WHY NATURAL LANDSCAPES CATCH AND STORE WATER, NUTRIENTS & CARBON

This previously unpublished article contains material which has been central to my teaching of permaculture for over a decade and in particular to the permaculture principle ***Catch and Store Energy****. It provides a framework for evaluating catchment management and land restoration strategies more fundamental than the indigenous biodiversity conservation framework which dominates the environmental mainstream.*

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CARBON SINK OR CARBON STORAGE: GREENHOUSE GAS AS A SYMPTOM RATHER THAN CAUSE.

According to the consensus of the global scientific community the "enhanced greenhouse effect" is already contributing to global climate change which is predicted to intensify over the next century. Climate change is now widely accepted as the greatest environmental threat to humanity.

Too much carbon dioxide and other greenhouse gases accumulating in the atmosphere from human activity over the last century is the cause. The solutions proposed fall into two broad categories,

- reducing the burning of fossil fuels (which is the primary source) and
- creating storages which will take carbon dioxide out of the atmosphere.

These storages of carbon are called sinks, predicated on the view that carbon is a pollutant to be got rid of.

There is now a great body of research, literature and debate about the relative value of carbon storage in trees (as opposed to the trees themselves). This storage is likely to become an internationally tradable asset to partially offset fossil fuel carbon currently being burnt. This idea of tradability is a legal response to the fact that "carbon storage" tied to ownership of trees and land is not currently useful to the corporations who need to create or buy more carbon storage to offset their massive outputs of greenhouse (carbon containing) gasses. This market solution has some merit from the top down management perspective of governments and corporations on how to respond to the buildup in the atmosphere of greenhouse gasses but the accounting and verification costs are likely to be so high that only large growers of monocultural tree plantations will benefit. The even larger carbon storage potential of soil humus has been slow to come onto the agenda for inclusion in carbon trading because of even greater complexity and uncertainty in accounting and verification.

The attempts by governments and corporations to work out political and economic survival strategies is being driven by the wider popular concern (at least in rich countries) for the well being if not survival of our children and grandchildren. The environmental movement sees the changes required for dealing with the greenhouse effects as reinforcing many of its other agenda's.

Permaculture thinking goes deeper in providing a positive view of carbon as "the staff of life" rather than a pollutant and that we should take every opportunity to catch and store carbon in trees and soil humus as the most important investment in natural capital we can make for the well being of future generations.

This change of mind set is not simply about taking a positive or optimistic view but arises from a more fundamental understanding of how nature works.

Life on land has evolved over hundreds of millions of years to store not only carbon but also water and mineral nutrients because these three resources are the drivers of biological productivity in all terrestrial ecosystems. The optimum processes for capture of these three resources are mutually reinforcing. In a low energy future these resources will again be critical to the well being of humanity while the threats from climate change will receded as fossil fuel use (and eventually population) declines. Land use and cultural patterns of organisation which mutually reinforce their capture, represent our best options for building the natural capital to support future generations.

SELF ORGANISING LANDSCAPES

Terrestrial landscapes are self organising systems which have been evolving since life from the sea colonised the land masses hundreds of millions of years ago. That evolution is structured to maximise the power for living systems from optimum use of climatic and earth energy sources.

The climatic energies (sun, rain, wind etc) influence not only the type of plants which grow but also the nature of soils and the shape of the land from river catchments to drifting desert dune fields.

The earth energies of tectonic uplift and volcanism builds and reshapes mountains and delivers rock minerals critical to soil fertility and all living things.

Changes in either or both the climatic or geophysical energies result in radical reorganisation of terrestrial landscapes and ecosystems. These larger scale system changes can cause massive erosion, physical destruction, biodiversity loss, habitat destruction and fragmentation, as well as new soil building and fertilising, rapid invasion and evolution of new life forms. The time scale for these changes in landscapes range from millions of years down to human life spans.

Humans like all other animals have evolved to take advantage of resources created by these larger processes but also have themselves become agents of change which is now geological in scale through the harvest and use of fossil fuels. Within a few human generations the low energy patterns observable in natural landscapes will again form the basis of human system design.

Although it is tempting to think of these natural landscapes as reflecting a stability in climatic and earth forces, long periods of climatic and geophysical stability actually result in a rundown of the available energy to ecosystems and people. Geologically young regions with recent[1] mountain building and volcanism tend to be much **more** biologically productive and more quickly develop larger storages of soil minerals, carbon and water which in pre-industrial times supported large populations of people despite their vulnerability to natural disasters. Geologically old regions (most of Australia) tend to have low biological productivity and supported fewer people.

