unnatural system, we must be able to connect our component, in this case the chicken, to other components. The essentials are:

- That the inputs needed by the chicken are supplied by other components in the system; and
- That the outputs of the chicken are used by other components (including people).

We can now list the characteristics of the chicken, as we know them. Later, we can see how these need to be linked to other components to achieve our self-regulated system, by a ground strategy of *relative placement* (putting components where they can serve each other).

1. Inputs (Needs) of the Chicken

Primary needs are food, warmth, shelter, water, grit, calcium, dust baths, and other chickens.

Secondary needs are for a tolerable social and physical environment, giving a healthy life of moderate stress.

2. Outputs (Products and Behaviours) of the Chicken

Primary products are, for instance: eggs, feathers, feather dust, manure, various exhaled or excreted gases, sound, and heat.

Derived products are many. From eggs we can make a variety of foods, and derive albumen. From feathers we can make dusters, insulation, bedding, rope, and special manures. Manure is used directly in the garden or combined with leaf and stem materials (carbon) to supply compost heat. Composted anaerobically, it supplies methane for a house. Heat and gases both have a use in enclosed glasshouses, and so on. Our list of derived products is limited only by lack of specific information and by local needs for the products.

Behaviours: chickens walk, fly, perch, scratch, preen, mate, hatch eggs, care for young, form flocks of 20-30 individuals, and forage. They also process food to form primary products and to maintain growth and body weight.

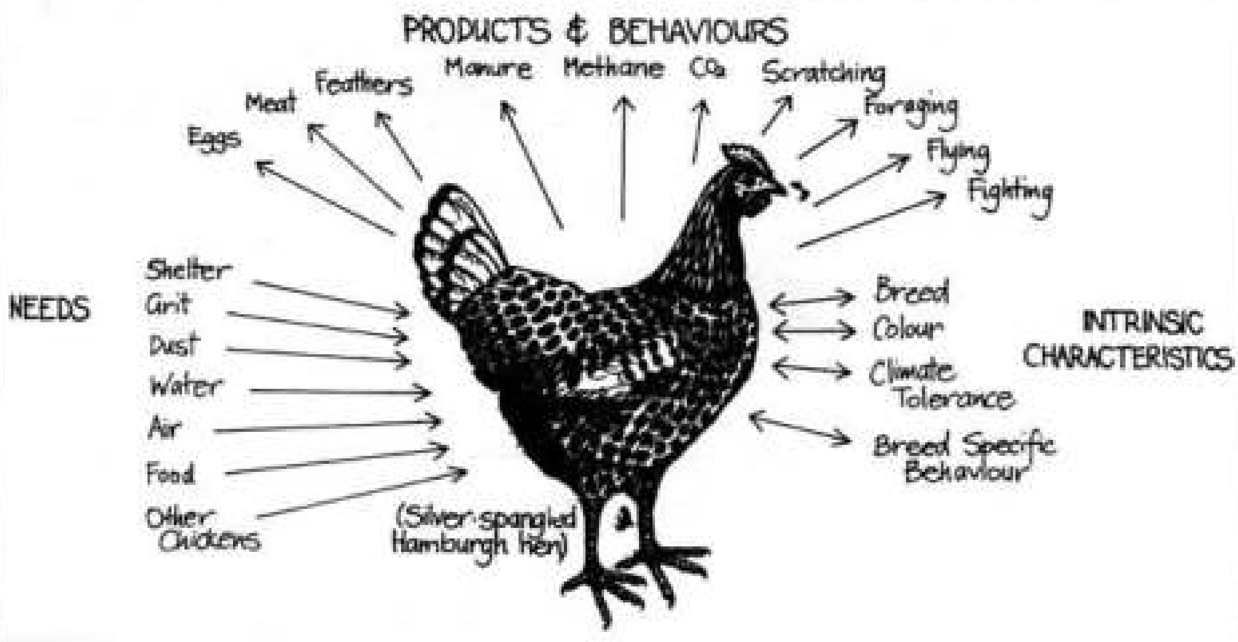


FIGURE 3.1
PRODUCTS AND BEHAVIOURS OF A HEN.
Analysis of these inputs and outputs are critical to self-governing design. A deficit in inputs creates *work*, whereas a deficit in output use creates *pollution*.

3. Intrinsics

Instrinsics are often defined as "breed characteristics". They are such factors as colour, form, weight, and how these affect behaviour, space needed, and metabolism; how climate and soil affect that chicken; or what its tolerances or limits are in relation to heat, cold, predation, and so on. For instance, white chickens survive extreme heat, while thickly-feathered large dark chickens survive extreme cold. Heavy breeds (Australorps) cannot fly over a 1.2 m fence, while lighter breeds (Leghorns) will clear it easily.

We can add much more to the above lists, but that will do to start with (you can add data to any component list as information comes in).

MAKING CONNECTIONS BETWEEN COMPONENTS.

To enable a design component to function, we must *put it in the right place*. This may be enough for a living component, e.g. ducks placed in a swamp may take care of themselves, producing eggs and meat and recycling seeds and frogs. For other components, we must also *arrange some connections*, especially for non-living components, e.g. a solar collector linked by pipes to a hot water storage. And we should *observe and regulate* what we have done. Regulation may involve confining or insulating the component or guiding it by fencing, hedging, or the use of one-way valves. Once all this is achieved, we can relax and let the system, or this part of the system, self-regulate.

Having listed all the information we have on our component, we can proceed to placement and linking strategies which may be posed as questions:

- Of what use are the products of this particular component (e.g. the chicken) to the needs of other components?
- What needs of this component are supplied by other components?
- Where is this component incompatible with other components?
- Where does this component benefit other parts of the system?

The answers will provide a plan of *relative placement* or assist the access of one component to the others.

We can choose our other components from some common elements of a small family farm where the family has stated their needs as a measure of self-reliance, not too much work, a lot of interest, and a product for trade (no millionaire could ask for more!) The components we can bring to the typical small farm are:

- Structures: House, barn, glasshouse, chicken-house.
- Constructs: Pond, hedgerow, trellis, fences.
- Domestic Animals: Chickens, cows, pigs, sheep, fish.
- Land Use: Orchard, pasture, crop, garden, woodlot.
- Context: Market, labour, finance, skills, people, land available, and cultural limits.
- Assemblies: Most technologies, machines, roads and water systems.

We will not list the characteristics of all of these elements here, but will proceed in more general terms.

In the light of linking strategies, we know where we *can't* put the chicken (in a pond, in the house of most societies, in the bank, and so on), but we *can* put the chicken in the barn, chicken-house, orchard, or with other components that either supply its needs or require its life products. Our criteria for placement is that, if possible, such placement enables the chicken to function naturally, in a place where its functions are beneficial to the whole system. If we want the chicken to work for us, we must list the energy and material needs of the other elements, and see if the chicken can help supply those needs. Thus:

THE HOUSE needs food, cooking fuel, heat in cold weather, hot water, lights, bedding, etc. It gives shelter and warmth for people. Even if the chicken is not allowed to enter, it can supply some of these needs (food, feathers, methane). It also consumes most food wastes coming from the house.

THE GLASSHOUSE needs carbon dioxide for plants, methane for germination, manure, heat, and water. It gives heat by day, and food for people, with some wastes for chickens. The chicken can obviously supply many of these needs, and utilise most of the wastes. It can also supply night heat to the glasshouse in the form of body heat.

THE ORCHARD needs weeding, pest control, manure, and some pruning. It gives food (as fruit and nuts), and provides insects for chicken forage. Thus, the orchard and the chickens seem to need each other, and to be in a beneficial and mutual exchange. They need only to be placed together.

THE WOODLOT needs management, fire control, perhaps pest control, some manure. It gives solid fuel, berries, seeds, insects, shelter, and some warmth. A beneficial interaction of chickens and woodlot is indicated.

THE CROPLAND needs ploughing, manuring, seeding, harvesting, and storage of crop. It gives food for chickens and people. Chickens obviously have a part to play in this area as manure providers and cultivators (a large number of chickens on a small area will effectively clear all vegetation and turn the soil over by scratching).

THEPASTURE needs cropping, manuring, and storage of hay or silage. It gives food for animals (worms and insects included).

THE POND needs some manure. It yields fish, water plants as food, and can reflect light and absorb heat.

In such a listing, it becomes clear that many components provide the needs and accept the products of others. However, there is a problem. On the traditional small farm the main characteristic is that *nothing is connected to anything else*, thus no component supplies

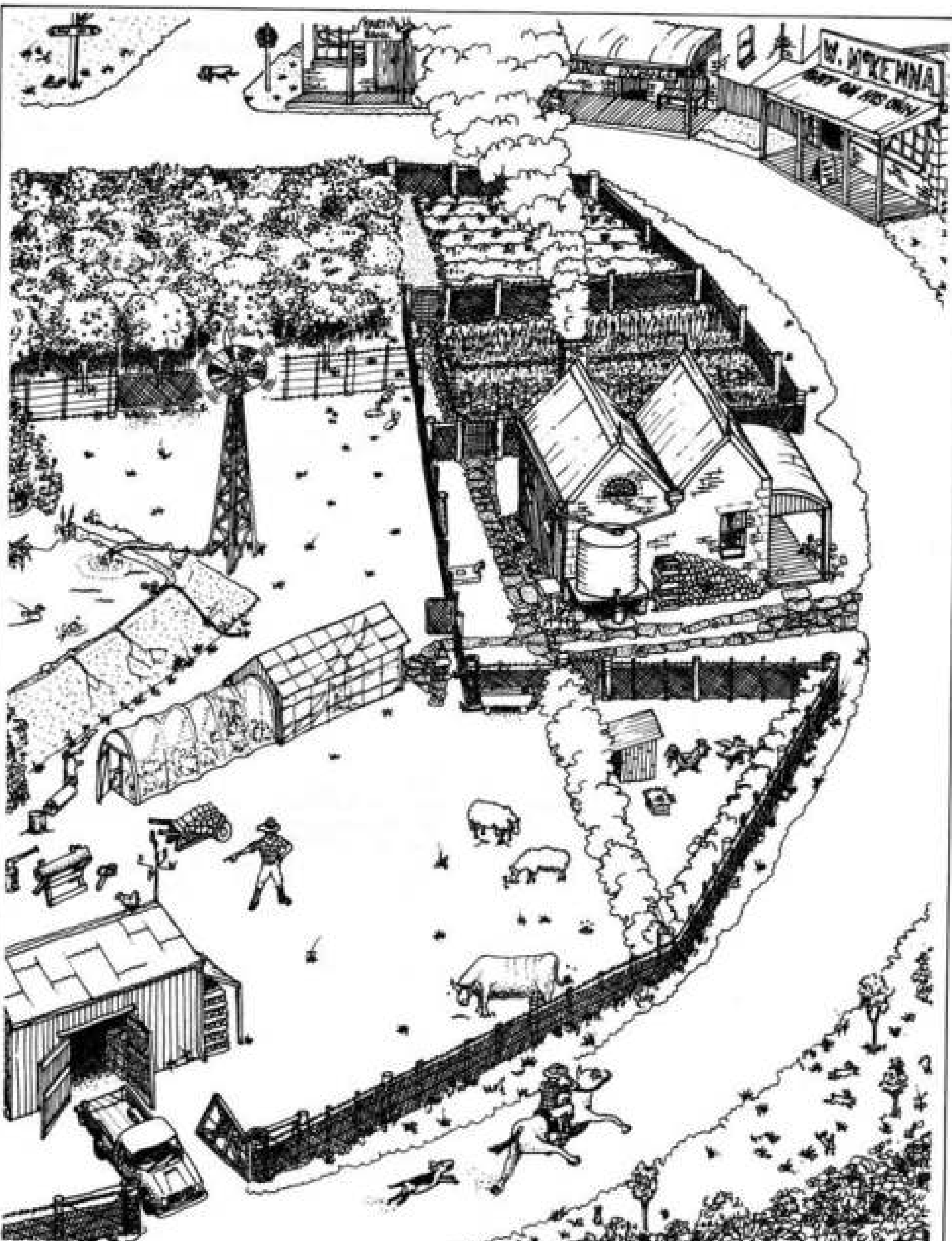


FIGURE 3.2
A TYPICAL SMALL FARM.
Villages and farms may contain all the components for self-governance but unless these components are placed in harmonious relationships to each other time, energy, and resources are wasted. In this figure unplanned and segregated systems all demand inputs.

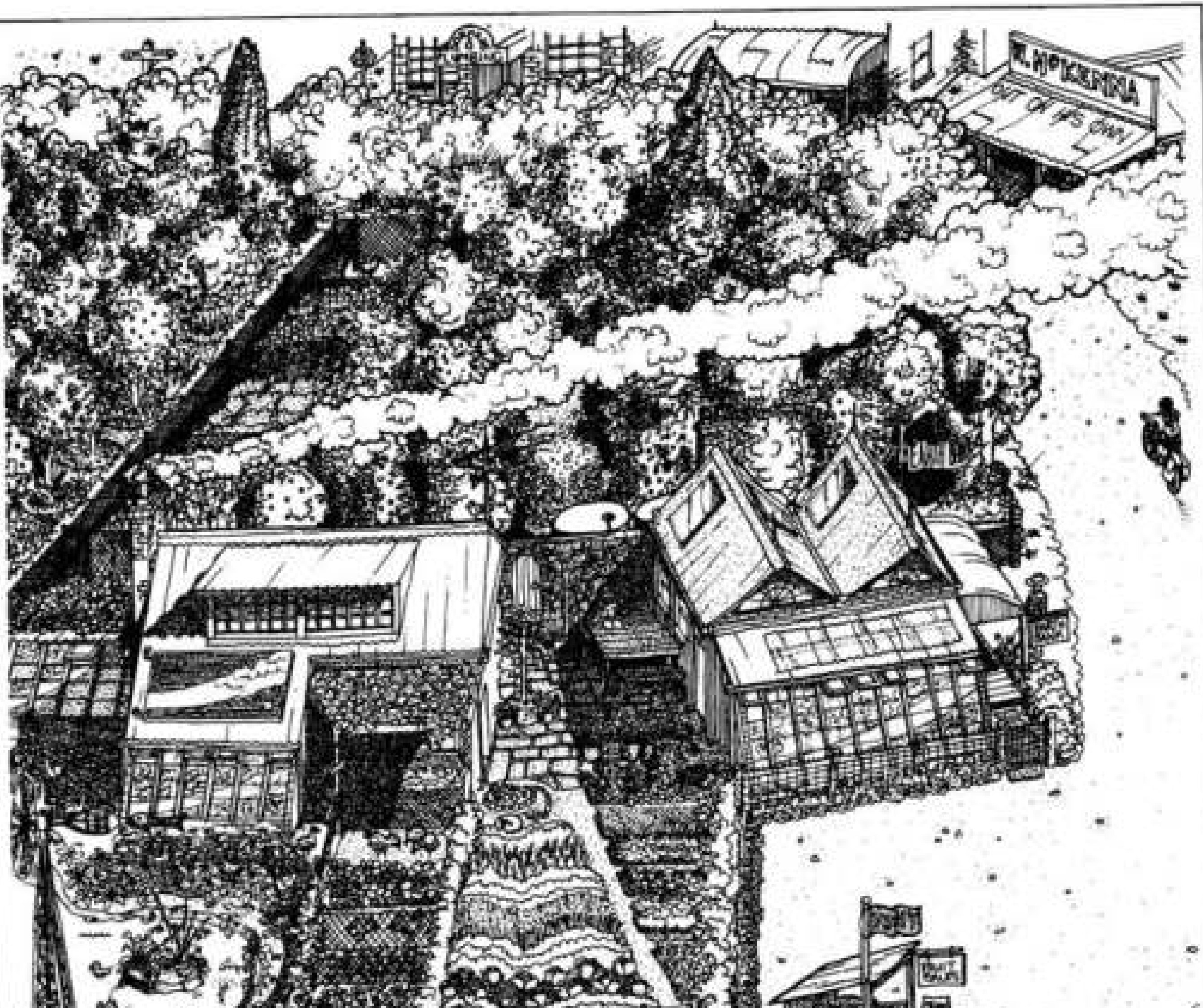


FIGURE 3.3
A RE-DESIGNED SMALL FARM.
In this figure many elements supply the energy inputs for others, and the system can be largely self-regulating.

the needs of others. In short, the average farm does not enjoy the multiple benefits of correct relative placement, or needful access of one system or component to another. This is why most farms are rightly regarded as places of hard work, and are energy-inefficient See **Figures 3.2 and 3.3**.

Now, *without inventing anything new*, we can *redesign* the existing components to make it possible for each to serve others. See **Figure 3.4– 3.5**.

Just by moving the same components into a beneficial design assembly, we can ensure that the chicken, glasshouse or orchard is working for us, not us working for it. If we place essential components carefully, in relation to each other, not only is our maintenance work minimised, but the need to import energies is greatly reduced, and we might expect a modest surplus for sale, trade, or export. Such surplus results from the conversion of "wastes" into products by appropriate use.

The chicken-house heats (and is heated by) the glasshouse, and both are heated by the chimney. The chickens range in the orchard, providing manure and getting a large part of their food from orchard wastes and pests, and from interplants of woodlot or forest components. A glasshouse also heats the house, and part of the woodlot is a forage system and a shelter-belt. Thus, sensible placements, minimising work, have been made. Market and investment control have been placed in the house, together with an information service using a computer, which can link us to the world.

Each part of this sort of design will be dealt with in greater detail in this book, but a simple transformation such as we made from **Figure 3.2** to **Figure 3.3** is enough to show what is meant by functional design.

A great part of this design can be achieved, as it was here, by analytical methods *unrelated to any real site conditions*. Note that before we actually implement anything, before we even leave our desk, we have developed a lot of good ideas about patterns and self-regulatory systems for a family farm. It only remains to see if these are feasible on the ground, and if the family can manage to achieve them. This is the benefit of the analytical design approach: it can operate without site experience! This is also its weakness. Until the chicken is actually heating the greenhouse, manuring the orchard, or helping to produce methane for the house, our system is just information, or potential. Until that chicken is actually in function, we have produced no real resources, nor have we solved any real problems on our family farm.

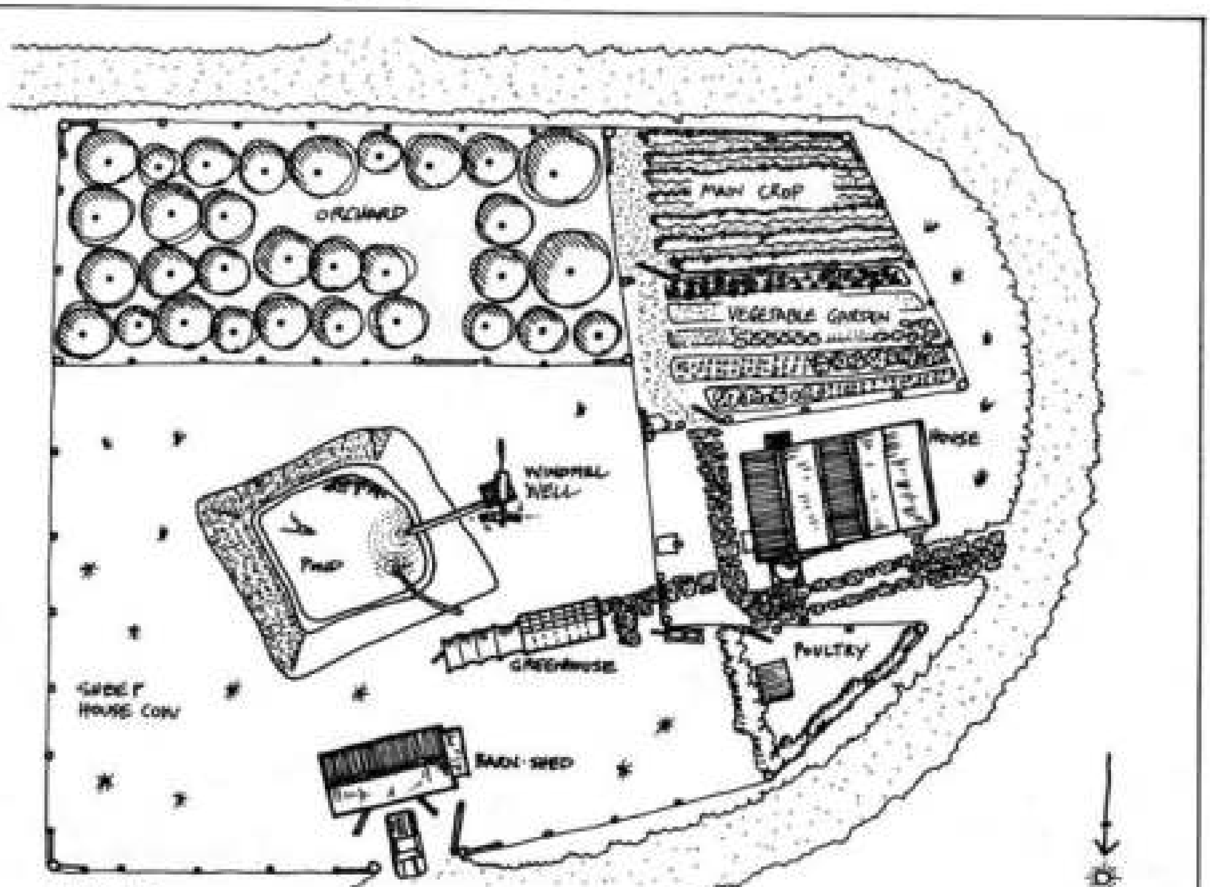


FIGURE 3.4
PLAN OF THE NON-INTEGRATED SYSTEM IN FIGURE 3.2.

Information as a Resource

RESOURCES are practical and useful energy storages, while INFORMATION is only a potential resource, until it is put to use.

We must never confuse the assembling of information with making a real resource difference. This is the academic fallacy: "I think, therefore I have acted."

Note also that we have arrived, analytically, at the need for *cooperation* within the system, and that any *competition* absorbs energy, hence consumes part of our slender resources. Our ideal is to allow the free expression of all the beneficial characteristics of the chicken, so that we avoid conflict and further regulate the system we have designed in light of real-life experience on the site.

3.3

OBSERVATION
DESIGN BY EXPANDING ON DIRECT OBSERVATION OF A SITE

Unlike the preceding analytic method, this way of arriving at design strategies starts on and around the site. Short practice at refining field observation as a design tool will convince you that no complex of map overlays, library, computer data, or remote analysis will ever supplant field observation for dependability and relevance.

Observation is not easily directed, and it is therefore regarded as largely unscientific and individualistic. Process and events, as we encounter them on a real site, are never revealed just by maps or other fixed data. Yet it is from the observation of processes and events (such as heavy rain and subsequent run-off) that we can devise strategies of "least change", and so save energy and time. No static method can reveal processes or dynamic interactions.

A camera and a notebook are great aids to observation, allowing a re-examination of information if necessary. A good memory for events helps. Video recorders are very useful to review processes.

How do we proceed? As we approach the problem, we can adopt any or all of these attitudes:

- A CHILD-LIKE AND NON-SELECTIVE APPROACH, in which "I wonder why..." may pre-face our actual observation.
- A THEMATIC APPROACH, where we try to observe a theme such as water, potential energy sources, or the conditions for natural regeneration.

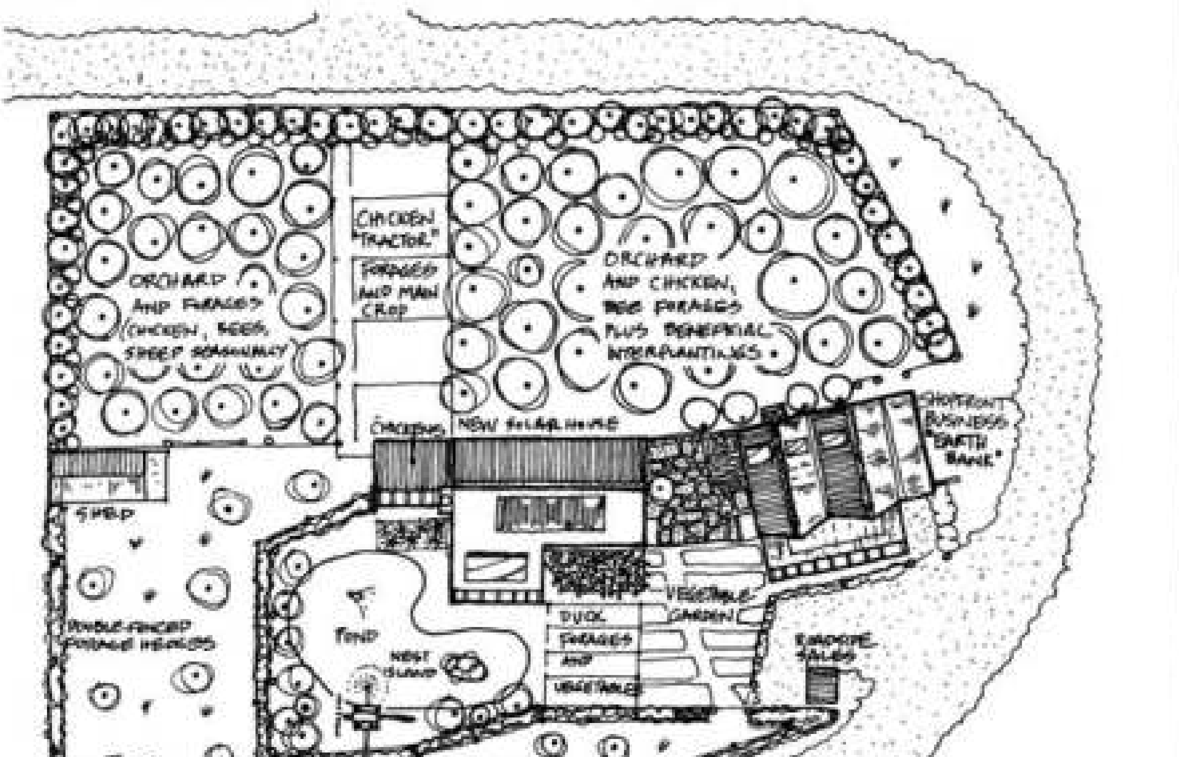


FIGURE 3.5
PLAN OF THE INTEGRATED SYSTEM IN FIGURE 3.3

• AN INSTRUMENTAL APPROACH, where we measure, perhaps using equipment, a factor such as temperature gradients, wind, or reflection from trees.

• AN EXPERIENTIAL APPROACH, using all our senses as our instruments, trying to be fully conscious both of specific details, sensations, and the total ambience of the site.

In order to develop a design strategy, possible procedural stages are as follows:

1. Make value-free and non-interpretative notes about what is seen, measured, or experienced, e.g. that "moles have thrown up earth mounds on the field." Make no guesses or judgements at this stage (this takes some discipline but gets a lot of primary data listed).

2. Later, select some observations which interest you, and proceed to list under each of them a set of SPECULATIONS as to possible meanings, e.g. (on the moles):

• That molehills are only conspicuous on fields, and may actually occur elsewhere.

• Or that they occur only on fields.

• That fields are particularly attractive to moles.

And so on. Many speculations can arise from one observation! Speculations are a species of hypothesis, a guess about which you can obtain more information. To further examine these speculations, several strategies are open to the observer:

3. Confirm or deny speculations by any or all of these methods:

• Library research on moles, and even on allied burrowing species (e.g. gophers).

• Asking others about moles and their field behaviour.

• Devising more observations on one particular THEME just to test out your ideas.

• Recalling all you know about moles or allied species in other areas or circumstances.

This process will start to further elaborate your knowledge of an existing and *specific site characteristic*, and may already be leading you to the next step:

4. Examination of all the evidence now to hand. Have we evolved any patterns, any mode of operating? What *other* creatures burrow in fields and are predators, prey, or just good friends of moles? Now, for the last decisive step:

5. How can we find a USE for all this information? What design strategies does any of it suggest? For example, we may now have found a *lot* of data on burrowers and fields, and look upon the mole (if mole it is) as a fine soil aerator and seed-bed provider, and therefore to be encouraged—*or* the very opposite. We may have discovered places where moles are beneficial, and places where they could well be excluded. Or possibly they are best allowed to go their way as natural components in the system. Methods of mole-control or data on how to prepare moles for eating may have surfaced, and so on.

As the research and observation phase (plus others' observations) goes on, the mole will gradually be seen to be *already connected* in one or other way to worms, upturned soils, fields, lawns, gardens, pastures, water percolation, and even perhaps soil production. Dozens of useful strategies may have evolved from your first simple observations, and the site *begins to design itself*. You may begin sensible trials to test some of your hypotheses.

Some cautious trials and further observation will, in time, confirm the benefits (or otherwise) of moles in the total system or in specific parts of it. A great deal of practical information will be gathered, which will carry over to other sites and to allied observations. A study of earthworms may have co-evolved, and the interconnectedness of natural systems has become evident.

No analytic method can involve one in the world as much as observation, but observation and its methods need to be practised and developed, whereas analysis needs no prior practice and requires less field research or first-hand knowledge. As an observer, however, you are very likely to stumble on *unique and effective strategies*, and thus become an innovator!

The uses and strategies derived from observation, experience or experiments on site are the basic tools of aware, long-term residents. A set of reliable strategies can be built up, many of them transferable to other locations. Here, we have used nature itself as our teacher. That is the greatest value of nature, and it will in time supply answers to all our questions.

Thus, the end result of systematic observation is to have evolved strategies for application in design. A second and beneficial result is that we have come to know, in a personal and involved way, something of the totality of the interdependence of natural systems.

3.4

DEDUCTION FROM NATURE
DESIGN BY ADOPTING LESSONS LEARNT FROM NATURE

The impetus that started Masanobu Fukuoka[3,4] on his remarkable voyage to natural farming was the sight of healthy rice plants growing and yielding in untended and uncultivated road verges. If rice can do this naturally, he asked, why do we labour to cultivate the soil? In time he achieved high- yielding rice production on his farm without cultivation, without fertilisers or biocides, and without using machinery.

Via our senses (which include the sensations of the skin in relation to pressure, wind chill, and heat), and the organised, patterned, or measured information we extract from observation, we can discover a great deal about natural processes in the region we are examining. In order to put our observations about nature to use, we need to look at the following:

STRUCTURE

We can imitate the structure of natural systems. If we have palms, vines, large evergreen trees, an "edge" of herbaceous perennials, a groundcover of bulbs or tubers, and a rich bird fauna in the *natural* system of the region, then we can reconstruct or imitate such a system structure on our site, using some native species for pioneers, bird forage, or vine supports. We can add to this the palms, vines, trees, tubers, and poultry that are of great use to our settlement (over that broad range of uses that covers food, crafts, medicines, and fuels).

After studying the natural placement of woody legumes or windbreak in natural systems, we can imitate these in designed systems. We can improve on local species by finding out-of-region or exotic species even better suited to those roles than those of an impoverished or degraded native flora and fauna. Certainly, we can carefully select species of a wider range of use to settlements than the natural assembly.

PROCESS

Apart from the structure of natural systems, we need most of all to study process. Where does water run? How does it absorb? Why do trees grow in some special sites in deserts? Can we construct or use such processes to suit ourselves? Some of the processes we observe are processes "energised" by animals, wind, water, pioneer trees or forbs, and fire. How does a tree or herb propagate itself in this region? As every design is a continuous process, we should most of all try to create useful self-generating systems. Some examples would be:

- On Lake Chelan (Washington state, USA), walnuts self-generate from seed rolling downhill in the valleys of intermittent streams. Similar self- propagation systems work for palms in the tropics, *Aleurites* (candle-nut) in Hawaii, and asparagus along sandy irrigation channels. Thus, we save ourselves a lot of work by setting up headwater plantations and allowing these to self-propagate downstream (as for willows, Russian olive, and hundreds of water-plant species, including taro in unstable flood-water lowlands), as long as these are not a problem locally.
- Birds spread useful bird forages such as elderberries, *Coprosma*, *Lycium*, autumn olive, pioneer trees or herbs, and preferred grains such as *Chenopodium* species. If we place a few of these plants, and allow in free-ranging pigeons or pheasants, they will plant more. The same applies to dogs or foxes in the matter of loquats, bears for small fruits, and cattle for hard seeds such as honey locusts. Burrowers and hoarders such as gophers will carry bulbs and root cuttings into prairie, and jays and squirrels, choughs, or currawongs spread oaks when they bury acorns.

If, in grasslands or old pastures, we see that a "pioneer" such as tobacco bush, a pine, or an *Acacia* provides a site for birds to roost, initiating a soil change so that clumps or coppices of forest form there, we can use the same techniques and allied species to pioneer our food forests, but selecting species of more direct use to us. Many native peoples do just this, evolving scattered forest nucleii based on a set of pioneer trees, termite mounds, compost heaps, and so on. We can provide perches for birds to drop pioneer seeds, and so set up plant nucleii in degraded lands around simple perches placed on disturbed sites.

- We can provide nest holes so that owls may then move in to control rodents, purple martins to reduce mosquitoes, or woodpeckers to control codling moth. Many nurse plants allow insect predators to overwinter, feed, or shelter within our gardens, as do small ponds for frogs and rock piles for lizards. If we want these aids to pest control, we need to provide a place for them. Some of these natural workers are very effective (woodpeckers alone reduce codling moth by 40-60%).
- To limit a rampant plant, or to defeat invasive grasses, we need only to look to nature. Nature imposes successions and limits on every species, and once we know the rules, we can use this succession to limit or exclude our problem species. Many soft vines will smother prickly shrubs. Browsed or cut out, they allow trees to permanently shade out the shrub, or rot its seeds in mulch. Kikuyu grass is blocked from spreading by low hedges of comfrey, lemongrass, arrowroot (*Canna spp.*), or nasturtiums. We can use some or all of these species at tropical garden borders, or around young fruit trees. We can smother rampageous species such as *Lantana* by vines such as chayote (*Sechium edulis*) and succeed them with palm/legume forests, by cutting or rolling tracks and then planting legumes, palms, and vines of our choice. Where rampageous grasses smother the trees, we set our trees out in a protecting zone of "soft" barrier plants such as comfrey, nasturtium, or indeed any plant we locally observe to "beat the grass", and we surround our mulched gardens with belts of such plants.

There are hundreds of such botanical lessons about us. Look long enough, and the methodologies of nature become clear. This is design by analogy: we select analagous or botanically-allied species for trials. If thistles grow around a rabbit warren, then perhaps if we disturb the soil, supply urine and manure, and sow seed, we will get globe artichokes (and so I have!) Or we can pen goats or sheep on a place, then shut them out and plant it. It was by such thinking that the idea of chicken or pig "tractors" evoled to remove such stubborn weeds as nut-grass, *Convolvulus*, onion-weed, and twitch before planting a new succession of useful plants. Or we can provide fences or pits to trap wind-blown debris (dried leaves, rabbit and sheep manures, seagrasses), which can be gathered for garden use. And so on...

All these strategies can be derived from observing natural processes, and used consciously in design to achieve a great reduction in work, hence energy inputs.

LANDSCAPE

Gullies, ridgetops, natural shade, the sides of multi-storey buildings, and exposed sunny sites all demonstrate different opportunities, just as various velocities and grades of streams or rock-falls present specific niches. We can find a use for each and every such special site, whether as an aid to food storage, food dehydration, as an energy source in itself, or as a site for a special animal or plant. We also create such opportunities over time as we grow groves of trees, raise earthbanks, build houses, or excavate caves. It is in the creation of microclimates that we find a natural diversity and richness increasing. Every clump of trees invites new species to establish, every shaded area provides a refuge from heat, and every stone pile a moist and shaded soil site. We can plan such evolutions, and plant to take advantage of them, using data derived from a close observation of natural systems.

PHILOSOPHY

Life is not all survival in a stable ecosystem. First by designing well, and then observing system evolution, we gain contemplative and celebratory time. In celebration we can incorporate the myths and skills that are important to future generations. In contemplation we find more refined, profound, or subtle insights into good procedures (Fukuoka[3,4]). To implement and manage a constructed or natural system inevitably leads to a more revelationary lifestyle, a more satisfied and contented life, and a sense of one's place in nature.

To become a philosopher is not necessarily to be of benefit to the natural world, but to become a designer or gardener is to directly benefit nature or society, and one will inevitably generate natural ethics and philosophies. To become a good designer is to be in search of an understanding of nature, and to be content with the search itself. It is to design by natural example, becoming aware, taking notes, sitting a long time in one place, watching the wind behave and the trees respond, thrusting your hand into the soil to feel it for moisture (it is always more moist on the shade side of tussock grasses, for example), and becoming sensitive to the processes and sights about you.

In microcosm and macrocosm, we can learn from the world, and these are the very best lessons to adopt. There are a thousand lessons to learn, some so obvious that we could pinch ourselves for failing to notice them. Such an experiential system of design, in broad and in detail, is almost obliterated by the classroom, the sterile playground, toys, and didactic education. The huge information store that is nature is a primary reason for its preservation. We can never afford such a fine teacher or an equivalent education system that operates without cost or bureaucratic involvement.

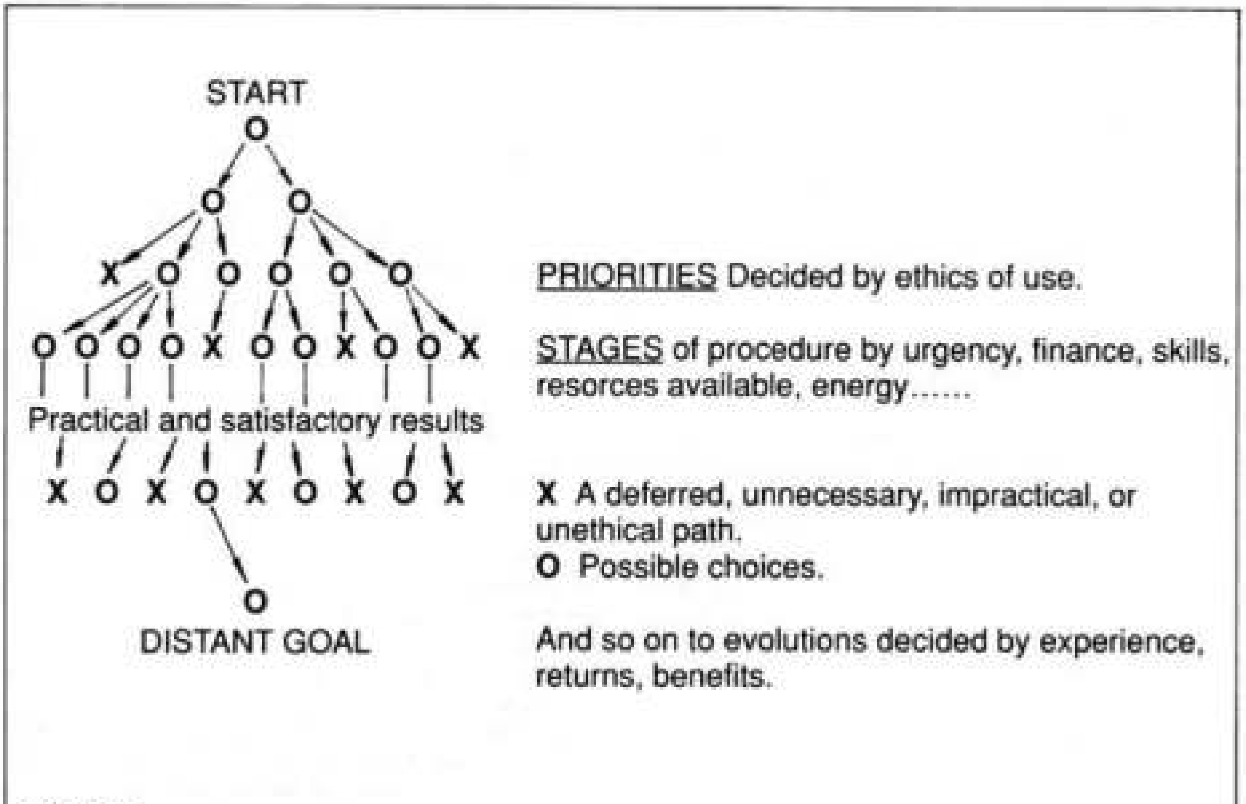


FIGURE 3.6
OPTIONS AND DECISIONS.

3.5

OPTIONS AND DECISIONS

DESIGN AS A SELECTION OF OPTIONS OR PATHWAYS BASED ON DECISIONS

For a specific site and specific occupants (or clients), a design is a sequence of options based on such things as:

- Product or crop options.
- Social investment options (capital available or created).
- Skills and occupations (education available).
- Processing opportunities on or off site.
- Market availability, or specific market options.
- Management skills.

That is, any design has many potential outcomes, and it is above all the stated aims, lifestyle, and resources of the client(s) that decide their options. Any sensible design gives a *place to start*. The evolution of the design is a matter for trial, following observation, and then acting on that information.

I sometimes think that the only real purpose of an initial design is to evolve *some sort of plan* to get one started in an otherwise confusing and complex situation. If so, a design has a value for this reason alone, for as soon as we decide to start doing, we learn how to proceed.

The sort of options open to people start with a general decision (a distant goal), which is often set by ethical considerations (e.g. "care of the earth"). This may lead directly to a second set of possible options, of which erosion control, minimal tillage, and perhaps revegetation of steep slopes are firmly indicated for a specific site in the light of this ethic.

Thus, an option, *once decided on*, also indicates other options, priorities, and management decisions. In practical terms, we may also have to consider costs, and perhaps decide to generate some short- or long-term income. This, in turn, may depend on whether we maintain a part-time, non-farm income, or (taking the leap) gather up our retirement allowance and go to it.

All of this can be plotted, rather like the decision pattern a tree makes as it branches upwards. Some options are impractical, or in conflict with other decisions and ethics, and are therefore unavailable. (See **Figure 3.6**).

Following through the options that arise from either our decisions, or the constraints of site and resources, we can see an apparently endless series of pathways. The process itself is inevitable, in that it leads to a series of innovative and practical procedural pathways, some of which may be very promising, and all of which agree with the ethical, financial, cultural, and ground constraints decided by the site and/or its occupants.

As a bonus, not one or two, but several dozen options may remain open, and this is always a secure position in which to be. In an uncertain world we need all possible doors open!

Options open up or close down on readily available evidence or as decision-points are reached. All will affect the number and direction of future actions, hence the overall design. To a great extent, this approach covers the economic and legal constraints not dealt with by either of the preceding analytic or observational approaches. It is wise, however, to implement a limited range of options for trial, or we may incur stress and work as a result of taking too much on.

3.6

DATA OVERLAY

DESIGN BY MAP OVERLAYS

In design courses at modern colleges, students are taught to labour assiduously over maps, overlays on those maps, and overlays on the overlays. This approach should also be considered. However, as a methodology, it is at once more expensive, possibly more time-consuming, and potentially the most confusing of all approaches. Like the system of options, it leads to certain inevitable ground placements, and perhaps to uneasy compromises not necessarily inherent in the preceding methods. The danger here is that the map overlays omit minutiae, and can never reveal evolutionary processes.

Where a mapping and hard data approach is weakest, however, is that some factors are not able to be mapped (ethical, financial, and cultural constraints), and that it is very difficult to include those site-relevant details revealed by observation, or indicated at once by our analytic method of component inputs and outputs. Despite this, a good site map makes any *landscape* design (and this is only part of the total design) much easier, and far more visual. A good map indicates a lot of sensible options and hypotheses (dam sites, soil/crop suitability) which can later be checked with actual site conditions, available clay for dams, existing useful vegetation, threatened habitat and so on.

The danger of the purely analytic and overlay approaches is that the very remoteness of such systems makes flexibility difficult, occasioning unforeseen work and expense, which are not incurred by the more empirical and flexible "observation" and "option" systems. The latter both allow a flexible response to fresh conditions.

3.7

RANDOM ASSEMBLY

DESIGN BY ASSESSING THE RESULTS OF RANDOM ASSEMBLIES

This is another analytic method, removed from the site itself. It is of value in assessing energy flows in the system, and is also a generator of creativity. Because it is based on a set of essentially random selections, it may reveal some very innovative designs.

The process is as follows: we select and list a set of design components, and with them a set of placement or connective strategies. If our components are arranged in a circle around these "connections", we can join them up at random, make a sketch of the results, and see what it is that we have achieved. This frees us from "rational" decisions, and forces us to consider unusual connections for their value; connections that would be inhibited from proposing by our limited education, by cultural restraints, or by normal usage. (See **Table 3.2**).

	House	
Windmill		Storage box
Glasshouse	**ATTACHED TO**	Yard or compound
Animal shelter	**BESIDE**	Caves
Trellis	**AROUND**	Trenches
Mounds	**OVER**	Swales
Compost heaps	**IN**	Ponds
Plants	**ON**	Chickens
Ducks	**UNDER**	Fish
Windbreak	**CONTAINING**	Barn
	Fence	

TABLE 3.2
RANDOM ASSEMBLY SELECTION

Having laid out a simple diagram, we can select any one component and connect it to others, creating images for further examination as to their particular uses and functions. Some simple examples are:

- Glasshouse OVER house
- Storage box IN glasshouse
- Raft ON pond
- Glasshouse ON raft
- House BESIDE pond

And, using more connections: glasshouse CONTAINING compost heap ATTACHED TO house BESIDE pond with cave UNDER, containing storages boxes with plants IN these.

We can sketch these, and see just what it is we have achieved in terms of energy savings, unique assemblies, special effects for climate, increased yield, compact design, or easier accessibility. As we do not usually think of these units *with respect to their connections*, this simple design strategy frees us to do so, and to achieve innovative results.

Having illustrated (by way of a diagram) random assemblies, we can then think out what would happen if we did in fact build them or model them. Rafts can, of course, be oriented quickly to suit seasons. Caves are cool and ponds in them almost immune from evaporation. Ducks are safe from predators on rafts. Glasshouses on rafts will warm contained water and create thermal storages and currents. Solar cells will light caves, and caves below houses supply storage and cool or warm air. Trees shade houses, and so on.

Thus, immune from ridicule and criticism, we can try various unlikely combinations and links of components (all of which probably exist somewhere), and try to assess what we have done *in terms of function*. This is, if you like, working backwards from assembly to function to benefits and system characteristics. The value of this approach is that it frees us to create novel assemblies and to assess them before trials.

Creative solutions may also be arrived at by constantly re-examining a problem, and by considering every form of solution, including that important strategy of doing nothing! (Fukuoka[3,4])

CREATIVE PROBLEM SOLVING
Restate a problem many ways, reverse the traditional approaches, and allow every solution to be considered. Simple solutions may be found by this process.

The art of thinking backwards, or in opposites, is often very effective in problem-solving. It is easier to drive an axle out of a wheel than to knock a wheel off an axle, easier to lower a potted vine down a dark shaft over a period of months than to grow it up from the bottom. So, if we worry away at problems in terms of restatements, turning things on their head and stating the opposite, we may find that real solutions lie in areas free from acquired knowledge and values.

3.8
FLOW DIAGRAMS
DESIGN FOR WORK PLACES

For designing any special work place, from a kitchen to a plant nursery, the preceding methods have limited uses. Here, we call in a different method—the "flow chart". We imagine how the process flows. In the kitchen we take from storage, prepare, cook, serve, and gather in the plates and food for waste disposal and return to storage.

Thus the processes follow a certain path. The best kitchens are U-shaped or compact, so that least movement is necessary. Storages are near the place where food, plates, or pots and pans are needed. Frequently-used items are to hand on benches, or in special niches. Strong blocks, bench tops, or tables are built to take the heavy work of chopping and the clamping on of grinders and flour mills. We can mark such designs out on the ground, and walk around these, preparing an imaginary meal, measuring the space taken up by trays, pots, and potato storages, and so creating an efficient work place. It should also involve the placement of traditional items, and agree with cultural uses.

It is advisable to involve an experienced worker in any such design, and to research prior designs or new aids to design, such as we find in office furniture which can be adjusted to the person. I have seen some excellent farm buidings such as shearing sheds and their associated yards built by worker-designers after years of observation and experience. Some people specialise in such design for schools, wineries, and golf courses. In general, it is mainly work-places which need such careful attention. Most other areas in buildings are of flexible use, and have the potential for multiple function.

The technique of flow charts is also applicable to traffic-ways and transport lines serving settlements, where loads or cargoes are to be received and sorted, and where schedules or time-place movements are integral to the activity.

3.9

ZONE AND SECTOR ANALYSIS DESIGN BY THE APPLICATION OF A MASTER PATTERN

Zone and sector analysis is a primary energy-conserving placement pattern for the whole site. When we come to an actual site design, we must pay close attention to locating components relative to the two energy sources of the site:

First, energy available *on site*: the people, machines, wastes, and fuels of the family or society. For these, we establish ZONES of use, of access, and of time available.

Second, energy entering or flowing *through the site*: wind, water, sunlight and fire may enter the site. To govern these energies we place intervening components in the SECTORS from which such energies arise, or can be expected to enter. We also define sectors for views, for wildlife, and for temperature (as air flow). To proceed to a discussion of the pattern in its parts:

ZONES

We can visualise zones as series of concentric circles, the innermost circle being the area we visit most frequently and which we manage most intensively. Zones of use are basic to conservation of energy and resources *on site*. We do not have endless time or energy, and the things we use most, or which need us often, must be close to hand. We plan our kitchens in this way, and we can plan our living sites with equal benefit to suit our natural movements.

We should not pretend that any real site will neatly accept this essentially conceptual conformation of pattern, which will usually be modified by access, site characteristics such as slope and soils, local wind patterns, and the technical problems of, for example, constructing curved fences in societies where title boundaries, materials, and even the education available is "straight".

In *zonation*, the village or dwelling itself is Zone 0, or the origin from which we work. The available energy in Zone 0 is human, animal, piped-in, or created on site. Whatever the sources, these energies can be thought of as *available* or *on-site energies*. In order to conserve them, and those other essential re-sources of work and time, we need to place components as follows:

<u>Zone 0</u> (the house or the village).

In this zone belongs good house design, attached glasshouse or shadehouse, and the integration of living components as sod roof, vines, trellis, potplants, roof gardens, and companion animals. In some climates, many of these structures are formed of the natural environment, and will in time return to it (bamboo and rattan, wattle and daub, thatch, and earth-covered or sheltered structures).

<u>Zone 1</u>

Those components needing continual observation, frequent visits, work input, complex techniques (fully-mulched and pruned gardens, chicken laying boxes, parsley and culinary herbs) should be placed *very close to hand*, or we waste a great deal of time and energy visiting them. Within 6 m (20 feet) or so of a home, householders can produce most of the food necessary to existence, with some modest trade requirements. In this home garden are the seedlings, young trees for outer zone placement, perhaps "mother plants" for cuttings, rare and delicate species, the small domestic and quiet animals such as fish, rabbits, pigeons, guinea pigs, and the culinary herbs used in food preparation. Rainwater catchment tanks are also placed here. Techniques include complete mulching, intensive pruning of trees, annuals with fast replacement of crop, full land use, and nutrient recycling of household wastes. In this zone, we arrange nature to serve our needs.

<u>Zone 2</u>

This zone is less intensively managed with spot-mulched orchards, main-crop beds, and ranging domestic animals, whose shelters or sheds may nevertheless adjoin Zone 1 or, as in some cultures, be integrated with the house. Structures such as terraces, small ponds, hedges, and trellis are placed in this zone. Where winter forces all people and animals indoors, joint accommodation units are the normality, but in milder climates, forage ranges for such domestic stock as milk cows, goats, or poultry can be placed in Zone 2. Home orchards are established here, and less intensive pruning or care arranged. Water may be piped from Zone 3, or conserved by species selection.

Zone 3
This area is the "farm" zone of commercial crop and animals for sale or barter. It is managed by green manuring, spreading manure from Zone 2, and soil conditioning. It contains natural or little-pruned trees, broadscale farming systems, large water storages, soil absorption of water, feed-store or barns, and field shelters as hedgerow or windbreak.

Zone 4
This zone is an area bordering on forest or wilderness, but still managed for wild gathering, forest and fuel needs of the household, pasture or range, and is planted to hardy, unpruned, or volunteer trees. Where water is stored, it may be as dams only, with piped input to other zones. Wind energy may be used to lift water to other areas, or other dependable technology used.

Zone 5
We characterise this zone as the natural, unmanaged environment used for occasional foraging, recreation, or just let be. This is where we learn the rules that we try to apply elsewhere.

Now, any one component can be placed in its right zone, at the best distance from our camp, house, or village. As our very perfect "target" model does not fit on real sites, we need to deform it to fit the landscape, and we can in fact bring "wedges" of a wilderness zone right to our front door: a corridor for wildlife, birds, and nature (**Figure 3.7**). Or we can extend a more regularly used zone along a frequently used path (even make a loop track to place its components on).

Zoning (distance from centre) is decided on two factors:

1. The number of times you need to visit the plant, animal or structure; and
2. The number of times the plant, animal or structure needs you to visit it.

For example, on a yearly basis, we might visit the poultry shed:

- for eggs, 365 times;
- for manure, 20 times;
- for watering, 50 times;
- for culling, 5 times; and
- other, 20 times.

Total = 460 visits; whereas one might visit an oak tree twice only, to collect acorns. Thus the zones are "frequency zones for visits", or "time" zones, however

TABLE 3.3:
SOME FACTORS WHICH CHANGE IN ZONE PLANNING AS DISTANCE INCREASES.

Factor or Strategy	ZONE I	ZONE II	ZONE III	ZONE IV
Main design for:	House climate, domestic sufficiency.	Small domestic stock & orchard.	Main crop forage, stored.	Gathering, forage, forestry, pasture.
Establishment of plants	Complete sheet mulch.	Spot mulch and tree guards.	Soil condition-ing and green mulch.	Soil conditioning only.
Pruning and trees	Intensive cup or espallier trellis.	Pyramid and built trellis.	Unpruned and natural trellis.	Seedlings, thinned to selected varieites.
Selection of trees	Selected dwarf or multi-graft.	Grafted varieties and plants managed.	Selected seedlings for later grafts. by browse.	Thinned to selected varieties, or
Water provision	Rainwater tanks, bores wind pumps, reticulation.	Earth tank and wells, bores,	Water storage fire control.	Dams, rivers, in soils, dams.
Structures	House/green-house, storage integration.	Greenhouse and barns, poultry sheds.	Feed store, field shelter.	Field shelter grown as hedgerow and woodlot
Information	Stored or generated by people.	In part affected by other species.	As for II.	Arising from natural processes.

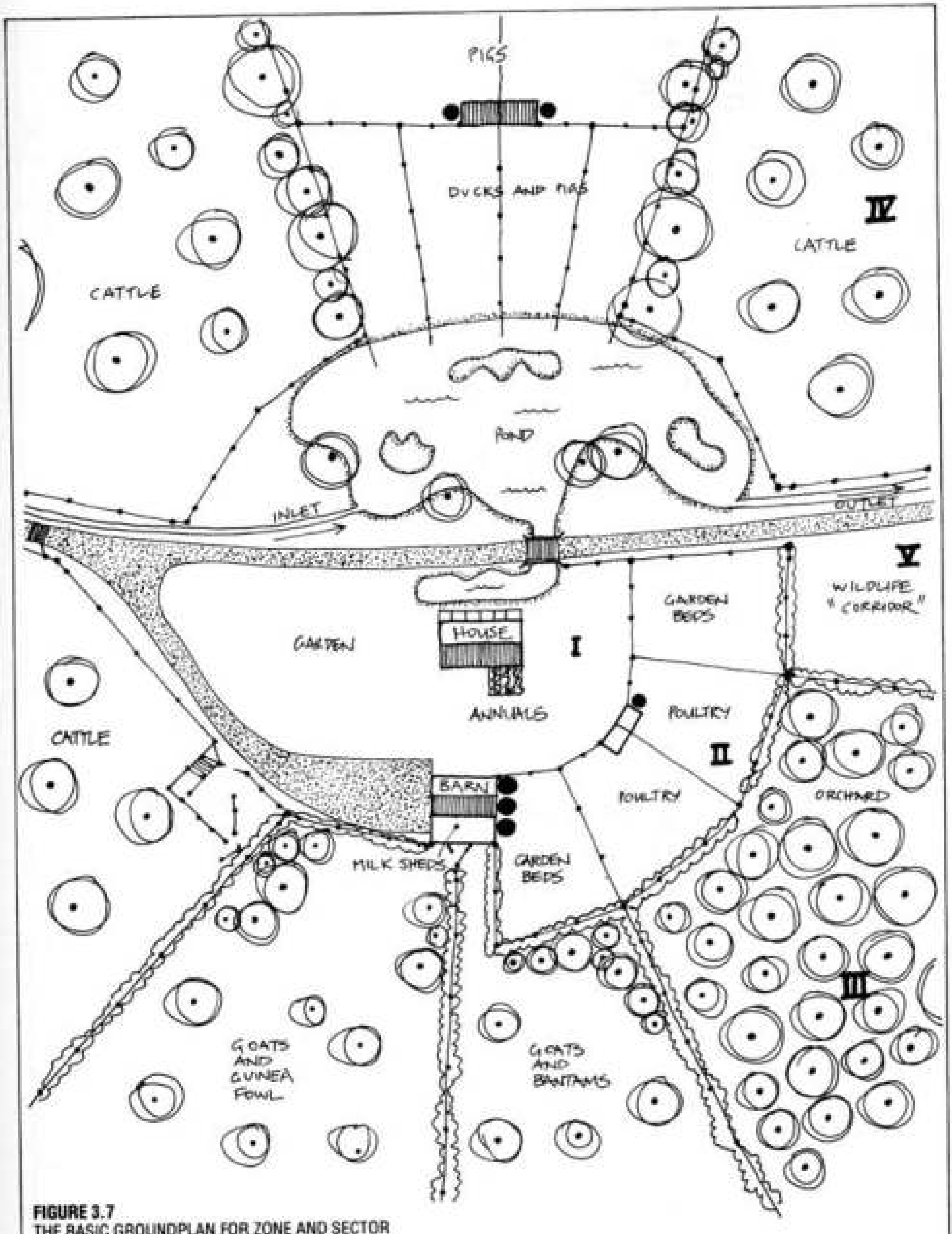


FIGURE 3.7
THE BASIC GROUNDPLAN FOR ZONE AND SECTOR ANALYSIS.
If this pattern only is carefully applied to a site great benefits result.