1 The last 100,000 years

The inexorable force of gravity causes water, organic matter and nutrients to constantly be flowing away to the ocean or being locked up in deep or unavailable earth storages where they are effectively lost to terrestrial systems. These forces have been so consistent in their effects since life emerged out of the sea, that all terrestrial ecosystems and landscapes can be seen as design responses to overcome or at least limit the effects of these forces. **Thus we can say that all terrestrial ecosystems have co-evolved to catch and store the energy in water, mineral nutrients, and organic carbon as effectively as possible.**

WATER STORAGE IN LANDSCAPE

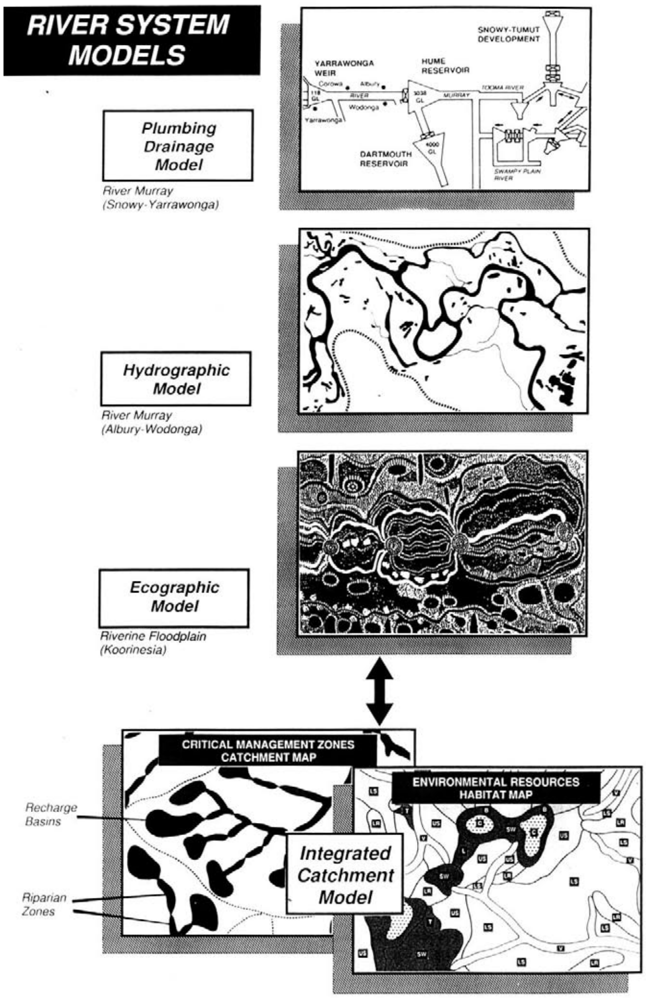
Water is perhaps most easily understood as a limiting factor, especially in Australia, the driest inhabited continent. The erratic nature of rainfall and the constant needs of microbes, plants and animals for moisture means that landscapes have evolved as efficient rain water storages. Vegetation holds substantial quantities of rain water both in their tissues and in the humid air and moisture trapped by forest canopies and under stories. Forest litter and mulch act as an open sponge absorbing and holding water. Soil chemistry balance and humus development in topsoils provides a more stable moisture supply for plants while deep subsoils especially clay provide very stable if harder to access moisture. Rainwater which infiltrates beyond the reach of plants contributes to catchment productivity by slow release through springs and soaks lower down the landscape especially along gullies and water courses. It is these springs and soaks which sustain the base flows in streams and rivers between runoff events. Deep rooted plants can recycle water from ground water aquifers but some water moves down into deep ground water storage, beyond landscape or plant recycle mechanisms.

The pattern of these storages is from more ephemeral to more permanent as water moves down under the influence of gravity.

Catchment landscapes show similar patterns of development which also involve major water storages such as the deep pools, and in dryer climates, gravel and sand filled stream beds. The pool and riffle pattern of stream beds acts to filter and oxygenate water. Swamps and wetlands are even more important as temporary storages and important filters. They have been called the kidneys of catchment landscapes because of their role in filtering and purifying water. Streams and wetlands are also systems for ameliorating the destructive forces of large flood flows which recur at intervals from 1 to 1000 years or more. In the process some of the energy from flood is captured as new alluvial soils of floodplains.

Changes in our thinking about catchments and rivers is graphically illustrated by Tané's plumbing drainage, hydrographic and ecographic models of river systems[2].