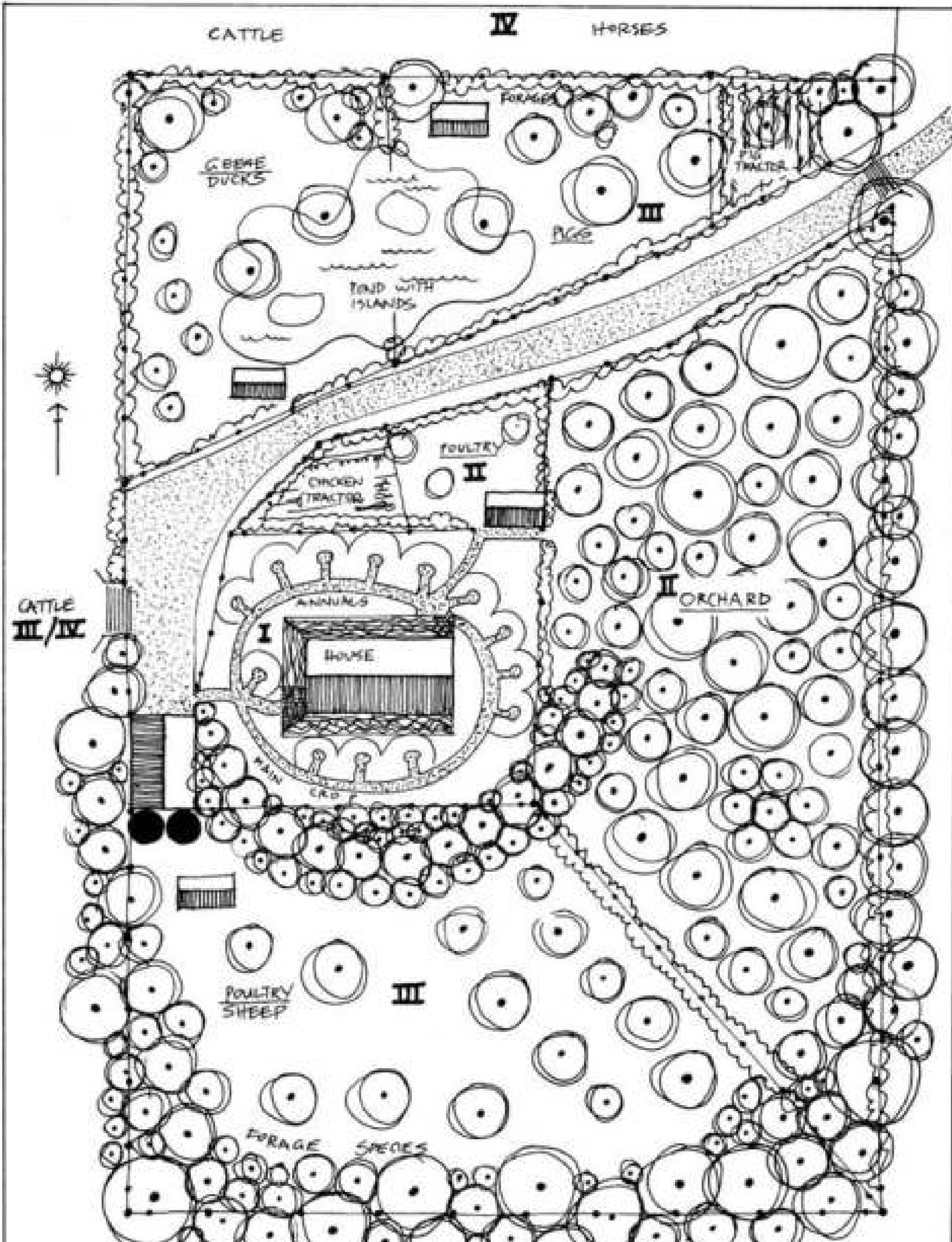


FIGURE 3.8
GROUND PLAN FOR A MIXED SMALL FARM.

you like to define them. The more visits needed, the closer the objects need to be. As another example, you need a fresh lemon 60–100 times a year, but the tree needs you only 6–12 times a year, a total of 66 to 112 times. For an apple tree, where gathering is less, the total may be 15 times visited. Thus, the components or species space themselves in zones according to the number of visits we make to them annually.

The golden rule is to develop the nearest area first, get it under control, and then expand the perimeter. A single perimeter will then enclose all your needs.

Too often, the novice selects a garden away from the house, and neither reaps the plants efficiently, nor cares for them well enough. Any soil, with effort and the compost from the recycling of wastes, will grow a good garden, so stay close to the home.

Let us think of our zones in a less ordered way, as was well described by Edgar Anderson for Central Honduras (Anderson, E., 1976):

> Close to the house and frequently more or less surrounding it is a compact garden-orchard several hundred square feet in extent. No two of these are exactly alike. There are neat plantations more or less grouped together. There are various fruit trees (nance, citrus, melias, a mango here and there, a thicket of coffee bushes in the shade of the larger trees)... There are tapioca plants of one or two varieties, grown more or less in rows at the edge of the trees. Frequently there are patches of taro; these are the framework of the garden- orchards. Here and there in rows or patches are corn and beans. Climbing and scrambling over all are vines of various squashes and their relatives; the chayote (choko) grown for the squashes, as well as its big starchy root. The luffa gourd, its skeleton used for dishrags and sponges. The cucurbits clamber over the eaves of the house and run along the ridgepole, climb high in the trees, or festoon the fence. Setting off the whole garden are flowers and various useful weeds (dahlias, gladioli, climbing roses, asparagus fern, cannas). Grain amaranth is a 'sort of encouraged weed that sows itself.'

Around the "dooryard gardens" described above, Anderson notes the fields (in Mexico) "dotted here and there with volunteer guavas and guamuchiele trees, whose fruit was carefully gathered. Were they orchards or pastures? What words are there in English to describe their groupings?"

Anderson is contrasting the strict, ordered, linear, segmented thinking of Europeans with the productive, more natural polyculture of the dry tropics. The order he describes is a semi-natural order of plants, in their right relationship to each other, but not rigorously separated into various artificial groups. More than that, the house and fence form essential trellis for the garden, so that it is no longer clear where orchards, field, house and garden have their boundaries, where annuals and perennials belong, or indeed where cultivation gives way to naturally-evolved systems.

Monoculture man (a pompous figure I often imagine to exist, sometimes fat and white like a consumer, sometimes stern and straight like a row-crop farmer) cannot abide this complexity in his garden or his life. His is the world of order and simplicity, and therefore chaos.

When thinking of placing components into zones, remember that intrinsic properties and species-specific yields are available from a component wherever it is placed (all trees give shade), so that we don't include these "intrinsics" in assessing function in design.

JUDGING ZONAL PLACEMENT

Place a component in relation to other components or functions, and for more efficient use of space or nutrient. Look for products that serve special needs not otherwise locally available.

The amount of management we must always provide in a cultivated ecosystem is characterised by conscious placement, establishment, guidance, and control energies, akin to the adjustments we normally make to our environment as we traverse it on our daily tasks.

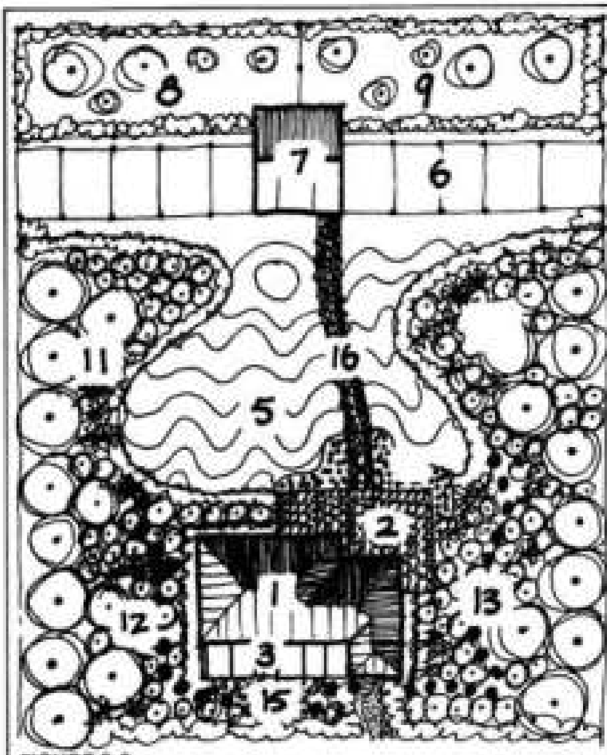


FIGURE 3.9
Design for a 1,000 square metre block. See text.

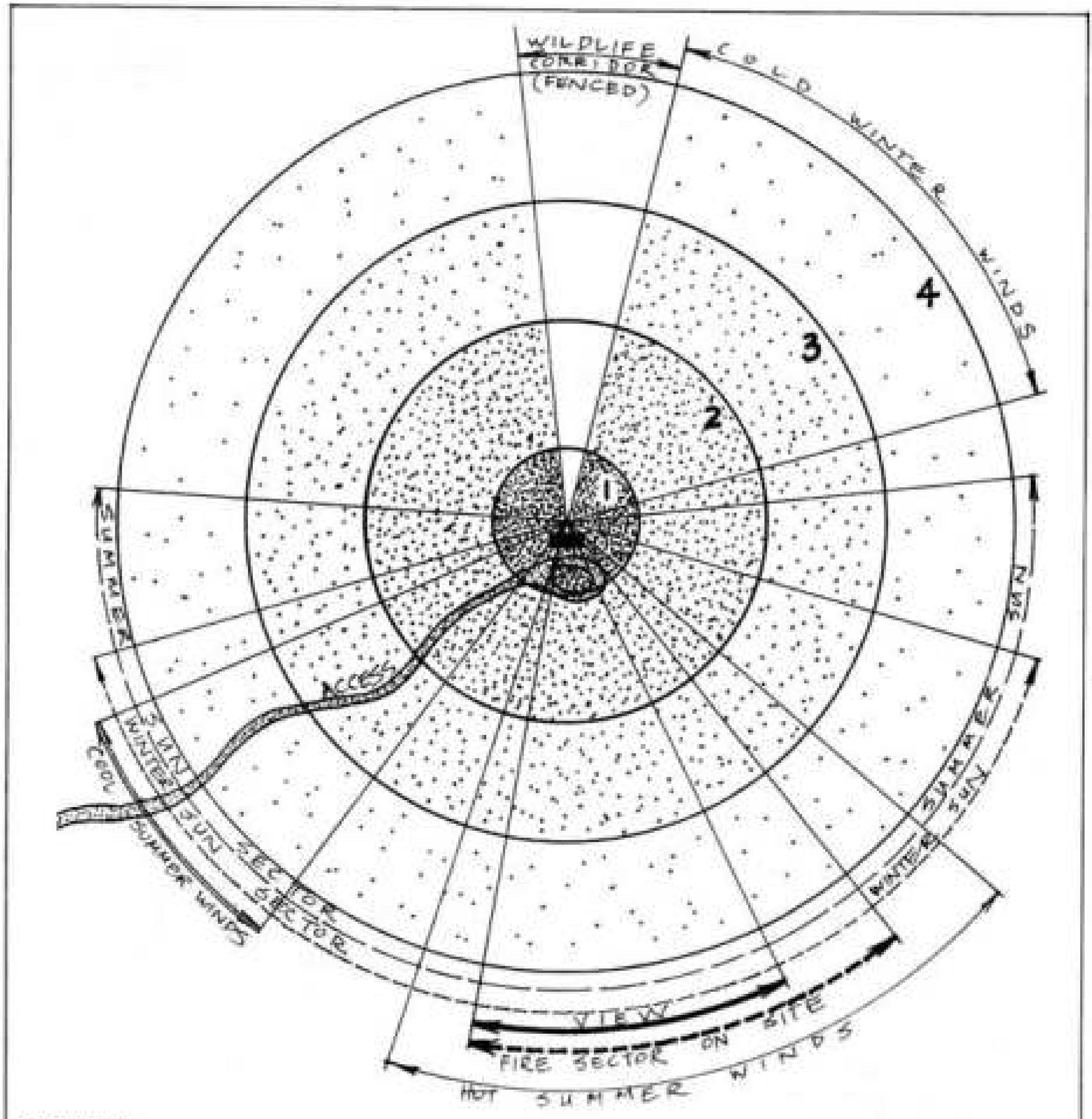


FIGURE 3.10
SECTOR ANALYSIS.

PLACEMENT IN SECTORS

Next in a permaculture design, we consider the wild energies, the "elements" of sun, light, wind, rain, wildfire, and water flow. These all come from *outside* our system and pass through it: a flow of energies generated elsewhere. For these, we plan a "sector" diagram based on the real site.

Our sectors are more site-specific than are the conceptualised zones. They outline the compass directions from which we can expect energy or other factors. Some factors we may invite in to our homes; we need sunlight for technologies and plant growth. Some we may exclude (such as an unpleasant view of a junkyard). More commonly, we plan to regulate such factors to our advantage, placing our zonal components to do so.

Whereas settlement or house is the ground zero for zones, it is the through point for sectors. Energies from outside can be thought of as so many arrows winging their way towards the home, carrying both destruc-tive and beneficial energies; we need to erect shields, deflectors, or collectors. Our choice in each and every sector is to block or screen out the incoming energy or distant view, to channel it for special uses, or to open out the sector to allow, for example, maximum sunlight. We guard against catastrophic fire, wind, or flood by protective embankments, dense trees, ponds, roads, fences, or stone walls, and we likewise invite in or exclude free-ranging or undomesticated wildlife by placements of forage systems, fences, nest boxes, and so on. Thus we place hedges, ponds, banks, walls, screens, trellises, hedgerows or any other component of design to *manage incoming energy*.

If you like, we place our components in each zone as though zones could be rotated about Zone 0. For any one component, it stops rotating when it is working to govern energies in the sector diagram. Thus, by "revolving" our zones, we find a place where our selected component (a tree, fence, pond, wall, or animal shed) works to govern sector factors. Given that we have both zone and sector energies controlled, then our component is well placed. Then we combine the two diagrams to make a spiderweb of placements, putting every main system in its right place in terms of energy analysed on the site (**Figure 3.10**).

To sum up, there should be no tree, plant, structure, or activity that is not placed according to these criteria and the ground plan. For instance, if we have a pine tree, it goes in Zone 4 (infrequent visits) AWAY from the fire danger sector (it accumulates fuel and burns like a tar barrel), TOWARDS the cold wind sector (pines are hardy windbreaks), and it should also bear edible nuts as forage.

Again, if we want to place a small structure such as a poultry shed, it should BORDER Zone 1 (for frequent visits), be AWAY from the fire sector, BORDER the annual garden (for easy manure collection), BACK ONTO the forage system, possibly ATTACH to a greenhouse, and form part of a windbreak system.

There is no mystery nor any great problem in such commonsense design systems. It is a matter of bringing to consciousness the essential factors of active planning. To restate:

<u>The Basic Energy-Conserving Rules</u>

Every element (plant, animal or structure) must be placed so that it serves at least two or more functions.
Every function (e.g. water collection, fire protection) is served in two or more ways.

With the foregoing rules, strategies, and criteria in mind, you can't go far wrong in design.

<u>Placement Principle</u>

If broad initial patterning is well analysed, and good placements made, many more advantages than we would have designed for become obvious.
Or, if we start well, other good things naturally follow on as an unplanned result.

This is the broad pattern approach. Given that the scene has been set, *observation* comes into play to evolve other pattern strategies. If we watch just how our animals move, how winds vary, or how water flows, we can evolve guiding patterns that achieve other desirable ends, e.g. making animals easy to muster, bringing them to sites where their manure is needed, steering cool winds to ameliorate excess heat input or to direct them to wind turbines, and directing water to where it is needed in our system.

SLOPE, ASPECT, ELEVATION, AND ORIENTATION.

No site is quite flat, and many have irregular configurations; thus our neat spider webs of zone and sector overlays are distorted by a more realistic landscape. To use these irregularities to our advantage, we need to further consider these factors:

With zones and sectors sketched in on the ground plan, slope analysis may proceed. High and low access roads, the former for heavy cargo or mulch, the latter for fire control, can now be placed. Provision for attached glasshouse, hot air collectors, reflection pond, solar pond, and shadehouse should be made at all homestead sites where climatic variation is experienced.

Slope determines the unpowered flow of water from source to use point, and slope and elevation will permit the placement of hot air or hot water collectors *below* their storages, where the **thermosiphon** effect can operate without external energy inputs. The simple physics of flow and thermal movements can be applied to the placement of technological equipment e.g. solar hot water panels, taking advantage of slope. Where no slope exists, towers for water tanks and hollows for heat collectors (or solar ponds) can be raised or excavated for the same effect.

However, in the normal humid landscape (where precipitation exceeds evaporation), hill profiles develop a flattened "S" curve that presents opportunities for placement analysis of components and systems, as per **Figure 3.11**.

The ancient occupied ridgeways of England testify to the commonsense of the megalithic peoples in landscape planning, but their present abandonment for industrial suburbs in flatlands does little credit to the palaeolithic planning of modern designers. The difference may be that the former planned for themselves, while the latter design for "other people".

Slope gives immense planning advantages. There is hardly a viable traditional human settlement that is not sited on those critical junctions of two natural ecologies, whether on the area between foothill forests and plains, or on the edge of plain and marsh, land and estuary, or some combination of all of these. Planners who place a housing settlement on a plain, or on a plateau, may have the "advantage" of plain planning, but abandon the inhabitants to failure if transport fuels dry up. They then have to depend on the natural environment for their varied needs but have only a monocultural landscape on which to do so. Successful and permanent settlements have always been able to draw from the resources of at least two environments.

Similarly, any settlement which fails to *preserve* natural benefits, and, for example, clears all forests, is bent on eventual extinction.

The descending slopes allow a variety of aspects, exposures, insolation, and shelter for people to manage. Midslope is our easiest environment, the shelter of forests at our back, the view over lake and plain, and the sun striking in on the tiers of productive trees above and below. **Figure 3.11** shows a broad landscape profile, typical of many humid tropical to cool climates, which we can use as a model to demonstrate some of the principles of landscape analysis.

On the high plateaus (A) or upper erosion surface, snow is stored, and trees and shrubs prevent quick water run-off. The headwaters of streams seek to make sense of a sometimes indefinite slope pattern, giving way to the steep upper slopes (B), rarely (or catastrophically) of use to agriculture, but unfortunately often cleared of protecting forest and subject to erosion because of this.

The lower slopes (C) are potentially very productive mixed agricultural areas, and well suited to the structures of people and their domestic animals and implements. Below this are the gently- descending foothills and plains (D) where cheap water storage is available as large shallow dams, and where extensive cropping can take place.

This simplified landscape should dictate several strategies for permanent use, and demands of us a careful analysis of techniques to be used on each area.

The main concern is water, as it is both the chief agent of erosion and the source of life for plants and animals. Thus the high plateau is a vast roof where rain and snow gather and winds carry saturated cloud to great heights. At night the saturated air deposits droplets on the myriad leaves of the ridge forests.

The gentle foothill country of area (C), brilliantly analysed for water conservation by Yeomans[5], supports the most viable agricultures, if the forest above is left uncut. Here, the high run-off can be led to midslope storage dams at the "Keypoint" indicated in **Figure 3.11** (examined in much more detail in Yeomans' books). Using the high slopes as a watershed, and a series of diversion catchment drains and dams, water is conserved at the keypoints for later frugal use in fields and buildings. The water is passed with its nutrients to low dams, and released as clean water from the site. (This is the ideal: the reality often falls far short of it.) The lower slopes—those safe to use tractors on at least—can be converted to immense soil-water storage systems in a very short time (a single summer often suffices). This is a matter of soil conditioning, afforestation, water interception, or a combination of these.

The plains of area (D) are the most open to wind erosion and the most resistant to water erosion. However, it is here that great damage can occur by salting. Red and dusty rains and plagues of locusts are a result of the delinquent use of the plough, heavy machinery, and clean tillage of these flattish lands, together with the removal of trees and hedgerows, and the conversion of the plains to monocultures of extensive grazing and grain cropping.

It is on the plains areas that water is most cheaply stored, in soil and in large surface dams, where no-tillage crops, **copses** and **hedgerows** are desperately needed. This is where broadscale revolutions in technique can be implemented to improve soil health, reduce wind and water losses, and produce healthy foods.

The forests on the high slopes, coupled with the thermal belt [Geiger[12]] of the house site make a

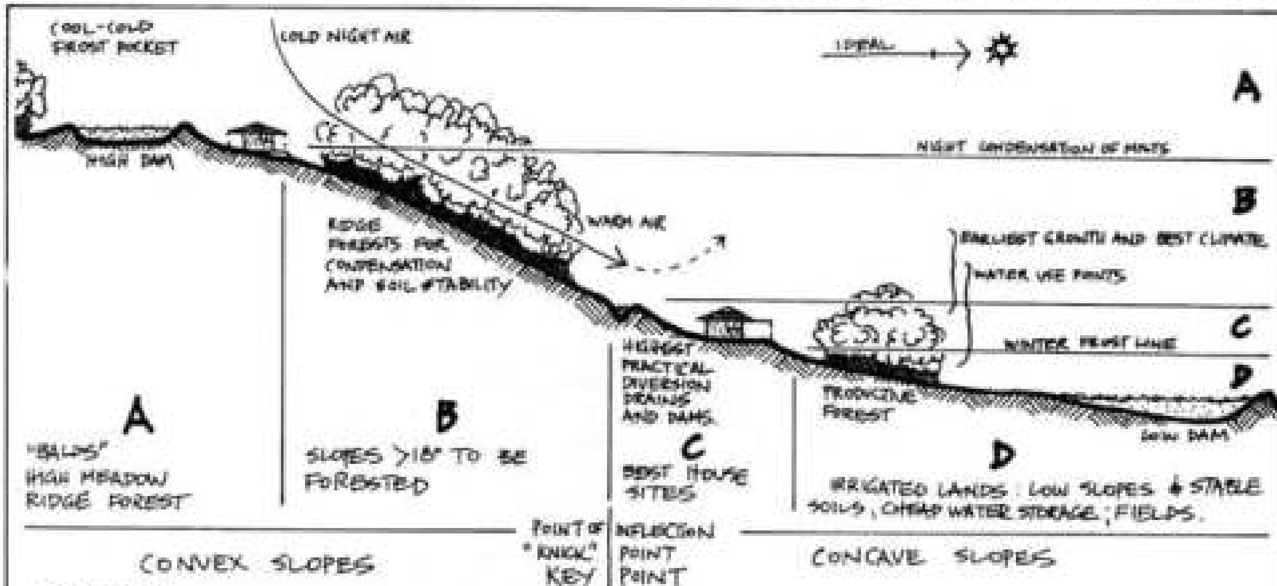


FIGURE 3.11
BROAD HUMID LANDSCAPE PROFILE.
Slope analysis and site planning in relation to aspect largely decide the placement of access, water supply, forests, and cropland. Here we supply such analysis to a cool, humid region.

remarkable difference to midslope climate and soil temperatures. Anyone who doubts this should walk towards an uphill forest on a frosty night, and measure or experience the warm down-draught from high forests. If these are above Zones 1 and 2, they present little or no fire danger. Their other functions of erosion control and water retention are well attested.

Downslope, reflection from dams adds to the warmth. Solar collectors placed here transmit heat, as air or water circulating by thermosiphoning alone, and assist house, glasshouse or garden to function more efficiently. Even very slight slopes of 1:150 function to collect water and heat if well used in the design.

The easy, rounded ridges of non-eroded lower slopes and their foothill pediments are a prime site for settlement. They allow filtration of wastes, inseparable from large populations, through lowland forest and lake, and the conversion of these wastes into useful timber, trees, fruits, and aquatic life.

If zone and sector are imposed in plan, sun angle and landscape slope are assessed in elevation. These determine the following placements:

SUN ANGLE describes the arc of the sun during summer and winter months, and so decides eave and sill placement of windows, areas of shade, and reflection or absorption angles of surfaces. Also, in *every* situation (even hot deserts), some part of the system should be left open to the sun for its energy potential.

ASPECT describes the orientation of the slope. A slope facing the sun will receive considerably more direct solar radiation than a slope facing the shade side (south in the southern hemisphere, north in the northern). The shaded side of hills may delay thaw and thus moderate frost effects in vegetation. In mid-latitudes, we seek the sunny aspect of slopes to achieve maximum sunlight absorption for our settlements and gardens.

The final act in site planning is to orient all buldings and structures or constructs correctly, to face **mid- sky**, the sun, or the wind systems they refer to, or to shelter them from detrimental factors e.g. cold winter winds or late afternoon sun.

In summary, if the elements of the design are carefully zoned, the sectors well analysed, the sun angle and slope benefits maximised for use, and the constructed environment oriented to function, then a better ground design results than most that now exist. As I reassure all would-be permaculture designers, *you can do no worse* than those prior designs you see about you, and by following the essentially simple outline above, you may well do much better. Incredible as it seems, these essential factors are the most frequently overlooked or ignored by designers to the present day, and **retrofit** is then the only remedy for ineffective design.

3.10

ZONING OF INFORMATION AND ETHICS

In this book, I am concentrating on people and their place in nature. Not to do so is to ignore the most destructive influence on all ecologies: the unthinking appetite of people—appetite for energy, newspaper, wrappings, "art", and "recreation". We can think of our zones in other than product terms and management, as a gradation between an ecosystem (the home garden) managed primarily for people, and the wilderness, where all things have their right to exist, and we are only supplicants or visitors. Only excessive energy (human or fuel) enables us to assert dominance over distant resources. When we speak of dominance, we really mean destruction.

What is proposed herein is that we have no right, nor any ethical justification, for clearing land or using wilderness while we tread over lawns, create erosion, and use land inefficiently. Our responsibility is *to put our house in order*. Should we do so, there will never be any need to destroy wilderness. Indeed, most farmers can become stewards of forest and wildlife, as they will have to become in any downturn in the energy economy. Unethical energy use is what is destroying distant resources for short-term use.

Our zones, then, represent zones of destruction, information, available energy, and human dependency. The "ecologist" with large lawns, or no food garden, is as hypocritical as the "environmentalist" drinking from from an aluminium beer can and buying newspapers to read of destructive exploits. Both occupations exploit wilderness and people.

In Zone 1 we are *information developers;* we tend species selected by, and dependent on, mankind. All animal species tend their "home gardens", and an interdependency arises that is not greatly different from the parasite-prey dependency.

In Zone 2, already nature is making our situation more complex, and we start to *learn* from species other than our people-dependent selections. As we progress outwards, we can lose our person-orientation and gain real understanding of the necessity for all life forms, as we do not "need" to exploit most species. We in fact need and use only a few species of the hundreds of thousands that exist.

In wilderness, we are visitors or strangers. We have neither need nor right to interfere or dominate. We should not settle there, and thus leave wastelands at our back. In wilderness we may learn lessons basic to good design, but we cannot improve on the information already available there. In wilderness, we learn of our little part in the scheme of all things.

<u>Understandings</u>

1. Everything is of use. It is not necessarily needed by people, but it is needed by the life complex of which we are a dependent part.
2. We cannot order complex functions. They must

evolve of themselves.
3. We cannot know a fraction of what exists. We will always be a minor part of the total information system.

Thus, we are *teachers* only in our home gardens, and *learners* elsewhere. Nowhere do we create. Everything we depend on we have evolved from *what is already created*, and that includes ourselves. Thoughtful people (those who get recreation from trying to understand) need wilderness as schools need teachers. Should we lose the wilderness, or suffer it to be destroyed, we will be recycled for more appropriate life in any number of ways, some very painful and protracted. We can also state our first "error" thesis here; such errors, once made, lead us into increasing problems.

Type 1 Error
When we settle into wilderness, we are in conflict with so many life forms that we have to destroy them to exist. Keep out of the bush. It is already in good order.

3.11
INCREMENTAL DESIGN

Almost all engineering design is based on small changes to existing designs, until some ultimate limit in efficiency or performance is reached. The whole process can take centuries, and the end result can be mass-produced if necessary. Kevin Lynch (1982) in his book *Site Planning* writes of site designing by incremental adaptation of already-existing designs: design by following physical systems that have been shown to work. He believes the best site planning of the past to be a result of this process, and that it in fact works very well unless some external and important condition (e.g. market or land ownership) changes. He maintains that this fine-tuning of *successful* design for a specific climate and purpose can be totally inappropriate if transferred out of culture, climate, or if applied to a different purpose.

It is, however, the most successful way to proceed *after* selective placement and energy conservation is paid sufficient attention. Known effective design units and specifications, whether of roads, culverts, houses, garden beds, or technologies have been subjected to long tests, and have evolved from trials (or prototypes) to working and reliable standards. Even if "old-fashioned" (like overshot water wheels), they may yet represent a simplicity and an efficiency hard to beat without a considerable increase in expense and complexity.

Such continual adaptation is the basis of feedback in systems undergoing establishment, where we make additions or changes to houses or plant systems. It is not the way, however, to satisfy the demands of a complex system which (like a private home and garden) has to satisfy a complex set of priorities. Nor does it cope with changing futures, new information and sets of values, or simply self-reliance and self-governance.

3.12
SUMMARY OF DESIGN METHODS

To sum up, in whole farm planning and in report writing, outlining areas of like soil, slope, or drainage will suggest sensible crops, treatments, fencelines and land use generally. If we accept what is there, ethical land use dictates conservative and appropriate usage. But (as may happen) if someone is determined to raise wheat on all that land regardless of variations, they can probably do so only if they command enough energy or resources. I am sure we can grow bananas in Antarctica if we are prepared to spend enough money, or can persuade penguins to heat a glasshouse!

Insofar as we enter into village design, we may have financial and space constraints on upper or lower sizes: a "break-even" point and an "optimum" number of houses per unit area. However, if we neglect a foray into the social effects of settlement size and into the needful local functions related to settlement size, we may be designing for human misery, the under-servicing of needs, and even for such sociopathologies as riot and crime. Such designs may be economic (in cash terms), efficient for one use only, and totally inhuman. But they are built every day. For example, it was found that rats subjected to breathing in the same airstream of their fellows experienced severe instability, physiological stress, and consequent pathologies akin to crowding stress. This is called the "Bruce effect" after the experimenter who discovered it, and this effect may apply equally well to people. Yet in almost all cities, one can see people crammed into 16-40 storey office buildings with no opening windows and only a single airstream!

Site designing needs not a specialist approach, but rather a multi-disciplinary and bio-social approach that takes into account the effects the environment has on its intended occupants.

Perhaps if we assembled all our considerable, diverse, and effective knowledge of both the parts and the whole order of design into a type of computer search or game-playing programme, we might advance the whole design process as a realm of continuing and additive human knowledge, available to everyone. Such programmes could deal with a great deal of the fussy detail that now slows design—from plant list specifications to home construction details—leaving the designer with those imponderables about the processes observed on the land, the likely trends of future societies, future needs, and a measure of human satisfaction.

In elaborating just some of the basic approaches to design, without including specialist solutions, I want to stress that all the approaches outlined are not only useful, but necessary. Only by some sensible combination of all the methods given can one select and assess all the elements that enter into a total design assembly, and so evolve a design that includes a large degree of self-management, takes account of details on site, suits the ethics and resources of people, locates ground features in an integrated way, and provides for natural systems and access routes to be properly located.

3.13

THE CONCEPT OF GUILDS IN NATURE AND DESIGN

The methodologies of polyculture design rely more on species interaction than on configuration, although both are necessary inputs to a design. Thus, in designing for best (or most beneficial) species assemblies, we need to know about, and use, the concepts of species guilds and the co-actions of species.

In the natural world, we may often notice assemblies of plants or animals of different species that never-

TABLE 3.4
IMPETUS TO DESIGN

PERMACULTURE	MOST PRESENT–DAY DESIGN
STIMULATED BY: A perceived social problem.	STIMULATED BY: A drive to erect monuments or make money.
SUBJECT TO: Values of energy conservation, self–reliance, and harmonious human occupancy.	SUBJECT TO: Economic (as cash) considerations and the desire for profit.
MEDIATED BY: Consideration of long–term biosocial factors.	MEDIATED BY: Purely functional values for short–term cost and material factors.
ACHIEVED BY: Research and consultation with clients, or assisting people to gain an education in design.	ACHIEVED BY: External funding, little consultation, little client/people education.
REFINED BY: Allowing space, finance, and feedback to adjust activity, and allowing for new or overlooked needs as they occur.	REFINED BY: Selling off and not taking responsibility for the results.
LEADING TO: A dynamic and healthy area inhabited by people with the power and understanding to make necessary changes.	LEADING TO: A dislocated populatio, powerless to effect change easily. Hence, dependency and anxiety.

RESULTS

THE STABILITY OF DYNAMIC LOCAL ADJUSTMENT.	**THE INSTABILITY OF PERCEIVED INDIVIDUAL POWERLESSNESS.**

theless occur together over their range. Closer examination of such mixed assemblies often reveals a set of mutual benefits that arise from such convivial togetherness. These benefits offer help or protection to the whole assembly (as when one bird species acts as "lookout" for another, or defends others from hawks). When we *design* plant guilds, as we always try to do in a polyculture, we try to maximise the benefits of each species to the others. We can also add factors of convenience to ourselves, or which save us inputs of fertiliser or pesticides, as in the "apple-centred" guild described below .

A **guild**, then, is an harmonious assembly of species clustered around a central element (plant or animal). This assembly acts in relation to the element to assist its health, aid our work in management, or buffer adverse environmental effects (see **Figure 3.12**). Let us list some of the reasons to place species in association:

<u>To benefit as selected species by:</u>

- Reducing root competition from (e.g.) invasive grasses. Almost all our cultivated food trees thrive in herbal ground covers, not grasses.
- Assisting pest control in various ways:

— by providing **anti-feedants** (bitter or unpalatable browse or chemical deterrents), e.g. nasturtium roots provide root chemicals to tomatoes or gooseberries which deter whitefly. Many plants, fermented or in aqueous extraction, deter pests or act as anti-feedants when sprayed on leaves of the species we wish to protect.

— by killing root parasites or predators, e.g. *Crotalaria* captures nematodes that damage citrus and solanaceous roots; *Tagetes* marigolds "fumigate" soils against grasses and nematodes.

— by hosting predators, as almost all small-flowered plants [especially*Quillaja*, many *Acacia* species, tamarisk, *Compositae* (the daisy family) and *Umbelliferae* such as dill, fennel, carrot, and coriander] host robber-flies and predatory wasps.

- Creating open soil surface conditions, or providing mulch. For example, comfrey and globe artichokes allow tree roots to feed at the surface (unlike grasses, which competes with tree roots), while spring bulbs (daffodils) or winter-grown wild *Allium* species, whose tops die down in mid-spring do not compete with deciduous tree roots in summer dry periods, nor do they intercept light rains.
- Providing free nutrients: woody or herbaceous legumes fix nitrogen or other essential nutrients via root associates, stimulate soil bacteria or fungi, and benefit associated trees. Clovers; trees such as *Acacia*, *Casuarina*, and *Pultenaea*; sugar-providing grasses (sugar cane); and high humus producers (bananas) all assist orchard species. Many can be slashed or trimmed to give rich mulch below trees or between crop rows.
- Providing physical shelter from frost, sunburn, or the drying effects of wind. Many hardy windbreak species of equal or greater height, both as edge windbreak or in-crop crown cover exclude frost, nullify salty or hot winds, provide mulch, and moderate the environment towards protecting our selected species. Examples are borders of bamboo, cane grasses, *Casuarina*, hardy palms, and tamarisks. In-crop shade shelter of legumes are needed by such crops as avocado, citrus, and cocoa or coffee (or any crops needing partial shade). In-crop trees can eliminate frost effects in marginal frost areas.

<u>To assist us in gathering:</u>

- Culinary associates: it is of some small benefit in detailed planning to keep common culinary associates together (tomatoes with parsley and basil; potatoes with a tub of mint) so that we also gather them together for cooking, salads, or processing (dill with cucumbers). Thus we reduce work. Dill and apples also go well together, raw or cooked, and dill is one of the *Umbelliferae* that host predatory wasps below apple trees.

<u>Specific animal associates of a guild:</u>

We have made reference, in pest control, to host plants. These can be best specified by observing, researching, or selecing plants to host quite specific predatory wasps, lacewings, or ladybirds. Vertebrates that assist our selected crop species are:

- Ground foragers, e.g. pigs or poultry specifically used to clear up the fallen fruit that host fruit fly or larval forms of pests. Foragers can be run in orchards for that relatively short period of the year when fruit is falling and rotting, or they can be used to eat reject fruit and deposit manures.
- Insectivores: birds, in particular, that search bark crevices (woodpeckers, honey-eaters) for resting larvae and egg masses. To encourage these, plant a very few scattered flowering shrubs and herbaceous plants such as *Kniphofia*, *Banksia*, *Salvia*, *Buddleia*, and *Fuschia*. All of these provide insect and nectar foods for insectivorous birds.
- Mollusc control: snails and slugs are almost totally controlled by a duck flock on range, and several large lizards (*Tiliqua* spp.) also feed primarily on snails. Ducks can be ranged seasonally (autumn to spring) in plant systems, and in summer on marshlands. Ducks will eat seedlings, so that appropriate scheduling is essential.
- Guard dogs: for deer, rabbits, and other vertebrate pests. A small number of guard dogs, fed and kennelled in orchards, are sufficient control for fox predation on orchard poultry foragers. Such dogs, reared *with* domestic poultry, do not attack the flocks themselves.
- Hawk kites suspended over a berry crop, or flown as light model planes over an extensive grain crop deter all flock-bird predators of the crop, and are more dependable than natural hawks. They need to be removed when not needed, so that birds do not get

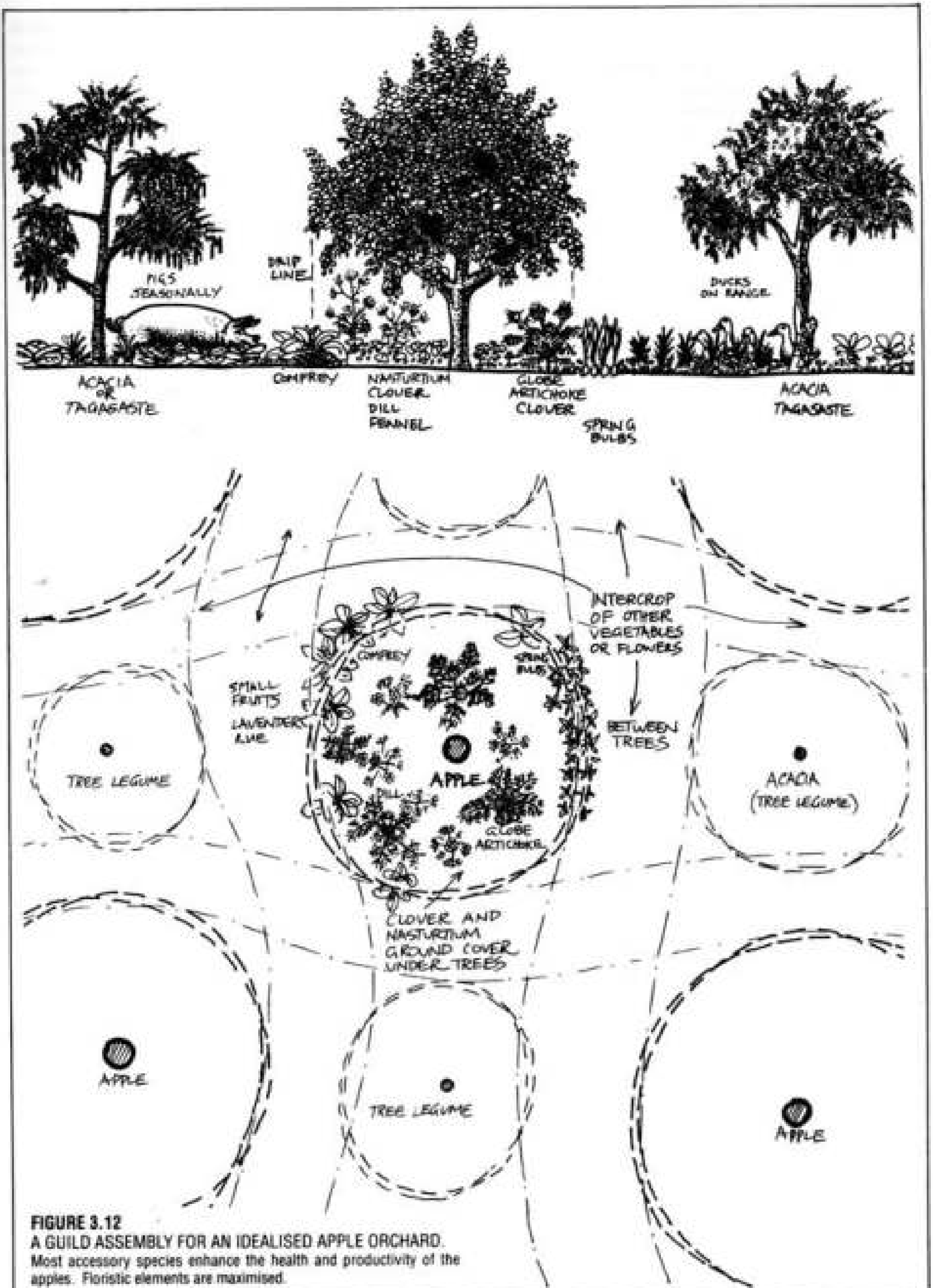


FIGURE 3.12
A GUILD ASSEMBLY FOR AN IDEALISED APPLE ORCHARD.
Most accessory species enhance the health and productivity of the apples. Floristic elements are maximised.

accustomed to them.

These are just part of the total guilds. Every designer, and every gardener, can plan such guilds for specific target species, specific pests and weed control, and specific garden beds or orchards.

ANALYTIC APPROACH TOWARDS SELECTING A GUILD

A guild of plants and animals is defined here as a species assembly that provides many benefits for resource production and self-management (more yields, but lower inputs). In general, the interactions between plant and animal species are thus:

- Most species get along fine; this is obvious from a study of any complex home garden or botanical garden; perhaps 80% of all plant species can co- mingle without ill effect.
- Some species greatly assist others in one or other of many ways. Positive benefits arise from placing such species together where they can interact (10–15% of all species).
- A minority of species show antagonistic behaviour towards one or more other species. This in itself can be a benefit (as in the case of biological pest control) or a nuisance (as in the case of rampancy or persistent weeds or pests). Perhaps as few as 5% of all species act in this way.

Now, to give the above classes of interaction a more useful analytic structure, we will allot symbols, as follows:

+ : this is used to indicate a *beneficial* result of interaction, with a yield above that of some base level (judged from a monoculture or control crop of the species).
o : this is used to indicate *"no change"* as a result of interaction, on the same basis.
–: this is used to indicate a *reduction* in yield or vigour as a result of interaction with another species.

Thus, for two useful species (each selected for a useful product), we have the simple tabulation of **Table 3.5**, which gives us all possible interactions.

The array is such that only three interactions benefit us, three are neutral, and three are antagonistic in effect effect. By grouping scores, we can analyse for beneficial effects in our interaction table, and act on these. However, because of the vagaries of weather in any given year, many times a peasant farmer may accept a (– +) effect just to ensure that he at least gets a crop, even if it is of the "losing" species. It is *always* safer to mix or complicate crop than to pin hopes on a single main crop. In fact, be guided by analyses but study reality!

STATES OF ACTION

In common usage, COACTION implies a force at work: one that restrains, impedes, compels, or even coerces another object. INTERACTION implies reciprocal action: two things acting on each other. This is an important distinction. A final category is INACTION, or an absence of any detectable action.

We cannot at this point guess which state applies, but when we put two species together, there are these possibilities:

- One acts on the other (co-action or unilateral action);
- Both act on each other (interaction or mutual action); and
- Neither act (inaction or neutrality).

TABLE 3.5
INTERACTION MATRIX OF TWO SPECIES (plant or animal).

		SPECIES A		
		+	O	–
	+	++	+O	+–
SPECIES B	O	O+	OO	O–
	–	–+	–O	——

It would seem probable that in the case of (++) and (– –) we have mutual action or interaction. In the case of (–o), (o–), (+o), (o+), (+–), (–+) *one only* needs to be acting, a form of co-action. In the case of (oo) neither acts, no effects appear, and both are inactive insofar as our measures can detect.

We need to observe and perhaps analyse each case, but it does seem probable that such states of action apply. Some such states can be named and examples given, for instance:

A. Mutual Action States

++ This is called symbiosis, and is common both in nature and in society. It is a "win-win" situation ideally suited to guild development. An example is the mycorrhizal associates of higher plants, where mutualism or fair trade occurs between a plant and its root associate.

-- Haskell (1970) has coined the word synnecrosis (*The Science Teacher 37(9)* Supplement), and it is obviously uncommon. War is our best example of a 'lose-lose' situation, but there are also battles between plants for light, nutrients, and space. There are forms of chemical warfare in both plants and animals.

B. Single Action States

–o Haskell calls this amensalism. It hurts the *actor*, not the other. A butterfly attacking a rhinocerous would fit, or a wasp parasite "glued" to a tree it attacks, as is the case with some pine trees and Sirex wasps.

o– Called allolimy by Haskell, it leaves the actor unaffected but hurts the other, e.g. a walnut tree beside an apple tree yields well, but the juglones secreted by its roots act to kill or weaken the apple. In the same way grasses act to weaken most deciduous fruit trees.

+o Termed commensalism. Even though the actor benefits, the other remains unaffected, e.g. an epiphyte attached to a sturdy tree, such as vanilla on a coconut trunk.

o+ Called allotrophy by Haskell. The actor is unaffected, the other benefits. Examples are a teacher and student relationship, or a charity where one hands on surplus goods to another person less fortunate.

+– Called parasitism, the actor benefits, the other loses *if* the actor is the parasite. All pathogens and parasites tend to weaken or take from the host.

–+ Self-sacrifice. The actor loses. This is the reverse of parasitism, and a better word might be self-deprivation to help others. This is often seen in nature, mostly as individuals helping members of the same family or species. Medals are awarded for this in human society, and we call it selflessness or even heroics.

oo Neither one acts. No one is hurt, no one wins. Neutrality pacts may achieve this result in society, or we observe it commonly in nature. There are critical areas in nature (water holes, salt licks, grooming stations) where antagonistic species agree on neutrality. In fact, many plant species appear to be basically neutral in behaviour.

Such analyses suit two-species interactions, but where we depart (in the designed system) from nature is that we may value (in the sense of obtaining a yield from) only one of these species. Let this be species A in **Table 3.6**. The other can be a weed or a species such as *Lantana*, which we might wish to eliminate. In this case, we can set up a matrix as diagrammed in **Table 3.6.**

TABLE 3.6
INTERACTION MATRIX OF TWO DIFFERENT SPECIES.

		SPECIES A (a palm)		
		+	**o**	**–**
	+'	**+'+**	**+'o**	**+'–**
SPECIES B (lantana)	**o'**	**o'+**	**o'o**	**o'–**
	–'	**–'+**	**–'o**	**–'–**

In order of benefit (increase in palms, less increase or decrease in lantana):
(–'+)>(o'+)>(–'o)>(+'+)>(o'o)>(–'–)>('–)>(o'–)>(+'o)
Best result....................>Neutral................>Worst result.

This is a very necessary type of analysis for selecting useful plants that will eliminate or weaken an unwanted weed species. All such analyses can be made using plant/plant, animal/animal, or plant/ animal pairs.

How do we *observe* co-action? This is quite simple in the field, *providing* there are plenty of examples to score, and we have set some criteria to score by. For example, take a town or area with a great many trees planted in the backyards. Select any one of these species for criteria, say an apple, then decide on how to score, e.g. (in compounds with apples and other species of plants growing):

+: apple tree healthy, bearing very well, not stunted or over-vigorous.
o: apple tree healthy, in fair order, bearing.
–: apple tree bearing poorly, sick or dying.
x: no apple tree in this yard.

TABLE 3.7
CO-ACTION MATRIX

	APPLE SCORE			
Other trees near, or in, yard.	**+**	**o**	**–**	**x**
WALNUTS	.	.	7	15
MULBERRY	5	5	1	3
ACACIA	7	5	.	3

Scoring can be of specific pairings:

		APPLE SCORE			
		+	**o**	**–**	**x**
	+	.	.	.	5
WALNUT SCORE	**o**	.	.	5	4
	–	.	.	.	.
	x	.	.	.	.

Then, we draw up a co-action matrix on a piece of paper, with the "apple" score at the top and "other trees" down the left side (**Table 3.7**). Tally the scores by walking from yard to yard.

We quickly see that where there are walnuts, apples are sick or absent (**o–**). However, healthy apple trees coexist with both mulberries and *Acacias* (**+o**) and (**oo**). Ideally, we use a similar score for *each species* of other tree, so that our co-action results score the same criteria for walnut, mulberry, and *Acacia* that we score for apple.

Additional field notes are useful. Healthy, untended apple trees often have quite a specific understory of spring bulbs, comfrey, clover, iris, nasturtium, etc. This too should be noted as we go. I have, in fact, carried out such analyses, and some of the results will be used as a real example in the next section.

BUILDING UP GUILDS FROM CO-ACTION ANALYSIS.

If we wish to construct a guild, then we need to bring two or more species into close proximity where we can judge the effects of one on the other. If we have a () result *anywhere*, we might be able to intervene with a third or fourth party which we can call an arbitrator, a buffer, or an intervenor.

- Apple next to walnut produces (**–o**): *not* desirable; the apple sickens or dies.
- Apple next to mulberry produces (**+o**): a good result.
- Mulberry next to walnut produces (**oo**): mutual inaction.

Thus, apple *then* mulberry *then* walnut gives us (**+oo**). By this *intervention strategy*, we have, in effect, cancelled out the (– –) and have a *nett benefit* in a three-three-species array. That is, we can use several two-species results to achieve a better result with three species, which goes beyond accepting (fatalistically) the primary conflict. Here, a mulberry is the *intervenor* or critical species or element in conflict resolution. We can take this further again by examining yet other co-actions:

- *Acacia* next to walnut gives (**o+**)
- *Acacia* next to mulberry gives (**o+**)

Now, apple–mulberry-*Acacia*-walnut gives us (**++o+**), which is much better again. So we proceed to isolating and *arranging* guilds to maximise benefits and eliminate conflicts. This is part of the skill of planning strip or zone placements of mixed species.

THE ROLE OF CONFIGURATIONS IN GUILDS

Here, we have to consider *placement* of interactive elements. Obviously, there is a commonsense close spacing for many plants and machine components, but as the distance between *living* components widens, we can never be quite sure that chemical or behavioural interaction ceases. Consider the case of two territorial birds, displaying or calling a mile or more apart. To us, they appear as individuals; to each bird, the other is in clear interaction. There is distant interaction, too, via pollen or spores in plants, and perhaps even by gaseous or chemical "messengers". This is certainly true of some mammals, so that effects of one on the other can be passed on by a sense of smell, even though they are not nearby at that time, e.g. urine marking territory. The great whales may well be communicating by sound around the whole globe.

Configuration in planning a guild with *intervening* species between hostile () species, comes in assessing the distance across the interaction boundary that the effect takes place, and in then arranging the guild species to obtain a maximum of (**++**), (**o+**), or (**+o**) effects. For example, we find a (**++**) condition with legume/grain or fruit-tree/tree legume interplants. We know that the effect, for grains, extends from 1.5–2 m into the crop; thus for a configurational design, we can spiral or strip-plant these two species for a *total positive edge interaction effect in crop*. Such careful guild analyses and configurations are the basis of species planning in permaculture.

For more critical geometric analyses, see such texts as Rolfe A. Leary's *Interaction Geometry: An Ecological Perspective* , USDA Forest Service, General Technical Report NC-22, 1976. This text has a useful reference list and is issued by the North Central Forest Experimental Station, Fulwell Ave, St. Paul, MN, 55108, USA.

3.14
SUCCESSION: EVOLUTION OF A SYSTEM

Nature shows us that a *sequence of processes* arise in the establishment of "new" systems on such devastated landscapes as basalt flows and ice-planed or flood-swept sites. The first living components are hardy *pioneer species*, which establish on these damaged or impoverished environments. Thus we see "weeds" (thistles, *Lantana*) occupying overgrazed, eroded, or fired areas. These pioneer species assist the area by stabilising water flow in the landscape, and later they give shelter, provide mulch, or improve soil quality for their successors (the longer-term forest or tree crop species).

To enable a cultivated system to evolve towards a long-term stable state, we can construct a system of mixed tree, shrub, and vegetable crop, utilising livestock to act as foragers, and carefully planning the succession of plants and animals so that we receive short-, medium-, and long-term benefits. For example, a forest will yield first coppice, then pole timbers, and eventually honey, fruit, nuts, bark, and plank timber as it evolves from a pioneer and young, or crowded, plantation to a well-spaced mature stand over a period of 15–50 years.

Unlike the processes of nature, however, we can place most of the elements of such a succession *in one planting*, so that the pioneers, ground covers, under-story species, tree legumes, herbage crop, mulch species, the long-term windbreak and the tree crop are all set out at once. So many species and individuals of each species are needed to do this that it is usually necessary to first create a small plant nursery to supply the 4,000-8,000 plants that can be placed on a hectare. While these are growing in their pots, we can fence and prepare the soil, and then plant them out to a carefully-designed long-term plan.

Where this approach is used, as it has been by many permaculturalists on their properties, quite remarkable changes occur over two to three years. Mulch is produced on site for the long-term crop, while weed competition, wind, and frost effects are nullified or moderated. Cropping can be continuous as the annuals or herbaceous perennials effectively control unwanted grasses and weed species. For instance, radish or turnip planted with tree seedlings control grasses until the small tree provides its own grass control by shading. **Figure 3.13** gives an indication of how a system can accept different species of plants and of animal browsers as it evolves.

3.15
THE ESTABLISHMENT AND MAINTENANCE OF SYSTEMS

Every design is an assembly of components. The first priority is to locate and cost those components. Where our resources are few, we look closely at the site itself, thinking of everything as a potential resource (clay, rock, weeds, animals, insects). We can think of labour, skill, time, cash, and site resources as our interchangeable energies: what we lack in one we can make up for by exchange for another (e.g. clothes-making in exchange for roof tiles). The best source of seed and plants is always neighbours, public nurseries, or forestry departments. From the early planning stages, it pays to collect seed, pots, and hardy cuttings for the site, just as it pays to forage for second-hand bricks, wood, and roofing.

The planning stage is critical. As we draw up plans, we need to take the evolution in *stages*, to break up the job into easily-achieved parts, and to place components in these parts that will be needed *early in development* (access ways, shelter, plant nursery, water supply, perhaps an energy source). Thus, we *design*, assess resources, locate components, decide priorities, and place critical systems. Because impulsive sidetracks are usually expensive, it is best to fully plan the site and its development, changing plans and designs only if the site and subsequent information forces us to do so.

On a rural (and sometimes urban) site, FENCING or hedgerow, SOIL REHABILITATION by mulch (or loosening by tools), EROSION CONTROL, and WATER SUPPLY are *the* essential precursors to successful plant establishment, for we can waste time and money putting out scattered plants in compacted, impractical, and dry sites. Any soil shaping for roads, dams, swales, terraces, or paths needs to be finalised before planting commences.

For priority in *location*, we need to first attend to Zone 1 and Zone 2; these support the household and save the most expense. What is perhaps of greatest importance, and cannot be too highly stressed, is the need to develop *very compact systems*. In the Philippines, people are encouraged to plant $4m^2$ of vegetables—a tiny plot—and from this garden they get 40-60% of their food! We can all make a very good four metres square garden, where we may fail to do so in 40 square metres.

Similarly, we plant and care for ten critical trees (for oils, citrus, nuts, and storable fruit). We can take good care of these, whereas if we plant one hundred or one thousand, we can lose up to 60% of the trees from lack of site preparation and care. Thus, ten trees and four metres square , well protected, manured, and watered, will start the Zone 1 system.

Starting with a *nucleus* and expanding outwards is the most successful, morale-building, and easily-achieved way to proceed. Broadscale systems have broadscale losses and inefficiencies. As I have made every possible mistake in my long life, the advice above is based on real-life experience. To sum up:

- Design the site thoroughly on paper.
- Set priorities based on economic reality.
- Locate and trade for components locally or cheaply.
- Develop a *nucleus* completely.
- Expand on information and area using species proved to be suited to site.

Precisely the same sort of planning (nucleus development) applies to any system of erosion control, rehabilitation of wildlife or plants, writing books, and creating nations. Break up the job into small, easily achieved, basic stages and complete these one at a time. Never draw up long lists of tasks, just the next stage. It is only in the design phase that we plan the system as a whole, so that our smaller nucleus plans are always in relation to a larger plan.

Instead of leaping towards some imaginary end point, we need to prepare the groundwork, to make modest trials, and to evolve from small beginnings. A process of constant transition from the present to the future state is an inevitable process, modest in its local effect and impressive only if widespread. Thus, we seek first to gain a foothold, next to stabilise a small area, then to develop self-reliance, and only after this is achieved to look for exportable yields or commercial gain.

Even in a commercial planting it is wise to restrict the total commercial species to 3–10 reliable plants and trees, so that easier harvesting and marketing is achievable, although the home garden and orchard can maintain far greater diversity of from 25-75 species or

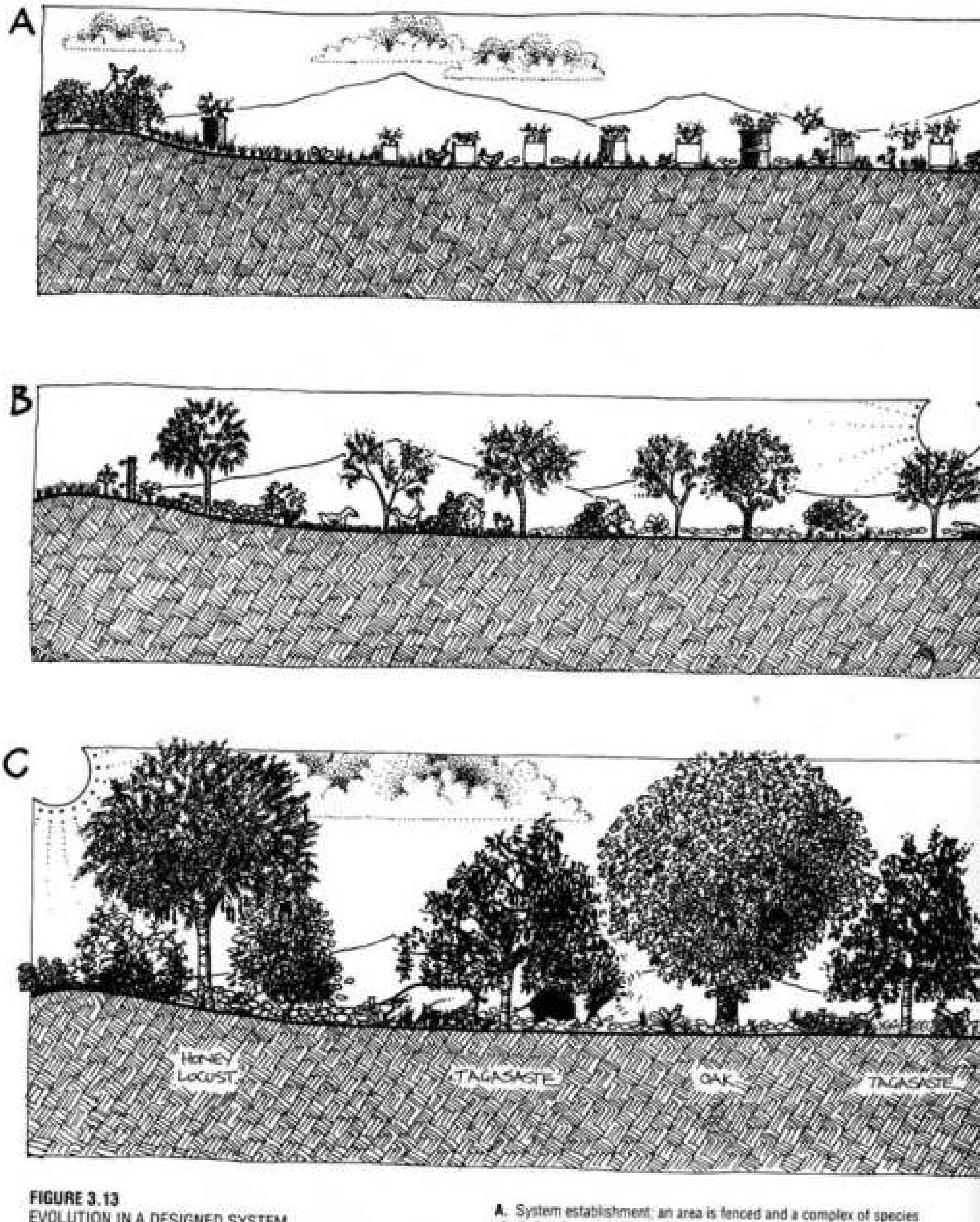
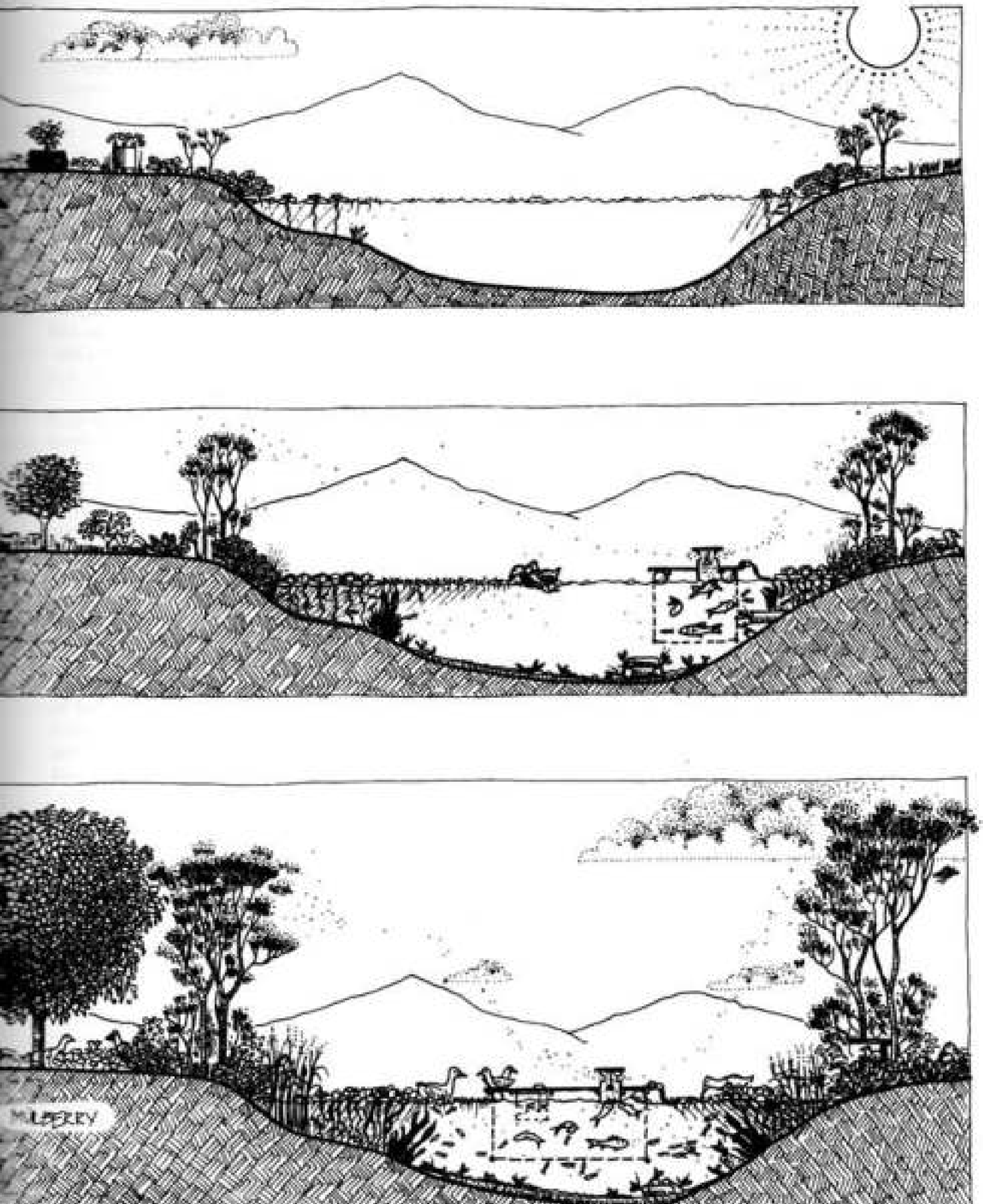


FIGURE 3.13
EVOLUTION IN A DESIGNED SYSTEM.
Pioneer species prepare for long-term evolution to a stable and productive system over a period of from 5 – 15 years.

A. System establishment; an area is fenced and a complex of species planted and protected from grazers by fencing and tree guards. Ponds are established. Only small livestock (chickens) and some annual crops can be harvested.



B. The system evolves to a semi–hardy stage. Geese, fish, and shellfish are introduced, and crops include some aquatic plant species.

C. An evolved system provides forage, firewood, aquatic and animal products. Larger foragers (sheep, pigs) can be grown seasonally. The system provides its own mulch and fertilizers. The mature system requires management rather than energy input, and has a variety of marketable yields (including information).

more.

Thus, our design methodologies seek to take into account all known intervening factors. But in the end it comes down to flexibility in management, to steering a path based on the results of trials, to acting on new information, and to continuing to observe and to be open or non-discriminatory in our techniques.

The success of any design comes down to how it is accepted and implemented by the people on the ground, and this factor alone explains why grand centralised schemes more often result in ruins and monuments than in stable, occupied, and well-maintained ecologies.

We can design any expensive, uncomfortable, or ruinous system as long as we do not have to live in it, or fund it ourselves. Responsible design arises from recommending to others the way you have found it possible to work or to live in a similar situation. It is much more effective to educate people to plan for themselves than to pay for a permanent and expensive corps of "planners" who lead lives unrelated to those conditions or people for whom they are employed to design.

3.16 GENERAL PRACTICAL PROCEDURES IN PROPERTY DESIGN

Except for the complex subject of village design, a property design from one-fourth to 50 ha needs firstly a clear assessment of "client or occupier needs", and stated aims or ideas from *all* potential occupiers (including children). A clear idea of the financial and skill resources of occupants is necessary so that the plan can be financially viable.

With a base map, aerial photograph, or a person as a guide, the designer can proceed to observe the site, making notes and selecting places for:

- Access ways and other earthworks;
- Housing and buildings;
- Water supply and purification, irrigation;
- Energy systems; and
- Specific forest, crop, and animal system placement.

All the above are in relation to slope, soil suitability and existing landforms. By inspection, some priorities may be obvious (fire control, access, erosion prevention). Other factors need to be tackled in stages as time, money, and species permit. At the end of each stage, trial, or project, both past performance and future stage evolution should be assessed, so that a guide to future adjustments, additions, or extension is assembled as a process. In all of this, design methodologies *plus* management is involved, and it is therefore far better to train an owner-designer who can apply long-term residential management than to evolve a roving designer, except as an aide to initial placements, procedures, and resource listings.

The restrictions on site use must first be ascertained before a plan is prepared or approved. In the matter of buildings, easements, health and sewage requirements, permits, and access there will probably be a local authority to consult. If water (stream) diversions are foreseen, state or federal authorities may need to be consulted.

The homely, but probably essential process of building up real friendship between residents, designers, officials, and neighbours should be a conscious part of new initiatives. Small local seminars help a lot, as district skills and resources can be assessed. There is no better guide to plant selection than to note district successes, or native species and exotics that usually accompany a recommended plant. Nearby towns, in gardens and parks, often reveal a rich plant resource.

As every situation is *unique*, the skill of design (and often of market success) is to select a few unique aspects for every design. These can vary from unique combinations of energy systems, sometimes with surplus for sale, to social income from recreational or accommodation uses of the property. This unique aspect may lie in special conditions of existing buildings, vegetation, soil type, or in the social and market contact of the region. Wherever occupants have special skills, a good design can use these to good effect, e.g. a good chemist can process plant oils easily.

A design is a marriage of landscape, people, and skills in the context of a regional society. If a design ended at the physical and human aspects, it would be still incomplete. Careful financial and legal advice, plus an introduction to resources in these areas, and a clear idea for marketing or income from services and products (with an eye to future trends) is also essential.

Over a relatively short evolution of three to six years, a sound design might well achieve:

- Reduction in the need to earn (conservation of food and energy costs).
- Repair and conservation of degraded landscapes, buildings, soils, and species at risk.
- Sustainable product in short-, medium-, and long-terms.
- A unique, preferably essential, service or product for the region.
- Right livelihood (good work) for occupants in services or goods.
- Sound and safe legal status for the occupiers.
- An harmonious and productive landscape without wastes or poisons.
- A cooperative and information-rich part of a regional society.

These then, or factors allied to them, are the test of good design over the long term. For many regions, a designer or occupant can provide species (as nursery), resources (as education), services (as food processing or lease), or simply an example of sustainable future occupations. Pioneer designers in a region should seek to capitalise on that pioneer aspect, and provide resources for newcomers to the region.

3.17
PRINCIPLE SUMMARY

Definition of Permaculture Design: Permaculture design is a system of assembling conceptual, material, and strategic components in a pattern which functions to benefit life in all its forms. It seeks to provide a sustainable and secure place for living things on this earth.

Functional Design: Every component of a design should function in many ways. Every essential function should be supported by many components.

Principle of Self-Regulation: The purpose of a functional and self-regulating design is to place elements or components in such a way that each serves the needs, and accepts the products, of other elements.

Chapter 4

PATTERN UNDERSTANDING

The curve described by the earth as it turns is a spiral, and the pattern of its moving about the sun... The solar system itself being part of a spiral galaxy also describes a spiral in its movement... Even for the case of circular movement, when one adds in the passage of time, the total path is a spiral... The myriad things are constantly moving in a spiral pattern... and we live within that spiral movement.

(Hiroshi Nakamura, from *Spirulina: Food for a Hungry World*, University of the Trees Press, P.O. Box 66, Boulder, California 95006, USA.)

The patterns and forms of a tree are found in many natural and evolved structures; an explosion, event, erosion sequence, idea, germination, or rupture at an edge or interface of two systems or media (here, earth and atmosphere) may generate the tree form in time and space. Many threads spiral together at the point of deformation of the surface and again disperse. The tree form may be used as a general teaching model for geography, ecology, and evolution: it portrays the movement of energy and particles in time and space. Foetus and placenta; vertebrae and bones; vortices; mushrooms and trees; the internal organs of man; the phenomena of volcanic and atom bomb explosions; erosion patterns of waves, rivers, and glaciers; communication nets; industrial location nets; migration; genealogy; and perhaps the universe itself are of the general tree form portrayed.

Simple or multiple pathways describe yin-yang, swastika, infinity, and mandala symbols. A torus of contained forces evolves with the energies of the pattern, like the doughnut of smoke that encircles the pillar of the atomic explosion.

(Bill Mollison, *Permaculture One*, 1978.)

Everything the Power of the World does is done in a circle... The wind, in its greatest power, whirls... The life of a man is a circle from childhood to childhood, and so is everything where power moves. Our teepees were round like the nests of birds, and these were always set in a circle, the nation's hoop, a nest of many nests....

(Black Elk.)

4.1 INTRODUCTION

It is with some trepidation that I attempt a treatise on patterns. Nevertheless, it must be attempted, for in patterning lies much of the ground skill and the future of design. Patterns are forms most people understand and remember. They are as memorable and repeatable as song, and of the same nature. Patterns are all about us: waves, sand dunes, volcanic landscapes, trees, blocks of buildings, even animal behaviour. If we are to reach an understanding of the basic, underlying patterns of natural phenomena, we will have evolved a powerful tool for design, and found a linking science applicable to many disciplines. For the final act of the designer, once components have been assembled, is to make a sensible pattern assembly of the whole. Appropriate patterning in the design process can assist the achievement of a sustainable yield from flows, growth forms, and timing or information flux.

Patterning is the way we frame our designs, the template into which we fit the information, entities, and objects assembled from observation, map overlays, the analytic divination of connections, and the selection of specific materials and technologies. It is this patterning that permits our elements to flow and function in beneficial relationships. The pattern *is* design, and design is the subject of permaculture.

Beyond the rigour of the simple Euclidean regularities beloved of technologists and architects, there remains most (or all) of nature. Nature imperfectly round, never flat or square, linear only for infinitesimal distances, and stubbornly abnormal. Nature flowing, crawling, flying, weeping, and in apparent disarray. Nature beyond precise measurement, and comprehensible only as sensation and system.

Nothing we can observe is regular, partly because we ourselves are imperfect observers. We tell fortunes (or lose them) on the writhing of entrails or cathode ray graphics, on the scatters of dice or bones, or on arrays of measures. Are the readings of tea leaves any less reliable than the projections of pollsters? Regular things are those few that are mechanical or shaped (temporarily) by our own restricted world view; they soon become irregular as time erodes them. Truth, like the world, changes in response to information.

There are at least these worthwhile tasks to attempt:

1. A MORE GENERAL PATTERN UNDERSTANDING, both as attempts at forming more general pattern models, and as examples of natural phenomena that demonstrate such models.

2. A LINKING DISCIPLINE that equally applies to geography, geology, music, art, astronomy, particle physics, economics, physiology, and technology. This linking discipline would apply to conscious design itself and to the information flow and transfer processes that underlie all our disciplines. Such a unifying concept has great relevance to education, at every level from primary to post-graduate disciplines.

3. GUIDES TO PATTERN APPLICATION: some examples of how applied patterning achieves our desired ends in everyday life, where rote learning, linear thinking, or Euclidean geometry have all failed to aid us in formulating sustainable settle-ments. It is in the application of harmonic patterns that we demonstrate our comprehension of the meaning of nature and life.

There have been many books on the subject of symbols, patterns, growth, form, deformation, and symmetry. The authors often abandon the exercise short of devising general models, or just as a satisfactory mathematical solution is evolved for one or more patterns, and almost always before attempting to create applied illustrations of how their efforts assist us in practical life affairs. Some are merely content to list examples, or to make catalogues of phenomena. Others pretend that meanings lie in pattern or number alone—that patterns are symbols of arcane knowledge, and they assert that only an unquestioned belief unlocks their powers.

The simple pattern models figured herein are intended to be a useful adjunct to designers and educators. They also illustrate how we can portray our thinking about life, landscapes, and the communality that is nature. Learning a master pattern is very like learning a principle; it may be applicable over a wide range of phenomena, some complex and some simple. As an abstraction, it assists us to gain meaning from life and landscape and to comprehend allied phenomena.

One can spend endless hours seeking further scientific, mystical, or topological insights into pattern. The process is addictive, and I am as unwilling to abandon this chapter as I was to start it, but I trust that others, better equipped, will expand and further explain the basic concepts. I believe that it is in sophisticated pattern application that the future of design lies, and where many solutions to intractable problems may be found.

We have a good grasp on the behaviours of pattern in natural phenomena if we can explain the SHAPES of things (in terms of their general pattern outlines); the networks and BRANCHING of tributaries (gathering flows) and distributaries (dispersal flows); the PULSING and flow regulation within organisms or the elements of wind, water, and magma; and illuminate how SCATTERED PHENOMENA arise.

Further, if WAVE phenomena and STREAMLINES are contained within our pattern analysis, as real waves or as time pulses, these and their refraction and interference patterns form another set of pattern generators, responsible for coasts, clouds, winds, and turbulent or streamlined flow. And, if we can show how the pattern outlines of landscapes, skeletal parts, or flow phenomena fit together as MATRICES (interlocking sets), or arise from such matrices (e.g. whirlwinds from thermal cells), then we can generate whole landscape systems or complete organisms from a mosaic of such patterns.

In nature, events are ordered or spaced in discrete units. There are smaller and larger orders of events, and if we arrange like forms in their *orders*, we will find clusters of measures at certain sizes, volumes, lengths, or other dimensions. This is true for river branches, social castes, settlement size, marsupials of the same form, and arrays of dunes, planets, or galaxies.

In the following pages, I will try to include all this and to derive it from the basis of a single "simple" model (**Figure 4.1**), which, understood in all its parts, has each of these phenomena, and a great many more subtle inferences, within it. Not all, or even many, of these shapes, symbols, symmetries, scatters, or forms will be individually described or figured here, but the basic pattern parts will be briefly described and related to each other. The basic model itself is derived from a stylised tree form.

We should not confuse the comprehension of FORM with the knowledge of SUBSTANCE—"the map is not the territory"—but an understanding of form gives us a better comprehension of function, and suggests appropriate strategies for design.

4.2
A GENERAL PATTERN MODEL OF EVENTS

When we look about us in the world, we see the hills, rivers, trees, clouds, animals, and landforms generally as a set of shapes, apparently unrelated to each other, at least as far as a common underlying pattern is concerned. What *do* we see? We can list some of the visible forms as follows:

- WAVES on water and "frozen" as ripples in dunes and sandstones, or fossilised quartzites and slates.
- STREAMLINES, as foam strips on water, and in streams themselves.
- CLOUD FORMS in travertine (porous calcite from hot springs), tree crowns, and "puffy" clouds or as cloud streams.
- SPIRALS in galaxies, sunflowers, the global circulation of air, whirlpools, and chains of islands in arcs.
- LOBES, as at the edge of reefs, in lichens, and fringing the borders of salt pans.
- BRANCHES, in trees and streams converging or diverging; explosive shatter zones.
- SCATTERS of algae, tree clumps in swamps, islands, and lichens on rocks.
- NETS as cracks in mud, honeycomb, inside bird bones, in the columns of basalt (as viewed from above), and cells of rising and falling air on deserts.

The NETS or cracks in mud and cooling lava are shrinkage patterns caused not by flow or growth, but by the *lateral tension* of drying or cooling, as are many patterns in iceflows and the cracked pattern of pottery, or the cracks in bark on trees. Thermal wind cells arise at the confluence of large heat cells on desert floors, forming a net pattern if viewed from above or below.

In all of these categories, I hope to show that one master pattern is applicable, and that even the bodies of animals are made up of bones, organs, and muscles of one or more of the forms above. I will link these phenomena—generated by growth and flow— into a single model form. That form is a stylised tree (**Figure 4.1**). Around the central tree form of this model are arranged various cross-sections, plans, longitudinal sections, and streamline paths, all derived from real sections, paths, or projections of the tree.

The evolution of such a form from an initial point in space-time, I call an EVENT. Such events can be abstract or palpable. They have in common an origin (O), a phase of growth (T1-T6: an expression of their energy potential), decay, and dissolution into other events of a like or unlike form. The event of a tree is at least three-dimensional, and must be thought of as extending into and out of a plane (P). However, many similar events such as migration patterns or glaciation can be as well portrayed (as they are seen in aerial photographs) as two-dimensional.

The curvilinear STREAMLINES (S1-S9), are seen to curve or spiral through the Origin, just as (in fact) the phloem (storage cells) and xylem (sapbearing cells) spiral through the X-X' axis, or earth surface plane (P), of a real tree. Not so easy to portray is the fact that the xylem is *external* to the stems and *internal* to the roots, and the phloem the reverse. At a zone in the plane (P), therefore, these cells INTERWEAVE or cross over as they spiral out of or into the media.

This deceptively simple "apple core" or tree shape, spiralling out of the plane (P) is a slow-moving vortex such as we see in tornadoes and whirlpools. Traffic through the streamlines is *in both directions*. In trees, sugars and photosynthetic products travel from crown to root margin, and water and minerals from roots to crown. Thus, each margin of our pattern is both collecting and distributing materials from different media. The tree trades both ways with elements of the media, and there is an active water and gaseous exchange with the media (M1, M2). Two-way trade is the normality of plants, organs, and natural forms.

As we know, a crosscut of a tree stem, the basis of the study of dendrochronology, reveals a target pattern of expanding growth (by which the tree adds bulk annually) and from which we can discover much about past occurrences of drought, seasonal changes, atmospheric compositon, fire, and wind (**Figure 4.1-F**).

Screw palms (*Pandanus* spp.) of the tropics develop *ascending* stem spirals, very reminiscent of fan turbine blades, and sunflowers create open seed spirals (in two directions), so common in many whorled plants. The stem itself forces open an ever-expanding flow through the X-Y plane between the media, allowing more material to pass through as time accumulates. The event expands the initial rupture of the surface between the media, allowing greater flow to take place, and this too is recorded in the target pattern of the stem, at the point of germination of the event (O).

4.3 MATRICES AND THE STRATEGIES OF COMPACTING AND COMPLEXING COMPONENTS

A set of intersecting sine waves developed over a regular square or hexagonal matrix will set up a surface composed of our core model shapes. It doesn't matter if we see the sine waves as static or flowing, the core model will still maintain its shape, and flow in the system does not necessarily deform the pattern. Such a pattern matrix (**Figure 4.2**) shows that our models **tessellate** (from the Latin *tesserae*, meaning tiles) to create whole surfaces. If landscapes are, in fact, a set of such models, they must be able to tessellate.

Convection cells on deserts arise from a roughly hexagonal matrix of air cells 1-5 km across, and matrices also underlie the spacing of trees in forests.

Glacial landscapes show whole series of such patterns, as do regular river headwaters. We could equally well have created a matrix by adding in samples of our core pattern as we add tiles to a floor. Thus we see the Euclidean concept of points and lines underlies our curvilinear forms. Even irregular models (**Figure 4.3**) tessellate. Such tessellae are centred on nets or regular grids.

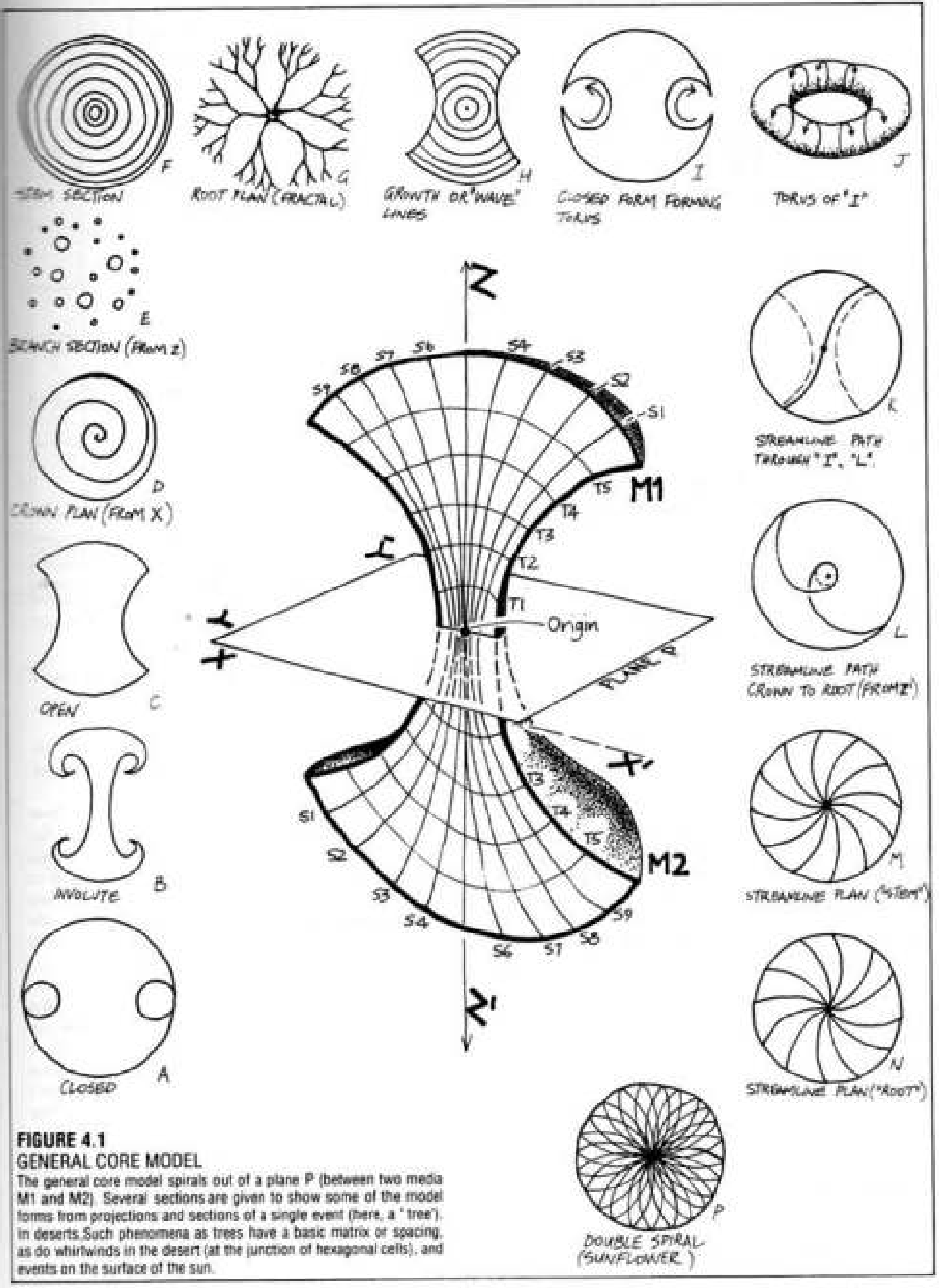


FIGURE 4.1

GENERAL CORE MODEL

The general core model spirals out of a plane P (between two media M1 and M2). Several sections are given to show some of the model forms from projections and sections of a single event (here, a " tree"). in deserts.Such phenomena as trees have a basic matrix or spacing, as do whirlwinds in the desert (at the junction of hexagonal cells), and events on the surface of the sun.

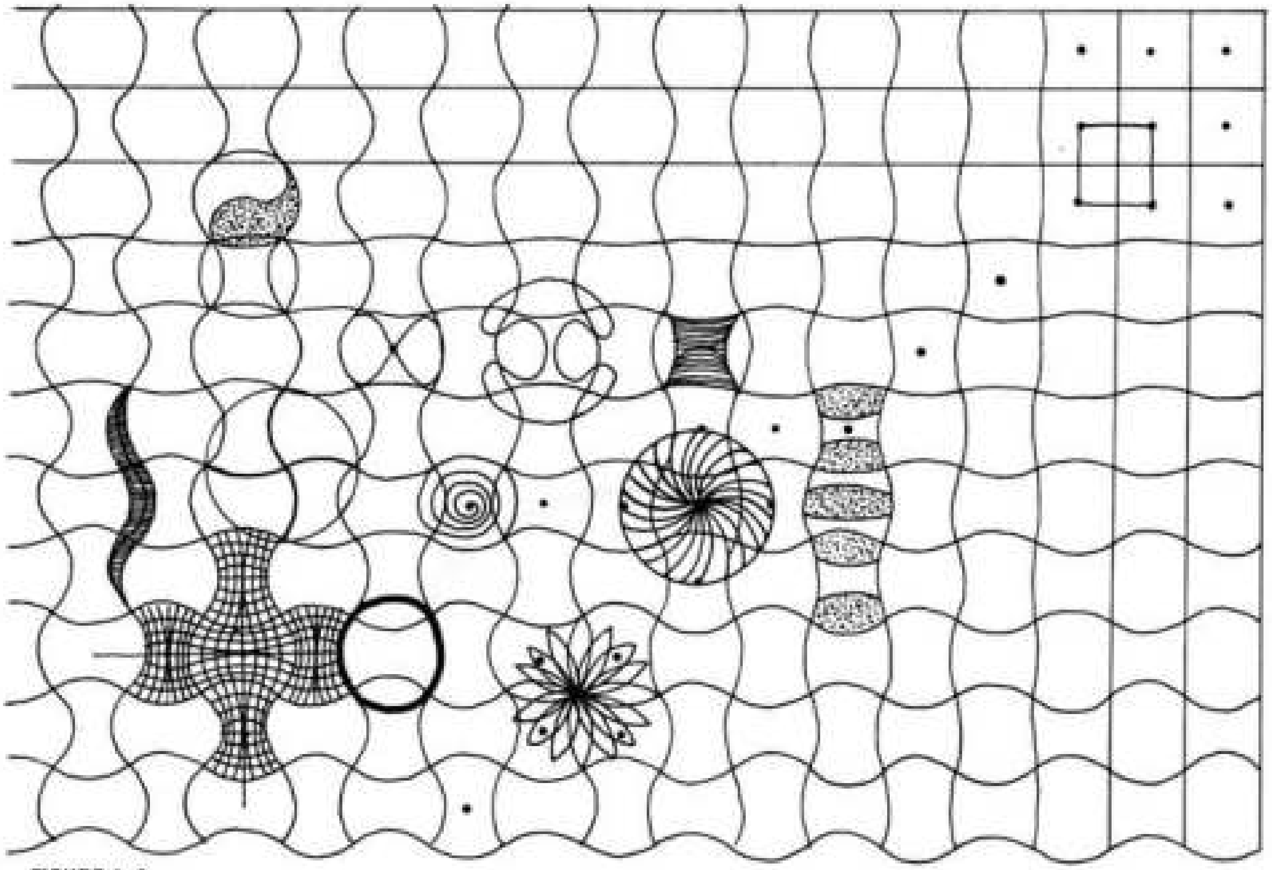


FIGURE 4. 2
PATTERN MATRIX OF TESSELATED PATTERNS.
Underlying many natural distributions (e.g. trees in a desert, heat or convection cells) and forming many patterns (such as honeycomb and cracks in mud) are matrices or grids based on approximate squares, hexagons, or intersecting sine waves.

The "growth lines" (T-series) of our models are, in effect, a series of smaller and smaller forms nested within the larger boundaries, as is the case with target patterns or tree cross-sections. The process is termed **annidation** (Latin *nidus*, a nest) and is used in practice to compactly store bowls or glasses, one within the other; it then becomes a strategy for fitting-in like components of the same or different size in a compact way.

If we *superimpose* two spirals of the opposite sense (spirals twisting in the opposite way), we develop the petal patterns of flowers and the whorls of leaves so common in vegetation, well illustrated by the seed patterns of sunflowers. The effect is also reproduced by simple reflection of such curves.

Thus we see that tessellation, annidation, or superimposition gives us a strategy set for developing complex and compact entities, or for analysing complex landscapes. As Yeomans[5] points out, ridges and valleys in landscape are identical reflections. If we model a landscape and pour plaster of Paris on the model, we reproduce the landscape in a reversed plaster model, but now the ridges are valleys.

Further, a set of our models invading into or generating from a portion of the landscape produce EXPANSION and CONTRACTION forms (**Figure 4.4**) typical of the edges of inland dunes and salt pans. This crenellated (wavy) edge produces **edge harmonics** of great relevance to design.

The study of matrices reveals that the T (time) lines are **ogives** of a tessellated model and develop from the "S" (stream) lines of the next model adjoining. We then come to understand something of the co-definitions in our core model, and its inter-dependent properties. Sets of such models and their marginal crenellations provide a complex interface in natural systems, often rich in production potential.

The earth itself is "a great tennis ball" (*New Scientist*, 21 April '77) formed of two core model forms. This earth pattern (**Figure 4.5**) of two nested core models can be re-assembled into a single continent and one sea if the present globe is shrunk to 80% of its present diameter. My old geology professor, Warren ("Sam") Carey may have been justified in his 1956 assertion that the earth was originally that much smaller. When re-assembled in this way, the globe shows an origin ("O" of our model) over each pole; the north polar origin is that of the seas, the antarctic origin that of the continents. At that time in earth history, all life forms were native to a single continent and all fish swam in one sea.

The pattern has been shattered by a total expansion of

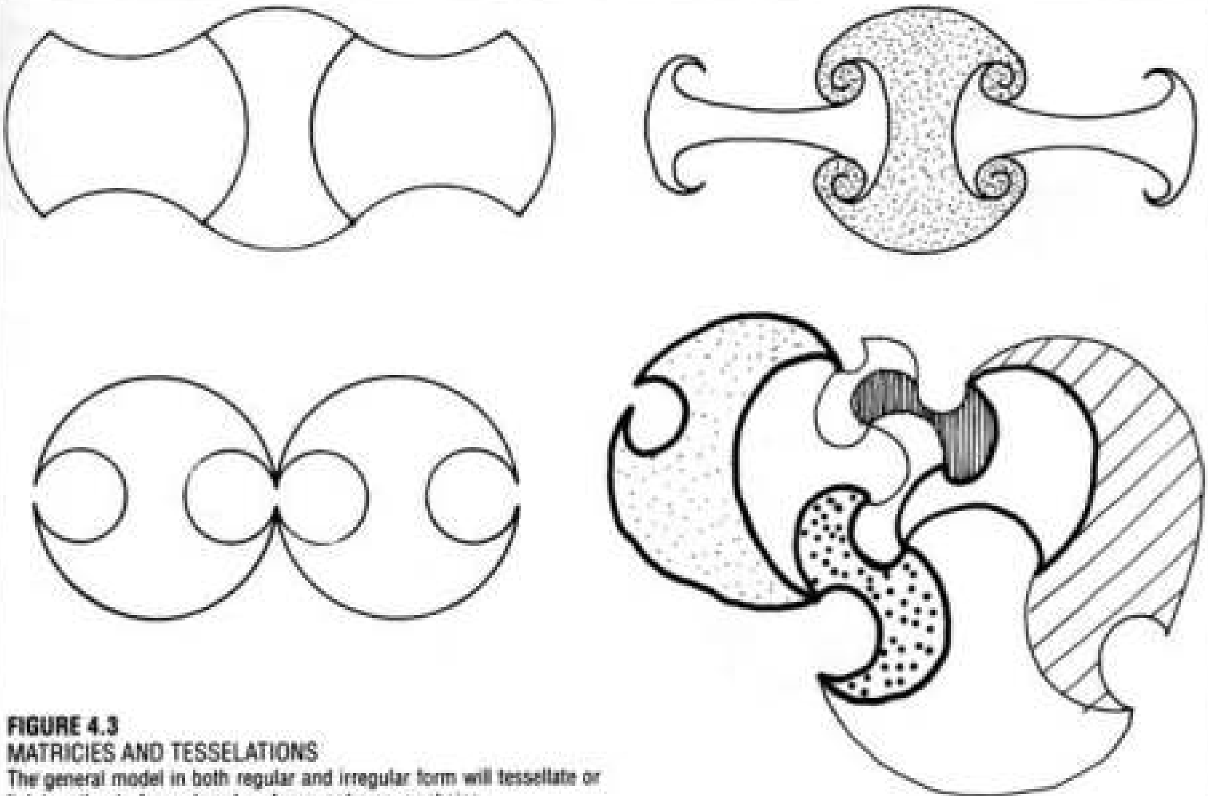


FIGURE 4.3
MATRICIES AND TESSELATIONS
The general model in both regular and irregular form will tessellate or link together to form closed surfaces, spheres, or chains.

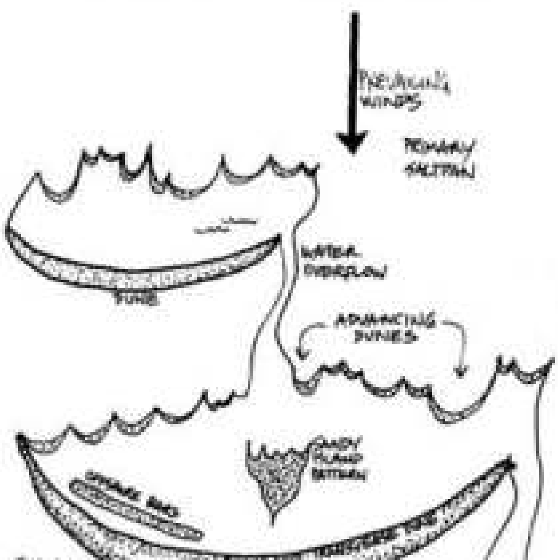


FIGURE 4.4
PATTERNS IN DESERTS
Repetitive patterning due to wind, sand, and rare heavy rains, is typical of deserts: this series of lunulate lagoons occurs in South Australia. Longitudinal dunes become crescentic transverse dunes due to water action.

the globe or by the spreading of oceanic plates cracking the continents apart rather like the net patterns on a mud patch, and isolating species for their present endemic development. The whole story is being slowly assembled by generations of biologists (Wallace, Darwin), geologists, and technicians analysing data from satellite surveys of the globe.

The original pattern shattered, continents now drift, collide, and form their own life pattern by isolation, recombination, and the slow migration of natural processes. The process also illustrates how irregularities may arise on an expansion of a previously regular matrix of forms; tension caused by expanding phenomena shatters the smooth flow of primary global events. At the end of a certain energy sequence, old patterns shatter or erode to make way for new patterns and succeeding forms of energy, as a decaying tree gives life to fungi and to other trees.

4.4
PROPERTIES OF MEDIA

Media, as a result of their chemistry, physical properties, or abstract characteristics, can be identified by us because they *differ* from each other. We distinguish not only air, water, earth, and stone but also hot, cold, salty, acid, and even some areas of knowledge as having different properties or validity. Every such

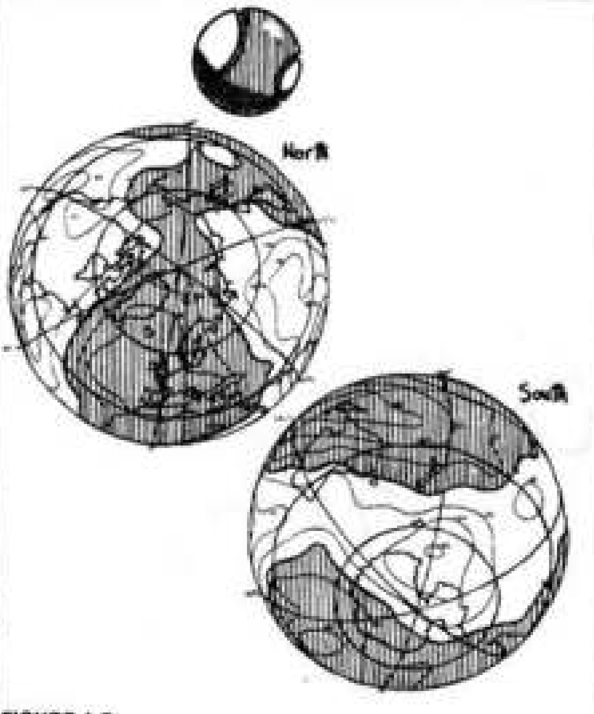


FIGURE 4.5
"THE GREAT TENNIS BALL OF EARTH"
Only two core models make up the geoid. Each is detectably higher than, or lower than, the other. Origins lie near the poles, and when the continents are re-assembled we have one great continent and one great sea.

difference has a more or less well defined BOUNDARY CONDITION, surface, or interface to other media or systems. Permaculture itself acts as a translator between many disciplines, and brings together information from several areas. It can be described as a framework or pattern into which many forms of knowledge are fitted in relation to each other. Permaculture is a synthesis of different disciplines.

Any such boundary is at times between, at times within, media, and (as in the case of the earth/air surface) these boundaries, surfaces, or perceptible differences present a place for things to happen, for *events to locate*. Thus, boundaries present an opportunity for us to place a translatory element in a design, or to deform the surface for specific flow or translation to occur.

If the media are in gaseous or liquid form, or composed of mobile particles like a crowd of people, swarm of flies, water, or dust clouds, then the media are themselves capable of flow and deformation.

In nature, many such media and boundaries can be distinguished. As one example, a pond (with part of its margin) is shown in **Figure 4.6**.

Although differently named (or not named at all), all these surfaces, edges, and boundaries separate different media, ecological assemblies, physical states, or flow conditions. Every boundary has a unique behaviour and a translation potential. Living translators (trees, fish, molluscs, water striders) live at each and every boundary. We can see that the establishment of complex boundary conditions is another primary strategy for generating complex life assemblies and energy translators.

"Most biologists," (says Vogel, 1981) "seem to have heard of the boundary layer, but they have a fuzzy notion that it is a discrete region, rather than the discrete notion that it is a fuzzy region."

Boundary/Edge Design Strategy
The creation of complex boundary conditions is a basic design strategy for creating spatial and temporal niches.

4.5
BOUNDARY CONDITIONS

Boundaries are commonplace in nature. Media are variously liquid, gaseous, or solid, in various states of flow or movement. They have very different inherent characteristics, such as relatively hotter, more acid, rough, harder, more absorbent, less perforated, darker, and so on. Even in abstract terms, society divides itself in terms of sex, age, culture, language, belief, disciplines, and colour (just to enumerate a few perceived differences).

In this confusion of definitions, social and physical, we can make one statement with certainty. People discriminate (in its true meaning, of *detecting a difference*) between a great many media or systems, and therefore recognise boundary conditions or "sorts", enabling them to define like and unlike materials or groups in terms of a large number of specific criteria.

Differences, whether in nature or society, set up a potential STRESS CONDITION. This may demonstrate itself as media boundary disturbances, friction, shear, or turbulence caused by movement, sometimes violent chemical reactions, powerful diffusion forces, or social disruption. Seldom do two different systems come in contact without a boundary reaction of one sort or another, as quiet as rust, as noisy as political debate, or as lethal as war.

If we concentrate our attention on the boundary condition, there are, crudely, two common or possible motions or particle flows—ALONG or ACROSS boundaries. In *longitudinal* flows (shear lines) between media, deflections and turbulence may be caused by local friction or the more cosmic Coriolus (spin) force. In *crossing* a boundary between media, the surfaces themselves may resist invaders (chemical or social); or various nets, sieves, or criteria may have to be by-passed by a potential invader.

However, these boundaries are, in nature, often very rich places for organisms to locate, for at least these reasons:

- Particles may naturally accumulate or deposit there (the boundary itself acts as a net or blockade).
- Special or unique niches are available in space or time within the boundary area itself.

• The resources of the two (or more) media systems are available at the boundary or nearby.

Special physical, social, or chemical conditions exist on the boundary, because of the reaction between the adjacent media. As all boundary conditions have some fuzzy depth, they constitute a third media (the media of the boundary zone itself).

This last statement is especially true of diffusive or flowing media, and of turbulent effects. Turbulence, in effect, creates a mix of the two or more media which may itself form another recognisable medium (e.g. foam on water, an emulsion of oil and water).

In our world of constant events, especially in the living world, more events occur at boundaries than occur elsewhere, because of these special conditions or differences. It is common to find that there are more different types of living species at any such boundary or edge than there are within the adjoining system or medium. Boundaries tend to be species-rich.

This "edge effect" is an important factor in permaculture. It is recognised by ecologists that the interface between two ecosystems represents a third, more complex, system which combines both. At interfaces, species from both systems can exist, and in many cases the boundary also supports its own species. Gross photosynthetic production is higher at inter-faces. For example, the complex systems of land/ocean interface—such as estuaries and coral reefs—show the highest production per unit area of any of the major ecosystems (Kormondy, E.J., 1959, *Concepts of Ecology*. Prentice Hall, NJ, USA).

Forest/pasture interfaces show greater complexity than either system in both producers (plants) and consumers (animals). It seems that the Tasmanian Aborigines burnt forest to maintain a large interface of forest/plain, since these transitional areas provided a great variety and amount of food. Animals are found in greater numbers on edges, for example, and a fire mosaic landscape is rich in species. Such mosaics were the basis of Australian Aboriginal landscape management.

In view of the edge effect, it seems worthwhile to increase interface between particular habitats to a maximum. A landscape with a complex edge mosaic is interesting and beautiful; it can be considered the basis of the art of productive landscape design. And most certainly, increased edge makes for a more stimulating landscape. As designers we can also *create* harmonic edge with plants, water, or buildings.

There are aspects of boundaries that deserve con-

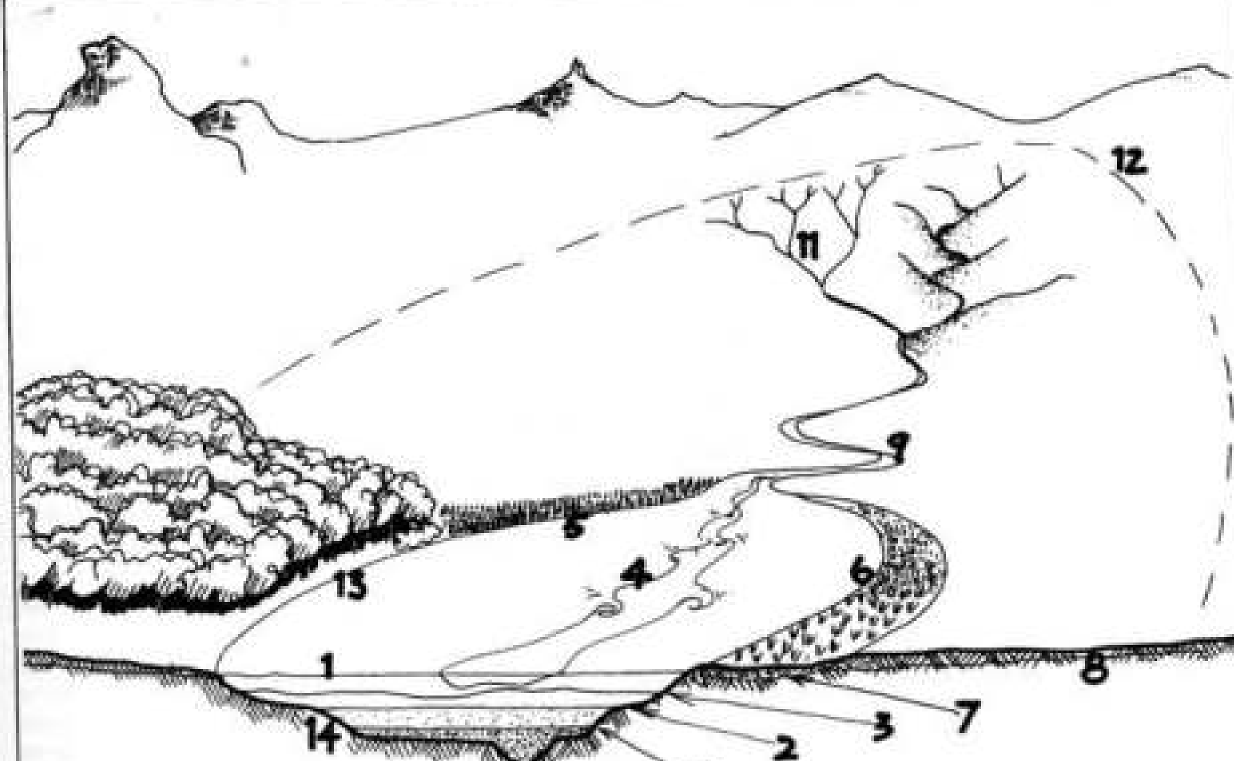


FIGURE 4. 6
EDGES AND SURFACES.
We can distinguish between many conditions or forms of media (air, water, earth, mud), physical conditions (flow, heat, salinity), and we can manipulate adjacent systems (forest, water, crop, grassland, gravels) to produce landscapes rich in borders, hence species and niches.

1 air/water	2 fresh/brackish	3 warm/cool
4 flowing/still	5 grass/water	6 marsh/water
7 anaerobic/subsoil	8 soil/subsoil	9 stream/bank
10 brackish/salty	11 stream order/sub order	
12 catchment/catchment	13 forest/water	14 water/mud

siderable design intervention:

- The geometry or harmonies of any particular edge: how we **crenellate** the edge.
- Diffusion of the media across boundaries (this may make either a third system or a broader area in which to operate—few boundaries are very strictly defined).
- Effects which actively convey material to or across boundaries; in nature, these are often living organisms or flow (bees, for example).
- The compatibility (or **allelopathy**) of species or elements brought into proximity by edge design.
- Boundaries as accumulators on which we can collect mulch or nutrients.

4.6
THE HARMONICS AND GEOMETRY OF BOUNDARIES

The amplitude, configuration, and periodicity of an edge, surface, or boundary may be varied by design.

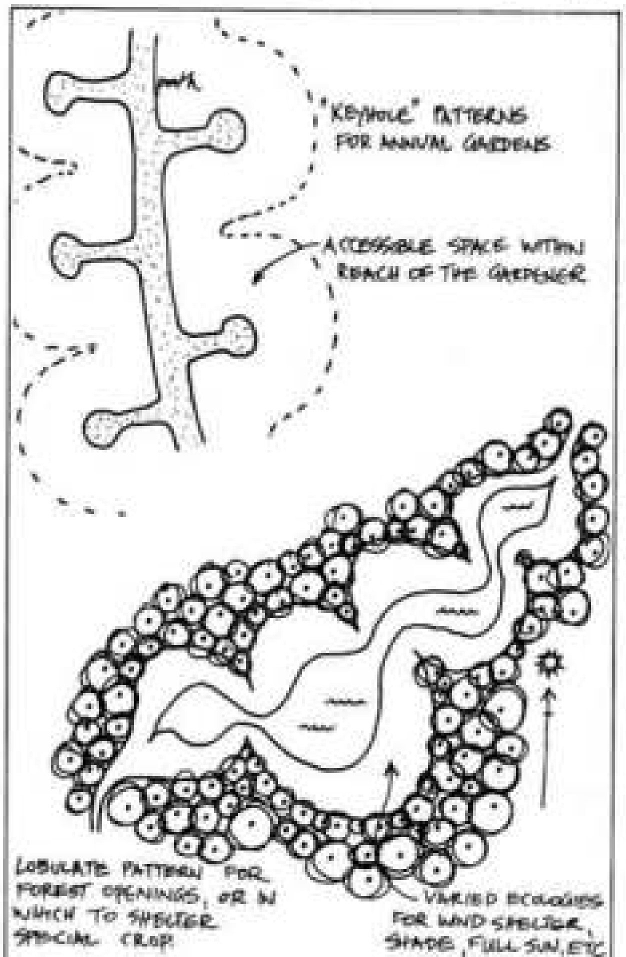


FIGURE 4.7
"Least path" design for home gardens, a keyhole pattern (common in nature) allows us to access garden beds most efficiently. Parallel paths take up to 50% of the area; keyhole beds <30% of the ground. (See also FIGURE 10.26 Gangamma's Mandala).

Edges and surfaces may be sinuous, lobular, serrate, notched, or deliberately smoothed for more efficient flow. While we may deliberately induce turbulence in salmon streams by using weirs, we are painstaking in using smooth and even conduits for energy generation in wind or hydraulic systems. We can deepen areas of shallow streams to make pools, or to prevent stream bank erosion, or to reflect sun energy to buildings; all these are manipulated to achieve specific effects on their boundaries or surfaces.

Notched or lobular edges, such as we achieve in plan by following hill contours, afford sheltered, wetter, drier, hotter, or more exposed micro-habitats for a variety of species. Serrate or zig-zag fences not only stand on their own, but resist wind-throw much better than straight barriers. Lobular embayments, like the keyhole beds of **Figure 4.7**, are obviously sheltered, spacious habitats for gardens and settlements.