2 Tané, H. ***The Case For Integrated River Catchment Management*** Keynote Address Proceedings of the International Conference on Multiple Land Use and Integrated Catchment Management Macaulay Land Use Research Institute Aberdeen UK 1996



The old plumbing drainage model depicted by the Murray Darling Basin Commission's system description for the managed flow of the Murray River has been largely discredited as destructive of natural resources. The storages (public dams) are too large and low down in the catchment landscape and the regulated flows are too fast and constant for the sustenance of river health and productivity which has evolved to use the seasonal variations and pulses of natural flows. The hydrographic model depicted by the mapping of floodplain water bodies recognises the sinuous and complex nature of natural river floodplains, which slow and divert the flow of water, as optimal for maintenance of natural resources. The ecographic model incorporates the latest understandings of rivers and their floodplains as highly productive ecosystems which are constantly renewing and rebuilding themselves in response to catchment change. Tané sees Aboriginal "abstract" paintings of these water dominated landscapes as a graphical description of how these physical and biological resource patterns form an integrated whole.

NUTRIENT STORAGE IN LANDSCAPE

How ecosystems and catchment landscapes evolve in response to the limited availability of mineral nutrients is more difficult to understand than water. This is due to the largely invisible nature of mineral nutrients and the subtle but important ways in which they control the productivity of every ecosystem. The essential elements of Carbon, Oxygen, Hydrogen and Nitrogen are abundant in the atmosphere and are supplied to living things through the energy harvesting system of photosynthesis and other associated processes in plants but the mineral nutrients of Calcium, Magnesium, Potassium, Phosphorous, Sulphur and trace elements essential to living things, occur in small and varying amounts in the diverse rocks types which make up the earth's crust. Plants can easily absorb these nutrients in water soluble forms but solubility also leads to leaching of the nutrients beyond the reach of plants. Consequently soil ecosystems have evolved to catch and store plant nutrients in non soluble but available forms.

Ecosystems develop against a geochemical background of nutrient imbalance and deficiency which they seek to overcome through mechanisms which mine bedrock and other inert sources as well as catch nutrients leaking from adjacent systems and atmospheric transfer. Humus is perhaps the greatest "invention" of nature which increases the mineral nutrient storage capacity of soils (as well as being an excellent contribution to increasing water and carbon storage). There are good ecological reasons for the veneration of humus in the organic, biodynamic and permaculture movements.

Over long periods of geological time, there is a loss of mineral nutrients from all ecosystems through the forces of gravity and leaching as well as periodic fires, droughts, floods and other natural disasters. In addition, chemical bonding (by natural processes) of nutrients into highly unavailable forms provides more and more difficulties for plants to obtain balanced mineral nutrition. Unless a landscape can mine or catch more than it loses, there is a progressive decline in productivity and replacement of high nutrient requiring species with those adapted to both low levels and chronic imbalance of mineral nutrients.

In Australia much of our exquisite biodiversity results from endless adaptations to lower and unbalanced mineral nutrients. Unfortunately humans, by our very nature, are completely dependent on very high and balanced mineral fertility in our foods. Without adequate and balanced mineral nutrition, humanity from hunter gatherers to great civilisations have crumbled because their soils could not provide them with the quantity or quality of food required.

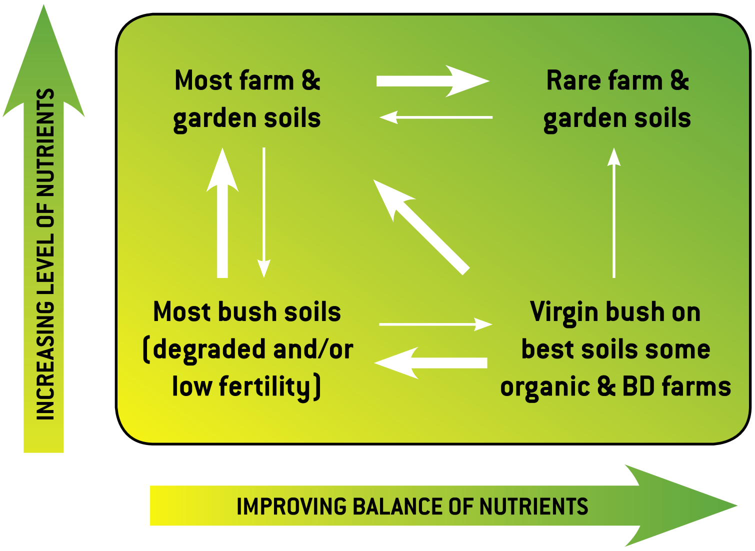
The American soil scientist William Albrecht[3] was one of the first to recognise that an ideal balanced soil in which all crops will give high and good quality yields was possible and he did the pioneering scientific work to identify the mineral and biological characteristics of this ideal soil. Albrecht's ideal mineral balance also increases the capacity of a soil to store water and resist erosion by creating a open absorbent fabric. In addition this ideal mineral balance optimises the conversion of soil organic matter and litter to humus.