As for surface and flow phenomena, we can partition water surfaces to reduce wind effect, or design to deliberately create turbulence and wind overturn. Islands, quoins, and rafts of many shapes have as many uses, and deflect flow to increase condensation or to encourage sand and snow deposition or removal. Surfaces can be pitted, ridged, spiralled, mounded, tessellated, tassled with plants or brush, paved, sprayed to stabilise mulch, mulched, or smoothed for water run-off.

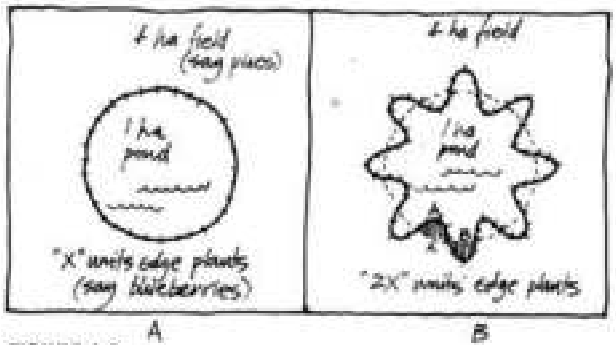


FIGURE 4.8
CRENELLATED POND EDGE
Without altering the area of a field and a pond, we can double the plants on the pond-edge (e.g. blueberries) by crenellating this edge to increase the earth/water interface.

When a boundary separates two things which differ, there is an opportunity for trade, transactions, or translation across the border. Where the boundary itself is difficult to pass, where it represents a trap or net, or where the substances and objects attempting to pass have no ability to do so, accumulations may occur at the boundary. Examples of this lie all about us, as stranded shells on the beach, people lined up at visa offices, and cars at stop lights or kerbsides.

People are, at heart, strandlopers and beach-combers; even our dwellings pile up at the junction of sea and land, on estuaries (80% of us live at water edges), and at the edge of forest, river, marsh, or plain. Invariant ecologies may attract the simple- minded planner, but they will not attract people as inhabitants or explorers.

In design, we can arrange our edges to net, stop, or sieve-through animals, plants, money, and influence. However, we face the danger of accumulating so much trash that we smother ourselves in it. Translators keep flow on the move, thereby changing the world and relieving it of its stresses. The sensible translator *passes on* resources and information to build a new life system.

There are innumerable resources in flow. Our work as designers is to make this flow function in our local system before allowing it to go to other systems. Each function carried out by information flow builds a local resource and a yield.

If you now carefully observe *every natural accumulation* of particles, you will find they lie on edges, or surfaces, or scattered nearby, like brush piled up against a fence (**Figure 4.9**). We can use these processes to gather a great variety of yields.

It follows that edges, boundaries, and interfaces have rich pickings, from trade both ways or from constant accumulations. Our dwellings and activities benefit from placement at edges, so that designing differences into a system is a resource-building strategy, whereas smoothing out differences or landscapes a deprivation of potential resources.

Objects in transit can be stopped by filters and nets. The edges of forests collect the aerial plankton that pass in the winds. Boundaries may accumulate a special richness of resource, as a coral reef collects the oxygen and energy of the sea, and the canopy of the trees the energy of the wind. We rely on translators, such as trees and coral, to store such impalpable resources, to process them into useful products, and to store them for use in their own system, with some surplus for our essential use.

Transactions at boundaries are a great part of trade and energy changes in life and nature. It seems that differences *make* trade; that every medium seeks to gather in those things it lacks, and which occur in the other medium. However, we should also look at the translator, which is often of neither medium but *a thing in itself*, the "connection or path between", created from the media, but with its own unique characteristics.

Plants, people, and pipes are translators. Nets, sieves, passes, and perforations are openings for translators to use, and (as traders know) there is no border so tight that a way does not exist for trade. Go-betweens or traders, like many plants and animals, are creatures of the edge. They seek to relieve the stresses caused by too much or too little in one place or another; or to accumulate resources (make differences) if they operate as storages. We can use naturally-occurring turbulence, trade, and accumulations to work for us, and by carefully observing, find the nets and go-betweens of use. We can use naturally-occuring turbulence, trade, and accumulations to work for us, and by carefully observing, find the nets and go-betweens of use.

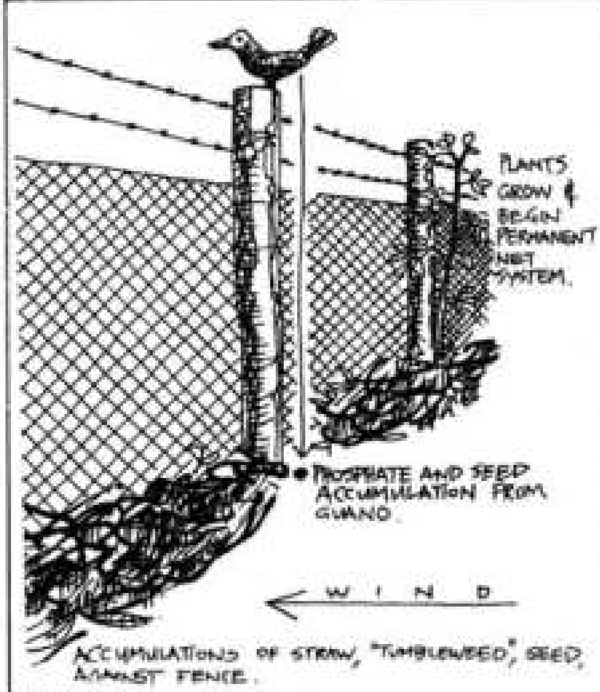


FIGURE 4.9
At powerlines and fences, perched thrushes and wood pigeons defecate, so that each post gains seed and manure, and each may generate a plant from nearby forests. Perches plus disturbed soil produce this result. Fences also act as mulch accumulators across wind.

4.7
COMPATIBLE AND INCOMPATIBLE BORDERS AND COMPONENTS

There are only limited interactions possible between two abstract or real systems brought into boundary contact. The sum of possible effects available are these:

- No difference in yields, stability, or growth (o,o)
- One benefits, at the expense of the other (+,-) (-,+)
- Both benefit (+,+)
- Both are decreased in yield or vitality (-,-)
- One benefits, the other is unaffected (+,o) (o,+)
- One is decreased, the other is unaffected (-,o) (o,-)

Almost all organisms or systems get along fine. A great many derive mutual benefit, and a very few decrease the yield of others or wipe each other out. It simply doesn't pay to attack others. In the long run one destroys oneself by accumulated injury or, more certainly, by pathogens in an animal or conflicts within a society that await a monocultural crop or repressive society. For our domestic plant groups, a powerful design strategy for yield and system stability is to select compatible components for complex edge and surface phenomena.

Many crops, like wheat and pulse grains, trees which bear on the crown, and mass-planted vegetable species, yield much better on the crop edge than they do within the crop. Taking examples where edge yield is marked (e.g. in wheat, lucerne); where there is a (+,+)

relationship, as is the case of crops such as wheat and lucerne (alfalfa); and presuming a two-fold yield increase on edges (it can be more for such trees as *Acacias* with hazelnuts), we can proceed as follows.

First, we need to measure just how far into each crop the edge effect extends, so that we can estimate a finite width of higher yield. We will assume 1 m for wheat and the same for lucerne, giving a 2 m width as a double edge. It is now quite feasible to sow a field in 2 m wide alternate strips of each crop, giving us (in effect) *nothing but edge*, and obtaining from this field about the same yield as we would have had we sown twice the area to single crop stands (**Figure 4.10**).

Two crops are a simple example, but if we extend the principle to many and varied crops on an even broader scale, we approach a new concept of growing, which we can call ZONE or EDGE CROPPING. These would produce a matrix of hedgerows or edge-rows, each suited in width to a particular crop. Such zonal strips are seen naturally occurring on coasts and around saltpans or waterholes.

This sort of setup might be a nightmare for the bulk-cropper (or it may not), but has immense potential for small shareholders in a single land trust, each of whom tend one or more crop strips. It is very like the older patterns of French-intensive agriculture and the farmed strips of modern Quebec, which produce a very productive crop mosaic. Polycultures can be composed of such mosaics or zonal strips.

For cases of (–,–) interactions, both crops suffer, but active intervention with a component acceptable to both systems may work:

Place an intervening, mutually-compatible component between two incompatible systems.

Compatible components may simply differ in sex, colour, chemistry, belief, or political conviction from the warring parties. However, in time a beneficial mosaic will impose itself on all expansionist systems, arising from the potential for differences carried *within* all life systems. Natural interveners arise, often as hybrids between apparently antagonistic systems. Our design intention in landscape systems is to build *interdependence into mosaics*..

Select and place components so that incompatibity is nullified, interdependence maximised.

After all, in the absence of tigers, Hindus need Muslims to eat cows; they may also need a Christian businessman between them to effect the transaction. The interdependence of mosaics of belief are called for as much as mosaics of plants.

The stupidity principle may here be stated in a different way:

Stupidity is an attempt to iron out all differences, and not to use or value them creatively.

It is our skill in organising spatial or functional distribution that may create beneficial interdependence in incompatible components. When we know enough to be able to select mutually-beneficial assemblies of plant and animal species

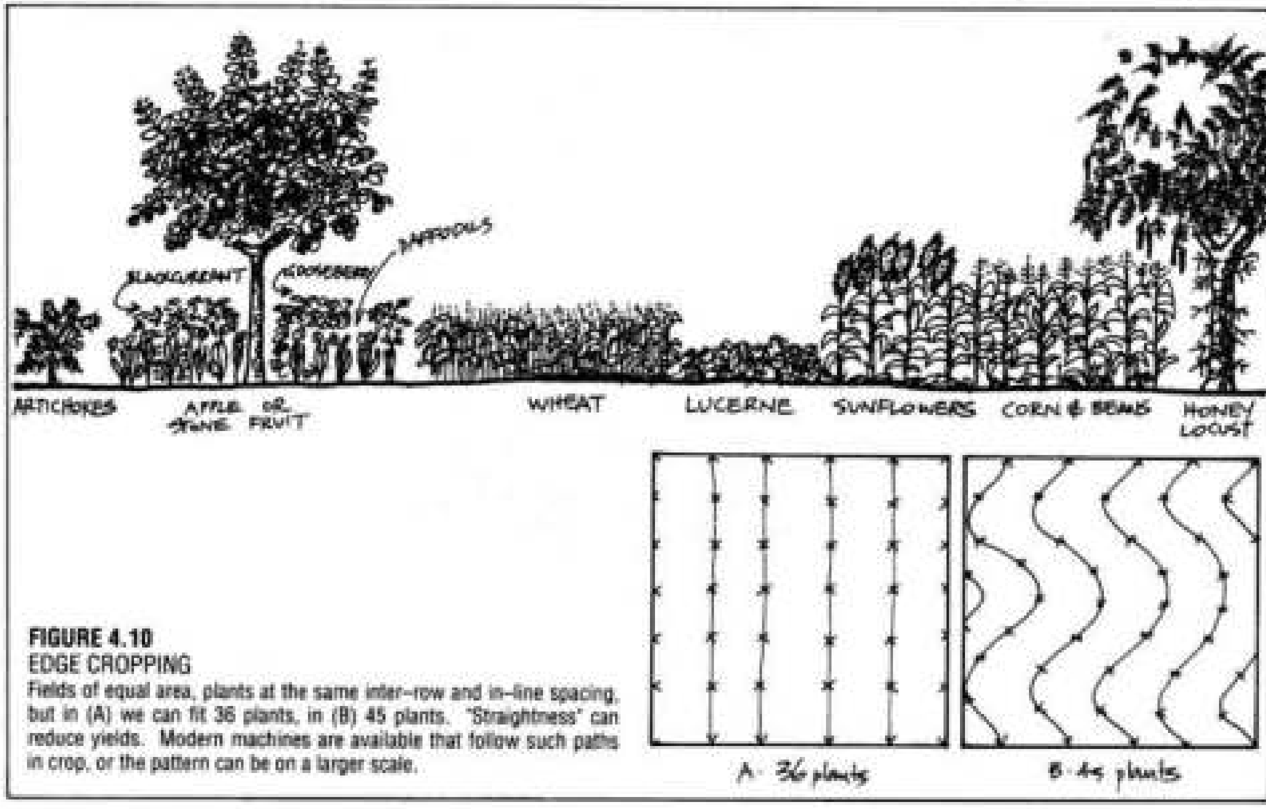


FIGURE 4.10
EDGE CROPPING
Fields of equal area, plants at the same inter-row and in-line spacing, but in (A) we can fit 36 plants, in (B) 45 plants. 'Straightness' can reduce yields. Modern machines are available that follow such paths in crop, or the pattern can be on a larger scale.

(**guilds**) then we have two powerful interactive strategies (edge harmonics and species compatibility) for design applications.

Mosaic design (the opposite of monoculture) means the creation of many small areas of differences. A few mistakes will occur, but good average benefit will result. This was the tribal strategy.

<u>A Golden Rule of Design</u>
Keep it small, and keep it varied.

Our tree model is not only *different from* its supporting media, but exists *because of* them. Stress builds *because of* impermeable boundaries. If a fence allows mice through but restricts rabbits, it is the rabbit plague that will break it down. If too much money accumulates on one side of a door it will either force the door open of itself, or those deprived of it will break in. The terrible pressures that gases and molecules can exert are harmless only when that pressure is free to disperse, or where potentially destructive energies are quietly released where there are no boundaries, multiple translators, or stress–relief mechanisms.

Because the event itself creates a third medium, it again sets up stress between itself and the media (M1 and M2). It can be seen, therefore, that *once any one difference of any sort, even an idea, exists anywhere, then it demands or creates conditions for the evolution of subsequent events.* That first event itself became *yet another difference*, which in turn needed translation, and so on. The process is self–complicating, continually creating of itself all that follows, and all that continues. All is stress, or the relief of stress, and that stress and relief is located between existing differences. One difference in the beginning was enough to generate the total range of subsequent events. There are no "new" events, just a continual expression of all possible events, each arising from some recombination of preceding differences. There are no miracles, just a realisation of infinite possibilities. Any event has the potential to spawn all possible events.

There are no new orders of events, just a discovery of existing events.
Every event we can detect is a result of a preceding event, and gives rise to subsequent events.

Between all media, some DIFFUSION can take place. This is greatly enhanced by such phenomena as surface turbulence, wave overturn, temperature differences, and pressure differentials. Boundaries between diffusing media are blurred, often seasonally different or sporadic in occurrence, and always in flux. Plants give pollens and chemicals to air, and actively intervene in radiative, gaseous, liquid, and general energy transactions with the atmosphere. Between plant groups, leaf, root and mulch exudates diffuse as chemical messengers. Water is the "universal solvent" of substances diffusing through the earth's crust, in plant systems, and in the atmosphere.

Diffusion is a quiet process operating on a broad front or over the entire surface of some media. It is analagous to, but differs from, the active transport systems that we have called events or translators. However, once an event has occurred, it *also* uses diffusive processes to gather or distribute materials, and thus *events merely enlarge the total diffusive area available*. A tree may have many acres of leaf, and evapo–transpiration will then exceed evaporation at that place by a factor of forty or more. We can grow many such trees on one acre, and thus increase the diffusion effect by factors of 1000 or more, so that gaseous exchange from leaves, and sugars in soils (or soil life) are both assisted by the trees.

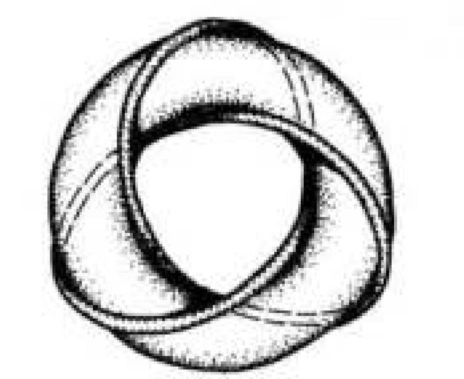


FIGURE 4.11
DNA, coiled around a plus–torus like a single path in the Robinson Congruence.

4.8
THE TIMING AND SHAPING OF EVENTS

We can see how an event takes place, but how is it shaped? Our bodies arise from the origin (O) of a zygote (a fertilised egg) on the surface of the uterus; the placenta is our root, the foetus the tree of ourselves. Animals are thus events broken free from the coiling connective cord or umbilical stem of their origins. Their eventual shape is a pattern laid down or encoded by the DNA of their cells, coiled as it is around a plus–torus like a ribbon around a doughnut (**Figure 4.11**).

When my son Bill was four, we were in the bath together, and he pointed to his toes. "Why are these toes?" he asked.

"What do you mean?" I hedged.

"Well, why don't they get bigger and bigger or longer and longer? Why do they stop at being toes?"

What limits size and growth? All flows pulse, whether they are blood, wind, water, lava, or traffic.

The pulsing may be organised by PULSERS (e.g. traffic lights), and results in WAVES, or time-fronts, or particles on fixed schedules. Such pulsers (**Figure 4.12**) are located in our bodies as chemical or physio-chemical spirals in sheets of cells that swirl in sequence to create a pulsing movement in our heart, organs, and viscera. Pulsers can start, run for a preset time, and stop. This is how we grow, and why we eventually die. All mammals have an allotted number of heartbeats in relation to their body size, and when these run out, we die. (A friend also theorises that we have a set quota of words; and when they are said, we die.)

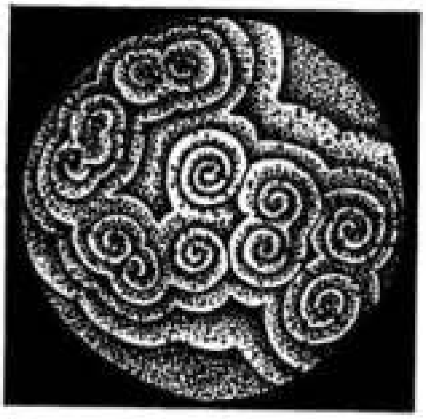


FIGURE 4.12
PULSERS
Pulsing, here from Winfree's 'doped' chemicals, may take the form of spirals revolving about a locus, in this case centripetal in action like a low pressure wind cell. Pulsing is regular in these chemical systems, as in muscle or flow phenomena.

Pulsers *plus* patterns account for shapes. They determine that a toe will stop at being a toe, and not grow into a monstrous appendage or stay as a midget toe. Thus, all living events carry their characteristic time-shape memories, and (it would appear) so do rivers, volcanoes, and the sun itself. The sun "pulses" every 11 years or so, affecting our ozone and climatic factors such as rainfall. Our own pulses have characteristic or normal resting rates, as do our peristaltic or visceral movements.

Pulsers act in concert to create peristaltic or heart contractions, but if they get the wrong signals, can move out of phase and send the organ into seizure. This spasm may cause damage or death (a heart attack). The pulses drive fluids or particles through vessels or arteries in cities and in bodies, and those then branch to serve specific cells, organs, or regions.

Figure 4.12 is a quite extraordinary spiral pattern which arises from the pulsing reactions of organic acids seeded with ionic (iron, cerium) catalysts. The pulses are quite regular, "at intervals of about a minute, but these may vary up to 5 minutes in living systems such as nerve tissue and a single layer of a social amoeba" (Winfree, 1978, "Chemical Clocks: A Clue to Biological Rhythm" *New Scientist*, 5 Oct '78). The system is one of spirals rotating about a pivot point which is not a source but an invariable locus around which a spiral wave is generated. It is sequences of such phenomena that create a peristaltic system. Spirals of this nature can revolve in two senses: either organising material *to* the pivot, or (revolving in the opposite sense) *dispersing* material to the periphery. We can envisage counter-rotating spirals doing both as they do in the circulation of the atmosphere as high or low pressure cells.

The phenomena is shared by nerve, heart, and brain tissue; organic and inorganic oxidation on two-dimensional surfaces; and in thin tissue subject to exciting stimuli. Ventricular fibrilation (a potentially fatal quivering of the heart) may derive from the spasm effect distributed over heart or nerve tissue, causing an "ineffectual churning" (Winfree, *ibid*). It may also account for involuntary spasm in muscle. Spasms can damage the cells of blood vessels, and cause a build-up of scar tissue or cholesterol at the injury site, or in muscle tissue—an area of hard waste products. The social amoeba *Dictyostelium* uses the pattern to move *towards* the pivot point where "they construct a multi-cellular organism which then crawls away to complete the life cycle" (Winfree, *ibid.*), a process resembling the precursor of hormonal control in the nervous system. Some such process may assemble more complex multi-species organisms like ourselves.

The cycling spirals can be found in biological clocks, such as those which govern the 24-hour metabolism of flowers and fruit-flies, stimulated by oxygen or light pulses.

Within a specific organism, specific pulsers exist; the 24-hour rhythm (CIRCADIAN) of birds is controlled by the pineal gland (*New Scientist*, 11 Oct '84) which secretes a regular nocturnal pulse of the hormone MELATONIN (the changing levels of melatonin trigger the annual cycles of breeding and nest-building in birds). Visual perception of light changes and day lengths regulate the production of melatonin in the pineal gland. Even small pieces of the gland in isolation will respond to light, and can be disrupted by flashes of light (as in lightning) at night. Thus, we see that not only expansion, but DISCHARGE PHENOMENA such as lightning (or sudden shock in people) disrupt or trigger initiatory reactions in life rhythms, and introduce irregularities in cycles or pulsers, just as expansion or shock introduces irregularity in fixed forms. The question arises as to whether the disturbance produced by shock or sudden stimulus is responsible for expansions, cyclic changes, or shape deformations on a more general scale.

Species and individual organisms need both SHAPERS (DNA) and TIMERS (biological clocks) to achieve a specific size and shape. The two must work synchronously to achieve the correct proportions of parts such as fingers and toes, but both are critical to the organism.

Branching patterns in bodies must have (already encoded) the correct angles and placements for their main branches, leaving room for sideshoots and forks, but not for interweaves or cross-points which damage the function of the organism. In order to generate the surface or boundary of a person, and their reticulation systems, patterns of incredible complexity and strict limits must be "known" by the cells or the cell organisers.

We ourselves are part of a guild of species that lie within and without our bodies. Aboriginal peoples and the Ayurvedic practitioners of ancient India have names for such guilds, or beings made up (as we are) of two or more species forming one organism. Most of nature is composed of groups of species working interdependently, and this complexity too must have its synchronistic regulators.

4.9 SPIRALS

Implicit in many of the phenomena discussed are the forms of spirals. These may be revolving (dynamic) or fixed (static), and arise as a consequence of deformations in flow, or are rather an intrinsic property of a specific velocity of flow over surfaces. Other spiral paths are traced out by orbiting bodies over time, or are shapes developed by organisms developing a compact form (e.g. molluscs) that is analagous to annidation. Spiral forms are made visible by plants as whorls of leaves and branches.

D'arcy Thompson (1952) in his book *On Growth and Form*, discusses some of the quantitative or geometric qualities of spiral phenomena, which are hidden or revealed in many natural forms. A long spiral in section is the "S" form of humid landscape slopes (and the yin-yang symbol). Three-dimensional spirals form long ribbons of complex shape. Even within the molecular forms of matter, DNA reveals a double-helix form. Spirals are, in effect, single streamlines of vortices, tori, or sap flows.

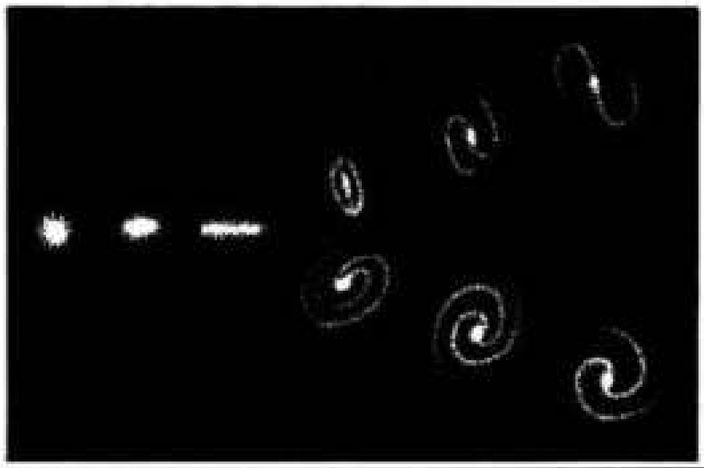
Spirals arise from the interaction of streaming and its subsequent deflection of flow around vortices. Storl (1978, *Culture and Horticulture*, Biodynamic Literature Rhode Island) points out the spiral arrangement of leaves in many plants, where leaves are from one-half way, one-third way, and so on around the stem from the preceding leaf, or to the next leaf. Such placements may progress in a regular (Fibonacci) series, each following on from the sum of the two preceding ratios: 1:2 + 1:3 = 2:5; 1:3 + 2:5 = 3:8, etc., so we get 5:13, 8:21, 13:34 and onwards. These sequences are found in plants and in planetary orbits, so that "Venus forms five loops (retrogressions) below the ecliptic in eight years." Storl sees a relation between the forms of plants and of planets in these progressions, as we can see in the orders of size.

Like so many real-life phenomena, natural spirals are not "perfect", but "show slight progression" and gradually lose phase over long periods (Storl, *ibid*). We can often use the spiral form in design, both to create compact forms of otherwise spread-out placements and to guide water and wind flows to serve our purposes in landscape. We can see the application of spiral forms to technology in everyday life as screws, propellers, impellers, turbines, and some gears. Some species of sharks and invertebrates develop spiral gut lining to increase absorption, or spiral cilia to convey mucus and food or particles in or out of the organism. Plants such as *Convolvulus* use spiral anchors in earth, as do some parasites in animal flesh.

Thus, spirals are found where harmonic flow, compact form, efficient array, increased exchange, transport, or anchoring is needed. We can make use of such forms at appropriate places in our designs.

4.10 FLOW OVER LANDSCAPES AND OBJECTS

The simple involuted mushroom, called an "Overbeck



HUBBARD'S GALACTIC CLASSIFICATION
Regular and usual galaxies have limited forms (eliptical, spiral, or barred) and slow rotations. Even galaxies can be ordered in terms of form.

jet" by D'Arcy Thompson (1942), is also shown in its "apple core" model form in **Figure 4.13**. While we can produce these patterns by jetting smoke, fluid, gases or oils into other media, they occur as a part of the natural streaming of fluids and gases past fixed objects such as bluff bodies (e.g. posts) in streams, islands in tides, and trees in wind. Jet streams at altitude can generate such vortices by pushing into different air masses, as can muddy water entering the sea.

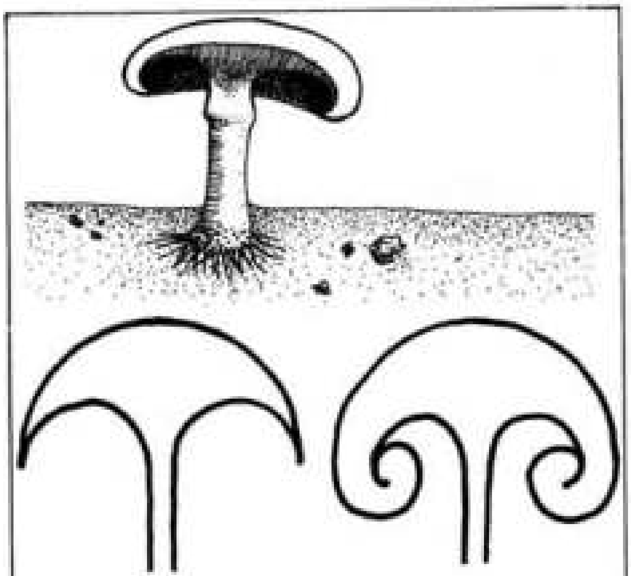


FIGURE 4.13
OVERBECK JET MODELS
The Overbeck jet is a simple half-form of the basic model, and occurs commonly in nature e.g. mushrooms, rivers flooding into the sea, and jellyfish.

Whirlpools or VORTICES are shed alternately from a fixed bluff body located in flow, each side generating its own vortex, each with a different rotation. Beautiful and complex forms are thus generated (**Figure 4.14**) and these are the basis of the work at the Virbela Institute on flowforms. The sets of vortices shed or generated downstream from fixed bodies in flow are called Von Karman trails.

The trails are stable at the 1:3.6 ratio shown in **Figure 4.14**. In many streams, and on foreshores, the clay–beds, silts, and underlying rock may develop such patterns, and posts fixed in streams commonly produce them in water. Trees and windbreaks produce similar effects in wind, as do waves at sea. In wind, they are called EKMAN SPIRALS, and in air the spiral lift effect compresses air streamlines to a height 20–40 times the height of the tree or fence fixed in the air flow.

It is obvious that the stable spirals of the Von Karman trails will produce successive pulses downstream, and this is in fact how we observe most flow phenomena to behave. Thus the pulsing of wind, water, and flow in general may rely on the elastic or deformation properties of the medium itself rather than on electro-chemical "timers" as found in organisms. In nature, there are many fixed impediments to perfect streamlined flow.

It is typical of Von Karman trails generated from a fixed body that the effect persists as 4–5 repeats (**Figure 4.14. C**), and then the stream of water gradually resumes streamlined flow. At higher velocities of stream flow, chaotic turbulence occurs, and at slower velocities, simple streaming persists around objects. Thus we see that the Von Karman trail is just one form

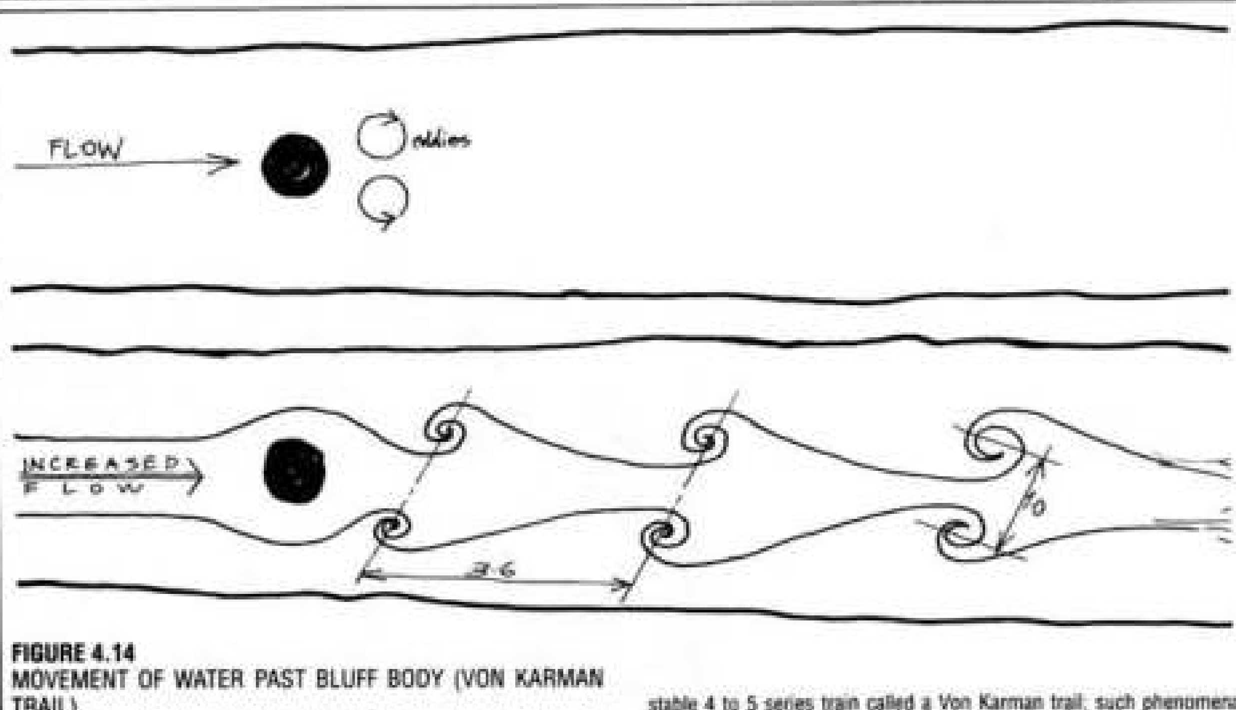


FIGURE 4.14
MOVEMENT OF WATER PAST BLUFF BODY (VON KARMAN TRAIL).
At certain modest flow speeds, water, wind, and even clouds form a stable 4 to 5 series train called a Von Karman trail; such phenomena were vital guides to Polynesian navigators (see Figure 4.26).

of pattern generated by specific flow conditions. It is nevertheless a common form in nature.

The spiralling of wind over tree lines produces a secondary effect, analagous to the streaming of tides around atolls; the wind *changes direction* past the obstacle (about 15°). Such effects may occur within media of different densities (temperatures) as when warm high-pressure wind cells ride over colder low-pressure fronts. The temperature, pressure, and velocity of wind or gas systems are often related:

- Low pressure – high velocity – cool temperature – (expansion).
- High pressure – low velocity – warmer temperature – (contraction).

Velocity in gases and fluids is strictly governed by contact with stationary surfaces, so that the velocity is effectively nil very close to static surfaces, increasing as a series of (imaginary) laminar sheet flows above that surface (**Figure 4.17**). This is the effect that is observed in viscous flow in small canals or vessels, and that governs the shapes and strategies of organisms such as limpets and starfish.

Thus, we see that media in flow can produce pulsers, vortices, and spirals as a result of irregular or obstructing objects or resistant media, and that these phenomena are interconnected.

The relationships between fluid flow, boundary conditions, and the form these impose on organisms is clear from our pattern models and their deflection states. Life as evolved by its internal and external patterns and flows is very well discussed by Vogel (1981) in a lively and scholarly book entitled *Life in*

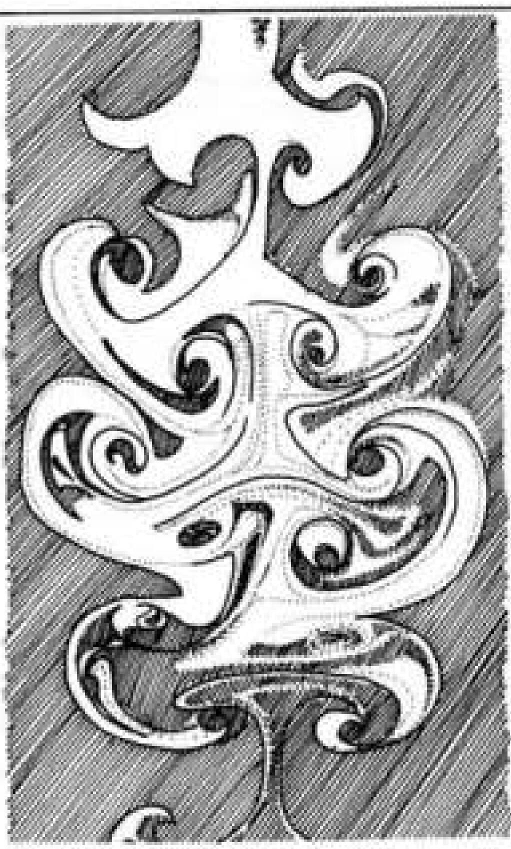


FIGURE 4.15
MOVEMENT OF BLUFF BODY THROUGH WATER.
A bluff body drawn through still water can make a theoretically endless trail of Overbeck jet forms, superficially resembling a Von Karman trail.

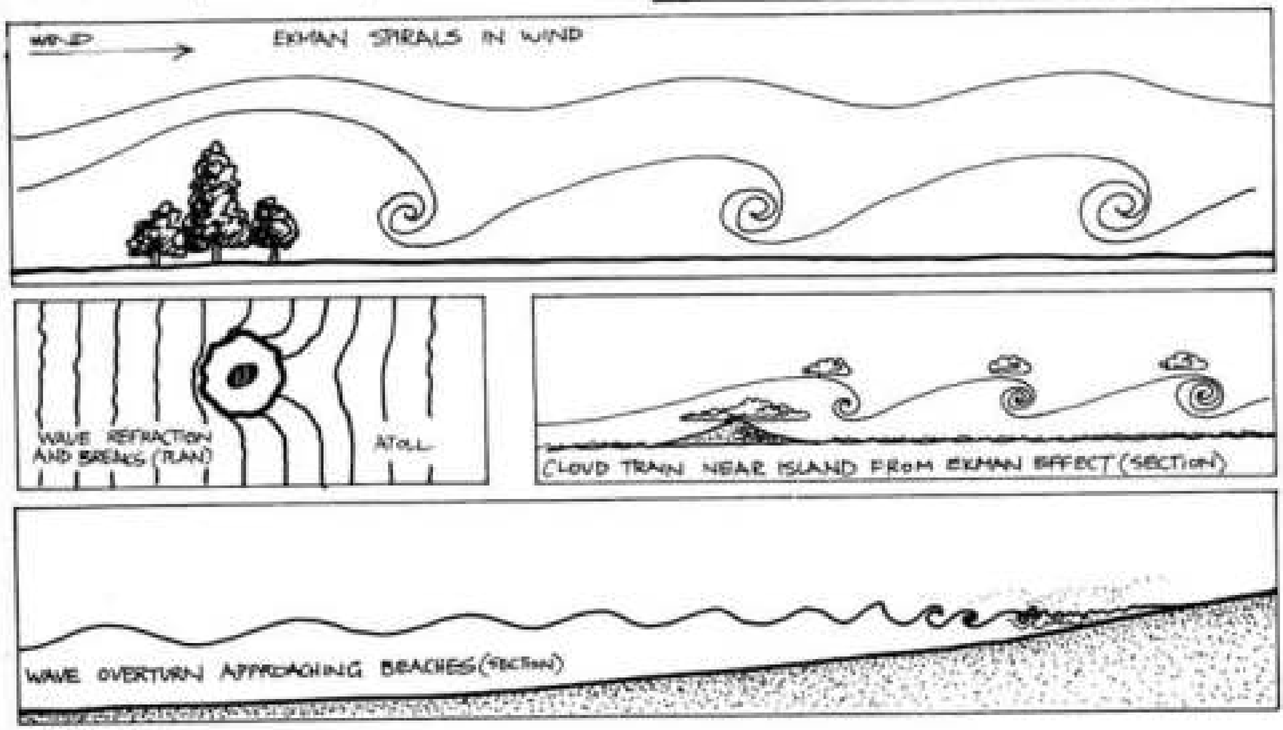


FIGURE 4.16
DIFFERENT TYPES OF TRAILS AND SPIRALS.
The effects of fixed bodies on wind, waves, tides, and cloud streets; various phenomena arise from flow forms.

Moving Fluids.

Carried in the flow of media, as a thistle-down in air, are many events looking for a place to happen. A "net", resting surface, or detonator is needed for these potential events to express themselves. We can provide many such receptors or triggers in our design systems, catching nutrients in flow and ensuring events for future growth in our system. Some such nets form starting-places for events, while others are resting or death places for those entities dependent on flow, or stranded out of their nutrient media.

Just as a series of corks floating on the sea have a predictable path to shore perpendicular to the wave fronts, so does matter flow in a wave-tank model. Similarly, drift-lines form at sea (STREAMLINES in the core model), and as these end on shorelines, they deposit or remove material.

It is along these streamlines that energy acts, by medium of the waves of growth or surface waves in motion. This is how the event and its material expands: streamlines diverge as wave fronts and *disseminate* into open media, but are strong, concentrated, and visible at constrictions, near origins, or in powerful or refracted flows. A small restricted orifice in the time-front or wave-front acts as a secondary origin. Just as a grub encircling a tree causes it to branch out at that point, so constrictions in the flow of

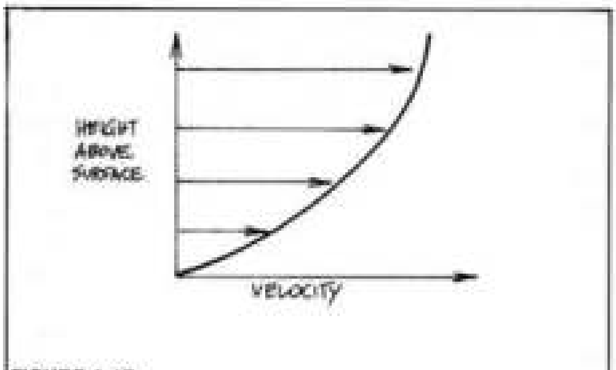


FIGURE 4.17
DIAGRAM OF LAMINAR SHEET FLOW.
Surface drag greatly affects stream flow in water or air. Velocities near a surface are close to zero, giving viscous flow, and only slowly increase as distance from the surface increases.

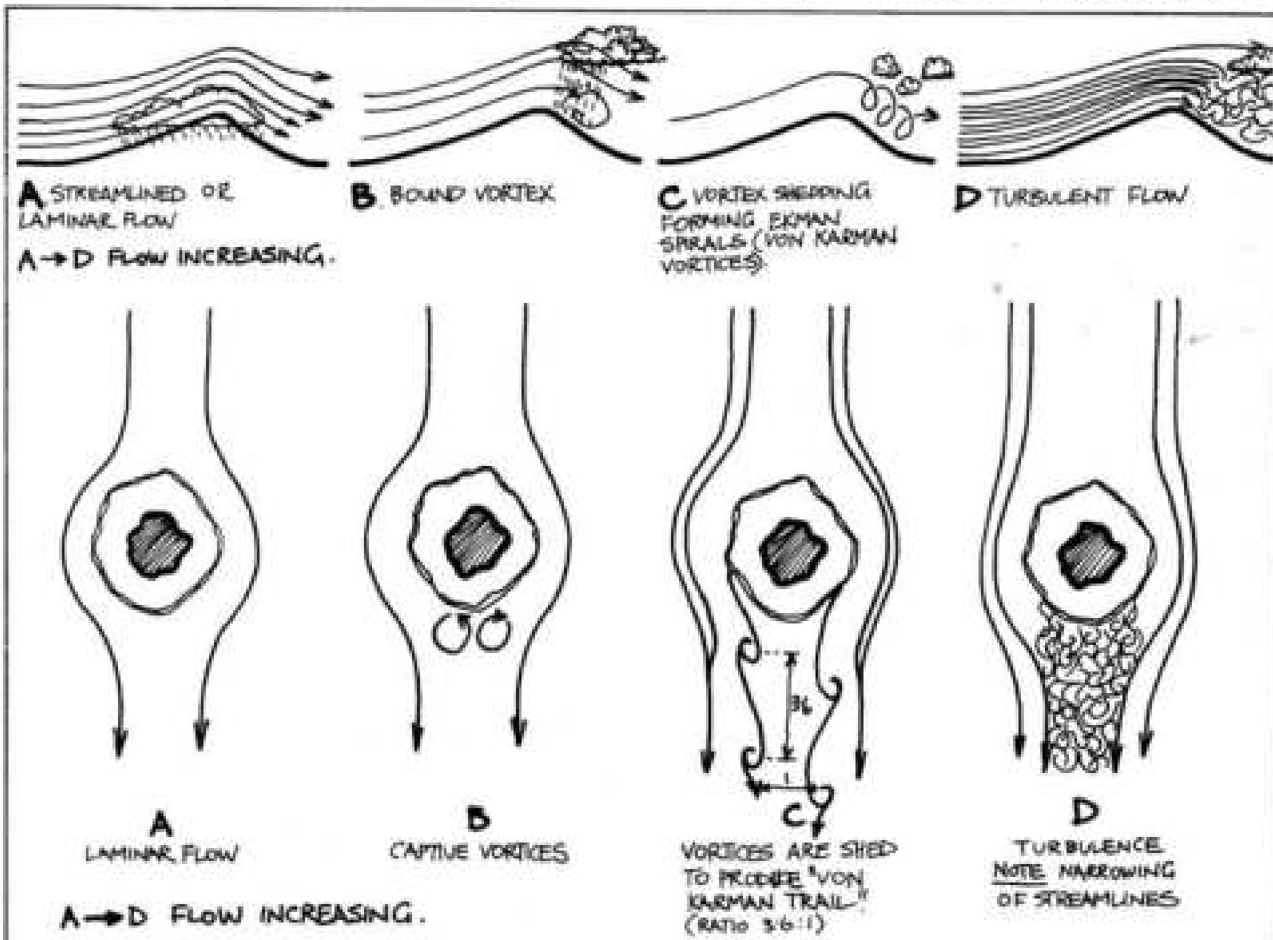


FIGURE 4.18
MEDIA IN FLOW
Flow at different velocities produces different downstream phenomena. Here velocity increases from A – D, as wind over an isolated island, or current flow past an atoll.

events generate secondary origins. I once watched this happen with a eucalypt that I planted in 1953, and saw it twin and twin again as swift-moth grubs encircled its stem. It is now a mighty tree, much branched, but the evidence of these minute constrictive events are still buried in its stem. As designers, we can impose small constricting events or place fixed objects in flow to produce such specific results. We can then be the external shapers of patterned events.

4.11
OPEN FLOW AND FLOW PATTERNS

Creatures that live in open flow conditions are specially shaped and adapted to surface or low-flow (high pressure) phenomena, and may erect or develop "chimneys" to draw fluids or gases through their burrows or bodies. Some life forms combine chimneys, spirals, and crenellations to effect an exchange between them and their fluid surrounds (Vogel, 1981).

All of these effects of flow are of great relevance to designers, engineers, and biologists, and their effects can be increased, nullified, or decreased by design. Natural effects can be used in a variety of ways, and the effects of orders may impose limits on design. Further data is given under Chapter 6: "Trees and Energy Transactions".

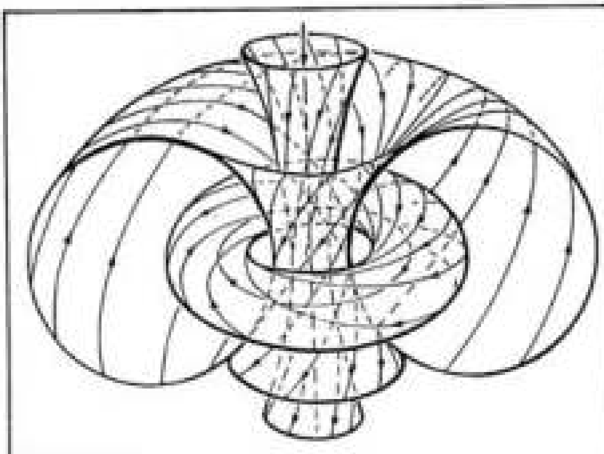


FIGURE 4.20
THE ROBINSON CONGRUENCE
Pattern for an electron, a massless particle, travelling up this page at the speed of light; energy as form, congruent also with the general model.

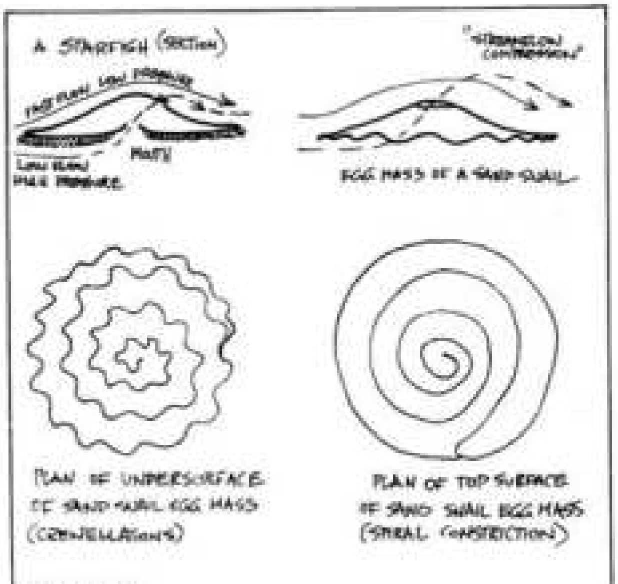


FIGURE 4.19
LAMINAR FLOW NEAR A SURFACE
(Arrows represent wind or water speed). Pressure is high near the surface, lower at a distance, thus a starfish (or a chimney) experiences a flow 'under and out the top' in flow conditions. The sand snail egg mass is built to be easily irrigated, the starfish gets food in the water stream by their configuaration in flow.

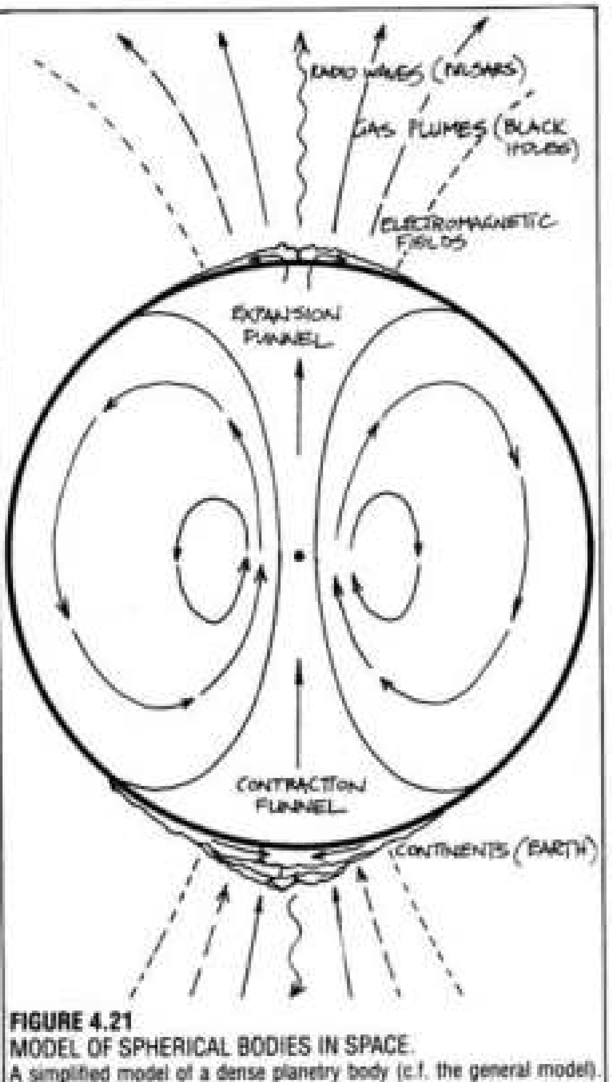


FIGURE 4.21
MODEL OF SPHERICAL BODIES IN SPACE.
A simplified model of a dense planetry body (c.f. the general model). Electro-magnetic fields and thermal convection create special conditions along the axis of spin. Many such bodies emit material at the poles before cooling.

4.12
TOROIDAL PHENOMENA

Implicit in our core model, and obvious in violent detonations such as atomic explosions, puffs from diesel exhaust pipes, or deliberately blown as smoke rings, are the rolling doughnut-shapes of TORI. A TORUS is a widespread natural phenomenon. The closed models (**Figure 4.13**) enclose such a torus, and we can imagine a slow-cycling torus of nutrients surrounding the stem of any tree as crown-drip carries nutrients to the ground, and the roots again return them via the stem of the tree.

Photographic stills of atomic explosions may reveal violently rotating tori around and crowning the ascending column of smoke and debris. Violent up-draughts caused by local heat create such tori in atmospheric thermals, much appreciated by soaring birds and glider pilots, who ride the inner (ascending) circle of the doughnuts of hot air that are generated, for example, over deserts on hot afternoons.

A complex toroidal form is the "Robinson Congruence" (**Figure 4.20**), portraying the space-time form of a mass-less particle such as a proton, representing, in effect, annidated tori.

DNA is also portrayed as encircling such an imaginary plus-torus in **Figure 4.11**. A Möbius strip—a one-sided twisted toroid (often portrayed by M.C. Escher in his art)—enables us to cross an edge without lifting our pencil. Many life forms produce tori (e.g. some sea snail egg masses). We rely on a torus of rubber to inflate our tyres and to seal circular hatches as O-rings.

A torus is, in effect, a special or truncated case of the Overbeck jet (**Figure 4.13**), as a foetus is a truncated "tree", and can be generated by *discontinuous* or explosive flow, or pulses in flow. A torus is a closed three-dimensional vortex. One such closed toroidal form, as found in black holes, is shown in **Figure 4.21**. Here, accretion of matter causes gaseous ejection at the poles, as the earth may have "ejected" seas and continents at the magnetic poles, or gathers in the violent energy of ionised particles that form the auroras, visible as polar tori in satellite images. Even the long curtains of the auroras seen from the ground contain vertical spiral columns (J. Reid *pers. comm.*).

4.13
DIMENSIONS AND POTENTIALS; GENERATORS

Our patterned systems may exist in two or more dimensions. We can tessellate two-dimensionally but need to envisage three dimensions for a tree form or glacier. The tree-forms of rivers flow down along S-shaped gradients; the generator of such a pattern is gravity. Sand dunes form on near-flat platforms of the desert, and have wind as their generator, as do waves on the sea. Neither gravity nor wind may much affect the creeping tree patterns of mosses, dendrites in shales, or the tree-like forms of mycorrhiza in plant cells. It is here that we see our tree form as the best way to grow or to gather nutrients in the absence of violent kinetic processes. The generator here is life or growth itself.

When kinetic forces do not act strongly, as in flat and essentially sheltered desert environments, **lobulation** and **latticing** still occur as freeze-thaw or swell-shrink patterns, as they do in ice floes on quiet ponds or in the hexagonal patterns of stones on tundra. The slow growth of crystals into rock cavities or ice is still related to our general model; the generator of pattern here being at the level of molecular forces, as in many purely chemical processes, and the forms generated are fractals.

In hill country, energies are usually a combination of stream flow and gravity. On plains, icepacks or flat snowfields, it is freeze-thaw or the swelling of clay in rain that produces lobulations or networks of earth patterns. Lobulation, the production of such shapes as in **Figure 4.7**, differs in origin and mode of expression from the kinetic-energy (flow) systems we have been discussing. I sometimes think of the lobulated forms as a response of nature, or life, to a world that threatens "no difference".

If the hills wear down, then the antepenultimate surfaces will produce their lateral, two-dimensional life patterns, as does the lichen on a rock. Kinetic erosion processes are then exchanged for physical and chemical process at the molecular level, but even this creates a sufficient difference in media for life forms to express themselves, and for differences to arise in the patterns of surfaces.

4.14
CLOSED (SPHERICAL) MODELS; ACCRETION AND EXPULSION

Although trees (including tree roots) may approach spherical form, the best examples are found in spherical bodies in space. These deflect light, dust, and gas towards them, and may capture materials. In their early formation, they themselves may have had dense cores that assembled their share of galactic materials, and around these cores a torus of matter of low- or high-speed rotation can form. This is the model presented for most bodies (*New Scinetist*, 4 April '85, pp. 12-16). A general model is given in **Figure 4.21**.

As matter accumulates in this way, bodies can respond by:

- Becoming more dense – to a limit of 10^{14} g/cm^3;
- Swelling or expanding (producing shatter effects); and
- Ejecting material at the poles.

Or any combination of these depending on the state of the matter attached or attracted to the core.

For pulsars, the ejection is radio waves, and for black holes high-speed gas plumes. For trees, of course, we find expansion and transpiration, not localised to the axis of growth.

However, along the Z–Z (ejection) axis of **Figure 4.1**, rotating tori speed up ejection at north poles, and slow it down at south poles, so that less viscous materials are likely to be emitted at north polar emitters. This general effect may be portrayed in one model, but each case needs study. Weak gravitational waves permeate the astronomical system as pulsers permeate or orchestrate biological systems, aiding both dispersal and accumulation depending on the sense of rotation of the accreting system, or the electromagnetic fields interacting with incoming particles. It seems probable that weak fields within the sun creates its pulsers, which proceed from pole to equator as a roll or torus of turbulence over an 11-year period.

4.15
BRANCHING AND ITS EFFECTS; CONDUITS

Various sections, plans, and views of our one tree model reveal very different sectional PATTERNS, all of which are inherent and most of which recur in many other natural forms. Benoit Mandelbrot assembled his own insights, and the speculations of others, to found a mathematics of **fractals** (his term, from the Latin *fractus*, or shattered), which is evolving to make sense of irregular phenomena, as Euclid did for more regular and measurable forms (*New Scientist*, 26 Apr '84, p.17 and 4 Apr '85, p.31–35).

Fractals are as common in nature as in abstractions, and examples are as diverse as impact shatter-zones, clouds, forked lightning, neurone nets and their signals, computer searching procedures, plant identification keys, snowflakes, and tree branches or roots. Some typical fractal forms are illustrated (**Figure 4.22**). Others make up the complex lengths of coastlines and the intricacies of turbulence.

In our tree form (**Figure 4.1**), these fractal patterns (as branches and roots) are contained within a form that would be comprehensible to Euclid, having straight axes, a plane, and regular curved lines, which can be drawn as arcs of perfect circles. Thus the apparent chaos of fractals can be seen to underlie quite regular (but never perfect) shapes in nature as branches underlie the crown canopy of a tree. As Mandelbrot has demonstrated, fractals have their own regular generators and evolutions.

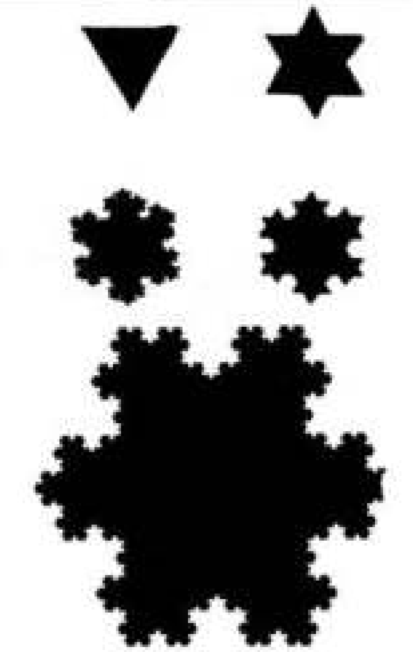
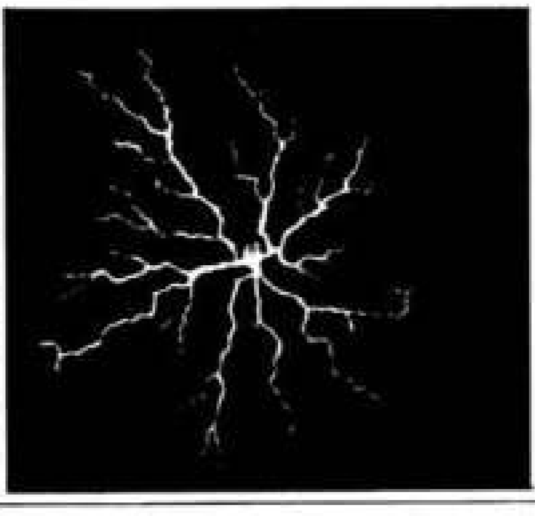
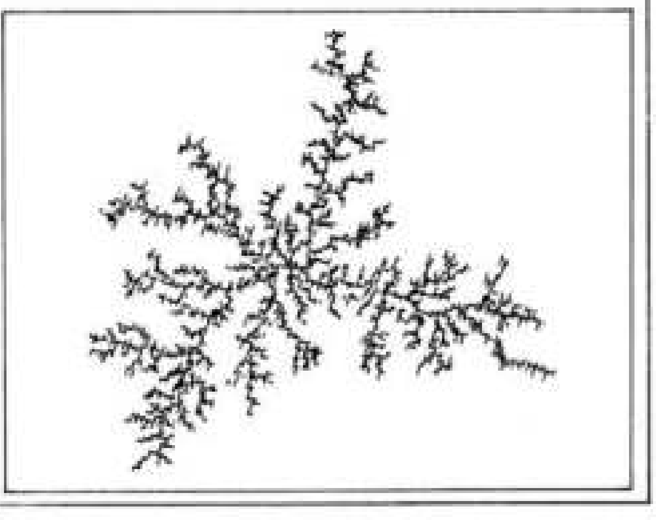


FIGURE 4.22
SOME FRACTAL FORMS
Fractal forms mat be generated by repetition of relatively simple form generators, as are some crystalline formations and such phenomena as tree roots, tree branches, coasts, lightning strikes, shatter zones, information nets, and so on.





Looking down on a bare winter-deciduous tree, we see a typical fractal, which we can also find in the fulgurites (sand fused by lightning) in sand dunes, and in the shatter zones of explosions. Tree roots are, in fact, a slow shatter or explosion underground. One way to plant an apple tree in very hard ground is to detonate a small plug of gelignite a foot or two below the surface; the roots will follow the shatter pattern, and further elaborate it.

Scatters of objects may at first seem to present a class of events unrelated to either flow models or frac-tals, but fractals are being used to describe the scatters of tree clumps in grassland, or lichen on a stone. In a sense, the surface of spheroids created by branched phenomena (like the plan view of a tree crown) may show such apparently random scatters as growth points; or a curved section through the cut or pruned branches below the crown of a tree would also appear to be a scatter of points (**Figure 4.1.E**). These can be measured by fractal analysis.

Fractal theory may give us a way to measure, compute, and design for branched or scattered phenomena, but we also need to understand the physical advantages of developing ever smaller conduits. Vogel (1981) gives many insights into this process and its effects. Large conduits are of use in mass transport, but both the laminar flow patterns within them and the fact that they have a small surface area relative to their volume makes them inefficient for the *diffusion* of materials or the conduction of heat across their walls.

Ever smaller conduits have different qualities: flow is slow, almost viscous in very small tubes or branches; direction changes in small branches are therefore possible without incurring turbulence or energy losses. Walls can be permeable, and efficient collection, exchange, and transfer is effected (whether of materials or physical properties such as heat and light). Many small conduits efficiently interpenetrate the exchange media.

Wherever there is a need to collect or distribute materials, or to trade both ways with media, branching is an effective response. In design, therefore, we need to use "many paths" in such situations as home gardens, where we are always trading nutrients as our main activity. There is little advantage in forming these paths as straight lines (speed is not of the essence), but rather in developing a set of *cul de sacs* or keyhole-shaped beds (this is also the shape of sacs in lungs). Convoluted paths in gardens have the same effect. They either bring the gardener into better contact with the garden, enabling collection and servicing to occur, or create better mutual exchange between the species in the garden.

The high-pressure/low-flow nature of minor branches demands a very large total cross-sectional area of these in relation to the main supply arteries. Such small conduits may develop areas which in sum are 300–1,600 times that of the supply artery (our main roads are therefore much less in area than the foot tracks that lead off them). As an applied strategy, multiple small paths enhance our access to food systems, or in fact any system where we both take and give materials.

In organisms, the multiple branches give the being a chance to recover from injury, preserve information, and permit regrowth in the event of minor damage. It is a fool-proof system of interchange. Another way to effect interchange is to elaborate on the walls of larger conduits by involutions, attached fins, irregular surfaces, or to create spirals in fluids or gases by bending or spiralling the conduits themselves, and in general inducing a larger surface of contact between the material transported and the media with which we wish to exchange nutrients, heat, or gases.

Branching in trees is as often a result of external forces (wind and salt pruning, secateurs, or insect attack) as it is a result of internal cell patterns; it is as much forced upon things as it is the "best thing to do." We must therefore see the branched form as an interaction between an organism or process, the purpose it serves, and the external forces of the media in which the organism is immersed (the forces acting on it externally to deform the perfect pattern).

Along the streamlines (S1–S9 of our model **Figure 4.1**), fluids and gases may pass in conduits or along "transmission cords", food and signals are relayed to cells, and gases exchanged. Organs served by or serving these systems are half-models of our tree (kidneys, lungs) or branching fractals (mesenteries).

No matter how long or complex conduits are, in the end their contents diverge, escape, and disperse, and at the intake materials are gathered from dispersed sources. It is this gathering and dispersal from both

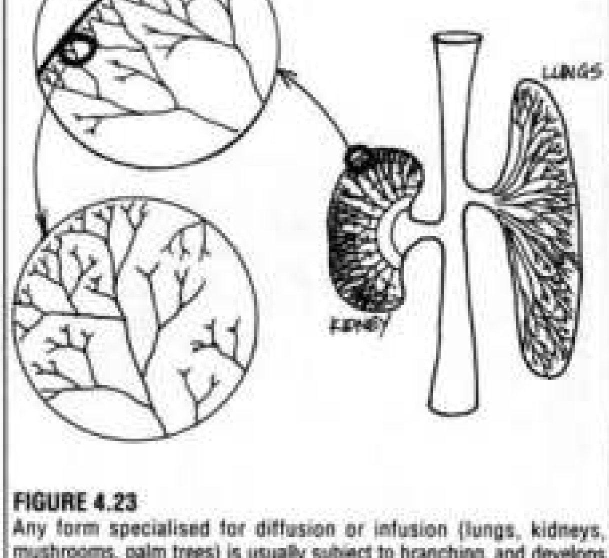


FIGURE 4.23
Any form specialised for diffusion or infusion (lungs, kidneys, mushrooms, palm trees) is usually subject to branching, and develops a "half-model" in one medium. The alvioli of the lungs further resemble the "keyhole beds" of a well-designed garden.

ends or margins of events that is a basic function of the tree-like forms that pervade living natural systems and such phenomena as rivers or lava flows.

4.16

ORDERS OF MAGNITUDE IN BRANCHES

Streams take up many ground patterns depending on the processes that have formed the underlying landscape (block faulting, folding, volcanism) and the erosion and permeability characteristics of the underlying rock itself (limestone, mudstone, sandstone, clay). That is, the ultimate pattern of a stream network in landscape depends on *process* and *substrate*; or we could call these process and *media* in terms of our model.

We can easily see that stream patterns are the sum of preceding events that gave rise to the geological processes and rock types, so that streams have a lot to tell us about such processes, a skill learnt in photo interpretation. **Figure 4.24** demonstrates some of the information so clearly told by stream patterns alone.

However, if we abstract a fairly normal dendritic (tree-like) stream branching pattern as in **Figure 4.25**, we can find out these things from the pattern alone:

- The ORDER of channels; the volume, or SIZE, of branches.
- The NUMBER OF BRANCHES in each order.
- The TOTAL CHANNEL LENGTH in each order.
- The MEANDER FREQUENCES in each order, or the behaviour of flow in the orders of branches.

Streams usually have from one to seven orders, depending on their age, size, or gradient (fall over distance). An easy gradient develops as streams cut back their headwaters and fill in (aggrade) their lower reaches; meanders increase, and the velocity of flow decreases. These older streams, like a mature tree, have developed all their branches (as has an old company or an old army). Unless stream conditions themselves change (by a process of stream capture, an increase in rainfall, or a change in landscape), streams (and businesses) maintain an equilibrium of order. Looking at our dendritic, peaceful stream, we may find something as can be seen in **Table 4.1**.

As the branches join up to make ever larger orders of channels, then about 3 times as many smaller branches join up to make each larger group, and so on. However, the individual lengths (of any one branch in each order) increase by 2 times as the order increases from 1–6. This is a very general rule of stream branching, even in non-dendritic patterns, and holds true for many streams. Similarly, meanders or bends also occur in a predictable way depending on the volume and gradient (flow). Regular meanders depend on certain velocities and stream width (as do stability of Von Karman vortex trails; **Figure 4.14**). The ratio for meanders or trails is about 1:3.6 (Vogel, 1981).

Such regularity in branching may remind us of PULSERS (wave fronts), and indeed as each size order changes, so does the behaviour not only of the water flow, but of its associated flora and fauna and their shapes. In the rills and runnels, streamlines and turbulent flow is observed. High in the stream gradients (the flattened S-curve of the stream bed in profile) we find insects and fish with suctorial parts able to stick on rocks, flattened fins to press them into the stream bed, flattened bodies and very streamlined profile. In the middle orders, we get less turbulent water flow, more spiralling, less oxygenation, and more

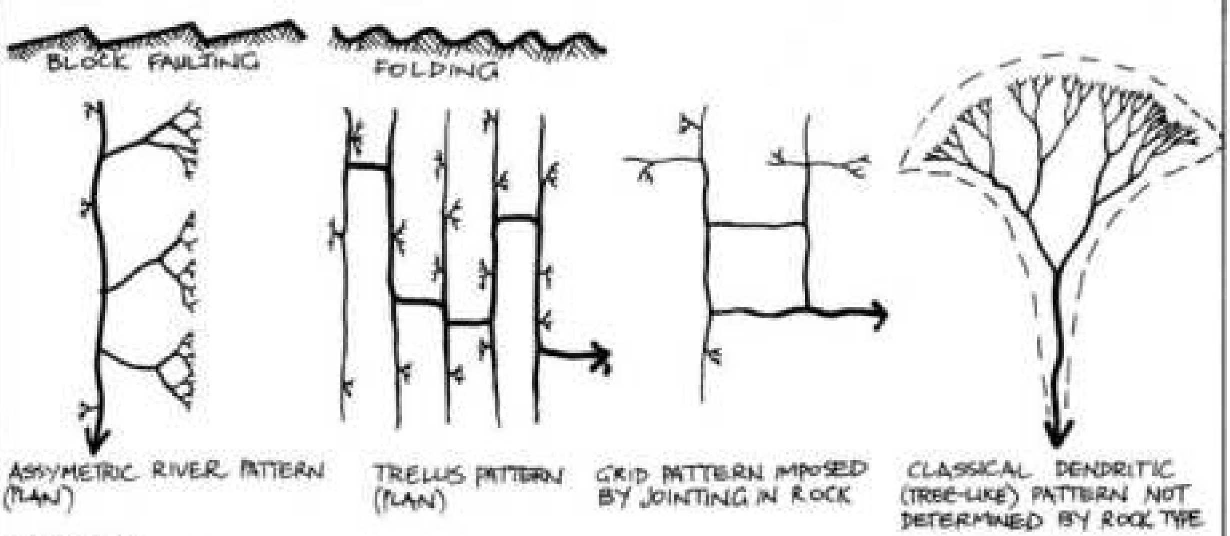


FIGURE 4.24
STREAM PATTERNS
Although the plan patterns of rivers are often decided by the physical structures of landscape, the *orders of size* and branches are comparable to the dendritic pattern.

free-swimming but very active fish of high oxygen demand; these may not live in the still water of higher order streams and low oxygen levels. Thus, we see that gaseous exchange is affected by turbulent flow, and that this in turn determines the life forms in these areas (Vogel, 1981).

In the lower stream or estuaries, we get weak swimmers, less streamlined shapes, flat fish such as flounders, bulky molluscs, jellyfish in quiet areas and lower oxygen levels. We can list many of these life changes which are coincidental with changes in stream order, so we see that the order of streams is very much connected to the behaviour of the water, the landscape, and the shape of life forms in the watershed. Branching of pathways therefore changes species, behaviour, flow, and rates of exchange of nutrients or materials carried by the stream. When we examine a tree, we find that birds and insects are also confined to, or modified to suit, the orders of branching.

4.17 ORDERS AND DIMENSIONS

It is in the order of branching (as in our river) that we can gain insight into the order of orders, and the functions of orders. At each point of branching (or size and volume change) everything else changes, from pressures, flows, velocities, and gaseous exchange, to the life forms that associate with the specific size of

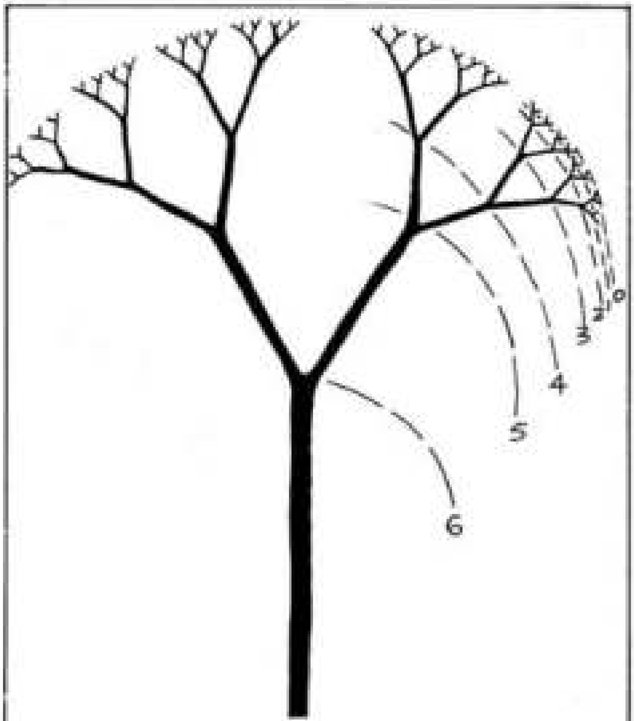


FIGURE 4.25
DENDRITIC BRANCHING.
A regular 'tree' based on the proportion of real rivers. The ogives, or curved lines, can be viewd as pulses of growth, waves approaching the viscous 'shoreline' of the leaves or (in the case of rivers) the slow seepage of upland rills. Here, seven orders of branches exist; more orders become difficult to develop towards the diffusion surface, where viscous flow slows the movement of fluids.

TABLE 4.1:
STREAM ORDERS AND SOME RATIOS.

A Folk Name	B Stream Order	C Number of Channels in the Order	D Ratio of bifurcation/	E A. Length Channels branching	F Ratio of Length (km)
Sheet Flow	0	-		-	
			-		-
Rill	1	308		0.28	
			x 3.5		x 2.0
Runnel	2	87		0.56	
			x 3.3		x 2.0
Creek	3	26		1.12	
			x 3.3		x 2.3
Stream	4	8		2.56	
			x 2.7		x 2.2
River	5	3		5.76	
			x 3.0		-
Estuary	6	1		-	
Average			(≈3.0)		(≈2.0)

(Modified after Tweadie, *Water and the World*, Thomas Nelson, Australia, 1975.)
(Arrows indicate ascending orders by factor of increase)

branches. This is how we make sense of the fish species in streams, and the bird species in a tree. Each has its place in a set or order of branches, on the bark of stems, or the leaf laminae of the tree.

This order, or size–function change, produces physical, social, and organic series. Not only species change with order, but so does behaviour. We cannot get a riot of one person, and fewer than 15 rarely clap to applaud as an audience. When we therefore come to *construct* hierarchies, the rules of order should guide us.

An array of orders is observed in a wide range of phenomena such as human settlement size, numbers in social hierarchies, trophic levels (food pyramids), and the size of animals in allied zoological families. The size of the factor itself (times 3 for river branches) changes with the dimensions of the system (times 10 for trophic pyramids). Physical entities from protons to universes display such order, with a consequent increase in the ratio, dimensions, and behaviours associated with size change (giant and dwarf stars behave very differently).

As designers, we need to study and apply branching patterns to roads or trails, and to be aware of the stable orders of such things as human settlements, or we may be in conflict both with orderly flow (can we increase the size of a highway and not alter *all* roads?), with settlement size (villages are conservative at about the 1000–people order, and unstable much below or above that number), with sequences of dam spillways, and even with the numbers of people admitted to functional hierarchies where information is passed in both directions. We can build appropriate or inappropriate systems by choosing particular orders, but we do better to study and apply *appropriate* and stable size and factor classes for specific constructs. For example, in designing a village, we should study the orders of size of settlements, and choose one of these. This decides the number and types of services and the occupations needed, which in turn decides the space and types of shops and offices for a village of that size, and the access network needed.

In human systems, we have confused the order of hierarchical function with status and power, as though a tree stem were less important than the leaves in total. We have made "higher" mean desirable, as though the fingers were less to be desired than the palm of the hand. What we should recognise is that each part needs the other, and that none functions without the others. When we remove a dominant animal from a behavioural hierarchy, another is created from lower orders. When we remove subordinates, others are created from within the dominants. So it is with streams.

Thus, we can see how rivers change their whole regime if we alter one aspect. We should also see that water is *of the whole*, not to be thought of in terms of its parts. Thus we refute the concept of *status* and assert that of *function*. It is not what you *are*; it is what you *do* in relation to the society you choose to live in. We need each other, and it is a reciprocal need wherever we have a function in relation to each other.

4.18
CLASSIFICATION OF EVENTS

All events are susceptible to classification over a variety of characteristics, and as, for example, clouds and galaxies have their pattern–names, so do many other phenomena. Some basic ways to classify events in a unified system are:

A. NATURE.

A1. Explosive, disintegration, erosion, impact, percussion.

A2. Growth, integration, construction, translation.

A3. Conceptual, idea, creative thought, insight.

B. STAGE.

B1. Potential only (ungerminated seed, unexplored idea, unexploded bomb).

B2. In process of evolution.

B3. Completed (growth and expansion ceased), articulated.

B4. Decaying (disintegrative, replaced or invaded by new events) disarticulated.

C. DIMENSION.

C1. One (linear phenomena), curves.

C2. Two (surface phenomena), tessellae, dendrites.

C3. Three (solid phenomena), trees.

C4. Four (moving solid phenomena), includes the time dimension.

C5. More (conceptual phenomena) models of particles or forces, states of energy.

D. LOCATION

D1. Generating across equi–potential surfaces (storms at sea).

D2. Within media (weather "frontal" systems).

D3. Through surfaces at 90° or so (trees).

D4. Englobements (some explosions and organisms).

D5. An idea, located out of normal dimensions of space–time.

By extending and applying these categories, all events can be given short annotations, e.g.:

- A sapling is: A2, B2, C3, D3.
- A falling bomb is: A1, B1, C4, D2.

4.19
TIME AND RELATIVITY IN THE MODEL

As we see the seed as the origin of the tree, so we can broaden our view, and our dimensions, and view the tree as the current time–focus of its own genealogy.

Before it in time lie its ancestors, and after it its progeny. It lies on the plane between past and future, and (like the seed) determines by its expression the forms of both, and is in turn determined by them. Just as the stem of the tree now encapsulates its history as smaller and smaller growth rings, so universal time encapsulates the tree in its own evolutionary history. This is difficult to portray, and has more dimensions that we can illustrate on a page. It is the basis of the Buddhist belief that all time is enfolded or *implicate* in the present, and that current events are part of a total sequence, all of which are enfolded in the present tree as ancestors, or siblings.

As we read this, we stand in the plane of the present; we are the sum of all our ancestors, and the origin of all our descendants. In terms of our model, we are at an ever-changing origin, located on the boundary of past and future. As well, we are spinning with the earth, spiralling with the galaxy, and expanding or contracting with the universe. As origins, we are on the move in time and space, and all these movements have a characteristic pulse rate.

Our bodies contain the potential for future generations, awaiting the events of pairing to create their own future events. Like a seed origin buried in the tree stem, we are buried in the stem of our siblings in a genealogy, whose branches thrive, die, and put forth new shoots and roots over time.

This is the case with all origins; they can all, even if ancient, be located in this matrix. If we know how to reconstruct the tree, we can find the place of the seed and vice versa. All rivers, erosion cells, and all glaciers originated, therefore, at the *central* stem of their courses, and built their pattern both ways along the kinetic gradient of their flow. Thus, in terms of the time dimension we see the present as the ORIGIN of both the past and the future (located as it is in the centre of our pattern).

Designers can move sideways in the waves of time (as a surfer on a wave-front), transporting seed from continent to continent, permitting natural or induced hybrid palms and legumes to weave an alternative future. Mankind is an active translator of life, and, of course, of death.

In all core models, including our own genealogy, the point where all the important action takes place is through the point of origin, which is always in the present. How we behave *now* may determine not only the future, but the past (and all time). Think of that, and realise that you are really where it's at, no matter when you are! I find great personal meaning in the Australian aboriginal life ethic, and little enough comfort in any pie-in-the-sky. If it *is* my actions which determine the sky, I want it to be full of life, and I choose to believe that I am part of all that action, with my own job to do in this life form, and other jobs to do in other phases.

4.20

THE WORLD WE LIVE IN AS A TESSELLATION OF EVENTS

I live in the crater of an ancient volcano, the caldera of which is in part eroded by the sea. Trees rise from the soils, and birds nest in them. From the seeds and eggs in the trees arise new life forms. Great wind spirals sweep in from the west with almost weekly regularity, bearing the fractal forms of turbulent clouds and causing, in autumn and mid-summer, lightning and thunder.

On this peninsula, the terminal volcanic core stands fast, refracting waves to either side, and creating a pinched neck of sand which joins us to the mainland. The hills are stepped by successive sea-level changes, and record the pulses of long-term cycles and successions. Day follows night, and life follows death follows life.

All of these phenomena are a unity of patterns long repeated and based on one master pattern, each one preparing for new evolutions and dissolutions. It is the number and complexity of such cycles that give us life opportunities, and life is the only integrative force in this part of the universe. Let us respect and preserve it.

An understanding (even a partial understanding) of the underlying patterns that link all phenomena creates a powerful abstract tool for designers. At any point in the design process, appropriate patterning can assist the achievement of a sustainable yield from flows, growth forms, or information flux. Patterns imposed on constructs in domestic or village assemblies can result in energy savings, and satisfactory aesthetics and function, while sustaining those organisms inhabiting the designed habitat.

Patterning is the way we frame our designs, the template into which we fit the information, entities, and objects assembled from observation, map overlays, the analytic divination of connections, and the selection of specific materials and technologies. It is this patterning that permits our elements to flow and function in beneficial relationships. The pattern *is* design, and design is the subject of permaculture.

Bohm (1980) urges us to go beyond regarding ourselves as interactive with each other and the environment, and to see all things as "projections of a single totality". As we experience this totality, incorporate new information, and develop our consciousness, we ourselves are fundamentally changed. "To fail to take this into account must inevitably lead one to a serious and sustained confusion in all that one does." The word "implicate" in the title of Bohm's work comes from the Latin "enfolded", and when we separate individuals, effects, or disciplines from this enfolded order, we must recognise only that we have part of the unknowable totality, not the truth itself. There are no opposites, just phases of the one phenomena.

For myself, and possibly for you if you take up the study of patterns, the contemplation of the forms of life and flow has enabled me to bring to consciousness the unity of all things, and the enfolded nature of Nature. In the matter of genealogy we can become conscious of ourselves in the time and pattern stream, and it is startling to realise that (as origin) we "determine", or rather define and are defined by, our ancestry as much as we define and are defined by our descent. We do not doubt our physical connection to either ancestry or descent. It is the sense of "all are present here" that is revealed by pattern: to be encapsulated in, and a pervading part of, a personal genealogical pattern which is itself a result of a pattern of innumerable variables.

Patterns tell us that all is streams, all particles, all waves. Each defines the other. It tells us that all is one plan. Although we find it difficult to see pattern in all the plan, it is there. We are the universe attempting to define its processes. A Kalahari bushman would say we are the dreams of a dreamer. What I feel we can never define is substance (except as process; this is all it may be). We can only know a few local patterns, and thus have some weak predictive capacity. It is the pattern that our local patterns cannot know that will surprise us, the strike of cosmic lightning from an unguessed source or stress.

Finally, pattern understanding can only contribute to the current and continuing evolution of new world views based on the essential one-ness of all phenomena. Lovelock (1979) has perhaps best expressed that combination of scientific insights and older tribal beliefs which assert the interdependence of animate and inanimate events. The universe, and this earth, behave as self-regulating and self- generated constructs, very much akin to a single organism or a thought process.

The conditions which make life possible are balanced about such fine tolerances that it seems close to certainty that many processes exist just to preserve this equilibrium in its dynamic stability.

From the point of view of biologists, Birch and Cobb's *The Liberation of Life* [1984; see a review by Warwick Fox in *The Ecologist* 14(4)] denies the validity of the existence of *individual* organisms or *separate* events; all exist in a *field of such events* or as an expression of one life force. Organisms such as ourselves exist only as an inseparable part of our event environments, and are in continual process of exchange with the animate and inanimate entities that surround us. We are acted upon and acting, created and creating, shaped and shaping. Fox asserts, as I have here, that "we must view the cosmos as an infinite complex of interrelated events"; all things "are in actuality enduring societies of events."

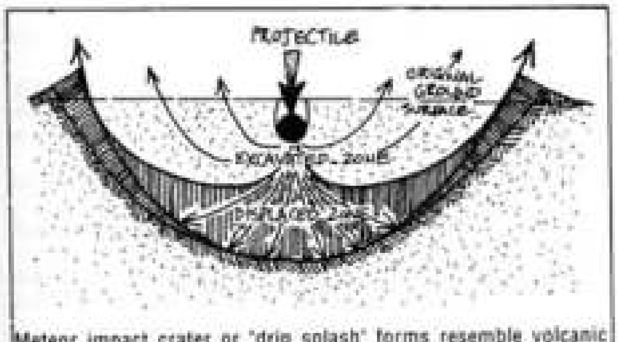
Theoretical physicists (Capra, 1976) contribute to such world views, all of which are in conflict with the current ethics that govern political, educational, and economic systems, but all of which are contributing to an increasing effort to unify and cooperate in a common ethic of earth-care, without which we have no meaning to the universe.

4.21

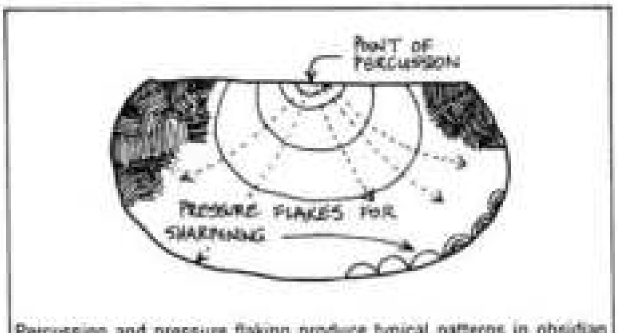
INTRODUCTION TO PATTERN APPLICATIONS

There are two aspects to patterning: the perception of the patterns that already exist and how these function, and the imposition of pattern on sites in order to achieve specific ends. Both are skills of sophisticated design, and may result in specific strategies, the harmonious resolution of problems, or work to produce a local resource. Given that we have absorbed some of the information inherent in the general pattern model, we need some examples of how such patterning has been applied in real-life situations.

A bird's-eye view of centralised and disempowered societies will reveal a strictly rectilinear network of streets, farms, and property boundaries. It is as though we have patterned the earth to suit our survey instruments rather than to serve human or environmental needs. We cannot perhaps blame Euclid for this, but we can blame his followers. The straight-line patterns that result prevent most sensible landscape planning strategies and result in neither an aesthetically nor functionally satisfactory landscape or streetscape. Once established, then entered into a body of law, such inane (or insane) patterning is stubbornly defended. But it is created by, and can be dismantled



Meteor impact crater or "drip splash" forms resemble volcanic calderas.



Percussion and pressure flaking produce typical patterns in obsidian or chert tools shaped by stone workers.

by, people.

A far more sensible approach was developed by Hawaiian villagers, who took natural ridgelines as their boundaries. As the area was contained in one water catchment, they thus achieved very stable and resource-rich landscapes reaching from dense cloud-forests to the outer reefs of their islands. The nature of conic and radial volcanic landscapes with their radial water lines suits such a method of land division. It is also possible for a whole valley of people to maintain a clean catchment, store and divert mid-slope water resources for their needs, catch any lost nutrients in shallow ocean enclosures (converting first to algae, then to crabs and fish), and thus to preserve the offshore reef area and the marine environment. Zulus and American Indians adopt the circular or zonal modes in their plains settlements.

Such models can be studied and adopted by future (**bioregional**) societies as sane and caring people become the majority in their region, and set about the task of landscape rehabilitation. Sensible land division is a long-delayed but essential precursor to a stable society.

4.22
THE TRIBAL USES OF PATTERNING

As I travel about the world, I find tribal peoples using an enormous variety of traditional patterns. These decorate weapons, houses, skin, and woven textiles or

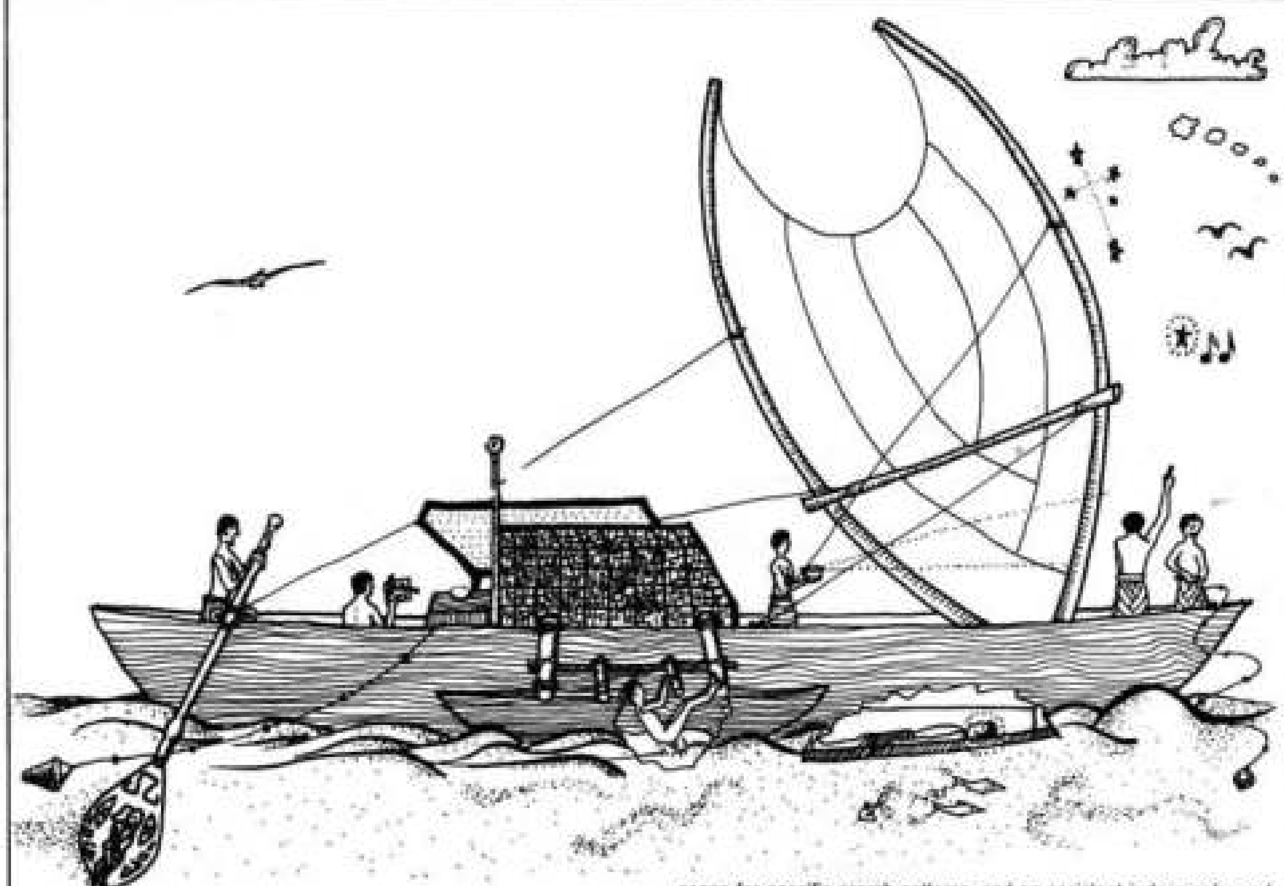


FIGURE 4.26
TRADITIONAL NAVIGATION RELIES ON PATTERN RECOGNITION.

• The helmsman sings to time the log line, and feels for current deflections through his steering oar. He or she sings to record the stages of the journey and the "rivers" (currents) of the sea.

• Lookouts note star patterns, bird flight, cloud trains, or light refracted from coastal lagoons. Water speed is recorded by a knotted float line.

• A skilled listener in a "black box" near the keel listens to wave refraction from the hull, predicts storms or islands from wave periods timed by chants.

• A navigator consults a voyage "chart" of sticks and cowries representing the interaction of phenomena and sings the navigation songs for specific search patterns, and an assistant judges solar and star elevations (latitude) via a water level.

• At night, the glow of life forms in deep sea trenches is awaited (the "lightning" from the deeps"), bird song and echoes from headlands are listened for, and the phosphorescent glow of the forests ashore is awaited.

• An experienced man lowers his testicular sac into the sea to accurately guage water mass temperature.

• The wind carries a variety of scents from forests, rock lichen, bird colonies, and fish schools; all are recorded.

• A net catches indicator organisms related to the water mass, and near shores a "lead line", or depth line, is used to find banks and sample bottom fauna picked up in soft grease.

• A crystal of calcite may be used to predict rain or to find the sun on overcast days by polarisation of light—"the lodestone" of navigators.

baskets. Many patterns have sophisticated meaning, and almost all have a series of songs or chants associated with them. Tribal art, including the forms of Celtic and ancient engraving have a pattern complexity that may have had important meanings to their peoples. We may call such people illiterate only if we ignore their patterns, songs and dances as a valid literature and as an accurate recording system.

Having evolved number and alphabetical symbols, we have abandoned pattern learning and recording in our education. I believe this to be a gross error, because simple patterns link so many phenomena that the learning of even one significant pattern, such as the model elaborated on in this chapter, is very like learning an underlying principle, which is always applicable to specific data and situations.

The Maori of New Zealand use tattoo and carved patterns to record and recall genealogical and saga information. Polynesians used pattern maps, which lacked scale, cartographic details, and trigonometric measures, but nevertheless sufficed to find 200–2,000 island specks in the vastness of the Pacific! Such maps are linked to star sets and ocean currents, and indicate wave interference patterns; they are made of sticks, flexed strips, cowries, and song cycles (**Figure 4.26**).

Pitjantjatjara people of Australia sing over sand patterns (**Figure 4.27**), and are able to "sing" strangers to a single stone in an apparently featureless desert. Many of their designs accurately reflect the lobular shapes and elaborate micro-elevations of the desert, which are nevertheless richly embroidered by changes in vegetation, and are richly portrayed in what (to Westerners) appears as abstract art. Some pattern mosaics are that of fire, pollen, or the flowering stages of a single plant, others are of rain tracks and cloud streets, and yet others involve hunting, saga, or climatic data.

Children of many tribes are taught hundreds of simple chants, the words of which hide deeper, secondary meanings about medicinal, sacred, or navigational knowledge. All this becomes meaningful when the initiate is given the decoding system, or finds it by personal revelation (intuition). A pattern map may have little meaning without its song keys to unlock that meaning. Initiation can also unlock mnemonic patterns for those who have a first clue as to meaning.

Dances, involving muscular learning and memory, coupled with chants, can carry accurate long-term messages, saga details, and planting knowledge. Many dances and chants are in fact evolved from work and travel movements. Even more interesting are the dance-imitations of other animal species, which in fact interpret for people the postural meanings of these species, although in a non-verbal and universally-transmittable way. We may scarcely be aware that many of our formal attitudes of prayer and submission are basic imitiations of primate postures, for the most part taken from other species. Even the chair enables us (as it did the Egyptians) to maintain the postures of baboons, and baboons were revered as gods and embalmed by the Egyptian chair-makers. We can remember hundreds of songs, postures, and chants, but little of prose and even less of tabulated data.

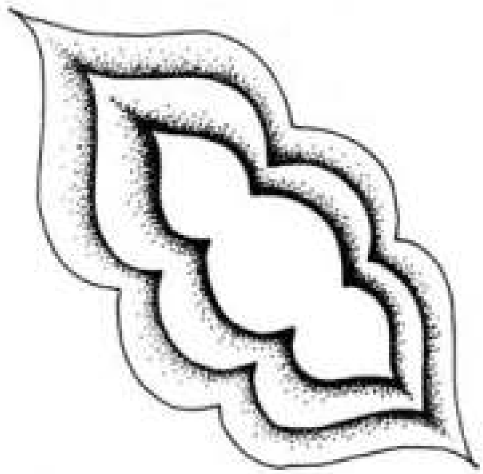


FIGURE 4. 27
SAND PATTERN MAPS (PITJANTJATJARA).
A song map of the Pitjantjara women. Such forms closely resemble desert claypans if the long axis is regarded as a flow axis, and the zones as lobular vegetation.

Anne Cameron (*Daughters of Copper Woman*, Vancouver Press, 1981) writes of song navigation in the Nootka Indians of British Columbia: "There was a song for goin' to China, and a song for goin' to Japan, a song for the big island and a song for the smaller one. All she [the navigator] had to know was the song and she knew where she was..."

The navigation songs of the women on canoe voyages record "the streams and creeks of the sea"—the ocean currents, headlands and bays, star constellations, and "ceremonies of ecstatic revelation". From California to the Aleutians, the sea currents were fairly constant in both speed and direction, and assisted the canoes. The steerswomen used the (very accurate) rhythm of the song duration to time both the current speed and the boat speed through the water. Current speed would be (I presume) timed between headlands, and boat speed against a log or float in the water. The song duration was, in fact, an accurate timing mechanism, as it can be for any of us today.

Song stanzas are highly accurate *timers*, accurate over quite long periods of time, and of course reproducible at any time. The song *content* was a record of the observations from prior voyages, and no doubt was open to receive new data.

People who can call the deer (Paiute wise men), the dolphin (Gilbert Islanders), the kangaroo (tribal Tasmanians) and other species to come and present themselves for death had profound behavioural, interspecific, "pulser" pattern-understanding. Just as the Eskimo navigated, in fog, by listening to the quail dialects specific to certain headlands, we can achieve similar insights if our ear for bird dialect is trained, so that song and postural signals from other species make a rich encyclopaedia of a world that is unnoticed by those who lack pattern knowledge. People who can kill by inducing fibrillation in heart nerves have a practical insight into pulser stress induction; many tribespeople can induce such behaviour in other animal species, or in people (voodoo or "singing").

The attempts of tribal shamans to foresee the future and to control dreams or visions by sensory deprivation, to read fortunes by smoke, entrails, water, or the movement of serpents, or to study random scatters of bones or pebbles are not more peculiar than our efforts to do the same by the study of the distribution of groups of measures or the writhing of lines on computer screens. By subjecting ourselves to isolation, danger, and stress, we may pass across the folds of time and scan present and future while we maintain these "absent" states, as described by Dunn (1921) in his *Experiment with Time*, and as related by participants in the sun dances of the Shoshone nation. As we drown, or fall from cliffs, our lives "pass before our eyes" (we can see the past and future).

We need to think more on these older ways of imparting useful or traditional information, and of keeping account of phenomena so that *they are available to all people*. Number and alphabet alone will not do this. Pattern, song, and dance may be of great assistance to our education, and of great relevance to our life; they are the easiest of things to accurately reproduce.

Apparently simple patterns may encode complex information. There may be no better example than that of the Anasazi spiral, with 19 intercepts on its "horizon" "horizon" line (**Figure 4.28**). This apparently simple spiral form is inscribed on a rock surface near the top of a mesa in desert country in the southwest USA. Three rock slabs have been carefully balanced and shaped, as gnomons which cast moon-shadows or (by their curvature) direct *vertical* daggers of sunlight to the points of the spiral. The 19 points at which the spiral intersects the horizontal axis are those at which the shadow of the moon is cast by a gnomon on the spiral, and indicate the moon elevation or 19-year (actually 18.6) cycle caused by the sway of the earth's axis.

Thus, one simple spiral records lunar and solar cycles for the regulation of planting, the timing of ceremonies, and (as modern science has just realised), the prediction of the 19-year (18.6 year) cycle of drought and flood. A very simple pattern encodement thus represents a practical long-term calendar for all people who live nearby. The Anasazi culture is extinct, and only a persistent investigation by Anna Soaer (an artist with *intuitive* observational skills) has revealed the significance of this arrangement. Scientists have often doubted the capacity of tribal peoples to pattern such long-term and complex events, which in terms of our clumsy alphabetical and numerical symbols are not only forgettable, but would take a small library to encode. The knowledge so presented is available to very few (ABC TV Science programme, Australia, 20th January '84). However, wherever tribes remain intact, there are many such sophisticated pattern-meanings still intact, all as complex and information-dense.

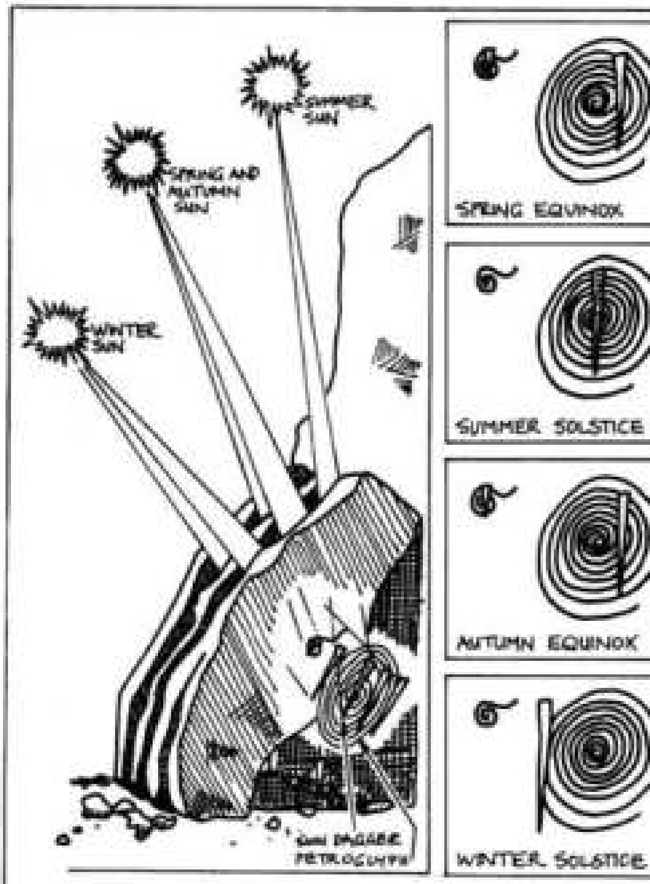
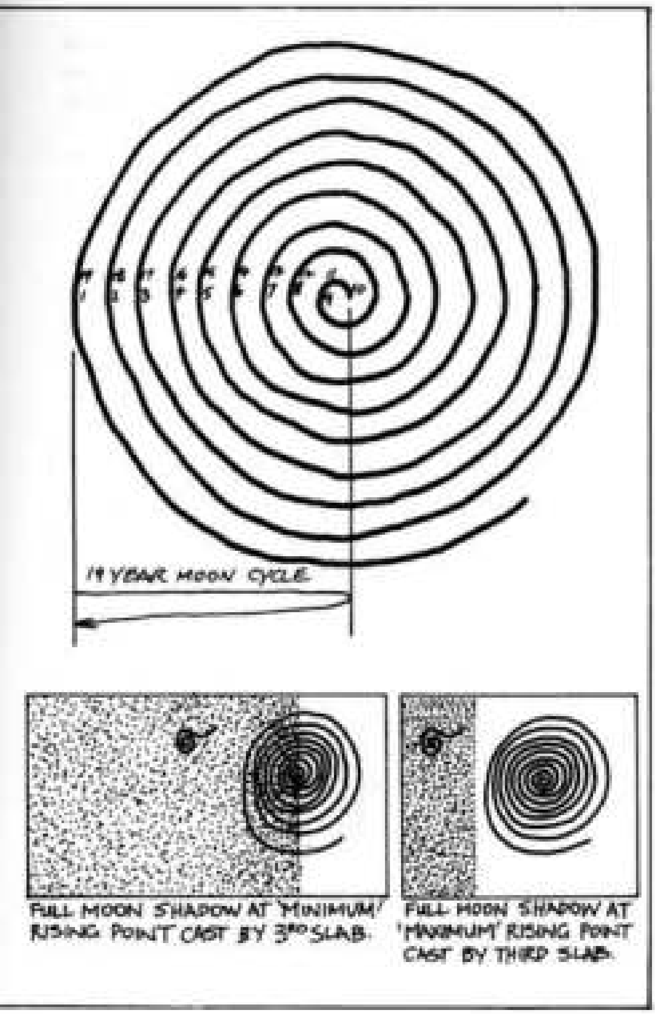


FIGURE 4.28
A petroglyph (rock carving) of the Anastasi Indians (North America) forms a long-term calendar of sun and moon cycles.

In the complex of time-concepts evolved by Australian Aborigines, only one (and the least important) is the linear concept that we use to govern our life and time. Of far greater everyday use was phenomenological (or phenological) time; the time as given not by clocks, but by the life-phenomena of flowers, birds, and weather. An example from real life is that of an old Pitjatjantjara woman who pointed out a small desert flower coming into bloom. She told me that the dingoes, in the ranges of hills far to the north, were now rearing pups, and that it was time for their group to leave for the hills to collect these pups. Thousands of such relationships are known to tribal peoples. Some such signals may not occur in 100 or 500 years (like the flowering of a bamboo), but when it does occur, special actions and ceremonies are indicated, and linked phenomena are known.

Finally, in tribal society, one is not wise by years, but by degree of revelation. Those who understand and



embody advanced knowledge are the most intuitive, and therefore most entitled to special veneration. Such knowledge is almost invariably based on pattern understanding, and is independent of sex or even age, so that one is "aged" by degree of revelation, not time spent in living (there are some very unrevealed "elders" in the world!).

4.23
THE MNEMONICS OF MEANING

Buddhists remind themselves of the pattern of events with their oft-repeated chant "Om mani padme hum"; pronounced "Aum ma-ni pay-may hung" by Tibetans and Nepalese, and meaning:

Om: the jewel in the lotus : hum

om · ma · ni · pay · may · hung

As Peter Matthiessen explains it (*The Snow Leopard*, Picador, 1980):

Aum (signing on) is the awakening or beginning harmonic, the sound of all stillness and the sounds of all time; it is the fundamental harmonic that recalls to us the universe itself.

Ma-ni: The unchanging essence or diamantine core of all phenomena; the truth, represented as a diamond, jewel, or thunderbolt. It is sometimes represented in paintings as a blue orb or a radiant jewel, and sometimes as a source of lightning or fire.

Pay-may: "Enfolded in the heart of the lotus" (mani enfolded). The visible and everyday unfolding of events, petals, or patterns thus revealing the essential unchanged core (mani) to our understanding. The core itself, or the realisation of it, is *nirvana* (the ideal state of Buddhism). The lotus represents the implicate order of tessellated and annidated events, and the process of unfolding the passage of time to successive revelations. At the core is unchanging understanding.

Hung (signing off): "It is here, *now*." A declamation of belief of the chanter in the words. It also prefaces the "Om" or beginning of the new chant cycle, although in a long sequence of such short chants, all words follow their predecessors. This is the reminder mnemonic of implicate time; all events are present *now*, and forever repeated in their form.

DORJE, or Dorje-chang, is the Tibetan Buddha-figure who holds the *dorje* (thunderbolt), represented as a radiant stone which symbolises cosmic energy. Dorje is "the primordial Buddha of Tibet", who began the great succession of current and past reincarnations. His colour is blue, for eternity, and he may carry a bell to signify the voiceless wisdom of the inanimate, or the sound of the void.

Dorje is an alter ego of Thor of the Norsemen, Durga of the Hindu, and of thunderbolts and "thunderers" of other tribal peoples. The *mani* or stone of Thor was Mjollnir, his hammer, from which derives Mjollnirstaun, and (eventually) Mollison (by way of invasions into Scotland, and migrations). Thus, even our own names may remind us of the essential oneness of the events and beliefs around us.

We can choose from tribal chants, arts, and folk decoration many such mnemonic patterns, which in their evolution over the ages express very much the same world concept as does modern physics and biology. Such thoughtful and vivid beliefs come close to realising the actual nature of the observed events around us, and are derived from a contemplation of such events, indicating a way of life and a philo-sophy rather than a dogma or set of measures.

Beliefs so evolved precede, and transcend, the emphasis on the individual, or the division of life into disciplines and categories. When we search for the roots of belief, or more specifically *meaning*, we come again and again to the one-ness underlying science, word, song, art, and pattern: "The jewel in the heart of the lotus".

Thus we see that many world beliefs share an essential core, but we also see the drift from such nature-based and essentially universal systems towards personalised or humanoid gods, dogma, and fanaticism, and to symbols without meaning or use in our lives, or to our understanding of life. Many other world-concepts based on the analogies of rainbows, serpents, and song cycles relate to aspects of the integrated world view, and are found in Amerindian and Australian tribal cultures.

4.24

PATTERNS OF SOCIETY

We can pattern the behavior of human and other social animals to represent aspects of their society. A set of such patterns, derived from studies I and my students made in Tasmania from 1969 to 1974 are illustrated in **Figure 4.29**. The central pattern represents the orders or castes of occupational level (status) in its long axis. There are seldom more than seven major occupational levels even in such rigorously-stratified hierarchies as the army. The width of the **Figure 4.29** represents the numbers of people at each level, and for this configuration we summed the numbers of people in several organisations (to sample some 35,000 people), including the local army, a multinational company, some churches and many small businesses.

Within the general "boat" pattern form so evolved, I have marked some arrows to represent genetic streaming (by marriage or sexual congress); important classes of occupation are:

1. LOW OCCUPATIONAL (RESOURCE) AREA—MANUAL AND UNSKILLED URBAN:
Characteristics are a general dearth of material resources, low status, part-time occupations, and a remarkable preponderance of male births and survived male children (about 140 males per 100 females). Large families. Serial polyandry is common or acceptable.

2. THE CENTRAL OR MOST POPULATED LEVEL; THE "MIDDLE CLASS":
Adequate resources, nine-to-five jobs, some job tenure, and a "normal" birth ratio of 104 males per 100 females. Mixed white collar and skilled technical workers, average family sizes. Monogamy is an ideal, but is often expressed as serial monogamy.

3. THE UPPER LEVELS:
Few people, extensive resources, flexible and often self-set times, and a high proportion of female children (about 100 females to 70 males or less); urban professionals or managers would typify the group. Small families, effective polygyny via concubines or mistresses.

4. VERY HIGH LEVELS:
Executive directors and landed nobility. Variable family sizes but a preponderance of female children (as per 3. above), and a habit of lateral intermarriage for economic alliances, facilitated by exclusive schools and resorts.

The imbalance of the sex ratios in these strata ensures a genetic turnover or diffusion between classes; a streaming of genetic materials between levels over generations.

4.25

THE ARTS IN THE SERVICE OF LIFE

Art, in the forms of song, dance, and sculptural or painted objects, or designs, is an ancient preoccupation of all peoples. There is little doubt that most (if not all) tribal art is intended for quite specific ends; much of

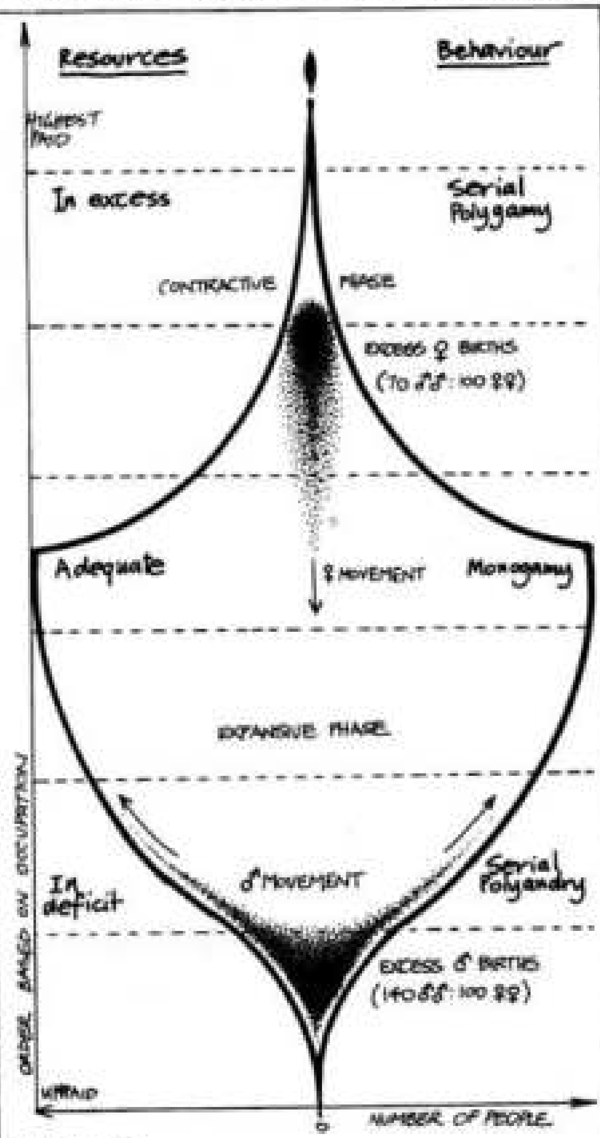


FIGURE 4.29
BEHAVIOUR PATTERNS IN SOCIETY.
The form of social hierachy based on occupational status. Note the over production of males (as a primary sex ratio) at the lower resource level, thus marital habits are based on resources and sex ratios. Width indicates number of people at each level. (n = 35,000 Tasmania, 1975).

tribal art is a public and ever-renewed mnemonic, or memory-aid. Apparently simple spiral or linear designs can combine thousands of bits of information in a single, deceptively simple pattern. The decorative function is incidental to the educational and therefore sacred information function in such patterns. "Decoration" is the trivial aspect of such art.

Much of modern art is individualistic and decorative; some "motif" art is plagiarised from ancient origins, but no longer has an educational or sacred function. Entertainment and decoration is a valid and important function of the arts, but it is a minor or incidental function. Social comment is a common art form in theatre and song, and spirited dances and songs are cheering or uplifting. But I know of no meaningful songs or patterns in my own "monoculture", based as it is on the jingles of advertisements and purely decorative and trivial patterns of art, and on education divorced from relevant long-term observations of the natural world.

The induction of moods and the record of ephemera are not the primary purposes of sacred or tribal art, which is carefully assembled to assist the folk records of the function and history of their society. Some modern sculptural forms, such as the "Flowform" systems of the Virbella Institute, Emerson College, Kent, UK (**Figure 4.33**) are modelled on older Roman water cascades, and serve both an aesthetic and a water-oxygenation function, assisting water purification. This is a small step towards applied art as patterning in everyday use, as are some engineering designs. We could well reintroduce or evolve pattern education, which gives *every* member of society access to profound concepts or specific knowledge.

Art belongs to, and relates to, people. It is not a way to waste energy on resources for the few. Sacred calendars melted down to bullion or objets d'art are a degradation of generations of human effort and knowledge, and the sacred art of tribal peoples hidden in museum storerooms are a form of cultural genocide, removing knowledge from its context, and trivialising objects to decorations or loot.

Human information, as a tribal art form, is most frequently debased and destroyed less for monetary gain than for the replacement of *public* information by an exotic, secretive, irrelevant and basically uninformed centralised belief system. The fanatic cares not what is destroyed if it empowers the repressive hierarchy that is then imposed. Most tribal art has been burnt, looted, destroyed, and broken by invading belief systems, destroyed by those seeking secret power rather than open knowledge, or by those who are merely destructive. Book-burning and image-breaking is the reaction of the alienated or intellectually-deprived to the accumulated wisdom of its revelationary ancestors. We most damage ourselves when we destroy information and aids to understanding.

It is a challenge to artists to study and portray knowledge in a compact, memorable, and transmissible form, to research and recreate for common use those surviving art forms which still retain their meaning, and to re-integrate such art with science and with society and its functions and needs. It is a challenge to educators to revive the meaningful geometries, songs, and dances that gave us, and our work, meaning.

4.26
ADDITIONAL PATTERN APPLICATIONS

A sophisticated application of pattern is found in the herb spiral (**Figure 4.30**) which I evolved in 1978 as a kitchen-door design. All the basic culinary herbs can be planted in an ascending spiral of earth on a 2 m wide base, ascending to 1 or 1.3 m high. All herbs planted on the spiral ramp are accessible. The construct itself gives variable aspects and drainage, with sunny

FIGURE 4. 30
HERB SPIRAL.
Pattern applied. A modest 2 m diameter by 1 m high earth spiral accommodates all necessary culinary herbs close to the kitchen door and can be watered with one 2 m sprinkler—a considerable saving in space and water as the ramp and walls exceed 9 m of plant space.

dry sites for oil-rich herbs such as thyme, sage, and rosemary, and moist or shaded sites for green foliage herbs such as mint, parsley, chives, and coriander.

This is a rare three-dimensional earth construct on a small scale, and compactly coils up a linear path or bed of herbs into one mound at the kitchen door, thus making the herbs accessible and convenient to the kitchen itself. If kitchens are not at ground level, roof or balcony gardens can carry pot-herbs in stepped walls, on wall shelves, in window boxes, or as stacks of pots in earth mounds.

Pattern analyses can also be applied to water conservation. For example, a mulch-pit (60 cm wide and deep), surrounded by a planting shelf and spill bank totalling 1.2 m (4 feet) across has a 3.8 m (12 foot) perimeter, but can be efficiently watered with *one* low-pressure sprinkler, whereas a 3.8 m straight row takes *three* such sprinklers.

Another advantage is the central (one-drop) mulch pit, so that the plants eventually overshade the centre to prevent evaporation. Such circle-mulch- grow pits are made 1.8 m (6 feet) across for bananas, and 1.8–3 m (6–10 feet) across for coconuts; all out- produce row crop for about one-third of the water use. A series or set of such gardens greatly reduce the path space and land area needed for home gardens, or orchards of banana and coconut (**Figures 4.31** and **10.26**).

A field application of patterned ground designed to direct flow, and capture materials in flow, is that of flood-plain embankments or tree lines (poplar, willow, tamarack), or both combined. These are very effective pattern impositions on landscape (although all occur naturally as rock dykes or resistant rock strata in the field) that can have several beneficial effects for a household or settlement nearby (**Figure 4.32**).

A more conscious and portable applied pattern set is that of the "Flowform" models being developed at the Virbella Institute by a small group of artist-technicians. Such turbulence basins are apparent in nature as shaped basins in streams flowing over massive sandstones or mudstone rocks. They are even in antiquity modelled in pozzelanic cement by Roman hydrologists. Flowforms are artificial replicates of the rock forms carved by turbulent streams, cast in concrete or fibreglass (**Figure 4.33**).

Stacked in sets below sewage pipe outfalls or above fish ponds at pipe inlets, they efficiently mix air and water by inducing turbulence in flow. Three distinct mixing effects are noticeable; the first a *plunge* or vertical overturn as fluid drops from one basin to another; the second as a figure-8 or lateral flow around the basins themselves; and the third (a fascinating process) as an interaction between these two, as water coursing around the basins deflects the vertical drop flow and switches it from side to side in a regular rhythm.

Within these major turbulence patterns [so clearly portrayed by da Vinci (Popham, A.E., *The Drawings of Leonardo da Vinci*, Jonathan Cape, London, 1946) and further analysed in terms of computer models and catastrophic theory by Chappell (in: *Landform Evolution in Australia*, ANU Press, Canberra 1978) for coastal uprush and backwash turbulence] are distinct vortices and counterflow, overfolds and cusps that further mix air and water at the edges of the basins and in the main flow stream.

Thus, artificial Flowform basins induce aeration, oxidise pollutants, and are themselves aesthetically pleasing and instructive hydrological pattern-models of naturally-occuring constructs. They have practical use in the primary treatment of sewage and organically polluted waters, and in the oxygenation of ponds for aquatic species production. Models of this type are the result of a long evolution beginning with wonder, sketches, analysis, observations, and then proceeding via constructed hydrological basins to practical applications over a wide variety of sites. In nature and in the Flowform system, the basins can be elongate, truncate, symmetrical, asymmetical, stepped in line, stacked like ladders, or spiralled to conserve space.

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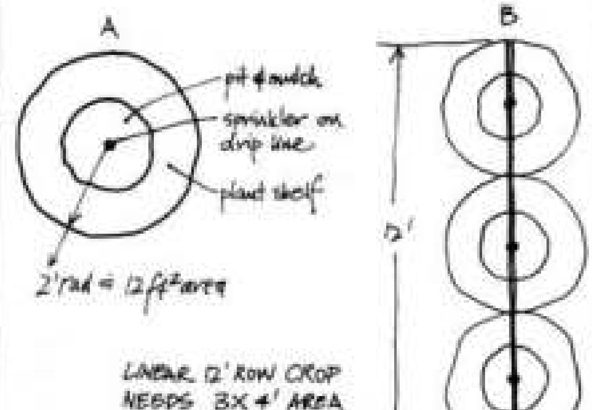

FIGURE 4.31
ROW CROP OR CIRCLE CROP
Here, a 4 m row of crop needs three 1.2 m sprinklers, while a circle of radius 0.6 m (4 m circumference) needs only one 1.2 m sprinkler, a saving of 60% in water use. Such systems apply only on the small scale, where plants can shade the inner circle.

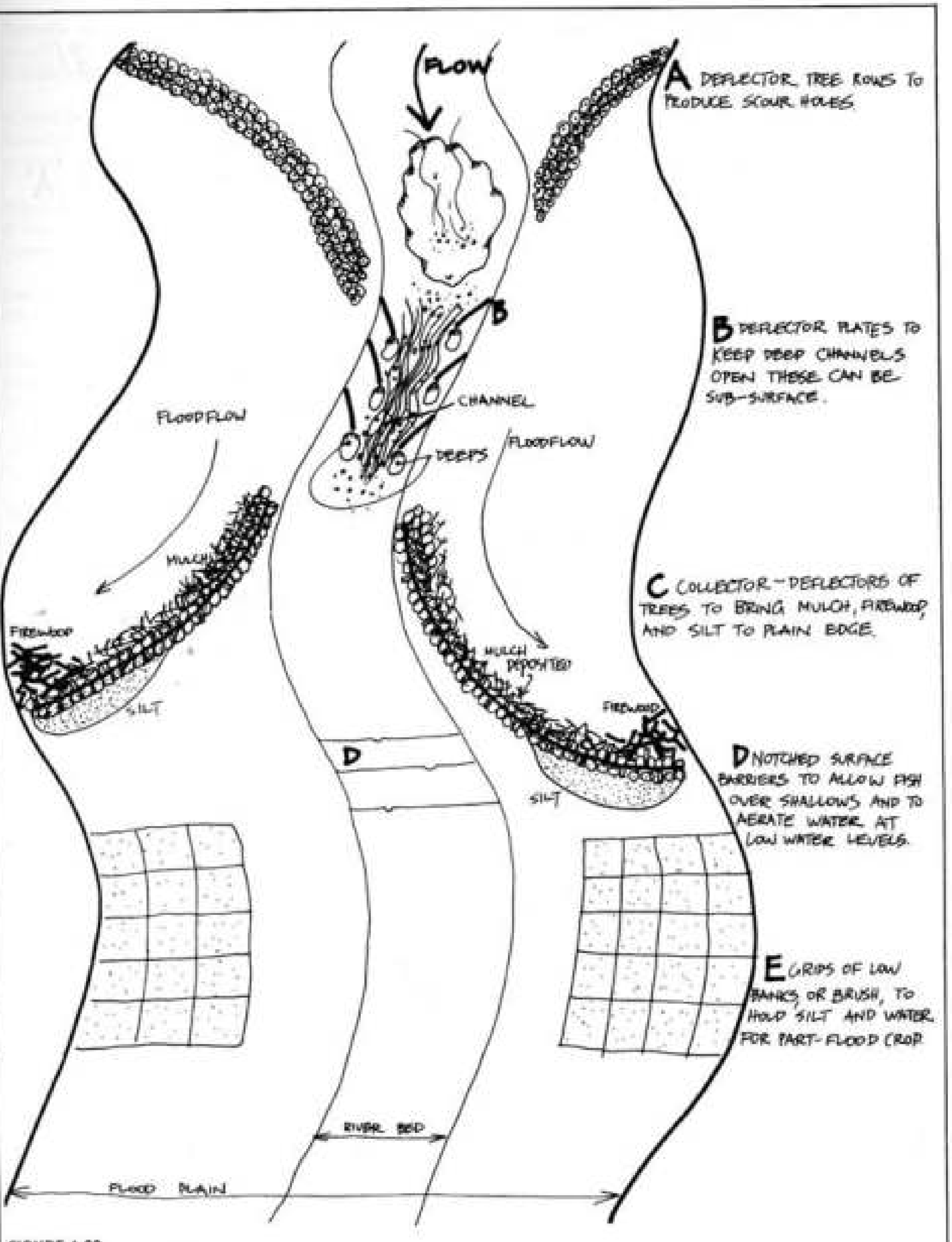

FIGURE 4.32
FLOW INTERCEPTORS ON FLOOD PLAIN.
Floodwaters carry silt, mulch, and firewood and can be used to scour out river sand. Here, several structures on a flood plain gather materials or direct water energy to benefit production.

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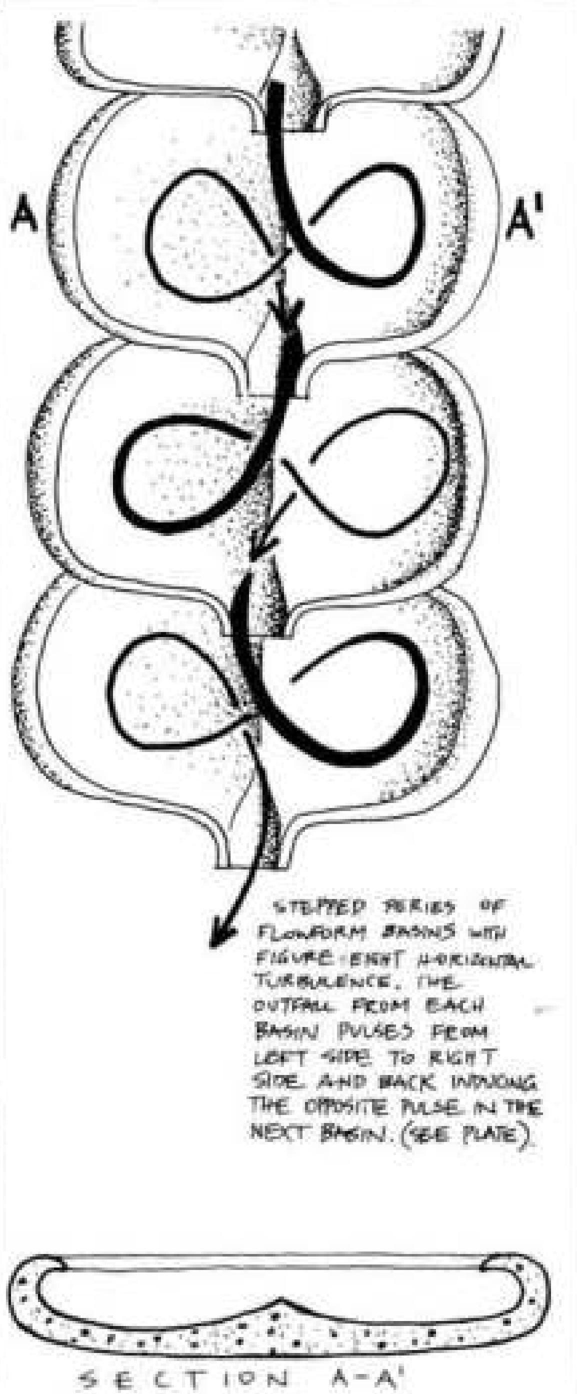
(Multiple examples of forms in nature, spirals)



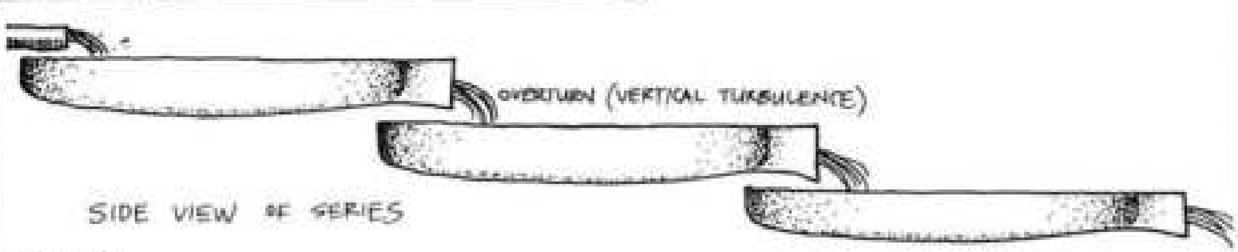


FIGURE 4.33
FLOWFORMS.
Of ancient usage, and natural occurence, can be neatly fabricated in concrete or glass reinforced plastic to aerate water in the case of a constant (or little varying) flow.

Tweedie, A. D., *Water and the World*, Thos. Nelson (Aust) Ltd., 1975.
(On the order of stream flow and stream patterns)

Virbela Institute, Emerson College, Forest Row, East Sussex RH18 5JX (Flowform designs and research, posters.)

Vogel, Steven, *Life in Moving Fluids; the Physical Biology of Flow*, Willard Grant Press, Boston, 1981.
(A sensitive and scholarly study of life forms in flow)

Weyl, Hermann, *Symmetry*, Princeton University Press, NJ, USA, 1983.

New Scientist, New Science Publications, Commonwealth House, 1–19 New Oxford St. London WC1A 1NG:

5 Oct '78 :	On pulsers and biological clocks
15 Nov '84 :	On the gravity anomalies in the geoid
31 May '84 :	The Robinson Congruence
7 Jun '84 :	Recombination of DNA in a plus-torus
20 Mar '79 :	The swirling of water
14 Jun '79 :	The spiral classification of galaxies
5 May '83 :	Symmetry, geometry, fractals
26 Apr '84 :	Fractals
5 May '83 :	Inversion and reflection of forms
17 Nov '83 :	On impact craters
21 Apr '77 :	"The great tennis ball of earth"
11 Oct '84 :	The pineal gland as a timepiece
4 Apr '85 :	Fractals, pulsars, black holes

4.28

DESIGNER'S CHECKLIST

Read in pattern analysis, and study the relationships of ORDERS and FORMS in nature. Patterned systems must be of appropriate size, or of the right order (i.e. note that *small* systems operate for things like frost protection and water conservation in crop).

When designing gardens, ponds, or access ways, try to minimise waste space by using spiral, keyhole, and least-path systems, clumped plantings, and sophisticated interplants.

Study and use edge effects, especially in relation to intercrop and in the construction of plant guilds, pond production, and fail-safe species richness in variable climatic regimes.

Use appropriate patterns to direct energies on site, and to lay out the whole site for zone, sector, slope, and orientation benefits. This approach alone creates the most energy savings.

Chapter 5

CLIMATIC FACTORS

If I go out shopping, a glance is sufficient to predict if I am likely to need an umbrella. However, long-term prediction of the weather, over a scale of more than about 10 days is a thankless task. This is because the dynamics of the atmosphere form a system whose behaviour is usually chaotic. The surface of the earth absorbs heat, and so heats the atmosphere from below, and this warm air rises. Heat is lost from the upper atmosphere, and this cooled air falls. A roughly hexagonal cellular array of vortices forms, with the ascending warm air feeding the descending cool air.

(Arun Holden, *New Scientist*, 25 Apr '85.)

The glass is falling hour by hour
The glass will fall forever
But if you break the bloody glass
You won't hold up the weather.
(Louis McNeice.)

5.1
INTRODUCTION

Climatic factors have their most profound effect on the selection of species and technology for site, and are thus the main determinant of the plant, animal, and structural assemblies we can use. There is an intimate interaction between site and local climatic factors, in that slope, valley configuration, proximity to coasts, and altitude all affect the operation of the weather. Such factors as fire and wind effects are site and weather related. It is the local climate that inevitably decides our sector strategies.

Although we will be discussing the individual weather factors that define climate, all these factors interact in a complex and continuously variable fashion. Interactions are made even more unpredictable by:

- longer-term trends triggered by the relative interaction of the orbits of earth, sun, and moon;
- changes included in the gaseous composition of the earth's atmosphere due to vulcanism, industrial pollution, and the activities of agriculture and forestry; and
- extra-terrestrial factors such as meteors, the perturbations in high-level atmospheric jet streams, the oceanic circulation, by fluctuations in the earth's magnetic field, and by solar flares.

There is a general consensus that world climatic variation (the occurrence of extremes) is increasing, so that we can expect to experience successively more floods, droughts, periods of temperature extremes, and longer or very intense periods of wind.

We have separated climatic studies from that of earth surface conditions, and there are climatologists who know little of the effects of forests, industrial pollutants, agriculture, and albedo (albedo is the ratio of light reflected to that received) on the global climate. There is no longer any doubt that our own actions locally greatly affect global and local climate, and that we may be taking unwarranted and lethal risks in further polluting the atmosphere.

Because climatic prediction may forever remain an inexact science, we should always *allow for variability* when designing a site. A basic strategy is to spread the risk of crop failure by a mixture of crop species, varieties, and strategies. This fail-safe system of mixed cropping is basic to regional self-reliance, and departure from such buffering diversity brings the feast-or-famine regime that currently affects world markets.

In house design, the interactions of thermal mass (heat storage) and insulation (buffering for temperature extremes) plus sensible siting permit us to design efficient and safe housing over broad climatic ranges. Strategies such as water storage and windbreak modify extreme effects. Many plant and animal species show very wide climatic tolerances, and local cultivars are developed for almost all important food plants. The variety of food grown in home gardens varies only slightly over a great many situations.

As designers, we are as interested in *extremes* as in means (averages). Such measures as "average rainfall" have very little relevance to specific sites. Of more value are data on seasonal fluctuation, dependability, intensity, and the limits of recorded ranges of any one factor. This will decide the practical limits that need to be included in a design.

People who are called on to design or instruct over wide climatic ranges would do well to read in more general treatments such as Eyre (1971) and James (1941), or in modern biogeographical texts. These treatments deal with world vegetation patterns and climatic factors.

Total site factors related to land configuration will impose specific limits to any design; soil data will also be specific to site. There is, therefore, no substitute in any one design for local observation, anecdotes, detailed maps of local factors, lists of locally successful plant and animal species, and analysis of local soils.

It is obligatory for any designer to study the regional long-term human and agricultural adaptations to climate. Above all, we should avoid introducing temperate (European) techniques and species to tropical and arid lands on any large scale. Aboriginal peoples were never so "simple and primitive" as we have been led to believe by the literature of their invaders. Native agricultural and pastoral management practices are often finely tuned to survival, are sometimes very productive, and above all are independent of outside aid.

5.2
THE CLASSIFICATION OF BROAD CLIMATIC ZONES

Most global climatic classifications are based on precipitation-radiation interactions as formulated by Vladimir Koppen (1918), and subsequently modified and updated by authors such as Trewartha (1954). **Figure 5.1** is from the latter reference. More closely-defined plant lists can be given by reference to the "Life Zone" matrix developed by Holdridge (**Figure 5.2**), which has enabled James Duke and others to annotate plant lists with concise climatic keys. Many plant compendia attach "zones of hardiness" to plant listings, commonly used in the USA. As given in *Hortus Third*, the zones are in **Table 5.1**.

Measures or cut-off points are usually chosen that approximate the limiting boundaries for life forms, and are mainly good approximations of lethal or optimum ranges. The main qualifying factors on the broad classification of climatic factors are:

- special mountain conditions;
- the modifying effects of coasts (and the extremes of continental interiors);
- local energy transfer by winds and oceanic currents; and
- long-term cyclic factors.

Some problems in this area are:

1. Instruments for accurate measurement are expensive, and often specific to a narrow range of the total spectrum of effects.
2. Averages in such areas as precipitation and radiation often refer only to one part of the total spectrum. We have few long-term records of fog precipitation, dew, long-wave radiation, ultraviolet incidence, or gaseous atmospheric composition.
3. We are aware that rain, sun, and wind interact in a dynamic and continuous fashion, so that averages mean little to a plant or animal subject to *the normally changeable effects* that may cover wide ranges of interactive measures.

In this chapter, we are concerned only with the very broad climatic zones (design specifics for each climatic zone are given in later chapters). These have been grouped as follows:

- TROPICAL: no month under 18°C (64°F) mean temperature, and SUBTROPICAL: coolest months above 0°C (32°F) but below 18°C (64°F) mean. In effect, frost-free areas.
- TEMPERATE: coldest months below 0°C (32°F), warmest above 10°C (50°F) mean temperature, to POLAR: warmest month below 10°C (50°F) or in perpetual frost (8°C or less) mean.
- ARID: mean rainfall 50 cm (19.5 inches) or less to DESERT: mean rainfall 25 cm (10 inches) or less. Includes sub-humid, or any area where evaporation exceeds precipitation.

5.3
PATTERNING IN GLOBAL WEATHER SYSTEMS; THE ENGINES OF THE ATMOSPHERE

Dense cold air flows continually off the polar ice caps. This high-pressure or down-draught air spirals out of the polar regions as persistent easterlies which affect high latitudes (60–80°) near the ice-cap themselves. Long spokes of this air curve outward to Latitude 30°.

As the spiral itself is caught up in (and generated by) earth spin, these cold cells of air drive a series of contra-rotating low-pressure cells (turning clockwise in the southern hemisphere and anti-clockwise in the northern). These in turn mesh with rotating spirals of high-pressure air which have risen at the equator, and are falling at Latitudes 15–40°.

The high-pressure mid-latitude cells turn anti-clockwise in the southern hemisphere and clockwise in

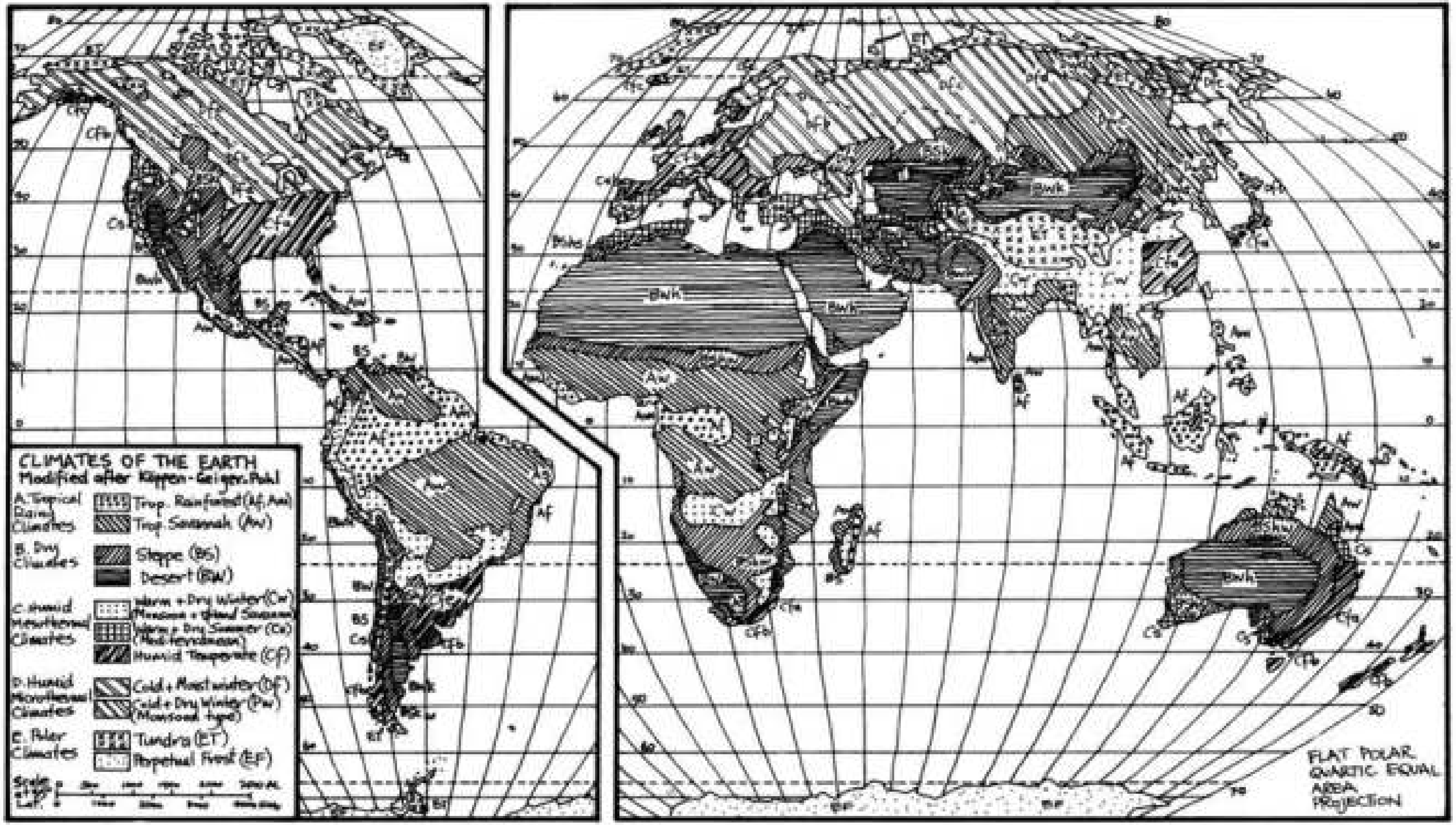
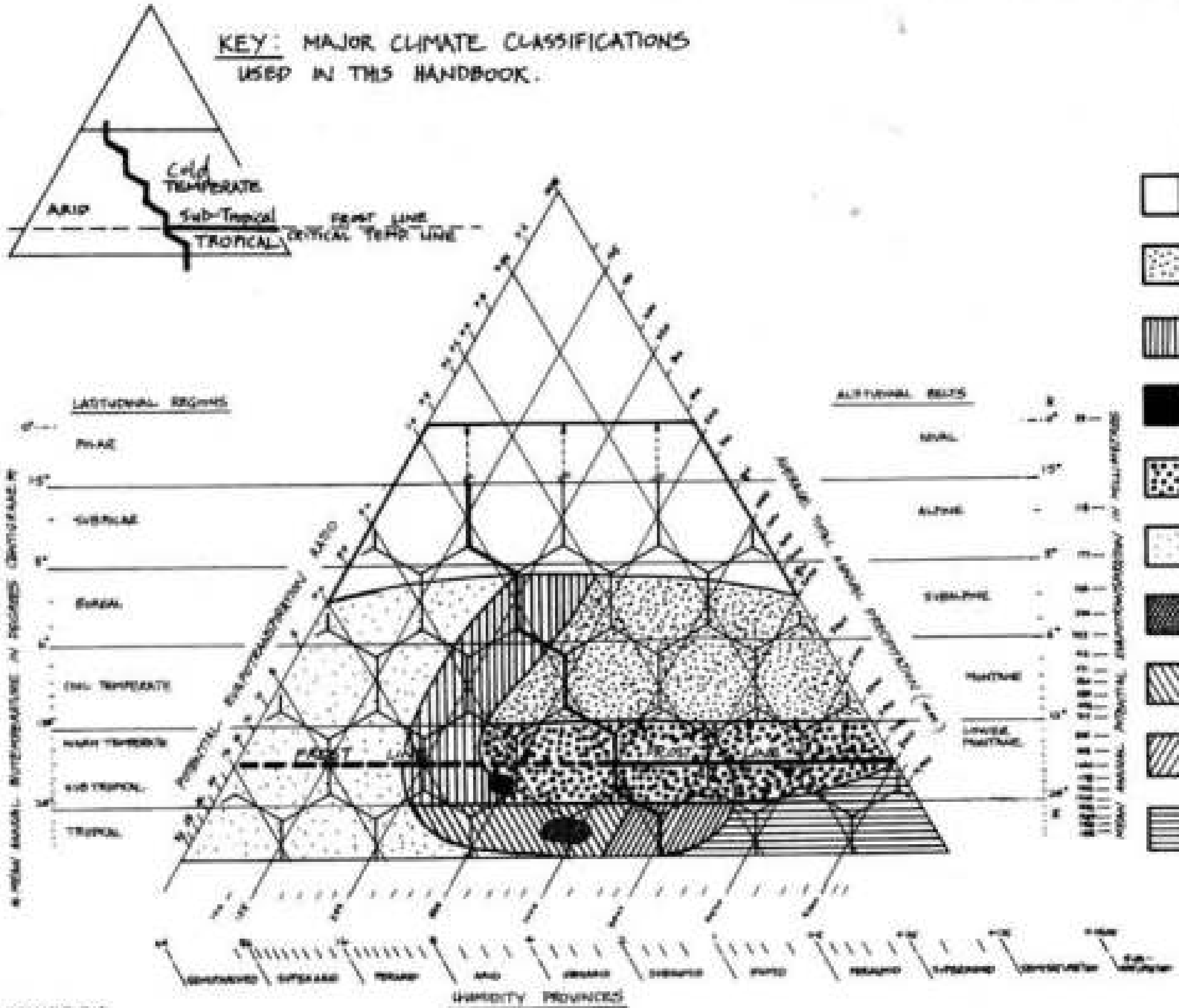


FIGURE 5.1
KOPPEN CLIMATE CLASSIFICATION.
A basic world classification; mionor subdivisions are specified in detailed maps or basic references.



BIOMES	% Area Land Mass	% Plant Mass
Tundra	8	1
Boreal forest	8	16
Chaparral	2.5	1
Temperate grassland	9.5	2
Temeprate forest	7	19
Desert	29	1
Tropical shrub and woodland	10	7
Tropical savannah and grassland	11.5	5
Tropical deciduous forest	4	9
Tropical evergreen forest	10.5	34
TOTAL	100	95
(Human croplands	0.5)	

FIGURE 5.2
HOLDRIDGE LIFE ZONE MATRIX
This analysis suits plant list classifications. The table gives the broad areas dealt with in this book.

TABLE 5.1
HARDINESS ZONES

ZONE	Av. Annual Min. Temp. (°F)	Av. Annual Min. Temp. (°C)	COMMENTS
1	Below -50	Below -45	Arctic tundra
2	-50 to -40	-45 to -40	Cold prairie and conifers
3	-40 to -30	-40 to -34	Conifers and mixed forests
4	-30 to -20	-34 to -29	Cold interiors of continents
5	-20 to -10	-29 to -23	Mixed forests, cool prairies
6	-10 to 0	-23 to -18	Broadleaf and deciduous forests
7	0 to 10	-18 to -12	Broadleaf forests
8	10 to 20	-12 to -7	Arid grasslands, savannah
9	20 to 30	-7 to -1	Semi-arid coasts and basins
10	30 to 40	-1 to 4	Sub-tropical, palms, coasts
11	40 to 50	4 to 10	Tropical forests, deserts
12	over 50	over 10	Equatorial rainforests, monsoon

the northern. Thus from Latitude 50–20°, and in the "roaring forties", about 15–18 alternating high–low pairs of great cells circulate the earth, all of them as smaller spiral systems around the great polar spiral itself (**Figure 5.3**). On westerly coasts, the alternation of cold polar and warm high pressure air arrives at about 10–day intervals, although some great high–pressure cells persist in place, thus blocking westward movement of winds and creating static oceanic conditions that can affect oceanic over-turn, and thus fisheries (e. g. the *el Niño* effect).

These great processions are disturbed and deflected by continents, stubborn high–pressure cells over cool land masses, and the relative intensity of the air cells, so that irregular cold–warm fronts arrive at any one site. Just as polar air is sometimes drawn strongly towards the equator in the lows, so warm tropical air masses are entrained in the outer circulation of the highs and bring heavy warm rains towards the poles. High level jetstreams may speed up or block this procession and the jetstream itself may also break up under stresses caused by shear.

The disturbances and impedences in the system cause cold fronts to pile up against each other and deflect polewards at high–pressure cells, and a sequence of warm– and cold–front rains (the cyclonic or spiral rains) of earth results.

All these wind belts shift north or south with the sun annually, and to some slower extent as a result of the 18.6–year moon cycle, so that periods of drought and excessive rain can result. The system appears chaotic, and subject only to short–term prediction, but of late we are learning to assess some of the effects of the long–term cycles.

The great spiral circulation of the south polar regions is shown in **Figure 5.3**. About 12–18 cold fronts (cloud bands) circle from west to east around the poles, arriving as "cyclonic fronts" every 10 or so days on coasts in that region. They affect areas up to 30° south, with four or so large fronts continuous with (and probably driving) cloud up to 10° south or north latitude, mostly along the western margins of South America, Africa, and the south Atlantic. It is now clear that it is the *oceanic* circulation that drives the air masses, rather than the opposite.

The fronts are dragged in a curve to the west as the earth spins to the east. Each cloud front is a result of the meeting of cold polar and warm sub–polar air masses or high–pressure cells. The low–pressure areas rotate clockwise, the highs anti–clockwise in a series of cog–like spirals or tori that travel every 3–4 months around the poles. Rotation is in the opposite sense in the northern hemisphere. It is the cold, dense, dry polar air sweeping off the ice–caps, and the hot rising air of the equatorial calms which drives these great wheels; clear–air (descending) intrusions are of hot–dry and cold–dry continental air (Australia, Africa) or air descending from the equatorial (rising) congruence (**Figure 5.4**).

In the next sections of this chapter, I will be discussing CLIMATIC FACTORS under parts, as below:

- Precipitation (rain, fog, dew, evaporation–5.4);
- Radiation (light, heat, frost, solar input–5.5);
- Winds (normal winds, hurricanes and tornadoes - 5.6);
- Landscape effects (altitude, valleys, slopes–5.7); and
- Latitude–altitude factors (5.8).

5.4
PRECIPITATION

There are two basic inputs to precipitation: that of rainfall, snow, and hail (WATER FALLING from the clouds), and that of CONDENSATION (water condensed or trapped from sometimes clear air or fogs by cool surfaces). Although the latter may be of critical importance on seaward slopes and at higher altitudes (cloud forests), the only reliable and widespread measures we possess are of "rainfall". World rainfall averages about 86 cm (34 inches). While we may take 50 cm (20 inches) of rainfall or less as semi-arid, and 25 cm (10 inches) or less as arid and desert, we can locally experience seasonal or relative aridity due to long-term cycles and weather effects caused by periodic fluctuations in jetstreams or oceanic currents *in any climate*. Longer periods of increased aridity can also be caused by deforestation on a broad or local scale.

It is because of the potential for changes in precipitation that we give so much space in later chapters to water storage strategies and the conservation of water. Water promises to be the main limiting factor for survival and growth, and the major future expense of food gardens and agriculture. Thus, any strategy we can adopt to generate, conserve, or store water is critical to our design approach. Any gardener knows that climatic averages are at best a very general guide to precipitation effects in the garden or orchard. It is a much safer strategy to see to it that both the species chosen and water strategies developed ensure some yield in "drier than usual" conditions. After all, a fish population out of water for an hour is as dead as if a year-long drought were in effect.

Our annual gardens and crops are also susceptible to short-term changes in available water. People live, and garden, in average annual rainfalls of 10 cm (4 inches) or less, and they manage to both exist and produce crops. Exotic (non-local) water enters dry regions as rivers and underground aquifers, and this enables us to make judicious use of that water and to implement a great variety of local strategies to cope with the lack of actual rainfall.

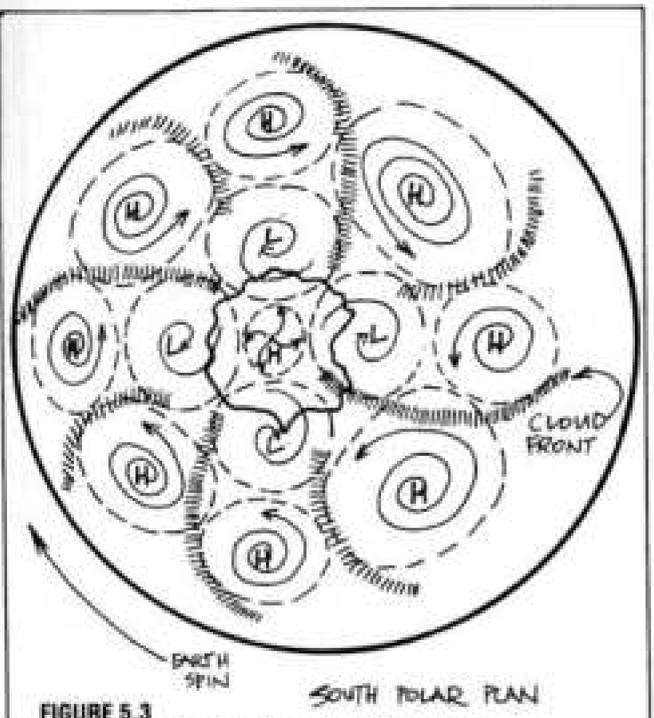


FIGURE 5.3
SPIRAL AIR CELLS AROUND THE SOUTH POLE.
Cloud bands (shaded) bring rains on the E-NE sides of high pressure, and the S side of low pressure cells. Earth spin produces a drag effect. This pattern affects climate to 25° Latitude, when cyclones feed the system.

Rainfall averages are best used as broad indicators rather than as definable limiting factors. Of far more use to us is the expected DISTRIBUTION of rainfall (including extremes such as 100-year flood records) and data on the INTENSITY of rains, as these factors are a limiting influence on the size of road culverts, dam spillways, and the storage capacity needed to see us over dry periods. Flooding histories of sites and districts often indicate the real limits to the placement of plant systems, fences, and buildings, so that attention to flood records avoids future costs and disappointment If flood data is omitted, life itself can be at risk in intense periods of rain.

As precipitation rises, available light decreases. Thus, in extremely cloudy industrial or fog-bound humid climates, *light* becomes the limiting factor for some plants to ripen or even flower. At the dry end of the rainfall spectrum (as we reach 50 cm or 20 inches mean rainfall) sun is plentiful and *evaporation in excess of precipitation* becomes the limiting factor. That factor determines our arid-land storage strategies, just as the depth of seasonally frozen soils and ice cover determines water reticulation strategies in cold climates.

Rainfall is conveniently distinguished by the processes causing rain as:

- OROGRAPHIC: the cooling of air as it rises over mountains or hills.
- CYCLONIC or FRONTAL: the over-riding of cool and warm air masses of the polar circulation.
- CONVECTIONAL: columns of hot air rising from deserts or oceans into cooler air.

Apart from rain, we have dew and fog. DEW is a common result of clear nights, rapid radiation loss, and a moist air mass over coasts and hills. It occurs more frequently in clear-sky deserts than in cloudy areas, and a slight wind speed (1-5 km/h) assists the quantity deposited. Both still air and strong winds reduce dewfall. Intensity of deposition is greatest 3-100 cm above ground level; the highest deposition due to areas of dry ground, the lower due to wet earth, which chills less quickly.

Not to be confused with dew (a radiation heat loss effect from earth with *clear* night skies) is the moisture found on leaves above warm damp ground on *cloudy* nights. This is either GUTTATION (water exuded from the leaves) or DISTILLATION from rising ground vapour; it represents no net gain to total precipitation. The waters of guttation cling to the tips of leaves, dew to the whole leaf area.

Only in deserts is the 4-5 cm (1-2 inches) of dew per year of any significance in precipitation. Dew in deserts can be regarded as an accessory to, rather than a replacement for, trickle irrigation. Dew may be captured by building piles of *loosely-stacked* stones, where low night winds cool rock surfaces and dew can accumulate to dampen the ground below. In the Negev desert and other dry areas, some plants are associated only with these dew condensers. Each mound of stones may suffice to water one tree (**Figure 5.5**). Very large radiation traps, such as those on Lanzarote in the Canary Islands (**Figure 5.6**) may grow one grape vine in each hole.

The most efficient dew-collectors are free-standing shrubs of about 1-2 m (3-6 feet) in height. Groups or solid stands of plants and grasses do less well in trapping dew, and this may help to explain the discrete spacing of desert plants, where perhaps 40% more dew is trapped on scattered shrubs than would be caught in still air, or on closed vegetation canopies.

It is possible to erect metallic mesh fences 1 m (3 feet) or so high, and to use these as initial condensers in deserts, growing shrubs along the fence drip-line, and moving the fence on after these plants are established. In Morocco such fences are proposed for deforested coastal areas.

FOG forms where warm water or the vapour of warm rain evaporates into cool air, or where cold ground chills an airstream and condenses the moisture. Chang (1968) concisely differentiates between:

1. RADIATION GROUND FOG: where, on clear nights, hollows and plateaus cool rapidly and fog forms, often in much the same pattern as the frosts of winter.
2. ADVECTION FOG: where cold offshore currents condense the moisture in warm sea airstreams. These are the coastal and offshore fogs that plague many coasts such as that of Newfoundland and parts of northwest Europe.
3. UPSLOPE OR OROGRAPHIC FOG: where warm, humid airstreams are carried up hill slopes, and condense as the air cools.

Unlike dew, fogs can provide a great quantity of moisture. Chang gives figures of 329 cm (128 inches) for

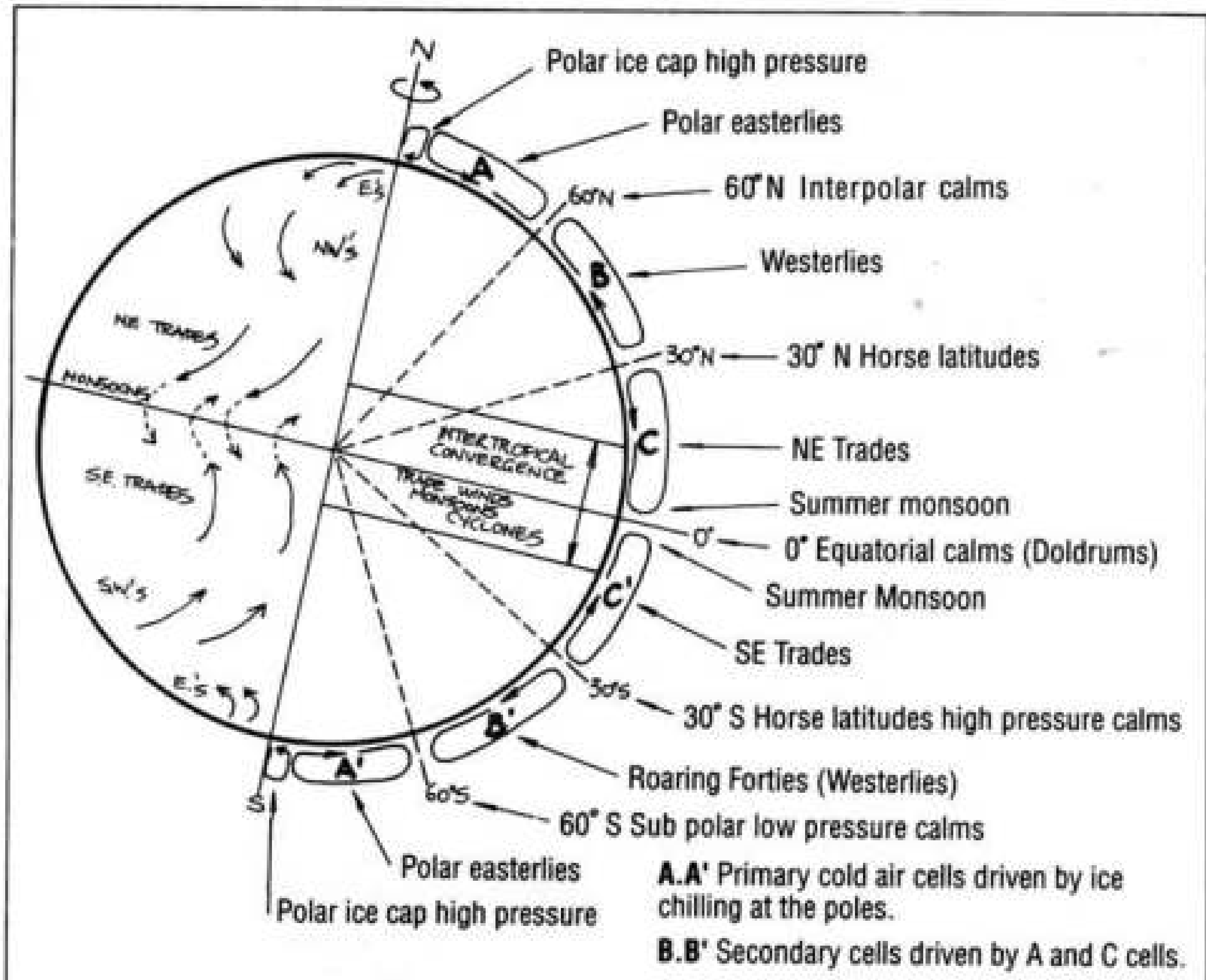


FIGURE 5.4
WIND DIRECTION AND PRESSURE CELLS.

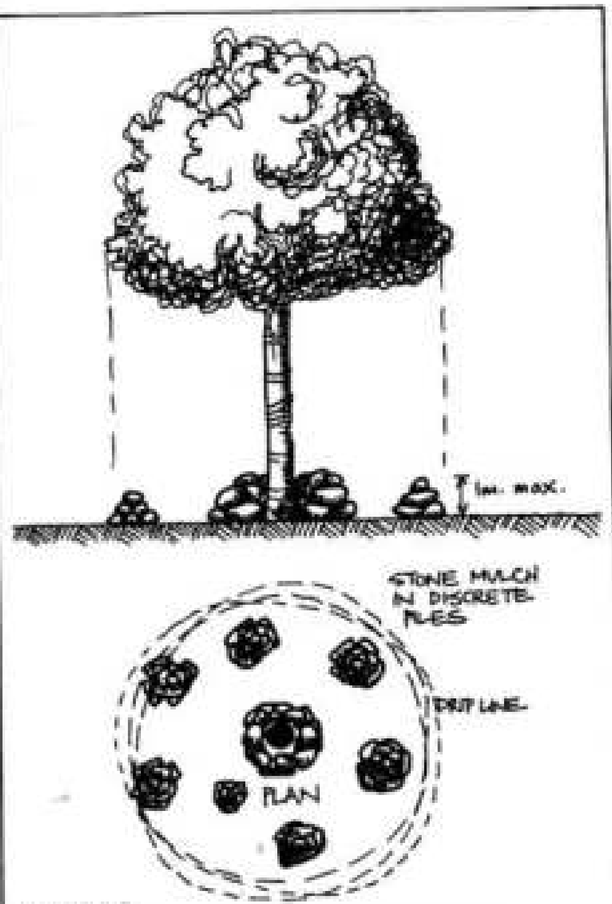


FIGURE 5.5
STONE MULCH UNDER TREE (CONDENSATION TRAP).
Loose piles of stone of less than 1 m high condense moisture from night air movement. Free air flow is permitted between stone piles.

Table Mountain, South Africa, and 127 cm (50 inches) for Lanai (Hawaii) from fog drip alone. In such areas, even field crops may thrive without irrigation. Typically, bare rock and new soil surfaces are colonised with lichens and mosses on sea-facing slopes, while rainforest develops on richer soils. Much of New Zealand experiences upslope fog precipitation, and unless burnt or cleared to tussock grasslands, dense forests will develop; the irregular canopy of such forests are excellent fog condensers. Even with no visible fog, trees will condense considerable moisture on sea-facing slopes with night winds moving in off warm seas over the land, and encountering the cool leaf laminae of forests.

In the very humid air of fog forests, giant trees may accommodate so much moisture, and evapotranspiration is so ineffective if fogs and still air persist, that more large limbs fall in still air than in conditions of high winds (which tend to snap *dry* branches rather than living limbs). It is an eerie experience, after a few days of quiet fogs, to hear a sudden "thump!" of trees in the quiet forests. Almost permanent condensation fogs clothe the tops of high oceanic islands, and hanging mosses and epiphytes rapidly develop there, as they do at the base of waterfalls, for the same reasons (free

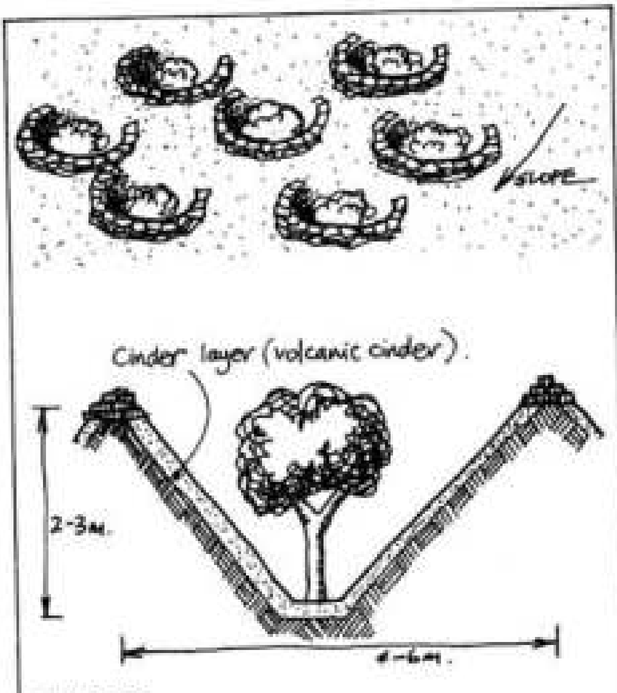


FIGURE 5.6
CONDENSATION TRAP OF LANZAROTE.
Cold air sinks in these cinder-covered pits, condenses on cinder.

moisture particles in the air).

5.5
RADIATION

SOLAR RADIATION

Incoming global radiation has two components: DIRECT SOLAR RADIATION penetrating the atmosphere from the sun, and DIFFUSE SKY RADIATION. The latter is a significant component at high latitudes (38° or more) where it may be up to 30% of the total incoming energy. Near the poles, such diffuse radiation approaches 100% of energy. We have reliable measures only of direct solar radiation, as few stations measure the diffuse radiation which occurs whenever we have cloud, fog, or overcast skies.

Light and heat are measured in WAVELENGTHS, each set of which have specific properties. We need to understand the basics of such radiation to design homes, space heaters, and plant systems; to choose sites for settlement; and to select plant species for sites. **Table 5.2** helps to explain the effects of differing wavelengths.

A minor component of terrestrial radiation at the earth's surface is emitted as heat from the cooling of the earth itself. The greater part of the energy that affects us in everyday life is that of radiation incoming from the sun.

Of the incoming or short-wave radiation (taken to be 100% at the outer boundary of the atmosphere):

- 50% never reaches the earth directly, but is scattered in the gases, dust, and clouds of the atmosphere itself.

TABLE 5.2
SOME WAVELENGTHS AND EFFECTS

WAVELENGTH (Millimicrons)	DESCRIPTION	COMMENT
0-400	Actinic or Ultra Violet: only 1.5-2% reaches the Earth, most being absorbed by the ozone layer.	Causes sunburn, skin cancers. May be increasing due to ozone layer destruction.
400-626	Visible light (white light) composed of:	The rainbow colours visible as differentiaited by water vapour or a prism. About 41% of radiation reaching Earth.
400-435	Violet	
436-490	Blue	
491-574	Green	
575-595	Yellow	
595-626	Orange	
627-5,000	Heat (long wave radiation) and radio waves	
627-750	Red	
751-3,000	Far red	
3,001+	Infra red	Emitted by bodies heated by combustion, or those which have absorbed short wavelengths. About 50% of radiation reaching Earth.

Of this 50%:

— half is reflected back into space from the upper layers of cloud and dust.

— half converts (by absorption) into long-wave or heat wavelengths, within the dust and clouds that act as a sort of insulation blanket for earth.

• 50% reaches the earth as direct radiation, mostly falling on the oceans. Of this 50%:

— 6%, a minor amount, is again lost as reflection to space.

— 94% is absorbed by the sea, earth, and lower atmosphere and re-emitted as heat or converted to growth.

Of the outgoing, or terrestrial, radiation (absorbed solar radiation and earth heat, including the added heat released by biological and industrial processes and condensation), the heat that drives atmospheric circulation:

67% is re-radiated to space, and lost as heat. In the atmosphere, therefore, most heat is from this re-radiated heat derived from the surface of the earth.

• 29% is released from condensing water as sensible heat.

Ozone in the upper atmosphere absorbs much of the ultraviolet light, which is damaging to life forms. Carbon dioxide, now 3–4% of the atmosphere, is expected to rise to 6%, and cause a 3°C (5.5°F) heating of the earth by the year 2060. This process appears to be already taking effect on world climate as a warming trend, and will cause sea level changes.

The effect of radiation on plants is different for various wavelengths, as in **Table 5.3**.

Other sources of light for the earth are the moon (by reflection of sunlight) and star light. Although weak, these sources do affect plant growth, and even fairly low levels of artificial light affects animal and plant breeding. The major effects of radiation overall are:

• PHOTOSYNTHESIS in plants, the basis of all life on earth.

• TEMPERATURE effects on living and inorganic substances, much used in house design.

• FLOWERING or GERMINATION effects in plants, of basic importance to the spread of specific plant groups; this includes the day-length effect.

Plants actively adjust to light levels by a variety of strategies to achieve some moderate photosynthetic efficiency. They may keep the balance between heat and light energies by adopting solar ranges to suit the specific environment (silvery or shiny leaves where heat radiation is high; red leaves where more of the green spectrum is absorbed and less heat needed). Leaves may turn edge-on when light and heat levels get too high, or greatly enlarge their surface area under a shady canopy. Trees have larger leaves at the lower layers.

COLOUR

When we look at any object, we see it by receiving the wavelengths of the light it REFLECTS or screens out. Thus, many plants reflect green/blue wavelengths, while flowers reflect a wider spectrum of light, becoming conspicuous in the landscape. About 10% of light penetrates or is transmitted by foliage, although he canopy of rainforests in very humid areas (tropical r temperate) may permit only 0.01% of light to pass hrough to the forest floor. Absorbed light, as heat, is e-radiated or used in growth.

In addition to leaf colour, plants have bark surfaces anging from almost white to almost black, the latter good absorbers and heat radiators, the former good eflectors. Leaf surfaces may vary from hard and shiny o soft, rough, and hairy. Typically, waxy leaf surfaces re found in coastal or cold areas, and in some nderstory plants, while woolly leaf surfaces are found n deserts and at high altitudes. The waxiness often gives a greater reflection of light regardless of colour, while dark or rough surfaces absorb light, so that dark evergreen trees become good radiators of heat.

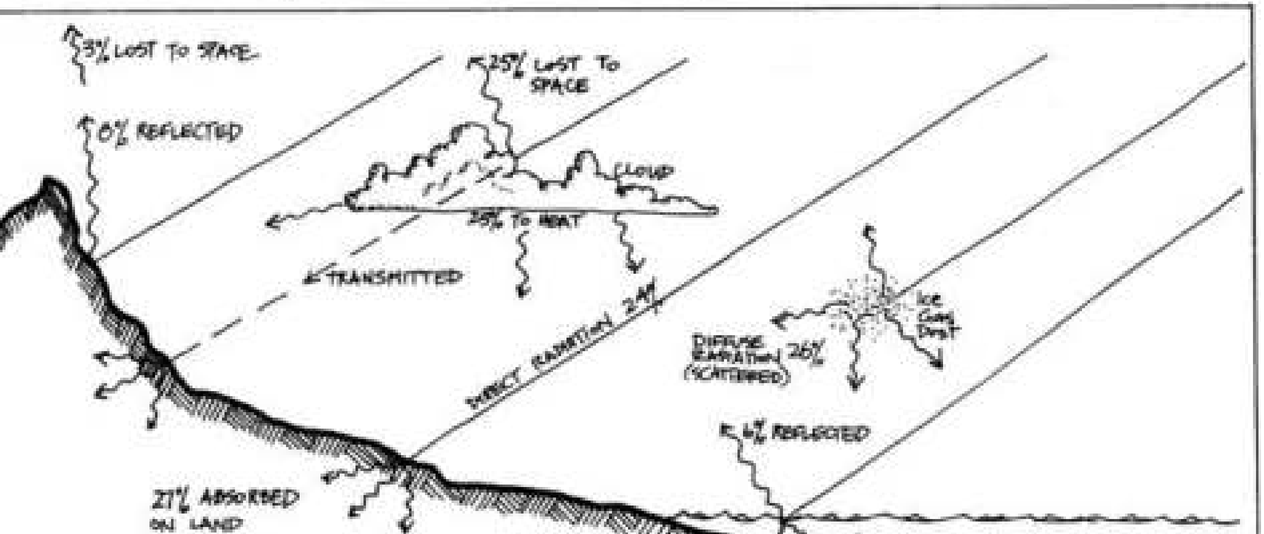
All of these factors (colour, reflection, heat radiation) are of as much use in conscious design as they are in nature, and can be built in to gardens or fields as aids to microclimatic enhancement.

ALBEDO AND ABSORPTION

The albedo (the reflected light value) of plants and natural surfaces determines how they behave with respect to incoming radiation. The light *reflected* goes back into the atmosphere, or is absorbed by nearby surfaces and by structures such as greenhouses. The light *absorbed* is converted into long-wave radiation, and is re-emitted as heat (**Figure 5.10**). Soils and similar dense materials normally absorb heat from

ABLE 5.3
HE EFFECTS OF RADIATION ON PLANTS IS DIFFERENT FOR VARIOUS WAVELENGTHS.

VAVELENGTH (Millimicrons)	DESCRIPTION	EFFECT
-280 (UV)	UV or actinic	Kills plants and animals. Germicidal.
81-315 (UV)	UV or actinic	Detrimental to plants, growth.
16-400	Violet	Plants shortened, leaves thickened.
10-510	Violet-Green	Strong absorption and growth in plants. Effective photosynthesis. Transmitted by fibreglass, several plastics.
11-610	Green-Orange	Low growth and photosynthetic effect.
11-720	Orange-Red	Strong absorption and photosynthesis, photoperiodic behaviour=day length effect.
1-1,000	Red-Far Red	Plants elongate, important for seed germination, flowering, photoperiodism, fruit colouration.
,000+	Infra Red	Absorbed and transpired into heat by plants; no strong growth effects.



IGURE 5.7
NCOMING SHORT-WAVE RADIATION.
The fate of radiation in differing media.

daytime radiation to a depth of 51 cm (20 inches) or so. As this takes time, the build-up of soil heat lags a few hours behind the hourly temperatures. Re-radiation also takes time, so that such absorbing surfaces lose heat slowly, lagging behind air temperatures. Thus we have our lowest soil temperatures just after dawn. The radiation loss at night produces frost in conditions of still air [in hollows, on flats, and in large clearings of 9–30 m (30–100 feet) across or more in forests]. Some frost (ADVECTION frost) flows as cold air down hill slopes and valleys to pool in flat areas. Frost forms rapidly on high plateaus. Dense autumn fogs often indicate the extent of winter frosts, and are clearly seen from high vantage points.

As designers, we use water surfaces, reflectors, and specific vegetational assemblies for forest edges. **Table 5.4** gives an indication of the value of diffuse reflectors, as **albedo**. A perfect reflector refuses 100% of light (mirrors); a perfect absorber is a BLACK BODY that absorbs all light and converts it to heat.

The fate of incoming waves encountering an object or substance is either:

- REFLECTED: turned away almost unchanged, as light off a flat mirror or off a white wall.
- REFRACTED: sharply bent or curved, as is light in water, images in curved glass, or sea waves around a headland.
- ABSORBED: soaked in, as when a black object soaks up light. This changes the wavelength (light to *heat* or short to *long* wavelength). All absorbed light is emitted as heat.
- TRANSMITTED: passed through the object.

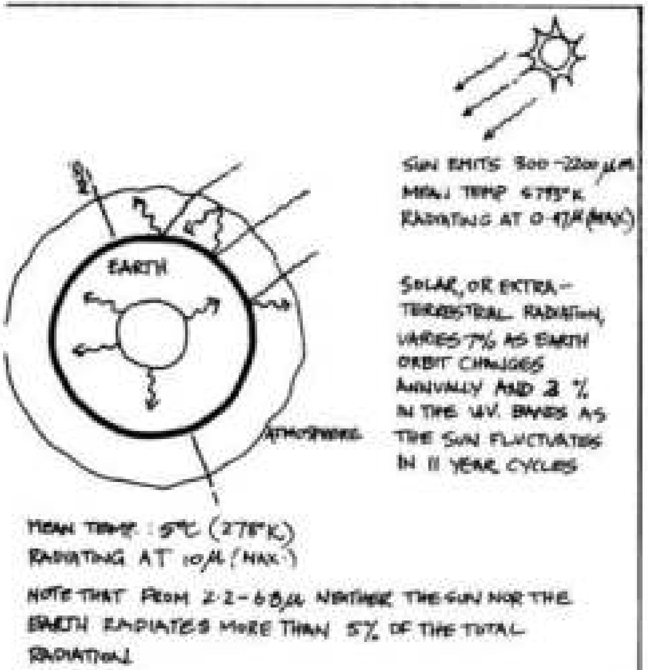


FIGURE 5.8
GLOBAL RADIATION.
Most heat is trapped by moisture, dust, or gases in the atmosphere; a little is emitted by the Earth itself.

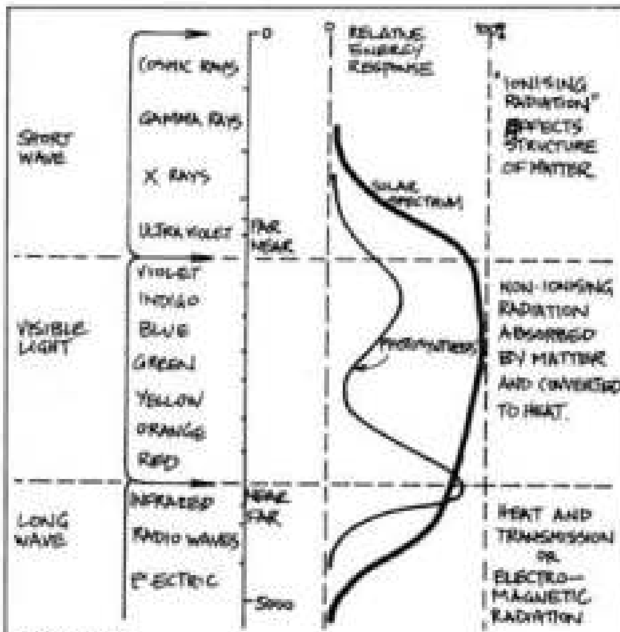


FIGURE 5.9
THE SUNLIGHT SPECTRUM (0–5,000 A)
Plant growth (photosynthesis) relies on two narrow bands of light, is damaged by extreme ultraviolet or heat wavelengths.

Different substances pass on, or are "transparent" to, different wavelengths due to their molecular structure.

Thus it is by our choice of the materials, colours, or shapes of fabricated or natural components that we manipulate the energy on a site. We can redirect, convert, or pass on incoming energy. The subject of radiation ties in with areas of technology as much as with natural systems, and this section will therefore serve for both areas of effect.

The earth itself acts like a "black body", accepting the *short* wavelengths from the sun, and emitting after absorption the *long* wavelengths from the surface and atmosphere. **Table 5.2** deals mainly with the short wavelengths, as they are those coming in as light and heat from the sun. The long wavelengths we experience are those re-radiated to earth from the atmosphere, or emitted by the hot core of earth. Curiously, snow is also a black body in terms of heat *radiation*. Black objects such as crows or charcoal can become effective *reflectors* if their shiny surfaces are adjusted to reflect radiation (a crow is black only at certain angles to incoming light).

HEAT (Longwave radiation)

It is difficult to store heat for long periods in field conditions, although it can be done in insulated water masses or solids such as stone and earth. There is some heat input every day that the sun shines or diffuse sky light reaches the earth. The mean temperature of the earth is 5°C (41°F), of the air at or near ground level 14°C (57°F), and of the outer layers of the atmosphere -50° to -80°C (-90° to -144°F). Normally, we lose about 1°C for every 100 m increase in altitude (3°F per 1000

TABLE 5.4
SOME ALBEDOS

	Reflected (%)	Absorbed (%)
"The perfect reflector"	100	0
White, smooth paint	96	4
Clean fresh snow	75-95	5-25
White gravel	50-93	7-50
Dense white clouds	60-90	10-40
Calm water (Sun 15° elevation)	50-80	20-50
Adapted desert shrubs	30-38	62-70
Sand dunes	30-40	60-70
Sandy soils	15-40	60-85
Dry hay	20-40	60-80
Wood edges	5-40	60-95
High sun, rough water	8-15	75-92
Young oaks	18	82
Young pines	14	86
Dark soils	7-10	90-93
Fir forest	10	90
"The perfect black body"	0	100

feet). In most conditions we experience a reduction in temperature with increasing altitude, but in many valleys, or on plains surrounded by mountains, cool air from the hills or cold air generated by rapid radiation loss from soils creates a condition where layers of dense cooler air are trapped below warmer air, and we have a TEMPERATURE INVERSION. It is in such conditions that fog, smog, and pollution can build up over cities lying in valleys or plains, where wind effect is slight. Such sites must be carefully analysed for potential pollutants.

As in the case of precipitation, it is advisable to research temperature extremes for site. Poultry (and many wild birds) do not survive temperatures greatly in excess of 43°C (109°F), nor do plants survive transplant shock from nursery stock when soil temperatures exceed 36°C (97°F), whether in deserts or in compost piles. Many plants are frost-affected at or below 0°C (32°F), and below this, sustained periods of lower temperatures will eliminate hardier plant species (even if well-established). Thus, the very widespread and sometimes economically disastrous black frosts that affect whole regions should be noted by site designers as much as flood periodicity. Livelihoods should not depend on broadscale plantings of frost-susceptible crops in these situations.

CONVECTION LOOPS AND THERMOSIPHONS

For building and garden designs, we should be aware of just how heat is stored and transmitted. First, we need to distinguish between lowgrade heat transmitted by CONVECTION, or the passage of air and water over slightly heated surfaces. It is this effect which operates in valley climates, and which creates valley winds. Cool air is heavier (more dense) than heated air; the same factor holds true for water or liquids, and other gases (and fluid flow generally).

Thus, providing heated air or water is contained in pipes or ducts, a closed loop circulation can be set up by applying heat to the lower part of that loop, providing that a least rise or height difference of 40 cm (about 18 inches) is built in to the loop; any greater height is of course also effective in producing a **thermosiphon** effect (**Figure 5.11**). This is the effect used in refrigerators driven by flames or heat sources.

In the atmosphere, columns of heated air over land ascend as an "Overbeck jet" (**Figure 4.13**), and at the top of this column, condensation and rain may occur as the air is cooled in the upper atmosphere. Such convectional rains are responsible for the mosaic of rainfall that patterns the deserts.

Convection loops will *not* occur in closed rooms, where hot air [at 8–10°C (1518°F) higher temperture] sits in a quiet or stratified layer below ceilings. As air is difficult to heat, and stores little heat, air convection is not an efficient way to heat building interiors, although it is the main "engine" of atmospheric circulation in the global sense.

Thermosiphons are useful in transferring heat from solar ponds or flat plate collectors to home radiators or hot water tanks; we should, wherever possible, site these heat collectors 0.5 m (1.6 feet) below the storage or use points so that they are self-regulated thermo-

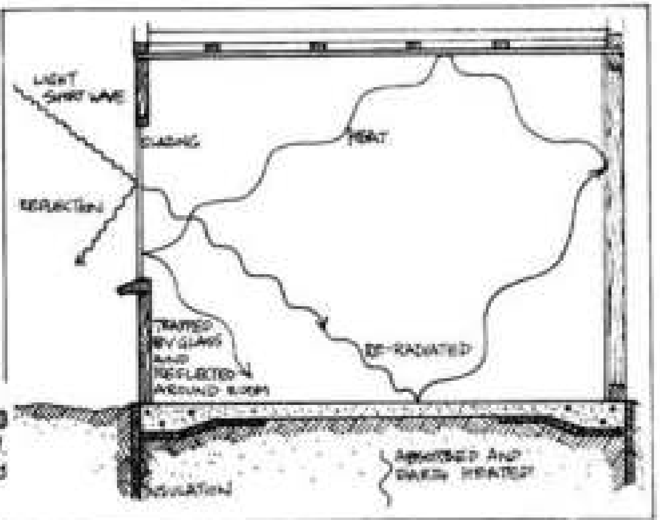


FIGURE 5.10
EFFECT OF LIGHT PASSING THROUGH A WINDOW.
Glass is less permeable to long (heat) radiation, thus it "traps" radiated heat but transmits short-wave light.

siphons.

HEAT TRANSFER

Heat flows from warmer to colder bodies, and just as warm air transfers heat to cool solid bodies by day, so warm bodies can heat large volumes of air at night. Bodies that are heated expand, decrease in density, and (where there is freedom to move) heated air or water rises as CONVECTION CURRENTS.

The common heat unit is that needed to raise one gram of water from 14.5°C to 15°C. In terms of incoming radiation, gram calories per square centimetre ($g/cal/m^2$) are termed LANGLEYS; the sun provides about 2 Langleys/minute to the outer atmosphere.

The quantity of heat received on earth is greatly affected by:

- latitude and season (the depth of atmosphere);
- the angle of slopes (which in turn affects reflection and absorption); and
- the amount of ice, water vapour, dust, or cloud in the air above.

This means that the Langleys received at ground level vary widely due to combinations of these factors. Nevertheless, most homes receive enough sunlight on their sun-facing areas to heat the water and space of the house, if we arrange to capture this heat and store it.

However, even when the sun is directly overhead on a clear day, only 22% of the radiant energy penetrates the atmosphere (1 atmosphere depth). In polar areas, where the slanting sun at 5° elevation passes obliquely through at a distance of 11 atmospheres, as little as 1% of the incoming energy is received! Slope has similar profound effects, so that slopes facing towards the poles receive even less energy from radiation.

It follows that siting houses on sun-facing slopes in the THERMAL BELT is a critical energy-conservation strategy in all but tropical climates, when siting in shade or in cooling coastal windstreams is preferred. Sun-facing slopes not only absorb more heat, but drain off cold air at night; they lie below the chilly hilltops, and above the cold night air of valleys and plains (**Figure 5.12**).

In hill country and mountains, these thermal belts may lie at 1000–5000 m. (3,280–16,400 feet), and on lower hill slopes at 100–200 m. (330–650 feet), whereas in hot deserts the frost levels may only reach to 10–15 m. (33–49 feet) up the slopes of mesas. Each situation needs specific information, which we can gain from local anecdotes, the observation of existing plants, or trial plantings of frost-susceptible species.

Winds travelling from warmer to cooler regions, or the opposite, bring ADVECTED (exotic, or out of area) warmth and cold to local regions. Thus we speak of advection fogs where these come inshore from coasts, and advection frosts when cold air flows down mountain slopes to pool in hollows.

The invasion of cool areas by warm advected air causes moisture condensation, which is critical to precipitation in forests, but a nuisance in enclosed buildings. Thus, we should attempt to bring only *dry* warm air into wooden houses, or provide ways to direct condensation moisture to the house exterior.

Intermediate grades of heat can be transmitted by CONDUCTION, as when solids are in contact. It is in this way that we heat an entire floor or wall by heating it in one place, and this is the basis of the efficiency of the slab-floored house, where the floor is previously insulated from surrounding earth. In open (uninsulated) systems, conduction effects are local, as

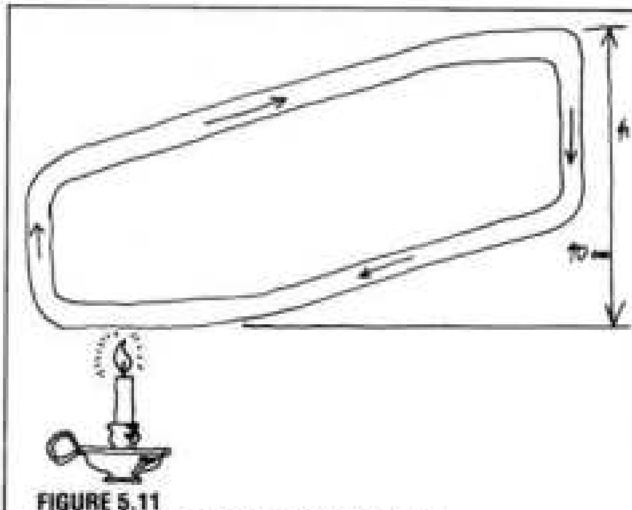
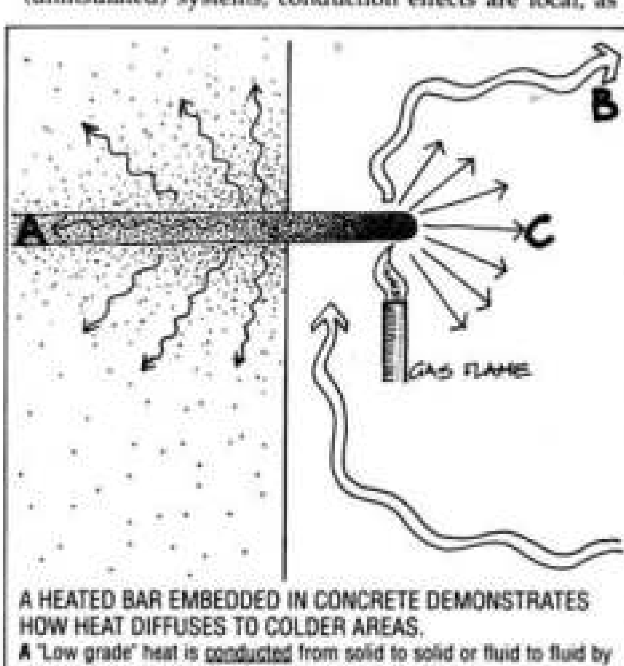


FIGURE 5.11
CONVECTION LOOP OR THERMOSIPHON.
Heat applied at "A" in a closed loop causes fluid flow in the loop if the top of the loop is 40 cm or more above the heated section of the loop.



A HEATED BAR EMBEDDED IN CONCRETE DEMONSTRATES HOW HEAT DIFFUSES TO COLDER AREAS.
A 'Low grade' heat is conducted from solid to solid or fluid to fluid by contact. Insulation is effective in trapping such heat.
B 'Medium grade heat' is convected by the movements of fluids or gases, as in air, wind, or water. Draught-proofing conserves this heat. Heated fluids rise.
C 'High grade heat' travels by straight-line radiation in all directions and can only be conserved by reflective (dust-free) surfaces or mirrors. This is how the sun heats the Earth.

heat is fairly rapidly radiated from solids or soil surfaces. Pipes buried in hot solid masses have heat conducted to their contents, or hot water pipes conduct heat to slab floors in which they are buried; such heating is most efficient in homes.

Intense heat trapped in solids and liquids is RADIATED, which is the effect transmitted across space by the sun. Radiant heaters affect air temperature very little, but radiation heats other solids and liquids (like our bodies) or dust in the air. Thus, we can keep very warm even in a draughty or cool room by the use of radiant electric, gas-fire, or wood-heated massive stoves; these are very efficient space heaters. As radiation crosses space, and is nondirectional, focused radiation can produce very intense heat locally.

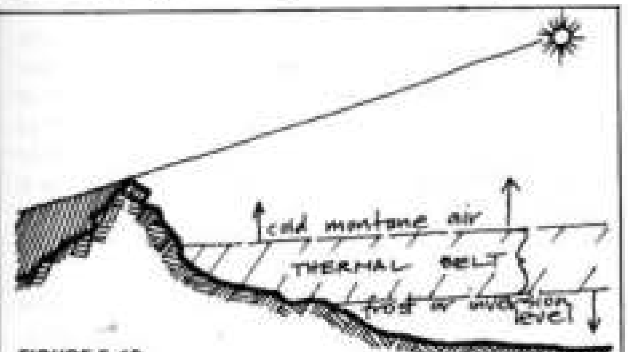


FIGURE 5.12
THERMAL BELT.
A midslope, moderate zone suited to gardens and housing; the shaded side of the hills accentuate cold, low evaporation, and suit very different species.

PLANTS AS HEATERS

Most or all Arum lilies, and species such as *Philodendron selluum* store fats which are "burnt" to create heat, so that the flowers heat up. Philodendrons may register 46°C (115°F) when the air is 4°C (39°F), and crocuses heat up to 15°C (27°F) above the ambient air temperature. The warmth generated is probably used to attract flies and heat-seeking insects to the pollen. Some plants (skunk cabbage, *Symplocarpus foetidus*), however, may use their heat to melt a hole in the spring snow, and so protect the blooms from cold [at 20–25°C (36–45°F) extra heat] as well as to provide a cosy incubator for the rest of the plant's growth" (*New Scientist*, 9 May '85) and to scatter odorous scents that attract pollinating flies. More amazingly, the shape of the first leaf of this species creates a vortex (from wind) that is contained within the hot leaf and carries pollen down to the unpollinated lower flowers, thus achieving fertilisation, in cold winds, without the presence of insects!

As all these "heaters" may have unpleasant smells, we should use them with caution. Understorey clumps of such species may assist frost-tender, fly-pollinated, or heat-starved plants, just as tall interplant systems may assist general heat requirements for some ground crops.

RADIATION AND GERMINATION OF SEED

The effect of soil temperatures alone on germination of a wide range of vegetable seeds can be profound. Between 0°–38°C (32°–100°F) the time to germinate (in days) can be reduced to one-tenth or one-fourth of that in cold soils by increasing soil temperatures. At the extremes of this temperature range, however, we find many plants have limiting factors which result in no germination. While almost all vegetable seed will germinate in soils at 15–20°C (59–68°F), such oddities as celery refuse to germinate *above* 24°C (74°F), and many cucurbits, beans, and subtropicals do not germinate *below* 10°C (50°F). Thus, we are really talking about waiting until 10°C is reached, or warming up the soil in greenhouses or with clear or black plastic mulch in the field before planting. Sometimes just the exposure of bare earth to the sun helps. A simple thermometer inserted 2.5 cm (1 inch) in the soil suffices to measure the soil temperature, or a special soil thermometer can be purchased. For specific crops, we can consult such tabulations as are found in Maynard and Lorenz (*Knotts Handbook for Vegetable Growers*, 1980, Wiley, N.Y.)

A second effect on germination is light itself, e.g. carrots need a definite quantity of light, and are usually surface-planted to effect this. We can surface-scatter such seeds, or first *soak* them overnight and then subject them to a day under a low-wattage light bulb or in the open before planting and covering them lightly (they react to this light *only if wetted first*). Larger seeds usually accept burial and germination in the dark, while some weed seed and desert seed will germinate deep-buried. For a few weed species such as wild tobacco, a mere flash of light (as when we turn over a clod of soil) suffices to start germination.

Next we come to *cold*, and we speak of the STRATIFICATION or VERNALISATION of seeds. Cold-area seed, and specifically tree and berry seeds from boreal or cold areas, should spend the period from autumn to spring in a refrigerator when taken to warmer climates. Apple seeds stored in sand or chestnuts in peat sprout in this way, and can be potted out as they shoot. This in fact reproduces the exposure to cold [at about 0°–5°C (32°–40°F)] that they normally experience at the litter level in cold forests or marshes. Wild rice and other "soft" aquatic seeds are stored in open ponds, or under water in an ordinary refrigerator.

Stratification can often be accomplished by keeping such seeds in sand or peat (or water for aquatics) in cold shaded valleys, or under open cool trellis in warm climates. They can be checked on late in winter and spring for signs of germination. The opposite of this is heat treatment, such as we can give to many tree legume seeds, by heating in an oven at 95°C (200°F) for a 10–20 minute period, or by pouring very hot (near-boiling) water over them, or by burning them in a light straw fire.

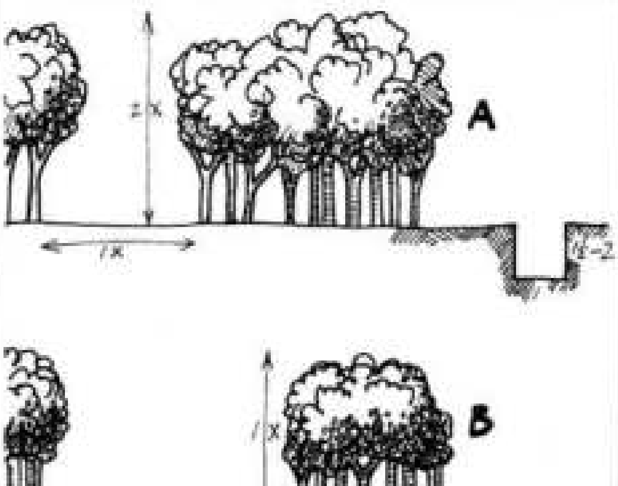
Many older gardeners will also feed seeds to themselves (in sandwiches), or their animals (chicken or cattle), collect the manure, make a slurry of it, and sow such seeds as tomatoes, berries, and tree legumes. The voyage through the digestive system is a compounded process of acid/alkali, hot/cold, mechanical cracking in teeth or in bird crops, and packaging in manure to which a lot of seeds are adapted.

FLOWERING

Day length (in fact, night length, but we will take the day side) varies over latitudes, and flowering plants are adapted to bloom and set seed in response to specific day lengths and the change of seasons. While many plants are DAY NEUTRAL and will flower if other factors are satisfactory, some will not flower at all in shorter or longer day-lengths than those to which they are adapted. This can be put to use, as when we transfer a tropical (short-day) corn to a temperate (long-day) hot-summer climate, and get a good green-leaf crop as fodder, or take tobacco from temperate to cool areas and get leaf rather than seed production. The same goes for some decorative foliage plants. But this effect is in fact the reason for choosing varieties from local growers, or selecting for flowering in new introductions so that a local seed source is available for all those crops we want in seed.

In New Guinea highlands (short days), cabbages from long-day climates may never flower, and some *Brassicas* reach 1-3 m in height, the leaves being plucked off at regular intervals for vegetable fodder, and the plant cut down only when too tall to reach!

Latitudes have specific day lengths as follows:



A: THIS CLEARING AND PIT SHOULD REDUCE FROST
B: THIS CLEARING AND PIT SHOULD INCREASE FROST

FIGURE 5.13
CLEARINGS IN TREES FOR FROST PROTECTION. (or pits in soils)
Frost loss is less in small steep-walled clearings that are about half the width of tree height.

- LOW LATITUDES (0-30°): Usually tropical climates, with colder mountain climates; equal or near equal days and nights.
- MID LATITUDES (30-50°): Cool to temperate climates with boreal mountain regions; long summer days and short winter days.
- HIGH LATITUDES (>50°): Very long summer days, and probably good radiation from diffuse light all the growing season. No plants grow in winter.

FROST

Frost is caused by radiation loss (rapid cooling) of the earth on clear nights, in still air. To reduce frost on any site (or in a small pit), it is necessary to have a *steep-sided* clearing or pit so that radiation is restricted to a small area of the sky. In such clearings, we have two effects: radiant heat from the vertical edges *plus* the obscuring of the horizon (hence less radiant heat loss at night). The proportion of heat loss on a cold night is proportional to the area of the night sky that is visible to the object losing heat. For example, a mouse in a cardboard tube in the ground loses very little heat, but a mouse on a mound on a flat sight is exposed to the whole sky and loses a great deal of heat.

The second factor is that the pit or clearing should be *small*; large clearings will create or contain *more* frost. The rule is to make the clearing (or pit) about one-half as wide as high, and to keep the sides trimmed to vertical. In forests, such clearings should not exceed 30m across (**Figure 5.13**).

It is necessary, therefore, to try to build up a complete crown cover to prevent frost on a site, and this is best done in stages. For example, we could plant the whole area to frost-tolerant legume like silver wattle (*Acacia dealbata*), then plant semi-hardy fruits in the shelter of these, eventually cutting back the *Acacia* as the frost-sensitive, protected trees gain height. It is obviously necessary to assist this process by supplying water to the selected trees, and this may also help ameliorate the frost effect on nights of high risk.

The effect of trees on soil moisture and frost may be profound at edges and in small clearings, as the tree crowns obviously create their own water distribution on the ground. Crown drip can direct in excess of 100% of rain to a "gutter" on the ground, and for some tree species with down-sweeping limbs and leaves, this is a profound effect. At the rain-shadow edges of forests, dry areas are to be expected. What makes this effect more pronounced is that the "wet" edges are more often than not also away from the sun (most rain comes from the polar side of sites). **Figure 5.14**.

The sunny edges of the forests help protect seedlings from frost, and these and small clearings are used to rear small trees, or to plant them out in frosty areas.

Some implications for designers are as follows:

- IN COMMUNITY AND PLANT HEALTH: Areas of severe direct or diffuse radiation, and especially where the atmosphere is thin (on mountains), where albedo is high (in snow, granite, or white sand areas, or over hayfields in summer) can produce severe radiation burns, skin cancers (very common in Australia), and temporary or longterm blindness.

Plants, too, must be screened against sunburn by partial shade and by white paint on their stems in conditions of severe radiation (especially young plants). Older plants may suffer bark damage, but will survive.

- FOR AUTOMATIC TRANSFER thermosiphon effects are best achieved by:
  - placing heat sources below storage and use points;
  - inducing cross-ventilation by building **solar chimneys** to draw in cool air;
  - actively fanning heated air to underfloor gravel storages where solar attics or trapped ceiling heat is the heat source; and
  - eliminating heat-induced condensation through the use of heat exchangers.
- IN HEAT STOVES: Massive earth, brick, stone, or concrete heat storage masses must be insulated to retain heat that is otherwise lost by *conduction* to the ground, or by radiation to the exterior of houses. Conduction is prevented by solid foam or air-trap insulation (straw). Radiation loss is prevented by reflection from double-glazed windows, or reflective insulation hanging in air spaces.

Reflective insulation doesn't work if it is dusty, dirty, or pressed against a conducting surface, hence it is of most use as free-hanging sheets, or ceiling sheets looped loosely across rafters. It can be kept clean (and effective) only in such situations as solar attics. Plain white paint is an excellent reflector for everyday use on walls or in concentrators.

- PLANT CHOICE: All plants with high biomass (e.g. trees) store heat in their mass (which is mainly water). Thus, fairly small clearings may be frost-free in cold climates. Dark evergreen trees absorb (and radiate) heat effectively; white-barked, shiny, or light-coloured trees reflect heat in cool districts, on forest edges, and where light itself is a limiting factor.
- WATER AND STONE are good heat storages, having a high specific heat. Thus, bodies of water are good heat storages. Air has a low specific heat and is a very poor conductor of heat, hence a good insulator. Many insulation systems work simply by trapping air, or by being poor conductors (cork, sawdust, wood).

These short examples, and some of the tabulated material, give the essential features of radiation that are applicable to everyday design. A preliminary design choice is to choose house sites for the maximisation of solar radiation in subtropical to cool climates and to shelter from radiation where excessive heat is a problem. Excess heat in one area of a house can be used in arid and tropical areas to "fuel" a cross- ventilation system, also essential in the humid tropics for cool dry air intake to the home.

Designers should always be aware of opportunities to convert light to heat, to reflect more heat on to cool areas, to light dark areas by reflection or by skylight placement, and to store heat below insulated slab floors.

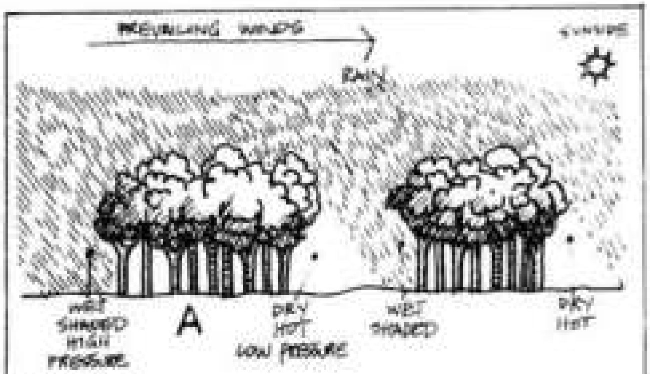


FIGURE 5.14
WET AND DRY SIDES OF A FOREST CLEARING.
Microhabitats develop due to combined sun and rain effects.

5.6
WIND

Both wind and water transport can influence (by impedence or reflection) the quantity of light and heat on any site. Particles or molecules carried in air have a profound effect on available light, and heat can easily be transported about our system by air and water, or by substances mixed in with them.

Of all of these elements, we have least control of wind in terms of storage or generation, but we can control its behaviour on site by excluding, reducing, or increasing its force, using windbreak and wind funnels to do so.

As a resident of a bare, cleared (once-forested) peninsula, when I speak of wind I know of what I write! The very table on which this book is penned rocks to gusts from the "roaring forties" and when the wind blows from the east, spicules of salt form on beards, clothes lines, and plants, burning off leaves and killing plant species; some hardy plants that withstand years of normal gales can die in salty summer winds.

When it comes to crop, winds of 8 km/h are harmless. Those of 24 km/h reduce crop production and cause weight loss in animals, and at about 32-40 km/h, sheer mechanical damage to plants exceeds all other effects; in fact, I have seen my zucchini uproot and bowl along like a tumbleweed. Trees are severely wind-pruned by a combination of mechanical damage and salt burn near coasts, and by the additional factor of sandblast in dunes (desert or coasts) and iceblast in cold climates. Wind transport of sands in deserts and incipient deserts buries fences, buildings, trees, and crops.

Although many sites are little affected by wind as a result of fortunate local conditions, or a general low level of wind effect in a region, very few coastal, island, sub-tropical or exposed hill sites can afford to ignore this factor.

There are broad categories of wind speed and effect, just as there are for rainfall and temperature. The Beaufort Scale is the normal way to report winds, and equivalents are given in **Table 5.5**.

More severe than mechanical damage are the minute sulphur and nitrogen particles carried by wind. In Colorado, Virginia, Utah, the Urals and in fact anywhere downwind of nuclear waste stores, tests, and accidents we can add plutonium and other radioactives to the wind factor. Dry sulphur, falling on leaf and soil, converts to acid in misty rains. On parts of the northeast coast of America and Canada, these rains can burn gardens and forests, or make holes in garments and tents in a few days. Near acid production factories, even paints and roofing are pitted and holed; this factor has become general in industrial areas and for many miles downwind.

Windbreaks may mean the difference between some crop and a good crop, but in severe wind areas, the difference is more absolute and may mean that susceptible plants will produce no crop at all. Thus, a list of wind-tolerant (frontline- trees) is a critical list for food production and animal husbandry.

DIRECTIONS AND SEASONS

Winds are fairly predictable and often bi-modal in their directions and effects in local areas. For the landscape designer, **wind-flagging** or older trees and wind-pruning tell the story; the site itself has summed total wind effects over time.

From Latitudes 0° to 35° north and south in oceanic areas, winds will be bi-modal and seasonal, southeast or northwest in the southern hemisphere, southwest or northeast in the northern hemisphere. Locally, the directions will be modified by landscape, but the phenomena of windward and leeward coasts are almost universal. From Latitude 35° to the limits of occupied coasts, westerlies will prevail in winter, easterlies more sporadically as highs or lows pass over the site and remain stationary to the east or west. Cold winds will

BEAUFORT NO.	KNOTS	km/h	MPH	DESCRIPTION
1	1	1	0.5	Calm
2	1 - 3	1 - 5	1 - 3	Light airs
3	4 - 6	6 - 11	4 - 7	Light breeze
4	7 - 10	12 - 19	8 - 12	Gentle breeze
5	11 - 16	20 - 28	13 - 17	Moderate breeze
6	17 - 21	29 - 38	18 - 24	Fresh breeze
7	22 - 27	39 - 49	25 - 31	Stormy breeze
8	28 - 33	50 - 61	32 - 38	Near gale
9	34 - 40	62 - 74	39 - 46	Gale
10	41 - 47	75 - 88	47 - 55	Strong gale
11	48 - 55	89 - 102	56 - 64	Storm
12	56 - 63	103 - 117	65 - 73	Violent storm
13	64 +	118 +	74 +	Hurricane

BEAUFORT NO.	EFFECTS	
0 - 2	Slight, no damage to crops or structures	
3 - 4	Damage to very susceptible species	Useful energy produced
5 - 6	Mechanical damage to crops, some damage to structures	Useful energy produced
7 - 12	Severe structural and crop damage. Damage to windmills.	

THE REDUCTION OF WIND VELOCITY IN FORESTS:

Penetration (m)	Reamining Velocity (%)
30	60 - 80
60	50
120	15
300 - 1,500	Neglible wind.

TABLE 5.5
THE BEAUFORT SCALE.

blow from continental interiors in winter, and warmer but still chilling winter winds blow in from the seas.

Islands and peninsulas from Latitudes 0° to 28° eperience two main wind modes, those of the winter winds or trade winds (southeast in the southern hemisphere, northeast in the northern hemisphere) and those of the monsoon. In effect, we look for two seasons of winds and two short periods of relative calms or shifting wind systems in these latitudes. These are the main winds of tropical oceanic islands.

In summer, the cross-equatorial monsoon winds deflect to blow from the northwest in the southern hemisphere, and as southwest monsoons in the northern hemisphere. Southeast Asia and the Pacific or Indian ocean islands are most predictably affected by these bi-modal systems. Although many sites are also affected by only two main strong wind directions, these are rarely as strictly seasonal in effect as they are closer to the equator.

WIND LOADS

On warm sea coasts, where onshore winds not only carry salt but also evaporate moisture, salt deposits on vegetation are the limiting factor on species selection, and only selected hardy species with fibrous or waxy surfaces can escape death or deformation by salt burn.

As well as inorganic materials, wind may transport organisms ranging from almost impalpable spores of fungi and ferns to very weighty insects such as plague locusts which are swept aloft by heated air columns, and carried as frozen or chilled swarms to down-draught areas. Here, they thaw out and commence feeding, or perish in oceans far from land. Mosquitoes, fruit flies, wasps, and spiders deliberately spin aerial floatlines and also migrate over mountain and oceanic barriers on windstreams. Flocks of migrating birds also take advantage of windstreams as they circle the globe.

Flow of air (wind) over leaf surfaces promotes rapid transpiration, as does high light intensity (Daubenmire, 1974). When we have both effects together, shrubs and trees may lose too much water, and trees guard against this combined factor by presenting whitish undersides of leaves to the light as the wind blows, thus carrying on a dynamic balance between the light and wind factors. Vines and trees may alter leaf angles to reflect light, trap air, or to reduce the area of leaf exposed to light or wind. Thus, both pigmentation and leaf movement are used to balance the effects of variable incoming energy, and leaf pores close down to prevent moisture loss.

WIND HARMONICS

In a radio programme on sailing (Australian Broadcasting Corporation, 19 Dec '84), Frank Bethwaite, a New Zealand-born Australian boat designer, pilot, and sailor outlined some of the characteristics of ground winds. Such winds do not blow steadily, but vary as gusts and calms in a predictable and locality-specific way; that is, the common winds of any one site have regular pulses.

He states that such regular variations are easily timed; a 49-60 minute frequency of gusting is typical of mid-latitudes, with gusts 40% stronger than lulls. In lulls, the wind *direction* also changes, as light crosswinds at about 15° to the main wind direction.

The variation in wind speed and direction is systematic and regular, and both frequencies, durations, and amplitudes can be obtained by combinations of stopwatches, anemometers, and wind vanes (or all of these recorded on automatic equipment).

Such "waves" of wind are made visible in grass-lands, or on the surface of waters viewed from a cliff. They are also, at times, reflected in clouds as "rank and file" systems. The lulls show as spaces between cloud ranks, and in these spaces, light clouds of different alignment represent the change of direction typical of lulls.

The gusts are ponderous, representing vortices; the lulls are of light crosswinds. Some periods are short (Bahrain, 5.25 minutes; Sydney, 6-12 minutes; Toronto, 10 minutes). Wave "fronts" on grasslands may come at every 14 seconds, with gusts at longer intervals. Sea waves themselves have a characteristic periodicity and speed, usually about 5-12 per minute, the period lengthening in storms.

In the westerly wind belts, we can distinguish between the PREVALENT WINDS of from 8-24 km/h, which blow for five out of seven windy days, and the ENERGY WINDS of from 16-40 km/h which blow on the other two days. The energy winds come from between 15°-20° off the direction of the prevalent winds (Michael Hackleman, *Wind and Windspinenrs*, Peace Press, California, 1974).

WINDBREAKS

It is the chill factor—the removal of heat from surfaces, and evaporation of fluids—that creates cool to cold climates in the tropics at lower altitudes than adiabatic or altitude factors would indicate. This chill factor retards plant growth, and lowers the efficiency of solar devices and insulation. In cyclonic or hurricane areas, catastrophic winds may become the over-riding design modification, around which all other factors must be arrayed.

We are not much concerned with sheltered and low wind-energy sites, except to choose them for our dwellings in exposed landscapes, but close attention must be paid to shelter strategies in exposed sites.

On sites with predictable wind patterns, revealed either by trees, derived from local knowledge, or indicated by wind records over time, we can plan directional, patterned windbreak of earthbank and trees. On sites where severe winds and sandblast may come from any direction (as in some deserts), the strategy is to impose a close rectangular or network pattern on windbreak.

However the windbreaks are arranged, buildings, gardens, and animal shelters can be arranged to face the sun and benefit from solar impact.

Essentials of a Windbreak

The essentials of windbreak are fairly well known and local lists of species for windbreak are often available from forestry and agricultural advisors or departments. Essentials are:

- Good species selection to be used as pioneers (easily grown);
- Initial protection of planting from mechanical or wind damage (bagging, fencing);
- Periodic or trickle irrigation to reduce desiccation;
- Anchoring by stones or mulch; and
- Species with 40–50% penetrability in the front line or as dominants.

Many fire-resistant plants are also wind resistant, and in addition to these, some drought-resistant but fire-prone species (pines) will withstand wind. What they have in common are ways of resisting desiccation and sandblast. Such plants have, as common features:

- Fibrous stems (palms).
- Fleshy leaves (aloes, agaves, *Euphorbias*).
- Hard, needle-like leaves or stems (pines, tamarisks, *Casuarinas*, some *Acacias*).
- "Furry" or hairy (tomentose) leaf covers, or waxy leaves (*Coprosma*, eucalypts, some pines, some *Acacias*).

Initial protection can come from:

- Individual open-ended plastic bags around stakes (a common and effective establishment method).
- Earth mounds, or side-cast earth banks of greater length than the tree line.
- Brush fences, even wire-mesh fences, or staked fences with 40% wind penetrability.
- Tussock or tough unmown grass to windward (leave if already present).

All of these can be used in combination in very hostile areas. It is usual for the windward rows of trees to be heavily wind-flagged, and for taller species to be placed in their lee. On coasts and in deserts, it is not until after the fourth or even fifth tree row evolves that wind-prone fruit or nut-bearing trees will yield, so windbreak is the *first* priority for gardens in these situations.

Substantial trellis is a more immediate alternative, but care should be taken to make this sinuous (if of brick or mud brick) or zig-zagged (if of timber), as it has to withstand persistent and severe forces until shelter grows on either side of it. Earth mounds can be better streamlined, being less sensitive to windthrow. The hollow from which the earth is taken to make the mound can be made to hold water or to give protection to young plants.

Tyre walls are sometimes feasible, and create great warmth inside the tyres, but are scarcely aesthetic unless very regularly arranged and planted. They have the advantage of being cheap, and can be removed once effective. Mesh fences, if stoutly built with a heavy top rail, can be the basis for fedges (fence-hedges) of thick-leaved vines, which on coasts may completely mound them over with tough semi-succulents such as *Rhagodia*, *Tetragonia*, *Carpobrotus*, or *Mesembryanthemum*. Rock walls and tyres may be similarly mounded with scramblers or cacti, some of which provide bee forage

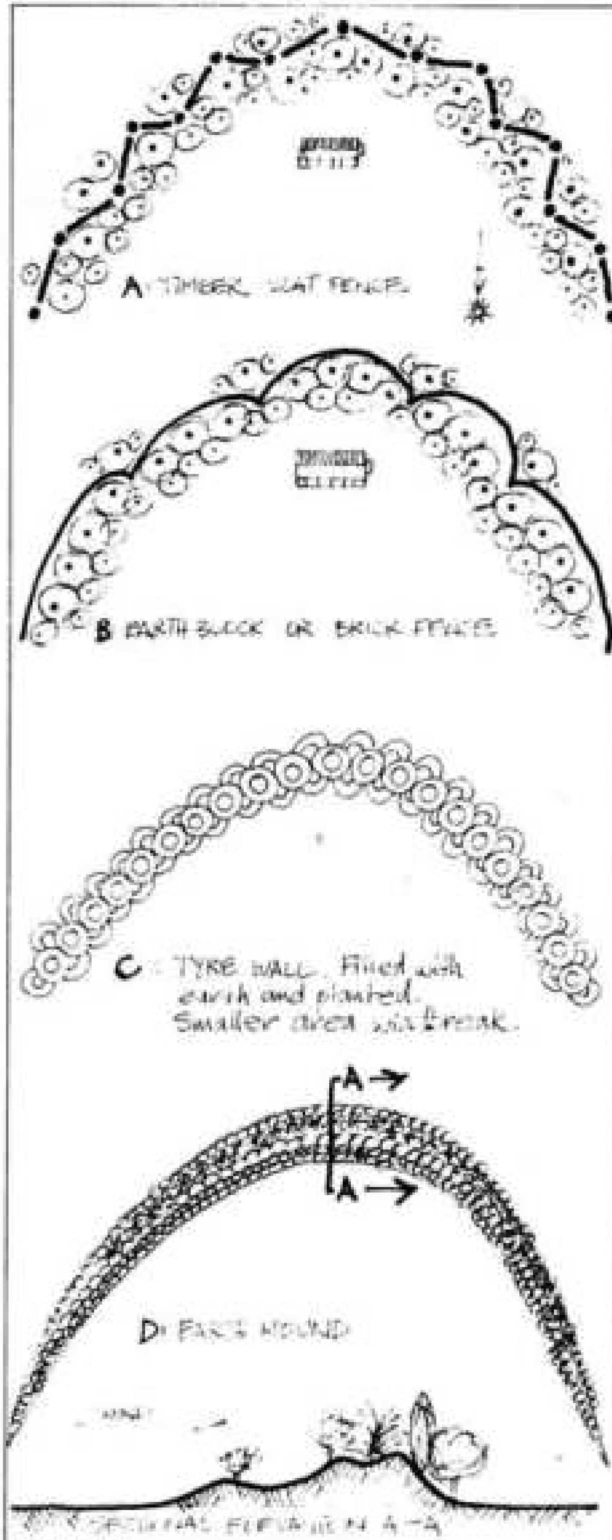


FIGURE 5.15
METHODS OF ESTABLISHING WINDBREAKS.
A variety of stable windbreaks using different materials.

and berries or edible fruits.

It is rare for tree canopies on dry saltwind coasts to gain more than 46 cm height in 1 m width (18 inches in 3 feet), so considerable width must be given to pioneer windbreaks in these situations, unless those hardy pioneers such as the Norfolk Island pines can be nursed to grow to windward. However, as this slow climb to height commences from *ground level*, a fence, building, earth bank, or barrier gives it a great start for far less spread (**Figure 5.15.D**).

Even a 46-62 cm (18-24 inch) high "fence" or mound earth will grow a sweet potato, strawberry, or cabbage in the lee, while hard-pruned canopies need not be barren, as many dwarf fruit, vine, and flower crops will grow below these if mulch and water are provided. In windbreak forests near coasts, small openings of 6–9 m (20–30 feet) provide garden shelter and admit light.

There is, in fact, a special charm about those 3–3.5 m (10–12 feet) high dense coastal shrubberies in which nestle small shacks, through which wander sandy paths, and in which people create small patches of scattered garden using wastewater and mulch. Once shaped, fruit trees in this situation seldom need pruning, and at times one wonders if the wind is not an advantage in that it forces compact and careful work, punishes carelessness, and promotes wastewater use.

Across the whole of the flattish peninsula of Kalaupapa on Moloka'i, the Hawaiians had built tiny stone fences of 25–50 cm (10–20 inches) high and only 4.5–5 m (15–18 feet) apart, behind which they grew a basic sweet-potato crop, and in which grew tough fern for mulch. All are now abandoned, but on the seaward coast, wild date somehow struggles to 4.5 m (15 feet) or so in the teeth of the tradewinds, and would have made a grand windbreak had the Hawaiians retained their land against tourism and graziers. Just to windward, the strong winds bring so much salt spray ashore that it crystalizes out in pinkish ponds, mixed inexorably with the red of the volcanic earth on which it forms. Even today, it is gathered as "Hawaiian salt", and is further mixed with the roasted kukui nut and chilies for a delicious raw-fish condiment.

Some Benefits of Shelterbelt

1. *Shelterbelt effects on house design*. For glazed areas and hot water (flat plate) collectors, wind chill factors remove 60% of heat alone. Shelterbelt (including thick vine trellis) around a house can effect a 20–30% saving in heating fuels in moderate to severe winters. Thus, in cold areas earthbanks plus shelterbelt, and a sun-facing aspect, is a critical design strategy. In deserts, where advected (wind-carried) heat is the most severe effect on human comfort, shelterbelt trees serve to reduce ground temperatures up to 15°C.

2. *Effects of exposure on livestock*. Blizzards will kill livestock and newborn lambs, and even hardy and adapted animals can lose 30% of their bodyweight in 3 days of blizzard. As well as shelterbelts in fields, we need to be very careful to design fences so that they do not form downwind or downslope traps, as herds escaping blizzards will pile up against them and smother in fenced corners. All moorland and high plateau fences should allow easy downwind escape to woodlots, sheltered valleys, or lower elevations.

In less severe conditions, sheep weight in unsheltered fields in New Zealand is 15% less than that of sheltered areas. Australia attributes 20% of all lamb losses to wind chill factors, and issues regular wind chill warnings at shearing time to prevent adult sheep loss.

Cattle fed winter rations on exposed sites will eat 16% less of this food, so that winter hay and concentrates need to be fed out in shelter for animals to obtain full benefit. Both heat and cold have similar effects on weight gain, and shelterbelt is one of the most effective ways of increasing livestock production, and conserving rations. Thus, in designing for livestock, fences, shelter, access to shelter, and feeding and watering points all need sensible placement, so that animals are not exposed to extreme temperatures. In the tropics and subtropics, a ridge planting of pines or *Casuarinas* with a wind gap left below the crowns affords both shade and an induced breeze that discourages flies and mosquitoes. Such ridges are also rich mulch sources for lower slopes.

3. *Civil construction*. Snowdrift across highways is more effectively and permanently blocked by hedgerow of hardy *Caragana* and *Elaegnus*, which are estimated to be 50% cheaper than stout fences, and of course outlast them. Juniper in high country actually grows better in areas of snow drift (below the sharp ridges where snow forms cornices), and swales at such places enable more snow melt, therefore more available root moisture for trees in spring and summer.

Wind shear on exposed highways or at caravan parks can cause casualties and property damage, so that we need to design windfast median strips and highway shelterbelt in areas of known hazard, but especially on mountain passes and near exposed coasts subject to gales.

4. *Shelter in and around croplands and orchards*. For croplands, a matrix of shelterbelt species 10–16 m in height and 33–66 m apart (*Casuarina*, poplar, Matsudana willow, trimmed eucalypt) affords wind protection for such crops as kiwifruit and avocado, and give the greatest increases in yield while reducing wind damage to fruit and leaf. For instance, citrus culled as damaged is 50% of the crop in unsheltered areas, versus 18.5% in shelterbelt systems, cotton yields are 17.4% higher within five times the height of the shelterbelt, and fall off to a 7.9% advantage at ten times the height of the belt.

Effects of shelterbelt are compound, and include more meltwater from snow, much greater fruit or seed set in bee-pollinated crop, the preservation of good shape in the trees, hence less pruning. Species selection of shelterbelt trees is essential, and a set of factors can be the criteria that assists the farm enterprise sheltered. These include:

- Nitrogen fixation or good mulch potential from leaves and trimmings;

- Hosting of predatory insects or birds that control crop pests;
- Least moisture competition with crop (although roots from the shelterbelt can be ripped or trenched at the edge of crops);
- Excellent forage yields or concentrated foods for livestock; and
- Natural barriers to livestock (thorny plants, or woven hedge).

Shelterbelt is planted as a succession from a tall grass to a taller legume to a long-term, tall, windfast hedge of e.g. *Casuarina*, poplar, willow, eucalypt, oak, chestnut. All this complex can be set out at once, and managed as it evolves to maturity. Quickset (by cuttings) hedges of poplar and *Erythrina* are popular because of their fast windbreak effect, but species must be chosen to suit a particular climate.

Where space is ample and winds strong, the profile of a windbreak can be carefully streamlined, and up to six rows of tree and tall grass lines established, giving a mixed yield of forage, timber, fuel, mulch, honey, and shelter. In more constricted areas, a matrix of single-tree lines is usual, and effective if close-spaced. However, there is no such thing as a standard shape or windbreak, and very different configurations are needed for different sites, functions, and as accessory species to the enterprise sheltered, the wind strength, and the wind load (salt, sand, dust).

5. *Effects of windbreak on soil moisture.* Windbreak is very effective in snowy areas, increasing soil moisture 4% to four times the height of the break, and that to 1.2 m depth in soils. Obviously, the benefits to trees in cold deserts are as a reserve of soil moisture that is rare in cold dry climates. The same effect occurs locally in the lee of tussock grasses, and can be used to establish a tree.

In foggy climates or facing sea coasts, we must add the effect of sea air condensation, which can be from 80–300% of rainfall as leaf drip. In hot deserts and hot winds, the advected hot winds are the major factor in soil moisture loss. Such effects are produced over large treeless areas of dry grain crop as well as in deserts.

The effects on grain crop of windburn and seed shattering in hot winds is insignificant for up to 18 times the height of the windbreak.

6. *Less soil loss due to windstorms.* Very serious soil losses of up to 100 T/ha/day in duststorm episodes (usually followed by torrential rain) are prevented by windbreak and soil pitting with tussock grasses. Approximately 50–70% of dusts settle out of the air 100 m into tree clumps, so that treelines are the essential accompaniment to any pastoral or crop system in arid areas.

On coasts, removal of mangroves and coastal dune vegetation results in a sudden acceleration of wind erosion on beaches and coastal soils, and following deforestation, up to 30% more silt per annum flows into and reduces the useful life of water storages.

7. *Windbreak and hedgerow as accessory to crop and livestock.* Quite apart from the above effects, windbreak species can be chosen to provide excellent crop mulch (*Prosopis*, *Acacia*, *Erythrina*, *Melia*, *Canna*) and fodders (all the foregoing species plus *Leucaena*, Fig, *Pennisetum*), and also to fix or recycle nitrogen and phosphatic fertilisers, or to mine trace elements (*Casuarina*, *Banksia*, *Eucalyptus camaldulensis*).

Dry or cold-deciduous species and monsoon deciduous trees give a natural leaf fall in crop, automatically adding growth elements to the crop. In every crop and orchard it is advisable to interplant leguminous trees for mulch, soil building, and in-crop windbreak or frost cover. Trees like avocado and crops like papaya can be grown on sub-tropical frosty sites providing there is a high canopy of hardy palms or light-crowned legumes (e.g. Butia palm, *Jacaranda*, *Tipuana tipu*). Such sites do not frost, as there is no bare-ground radiation at night, and advected frost is impeded.

Finally, forage and firewood from windbreak provides excess fuels to cook crop products, which is an important factor in the third world. In summary, well-chosen and designed windbreak can occupy up to 30% of the total area of any site without reducing crop yields, and if windbreak species are chosen that aid the crop itself, there will be an increase in total yield, soil quality, and moisture available.

Hedgerows and Shelterbelts

Shelterbelt species must be carefully selected to give multiple uses, to either ASSIST the crop yield, or ADD TO the end use yield (e.g. forage trees in pasture). This ensures the area occupied by shelterbelts adds to the

PERMEABILITY	WINDSPEED REDUCTION	DISTANCE OF EFFECT (H= Windbreak Height)
60%	20%	12 x H
50%	50%	27 x H
0%	100%	15 x H (with severe eddies)

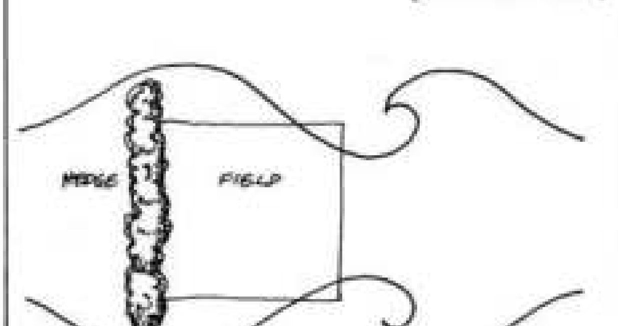


FIGURE 5.16
PERMEABILITY OF WINDBREAKS.
This figure shows how winds flow around a windbreaks which needs to be wider than the field for less permeable hedgerow.

total crop yields, rather than deducts from them. In general, we would gain in crop *or* pasture yield using nitrogen fixing and browse-edible shelterbelts species, and lose crop yield by using high water-demand, non-leguminous, and inedible shelterbelt species.

However, where we experience severe sea or desert winds, which greatly reduce all yields, we must select salt-resistant or sand-blast-resistant windbreak no matter what the intrinsic yields of the shelterbelt. It is rare for sea-front trees to bear effectively (e.g. the outer 4–5 rows of coconuts on exposed islands yield little crop), so that choice of frontline seacoast plants for seed or fruit yields is often irrelevant when considering species for multiple function.

For isolated trees, or trees whose canopy lifts above the general forest level, wind of even low speeds may increase the transpiration rate, sometimes doubling water use. The effect is greatest on water-loving plants, and much less on dry-adapted species which have impermeable leaf cuticle and good control of stomata, or a cover of spines and hairs.

Hot, dry winds, and winds laden with salt have the most damaging effect on plant yields (hence, animal yields), although at high wind speeds mechanical damage can occur, which prevents or reduces yields no matter what the humidity or salt content of the winds. Damaged crop plants such as corn or bananas suffer photosynethic inefficiency ranging from 20–85% when the leaf laminae are torn or frayed, or the midribs are broken (Chang, 1968).

Plants show different resistances to wind damage:

- *Wind tolerant* (and wind-fast). These are the many short or creeping plants at the boundary layer of still air near the ground, or the front-line plants of sea coasts, e.g. *Cerastium, Araucaria heterophylla*. Yields are little affected by strong winds.
- *Exposure tolerant*, e.g. barley, some *Brassicas*, *Casuarina* and *Coprosma repens*. Yields are reduced in strong winds, but dry matter yield is less affected than in wind-sensitive plants.
- *Wind sensitive*. These are the many important crops such as citrus, avocado, kiwifruit-vines, many deciduous fruits, corn, sugar cane, and bananas. Both plant height and yields rapidly decrease with increases in wind speed. For these species, very intensive shelterbelt systems are essential.

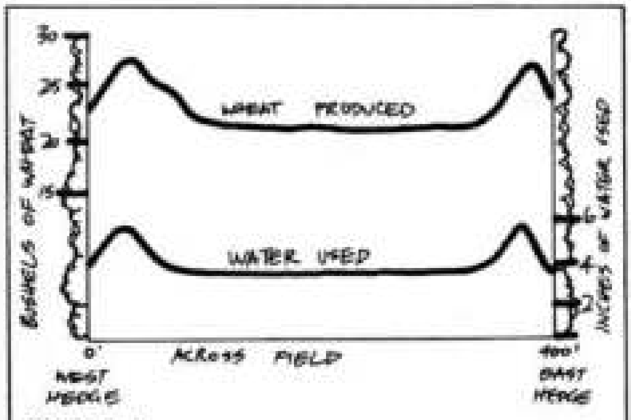


FIGURE 5.17
WATER USE AND WHEAT PRODUCED.
The efects of hedgerow increase yields on both sides but increase water use.

Problems arise when the plants used for shelterbelt (e.g. poplar) are themselves heavy water-use species with invasive roots. An annual root-cutting or rip-line may be necessary along such windbreaks to permit the crop sheltered to obtain sufficient water, but it is best to choose more suitable species in the first place.

Windbreak Height and Density

The height and density, or penetrability, of windbreak trees are the critical shelter-effect factors. Some configurations of windbelt may causes frost-pockets to develop in the still air of sheltered hollows. PERMEABILITY is an important factor if we want to reduce frost risk or to extend the windbreak effect (**Figure 5.16**).

Briefly, we need windbreaks spread at *no more than* 20 times the hedgerow height in any severe wind. In the establishment of wind-sensitive tree crop we may actually need continuous (interplant) windbreak. The length of windbreak needs to be greater than the length of the field protected, as wind funnels around the end of windbreaks in a regular flow pattern.

Windbreak Configurations

In general, species chosen for windbreak should permit 40–70% of the wind through, which prevents the formation of a turbulent wind overturn on the leeward side. Windbreak height is ideally one-fifth of the space between windbreaks, but is still effective for low crop at one-thirtieth of the interspace.

Sensible configurations are shown in **Figure 5.18**. Note that some wind shelter systems are placed throughout or within the crop or fruit area.

A. *Dense windbreak* with bare stem area below. Effects: good summer cool shade for livestock; poor to useless winter shelter. Clumps of such trees on knolls allow animals to escape heat, and flies and mosquitoes are much reduced.
Sample species: *Cupressus, Pinus, Casuarina*.

B. *Alternate* (zig-zag) planting of very permeable trees. Effects: good "front-line" seafront systems to reduce salt burn and provide shelter for more dense trees on islands and coasts. Species: *Araucaria, Pinus, Casuarina*.

C. *Compound windbreak* of high density. Effects: The best protection for eroding beaches, lifting the wind smoothly over the beach berm and trapping sand. Also effective in dust-storm areas as a dust trap. Species: Ground: *Convulvulus, Phyla (Lippia), Mesembryanthemum*. Low shrubs: *Echium fastuosum*, wormwood. Shrubs: *Coprosma repens*. Trees: *Lycium, Cedrus, Cupressus*, some plants.

D. *Permeable* low hedgerow of *Acacia* or legumes. Effects: Good effects on grass and crop growth, allows air movement to reduce frosts. Species: *Acacia, Leucaena, Prosopis, Albizia, Glyricidia*, tagasaste and like tree legumes.

E. *"Incrop "windbreak*

1: Savannah-style configuration of open-spaced light-crowned trees in crop or pasture. Effects: Excellent forage situation in arid areas, especially if trees provide fodder crop; pasture protected from drying winds. Species: Several fodder palms, *Inga, Acacia*, tagasaste, baobab, *Prosopis*.

2: Complete or almost-complete crown cover *in* tree crop. Effects: Excellent frost-free sub-tropic and tropic lowland configuration where fruit trees (F) are interplanted with leguminous trees (L) as shelter and mulch, with *Casuarinas* (C) as borders. Suited to humid climates, or irrigated areas. Species: Fruits (F) from palms, avocado, *Inga*, banana, citrus. Legumes (L) of tagasaste, *Acacia, Albizia, Inga, Glyricidia, Leucaena*. Borders (B) of *Casuarina*, low palms (*Phoenix canariensis*), *Leucaena, Prosopis*, and other wind-fast trees and tall shrubs.

The partial list of windbreak configurations given above covers only some cases, and in every case a designer must select species, study suitable total conformation, and allow for evolution or succession. As with all permaculture designs, general known principles are followed but every actual site will modify the design, as will the purposes for which shelter is intended.

Windbreak is essential for many crop yields, particularly in orchards. As discussed, wind causes mechanical damage, salt-burn, and may transfer (advect) heat and cold into the crop. Unless conditions are very severe, single-line windbreak spaced at 15 times height may have a satisfactory effect on ground conditions, and this is recommended for crops and grasslands. However, severe montane and coastal winds need more careful design, and a complex windbreak of frontline species able to buffer the first onslaught of damaging winds is needed (**Figure 5.19**).

For both tree crops and orchards, we have a very different potential strategy in that the windbreak may be composed of trees compatible with the protected forest or orchard system we wish to shelter, and can then be integral with the crop (**Figure 5.18 E1** and **E2**). Great success with such strategies has been demonstrated both for wind and frost moderation in susceptible crop such as citrus, avocado and macadamia nuts or chestnuts, using a protective interplant of hardy *Acacia, Casuarina, Glyricidia*, tagasaste, or *Prosopis* spaced *within* the crop. As all of the windbreak species mentioned fix nitrogen or phosphates, provide firewood, radiate heat, and shelter crop, it is sensible and beneficial to fully interplant any susceptible tree crops behind barriers of front-line windbreak. Windbreak in this instance is integral with the crop (as it is in natural forests).

The importance of windbreak extends to SOIL CONSERVATION. In dry light soils, windbreaks can reduce dust and blown sand to 1/1000th of unsheltered situations (Chang, 1968) within 10 times the height of windbreak. Thus, in crops in arid or windy areas, it is necessary to plant windbreaks closer together for the sake of soil conservation. The loss of soil at 20 times windbreak height is 18% of open situations, which is still too much when we can lose 8–40 t/ha in windstorms!

Similarly, WATER EVAPORATION can be halved in strong winds (32 km/h or more) for distances up to 10 times height. Over 24 km/h, 30% gain in soil water conservation is achieved. Only in still-air conditions is evaporation loss about the same for sheltered and open field conditions.

SNOW MOISTURE is increased by a windbreak of type A or B (**Figure 5.18**) when the snow is trapped on fields. The snow depth in winter bears a close correlation to dry matter yields in spring and summer,

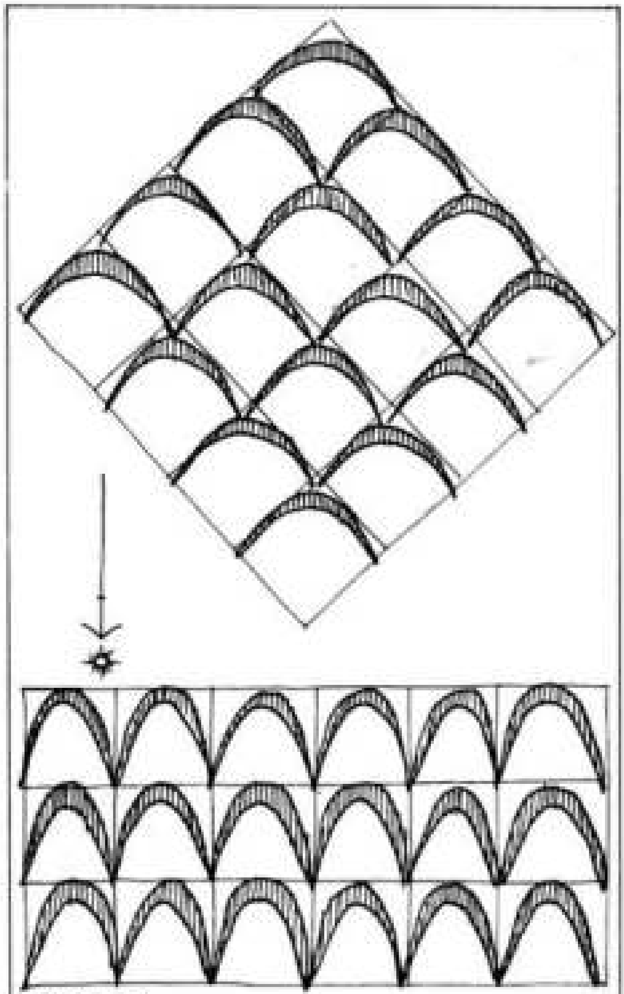


FIGURE 5.19
COMPLEX NETS FOR VARIABLE WINDS.
Two examples are given to suit straight-line fencing. Crescents are bowed towards the most damaging winds.

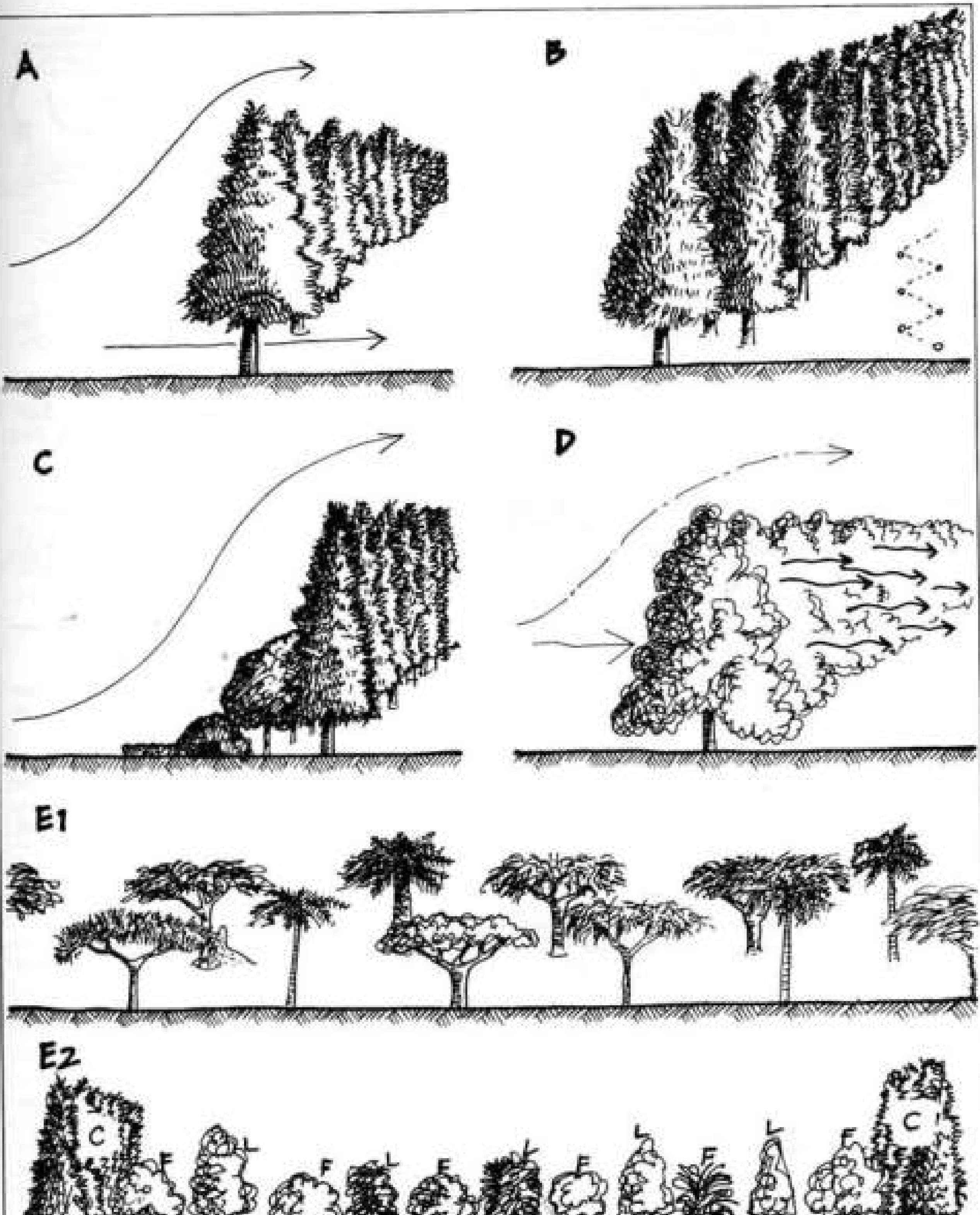


FIGURE 5.18
WINDBREAK CONFIGURATIONS.
There is no 'best' windbreak; every crop, site, or condition needs specific analysis. Here, A suits ridges , B tall vine crop, C coasts, D fields, E1desert crops, E2 mesothermal orchards.

so that crop yields are highest downwind from windbreak areas. Wherever snow blows across the landscape, windbreaks of savannah configurations create spring soil moisture traps. It is also possible to do this by using open swales in snow-drift areas. Windbreaks in exposed snowfield areas can be better established in the lee of earth bunds or in natural cornice just polewards of ridges.

CROP YIELDS vary in increase from the 100% increase in such crops as avocado to 45% in corn, 60–70% in alfalfa, 30% in wheat, and lesser gains (7–18%) for low crops such as lettuce. All these increases follow windbreak establishment on exposed sites. Effects are of course less in naturally sheltered situations or areas of normally low wind speed. However, almost all normal garden vegetables (cucurbit, tomato, potato) benefit greatly from wind shelter. For this reason, a ground pattern similar to that in **Figure 5.20** is recommended for such crops and wind-affected pastures.

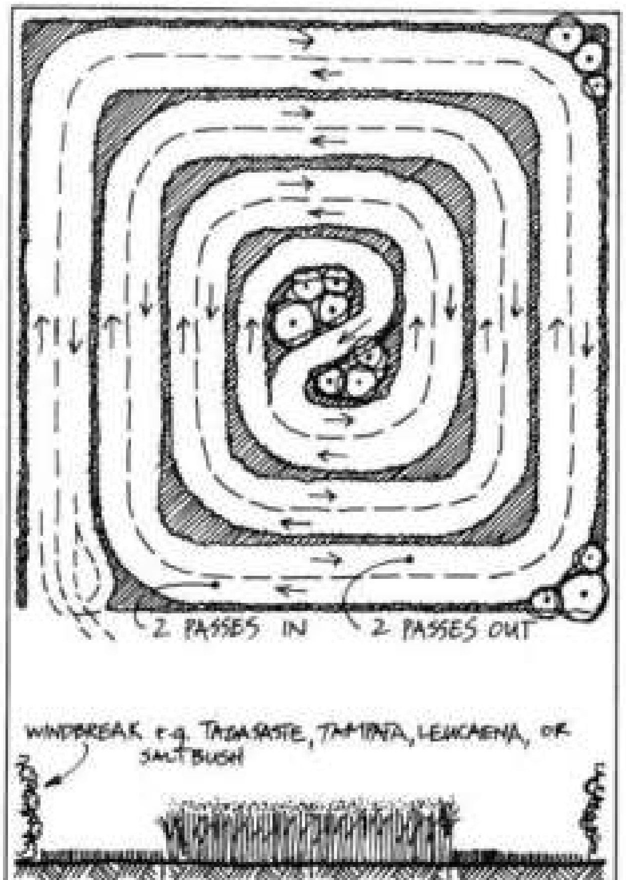


FIGURE 5.20
LOW LEGUMINOUS WINDBREAK IN CROP.
The spiral pattern allows a continual tractor path; it also provides a very sheltered crop environment for all wind directions.

HURRICANES (CYCLONES, TYPHOONS)

Very stable and still-air calms near the equator may produce fierce updraughts of air over warm oceanic

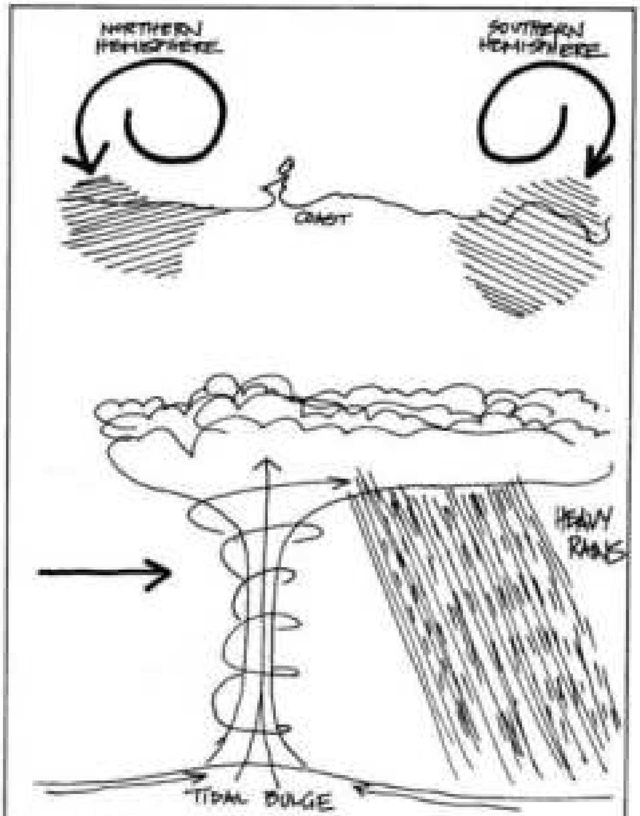


FIGURE 5.21
HURRICANES OR CYCLONES.
Rain and inshore, tidal effects are most severe to the poleward sides of the low-pressure cell, as is inland flooding, accentuated by the tidal bulge.

areas, which over some days or weeks build up to the great rising spirals of hurricanes. As these move slowly (usually at 24–32 km/h) across the ocean towards land, wind speeds around the vortex can reach 128–192 km/h, while within the vortex itself a "tidal bulge" rises up to 2.7 m (9 feet) above sea level (**Figure 5.21**); this water bulge causes a tidal surge at coastlines.

Vortices revolve anti-clockwise in the northern hemisphere, clockwise in the southern, and thus coastal areas to the north side have the highest water and wave levels in the northern hemisphere, and to the south side in the southern. The combined effects of rapidly fluctuating pressures, tidal bulge, wave and sea pile-up, and wave backwash create devastation on coasts. Although hurricanes cannot persist far inland, as the sea itself generates the vortex, the intense rains generated do reach well inland to flood rivers and estuaries, adding to the general destruction. With all effects combined in a "worst case" of high tides and prior rains, destructive wave attack can reach 6–9 m (20–30 feet) above normal high-tide wave levels.

As wind strength increases at sea, wavelength also increases, so that normal wave fronts arriving at 8 per minute in calm Atlantic conditions slow down to a storm frequency of 5 per minute before great winds. These wider-spaced waves travel fast, are larger, and create severe backwash undermining of shorelines.

Storm waves may therefore arrive long before a cyclonic depression or hurricane, and the change of wave beat gives warning to the shore crabs, birds, fish, and turtles, who either take shelter inland or go to sea to escape the approaching hurricane.

As modern satellite photographs are used to track the hurricane, there is usually a few days' warning for coastal areas, and evacuation is sometimes ordered. Well-built towns (such as Darwin, Australia, after its cyclonic devastation in 1972) can withstand cyclones with minimal damage, but such stoutness is usually only built in after an initial (and sometimes total) destruction. It is possible to strictly regulate and supervise buildings to be safe in hurricanes, and in areas where flimsy constructions are normal, to dig refuge trenches and caves for emergency shelter. All such shelter must be in well-drained hillside sites.

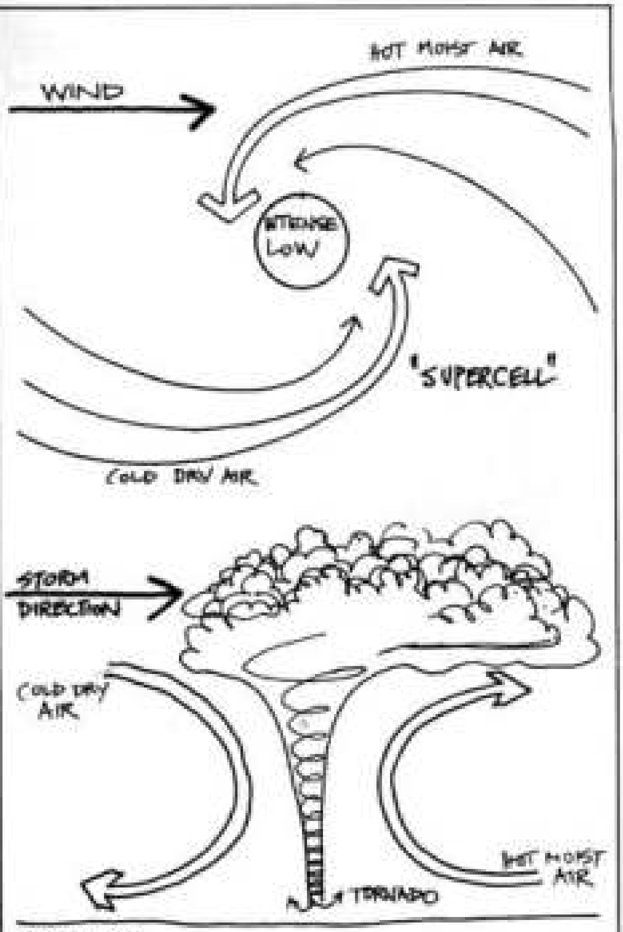


FIGURE 5.22
TORNADOES.
Unlike hurricanes, tornadoes occur over land and sea from shear effects at the junction of hat and cold air masses, creating intense low-pressure vortices.

TORNADOES

Hurricanes are large, slow phenomena covering hundreds of square miles, and mainly confined to coasts facing large stretches of tropical seas, with very large heat cells. Tornadoes, however, may occur in quite cold inland areas, last only seconds or minutes, and affect only a few square kilometres. Thus, they usually escape detection by satellite and ground sensors.

Nevertheless, the stresses placed on buildings, civil constructions, chemical or nuclear facilities, airfields and villages can be disastrous. Wind speeds may reach 120 km/h, at worst 280 km/h; these speeds can exceed hurricane winds. The conditions for tornadoes are:

- Thunderstorms with fast-growing cumulonimbus cloud;
- A persistent source of warm moist air to feed the updraught side of the front;
- An input of cold dry air entering the system from another direction; and
- A vortex formation in the resulting storm; this reaches the ground as a tornado, caused by wind-shear effects at the border of the conflicting system, or as a frontal dust storm in deserts.

Effects: Trees twisted off and broken; people and

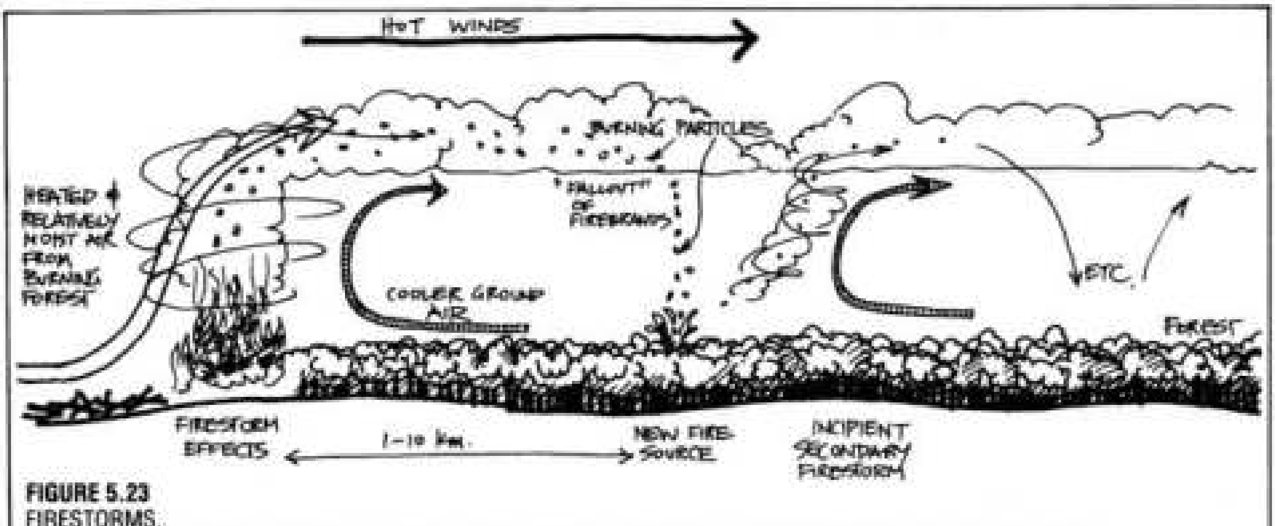


FIGURE 5.23
FIRESTORMS.
Wildfire can create fire tornadoes, especially at hill crests, and these spread burning particles downwind for many kilometres.

objects sucked out of cars and buildings; "rains" of soil, fish, frogs may fall out ahead of the disturbance.

FIRESTORMS

Intense wildfires (urban and rural) fanned by dry winds will create powerful vortices due to conditions very much like that of the tornado. The mass ignition of large areas of forests and buildings feed a powerful updraught. Colder dry air rushes in to replace the air consumed in burning, and fire tornadoes (firestorms) result, carrying large burning particles aloft on "smoke nimbus" clouds. Whole house sections pinwheel across the sky to drop out ahead of the main fire front, where they in turn set up secondary firestorm conditions. The effects on people and property are very much like those of tornadoes, but with the additional danger of intense heat.

5.7

LANDSCAPE EFFECTS

CONTINENTAL EFFECTS

Heat is transported on a world scale by two great circulations: that of the air masses, and those of oceanic currents. Of these, air masses are more wide-spread in their effect, and are least limited by land masses. Oceanic currents, or indeed proximity to any large body of water, have their greatest moderating effect on down-wind shorelines. Such effects may have little inland influence. The concept of continental climates was evolved to describe those extreme and widely fluctuating inland climatic zones that are not buffered by the effects of sea currents, and which demonstrate periods of extreme heat and cold, all the more marked on high mountains.

Thus, the third complication on the simple temperature-rainfall classifications is CONTINENTALITY. After this, only one special factor remains, and it is the effect of hills or ranges of mountains on local climate; these effects are very like the latitudinal effects on a global scale.

LATITUDE AND ALTITUDE

An average measure of temperature fall with altitude is: 9.8°C/km (5.4°F/1000 feet) in rainless or dry air; or 4–9°C/km (2.2–5°F/1000 feet) in humid and saturated conditions.

As a rough approximation, every 100 m (330 feet) of altitude is equivalent to 1° of latitude, so that at 1000 m (3300 feet) on the equator, the temperatures are about equivalent to a climate 10° off the equator with the same humidity. At 10° latitude off the equator, a plateau at 1850 m (6000 feet) has a climate more like that at 30° latitude, with a probability of wind chill to below freezing. For high islands or ranges of mountains, this altitudinal factor is crucial to design strategies for homes and gardens. Altitude effect alone enables us to grow a wide range of plant species on a high island, using the area from ocean to mountain- top.

High Altitude Effects

Mountains are not in fact strictly "latitude equivalents", as the air is more rarefied, air pressure less, and radiation therefore higher. On very high mountains of 4000 m (13,000 feet) and more, people may experience oxygen deficiency (mountain sickness), snow or radiation blindness, and suffer from the extremes of day-night temperature fluctuations. The mountain sickness of oxygen stress is not felt by locals, but can cause extreme fatigue, insomnia, and laboured

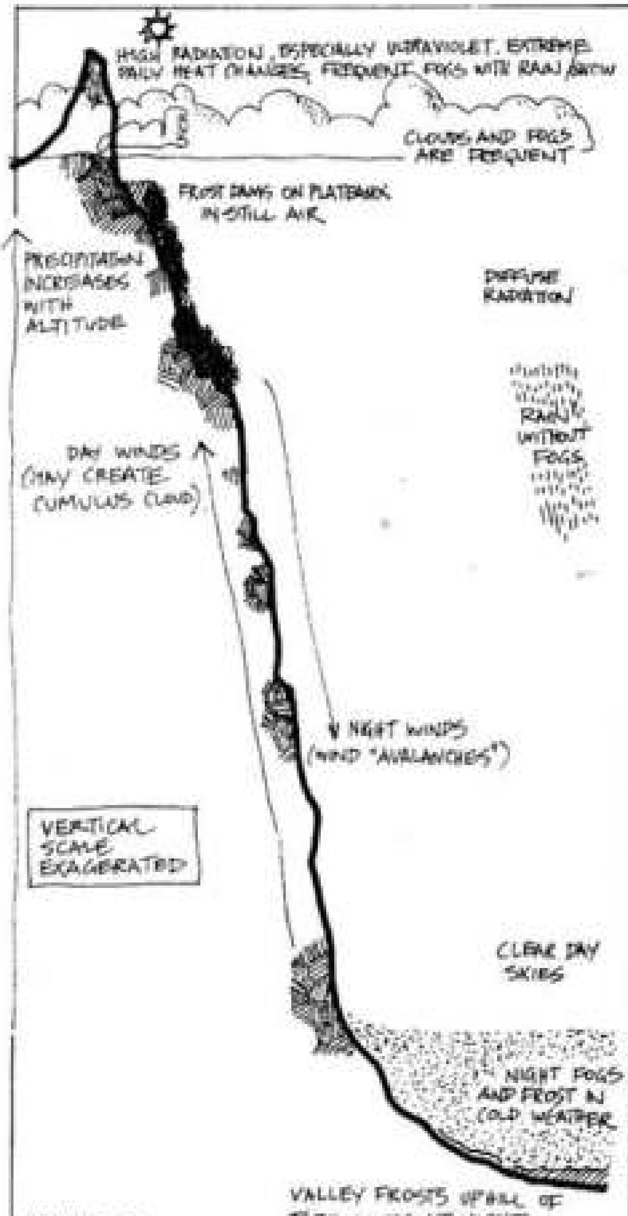
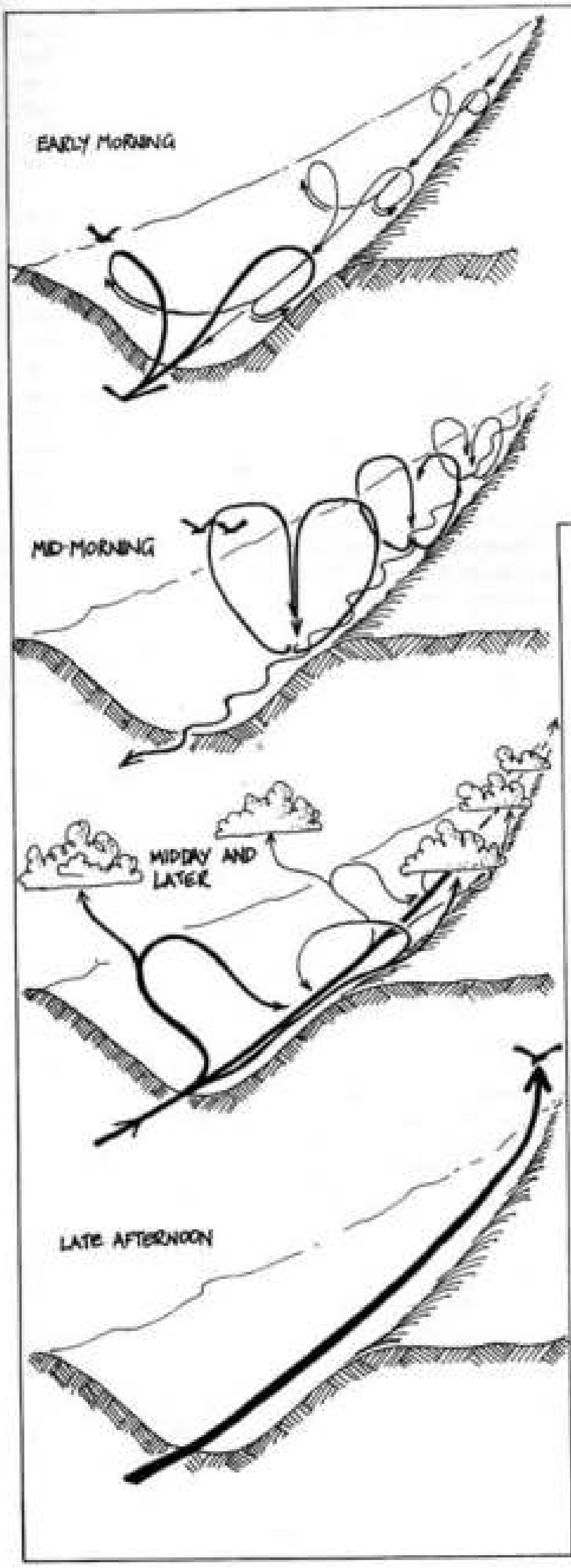


FIGURE 5.24
HIGH ALTITUDE LANDSCAPE.
Local effects may mask or eclipse wider climatic conditions in mountainous regions.



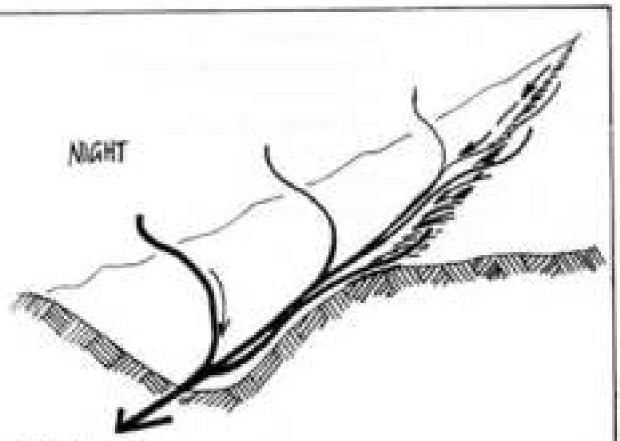


FIGURE 5.25
VALLEY WINDS
These follow a daily cycle. Many bird species use these winds to follow a daily migration (downhill at dawn, to ridge forests at evening). Both wind and temperature effects are local.

breathing in visitors. In the Peruvian Andes, day temperatures remain at 16–19°C (61–66°F) all year, but night temperatures fall rapidly to –10°C (14°F). Shade temperatures are lower than at sea level, due to the less effective heat transfer and insulation effects of the rarefied air. Water boils at lower temperatures due to the low atmospheric pressure, and snow may sublime directly to water vapour rather than melting. High mountains reduce the range of foods available.

Snow cover may serve as an insulating blanket, and prevent early spring thawing, or even autumn freezing if it covers unfrozen ground. Snow cover also causes intense reflection, and raises air temperatures just above the snow by day. At night, radiation from snow causes an extremely cold ground air layer, so that any plants protruding from snow suffer these extremes of diurnal temperature.

As great as the effect of altitude is, the effect of slope is even more pronounced. Daubenmire (1974) records that slopes of 5° towards the poles "reduce soil temperatures as much as 168 km distance" towards the poles, so that even a gentle slope away from the sun creates very much cooler conditions locally. The effect of cold ravines in near-permanent shadow is extreme indeed, and one may stand in hot sunlight in the Himalayas and gaze into icy depths where only the hardiest life forms exist, and where ice may permanently cover rocks and spray zones caused by waterfalls or rapids.

VALLEY CLIMATES

We have referred to the chill of narrow, shaded, high altitude gorges, but an opposite effect occurs in sun-facing wider valleys, sheltered from winds. Here, hot air builds up rapidly, soils are drier, and strong winds may be generated (upslope and up valley by day, downslope and down valley at night). **Figure 5.25** demonstrates this effect in moderate mountain areas of

3,000–4,000 m (9,850–13,000 feet).

In large valleys, and especially in cool moist climates, the upslope wind may result in the generation of a chain of cumulus clouds at the valley head, trailing off as a succession of clouds from mid-morning to evening. In more tropical humid climates, the cloud may be continuously held on the mountain tops; this forms part of the standing cloud of high islands. Such cloud (and rainfall) effects are accentuated by forest on the valley sides and ridges, as trees actively humidify the air streams by transpiration in hot weather.

Valleys in tundra and desert support tree populations absent from the plain or peneplain areas surrounding them, but the reasons may differ in that tundra valleys are likely to be protected by (driven) deep snow cover. This preserves warm or sub-lethal soil temperatures in winter (as well as providing excess summer melt moisture). Valleys in deserts remain moist due to the deep detritus which fills their floors; the shaded soils lose less moisture to evaporation. Lethal soil temperatures are also avoided by partial shading. Both ice-blast and sand-blast are modified or absent in valley floors, so that unprotected seedlings can survive high winds in the shelter of valleys.

Thus, valleys (or wadis) are preferred growing sites in deserts, and provide tree products in otherwise treeless tundras, although the latter sites are rarely occupied by human settlement.

In the field, we often notice a sudden coldness just before dawn in valley areas; this is the time of the greatest depth of cold air, and hence the greatest intensity of cold. Air flowing down from the mountains has pooled all night, and just before the sun rises, we (and many animals) are at our greatest exposure and lowest ebb. It is at this time that winds off glaciers flowing down cold valleys reach their maximum speed.

Without wind or air flow, radiation frost can form, as it does in sheltered hollows and tree clearings. In these areas, opening up the clearings or draining them of cold air may help reduce frost, if that is the aim (**Figure 5.13**).

When, some years ago, I grew such crops as tomatoes and cucurbits inside open tree canopies, I did prevent frost, but lost crop due to low light levels and a lack of wind or insect pollination. In such cases, a shade-side screen of reflector plants facing the sun would help to keep light levels up, and plants to attract bees need to be placed around the clearing. Arboreal or ground browsers within forests are also worrisome in gardens (possum and porcupine for example). Green-leaf vegetables, however, are not usually eaten, and can be successfully grown in small forest clearings or in open forest in frosty areas.

5.8
LATITUDE EFFECTS

Despite the weak light and short growing season at high (sub-polar) latitudes, the very long summer days provide more than a sufficient quantity of light for vigorous plant growth. The daily total for late summer (July) is 440 Langleys at Madras, India (13°N); 680 Langleys at Fresno, California (36°N); 450 at Fairbanks, Alaska (64°N). The average radiation in temperate areas is 1–5 times that of the tropics (Chang, 1968).

This is accentuated, on or near coasts, by the moderate temperatures from the convection of air over warm currents in such areas as Alaska and the northwest coastal regions of Europe. The benefit of these areas is that the generally lower temperatures, which suit photosynthesis, confer a photosynthetic efficiency that makes a considerable production of cereal, berries, tomatoes, potatoes, and vegetable crops tolerant of short season/long day conditions. The often deep periglacial soils provide the basis for the production of gigantic lettuce, cabbage, spinaches, and root crops, so that these areas are very favourable for agriculture in summer.

Such conditions prevail in Alaska, Ireland, Scotland, and parts of Norway. Shelter and added nutrients from seaweeds and manures yield rich meadows and heavy vegetable production during the long summer days. The small stone-walled fields of Ireland produce abundant sweet hay, root crops, and greens for storage during winter.

Conversely, the ample light at low (equatorial) latitudes is inefficient due to the extremely high temperatures there, and the excess light may mean that plants are light saturated. Photosynthesis may actually decline in the intense light, and the energy built into the plants may be less in sunlight than in partial shade. Shade (down to a level of 20% sunlight) is of great benefit in tropical deserts and sunny equatorial climates. Trials of shadecloth with 50–70% light transmission may greatly increase plant bulk and production, e.g. of sugar beet, thus the importance of tree shade and shadecloth in deserts and cleared-area tropics.

Similarly, temperatures above 25°C (77°F) sharply decrease photosynthetic efficiency, so that the normal desert or equatorial condition of high light and temperature is very inefficient for the production of plant material. In the arctic or high latitudes, 15°C (59°F) is *optimum* for adapted species and cultivars, and 20–24°C (68–75°F) for many useful food plants. Tropics are noted for a low production of those crops which can be also grown in temperate areas; light shade may be the essential component for increased yields.

In bright sunlight, leaf temperatures often exceed air temperatures, so that the diffuse light of overcast or cloudy days in high latitudes helps plant growth, especially after midday as temperatures would then also rise above optimum in direct sunlight.

Photosynethetic efficiency is limited by the ability of the leaf to obtain carbon dioxide or by low levels of available carbon dioxide. At high light intensity, we need to supply carbon dioxide (to the saturation level of 0.13% to obtain a 2–3 times increase in photosynthetic rate. Carbon dioxide can be supplied by composting or by housing animals in greenhouses where light is more than sufficient.

It follows that the summer periods of the high latitudes are ideal for biomass production, while equatorial regions evolve biomass mainly as a result of a year-round (inefficient) growth and perennial crops. The ideal of steady low light/low temperature conditions may be at times achieved below the closed forests of tropical mountains, but these sites are very limited in extent, and carbon dioxide concentration is also low. Rice, for example, yields 4–5 times better in temperate areas than in tropical ones, although up to three crops per year in the tropics helps to increase local yields over the year.

It should be feasible to assist tropical crop yields by spacing permeable-crowned trees throughout crops to reduce both light and temperature, e.g. using *Prosopis* trees with millet crops in India, or partially-shading taro in Hawaii. Grass growth in temperate areas also increases with shelterbelt, but this may reflect the *warmer* conditions and lack of mechanical wind damage that such trees as tagasaste provide. Trials of light-transmitting or thin-crowned palms and legume trees would quickly show results, and there are a good many observations to suggest that (if water is sufficient) crops under leguminous trees do much better in the tropics than a crop standing on its own.

Part of the problem in tropics (both for biomass production and nutrition) is that non-adapted temperate crops are persistently grown there. True tropical plants can not only stand much higher levels of light before saturation, but can also maintain photosynthesis at low (0.10%) carbon dioxide.

In summary, we do not have to accept the climatic factors of a site as unchangeable any more than we do its treelessness or state of soil erosion. By sensible placement of our design components, we can create myriad small differences in local climatic effects on any site. In the technical field, we can create useful conversions of energy from incoming energy fluxes such as wind and sun, and produce energy for the site. In the patterning of a site with trees, ponds, earth systems, or hedgerows, we can actively moderate for better climatic conditions, or to eliminate some local limiting factor.

5.9
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5.10
DESIGNER'S CHECKLIST

Check data on average rainfall, temperature, and wind speed and direction for the region (often found by contacting the Bureau of Meteorology).

Ascertain the general "hardiness" zone for plants and animals. This is based on temperature, with frost being the limiting factor. Make a survey of the plants that grow in the area, noting special circumstances surrounding plants that are "marginal"; what is the technique or microclimate that allows them to grow?

Find out about flood locations and periodicity, rain intensity, temperature extremes, and the *seasonal* rainfall pattern. Allow for extremes (e.g. no rain in summer) when designing.

Consider *total* precipitation (snow, hail, rain, fog, condensation, and dew) so that your design can include ways to trap and store moisture (dry climates) or ways to dispose of too much moisture (wet climates).

Consider *light availability*, especially on foggy coasts; light becomes the limiting factor for flowering plants.

Continental climates mean more temperature extremes, while maritime climates buffer severe heat or cold.

Altitude effects: approximately every 100 m of altitude is equivalent to 1° of latitude, so that a variety of plants can be grown if the property contains hills and flats. In the sub-tropics, even temperate-area plants can be grown on high islands or hills.

Note where frost is produced (in hollows, on flats, and in large clearings) and where it is absent (the "thermal belt" on hills, under tree canopies).

Note tree flagging on the site; this shows the direction of *persistent* winds (although winds, sometimes severe, may blow from other directions). You can put tall stakes with coloured cloth or plastic streamers at different locations and observe them seasonally. (**Figure 6.2**).

For accurate temperatures, you can have several maximum/minimum thermometers in different locations. These thermometers record the highest and lowest temperatures reached during 24 hours, and are helpful in locating microclimatic areas such as thermal belts (if on a sun-facing slope), cold drainage areas, frost hollows.

Site house and garden on the thermal belt if possible.

In minimal-frost areas, plant light-canopy trees *in* the garden for frost protection (tree canopies help keep rapid cooling of the earth to a minimum). Or plant into a steep-sided clearing or pit.

In houses, design so that you use light and radiation to best effect, particularly in temperate climates. Particular use should be made of the thermosiphon effect of heat, so that heat sources are placed below storage and use points.

Use the principle that white reflects, dark absorbs, heat. Plant shrubs and trees needing heat and light in front of white-painted walls.

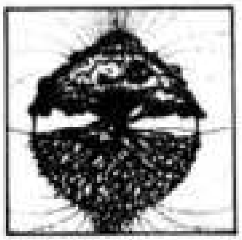
When planning windbreaks, consider:

• Trees that give multiple function, e.g. mulch (*Casuarina*), bee nectar (dogwood), sugar pods for animals (carob, honey locust), edible leaves (*Leucaena*, tagasaste), berries for poultry (*Coprosma repens*, Russian olive).

• The windbreak planting itself may need initial protecion and care (nutrients, water, weeding, or mulching).

• If the winds are *very severe*, look around the area to see what stands up to it, and plant it whether it provides multiple function or not. Plant more useful plants in its lee. Protection includes fencing, earth banks, tyre walls, etc.

• Choose a windbreak configuration that is effective for the particular design situation. In tropical and subtropical areas, a thin-crowned windbreak in crop can be used to advantage, providing shade and mulch for vegetable crop.



Chapter 6

TREES AND THEIR ENERGY TRANSACTIONS

On the dry island of Hierro in the Canary Islands, there is a legend of the rain tree: a giant 'Til' tree *(Ocotea foetens)*. "... the leaves of which condensed the mountain mists and caused water to drip into two large cisterns which were placed beneath. The tree was destroyed in a storm in 1612 A.D. but the site is known, and the remnants of the cistern preserved ... [This one tree] distilled sufficient water from the sea mists to meet the needs of all the inhabitants."

(David Bramwell)

For me, trees have always been the most penetrating teachers. I revere them when they live in tribes and families, in forests and groves... They struggle with all the forces of their lives for one thing only: to fulfill themselves according to their own laws, to build up their own forms, to represent themselves. Nothing is holier, nothing is more exemplary, than a beautiful strong tree.

(Herman Hesse, "Trees", *Natural Resources Journal*, Spring 1980)

I am astonished to find whole books on the functioning of trees which make no mention of their splendid mechanical and aerodynamic performance.

(Vogel, *Life in Moving Fluids*, 1981)

A point which is often overlooked is the effect of trees in increasing the total precipitation considerably beyond that recorded by rain gauges. A large proportion of the rime which collects on the twigs of trees in frosts afterwards reaches the ground as water, and, in climates such as those of the British Isles, the total amount of water deposited on the twigs from fogs and drifting clouds is considerable, and most of it reaches the streams or underground storage, or at least replaces losses from subsequent rainfall.

Of more importance, however, to hydraulic engineers is the effect of woodlands in modifying the run-off. The rush of water from bare hillsides is exchanged for the slower delivery from the matted carpet of the woodland, losses by evaporation may be much diminished and the melting of snow usefully retarded. In catchments from which flood waters are largely lost, woodlands may increase the available runoff by extending the period of surface flow. The maximum floods of rivers are reduced, and the lowest summer flow increased. Woodlands are usually much more effective than minor vegetation, such as gorse and heather, in preventing the soil from being carried from the land into an open reservoir.

To protect a reservoir from silting, it may be unnecessary to plant large areas, the silt being arrested by suitable planting of narrow belts of woodland, or by the protection of natural growth, along the margins of the streams.

Some engineers consider that in the case of small reservoirs the shelter afforded by a belt of trees along the margins is of value in reducing the amount of scour of the banks caused by wave action. Afforestation over considerable areas in large river basins would, in many cases, reduce the amount of silting in navigable rivers and estuaries.

A matter which does not receive sufficient attention in connection with hydraulic engineering is the effect of judicious planting or woodland conservation over small areas. A narrow belt of woodland along the foot of a slope will arrest the soil brought down by rains from the hillside. The encouragement of dense vegetation along the bottom of a narrow valley may check the rate of flood discharge to a useful extent. The planting of suitable trees along ridges and for a little way down the slope facing the rain bearing and damp winds, will produce the maximum of certain desired effects, in proportion to the area occupied. Suitable tree and bush growths in swampy areas and around their margins will increase their effect in checking flood discharge, and may prevent these areas from contributing large quantities of silt to the streams during very heavy rains. Areas of soft, cultivable soil liable to denudation may similarly be protected. Generally, a country which is, in the ordinary English sense of the words, 'well timbered' is, from the point of view of the hydraulic engineer, a favourable country; and in the development of new lands the future effects of a poposed agricultural policy should be considered from this point of view, and in consultation with hydraulic engineers.

(R.A. Ryves, *Engineering Handbook*, 1936)

6.1 INTRODUCTION

This chapter deals with the complex interactions between trees and the incoming energies of radiation, precipitation, and the winds or gaseous envelope of earth. The energy transactions between trees and their physical environment defy precise measurement as they vary from hour to hour, and according to the composition and age of forests, but we can study the broad effects.

What I hope to show is the immense value of trees to the biosphere. We must deplore the rapacity of those who, for an ephemeral profit in dollars, would cut trees for newsprint, packaging, and other temporary uses. When we cut forests, we must pay for the end cost in drought, water loss, nutrient loss, and salted soils. Such costs are *not* charged by uncaring or corrupted governments, and deforestation has therefore impoverished whole nations. The process continues with acid rain as a more modern problem, not charged against the cost of electricity or motor vehicles, but with the inevitable account building up so that no nation can pay, in the end, for rehabilitation.

The "capitalist", "communist", and "developing" worlds will all be equally brought down by forest loss. Those barren political or religious ideologies which fail to care for forests carry their own destruction as lethal seeds within their fabric.

We should not be deceived by the propaganda that promises "for every tree cut down, a tree planted". The exchange of a 50 g seedling for a forest giant of 50–100 tonnes is like the offer of a mouse for an elephant. No new reafforestation can replace an old forest in energy value, and even this lip service is omitted in the "cut-and-run" forestry practised in Brazil and the tropics of Oceania.

The planting of trees can assuredly increase local precipitation, and can help reverse the effects of dryland soil salting. There is evidence everywhere, in literature and in the field, that the great body of the forest is in very active energy transaction with the whole environment. To even begin to understand, we must deal with themes within themes, and try to follow a single rainstorm or airstream through its interaction with the forest.

A young forest or tree doesn't behave like the same entity in age; it may be more or less frost-hardy, wind-fast, salt-tolerant, drought-resistant or shade tolerant at different ages and seasons. But let us at least try to see just how the forest works, by taking one theme at a time. While this segmented approach leads to further understanding, we must keep in mind that everything is connected, and any one factor affects all other parts of the system. I can never see the forest as an assembly of plant and animal species, but rather as a single body with differing cells, organs, and functions. Can the orchid exist without the tree that supports it, or the wasp that fertilises it? Can the forest extend its borders and occupy grasslands without the pigeon that carries its berries away to germinate elsewhere?

Trees are, for the earth, the ultimate translators and moderators of incoming energy. At the crown of the forest, and within its canopy, the vast energies of sunlight, wind, and precipitation are being modified for life and growth. Trees not only build but conserve the soils, shielding them from the impact of raindrops and the desiccation of wind and sun. If we could only understand what a tree does for us, how beneficial it is to life on earth, we would (as many tribes have done) revere all trees as brothers and sisters.

In this chapter, I hope to show that the little we do know has this ultimate meaning: *without trees, we cannot inhabit the earth*. Without trees we rapidly create deserts and drought, and the evidence for this is before our eyes. Without trees, the atmosphere will alter its composition, and life support systems will fail.

6.2 THE BIOMASS OF THE TREE

A tree is, broadly speaking, many biomass zones. These are the stem and crown (the visible tree), the detritus and humus (the tree at the soil surface boundary) and the roots and root associates (the underground tree).

Like all living things, a tree has shed its weight many times over to earth and air, and has built much of the soil it stands in. Not only the crown, but also the roots, die and shed their wastes to earth. The living tree stands in a zone of decomposition, much of it transferred, reborn, transported, or reincarnated into grasses, bacteria, fungus, insect life, birds, and mammals.

Many of these tree-lives "belong with" the tree, and still function as part of it. When a blue jay, currawong, or squirrel buries an acorn (and usually recovers only