My own observations suggest it is reasonable to extend the concept of Albrecht's ideal soil for all crops and that this represents a biological optimum soil in which all plants will thrive. Within the constraints of climate, this soil will support the most productive biological system in terms of total energy capture and storage. Thus balanced and fertile soil is nature's most important, integrated and self reinforcing design solution for maximum power of terrestrial life by optimising capture of nutrients, water and carbon.

3 Walters, Charles Jr. editor ***The Albrecht Papers*** Acres USA 1975

We can think of soils on a matrix which combines level and balance of mineral fertility. On this matrix we can see how modern food production has increased, especially in Australia, by use of selected mineral nutrients but in the process has lead to increasing imbalance which is reflected in quality of food and leaching of soils.

SOIL FERTILITY AND BALANCE MIX



In future (perhaps within 100 years) after the fossil fuel energy subsidy to agriculture has declined, the mineral fertility and balance of our farmlands and entire catchment landscapes will become one of the most important resource management and economic issues, and yet the powerful means currently available to achieve this on a large scale will be very costly[4] or simply unavailable[5]. In this situation we will once again be dependent on the slower low energy processes of fertility building and balancing.

Soil is the most important storage for nutrients in temperate climates but in tropical systems, the oxidation and leaching rates are so high that natural systems rely more on storage of nutrients in living plants. Even in temperate ecosystems, plants represent an important storage which can be recycled to the soil by annual leaf drop, insect and herbivore browsing, or fire.

In clearing forests for agriculture, humans have mobilised the nutrients in large woody biomass for uptake by crops. Annual crops provide no permanent nutrient store but where perennial pastures or other perennial crops are grown, nutrient storage in plant biomass can be as great as that in native forest and woodland[6].

4 Primarily because energy to crush and transport minerals (especially lime which is required in tonnes per hectare) will be much higher for places remote from mineral sources.

5 Rock phosphate is one of the most important and severely depleted mineral resources. In countries where phosphate use has been widespread there is often abundant reserves locked up in agricultural soils, which can potentially be released by soil microbes but in many poorer countries where fertilisers have not been widely used these soil reserves do not exist.

6 Although total plant biomass in a pasture or an orchard is much less than in a forest, the nutrient rich nature of the vegetation means total nutrient storage may be higher. In the wet tropics, perennial pastures are generally inefficient at nutrient storage.

A balance between stored and available nutrients in all systems is an important measure of the balance between long term sustainability and short term productivity. For example, grazing by livestock converts nutrients in perennial pasture into more concentrated and useful forms (urine and faeces), but these nutrients are also more mobile and easily lost through leaching and gassing off.

CARBON STORAGE IN LANDSCAPE

As indicated previously carbon storage in living plants and soil humus are much more than a way of getting rid of unwanted atmospheric carbon dioxide. Carbon in staple crop plants provides the carbohydrate fuel to directly support human bodily energy needs. Clearly carbon storage by human food crops is literally "the staff of life" and will always be central in any consideration of sustainable land use. But the small quantities of carbon in human food is a minor part of carbon storage in landscapes.

Much larger quantities of carbon in fibrous fodder plants sustain grazing animals which in turn provide us with a myriad of renewable products and services from protein rich foods and wool, to "horsepower".

Particular forms of cellulose and lignin from some plants provide us with the material for fabrics, paper and ropes, as well as the myriad diversity of timber for every imaginable use.

Last, but perhaps most important to the post fossil fuel age, plants, especially trees provide a renewable fuel for cooking, heating, smelting and other tasks.

Timber and fuel forests, and to a lesser extent, pastures, fodder trees and fibre crops can be grown on marginal soils without the depth, structure or fertility to support human food crops. This fact is the single most important reason why storage of carbon by largely perennial plants and especially trees is so central to the permaculture strategy for sustainability.

TREES AND FORESTS AS MULTIPURPOSE CARBON STORAGE

Trees are especially important as storages of carbon for a number of reasons.

- Their capacity to continue to grow (and fix carbon) at very high rates for decades and then store that carbon for centuries.
- Actively growing forests can be accumulating biomass at rates of 5-35 tonnes per hectare per annum which is similar to grasslands but unlike grasslands the wood in trees is a long term storage which can be stable for centuries.
- The capacity of trees to grow on our poorest land unsuited to other food or even fibre crops[7].

7 See Article ***Hemp as a Wood Paper Pulp Substitute?*** Environmental solution or diversion from the search for sustainable forestry for discussion of the relative merits of Hemp and Trees as fibre crops and the importance of sustainable forestry to the permaculture agenda.

- Wood in straight and tall trees continues to increase in value long after the rate of growth has slowed because larger, slower grown trees provide sawlogs with a great variety of durable product uses.
- In Europe where there is a sophisticated market for forest wood products, trees capable of yielding sawlogs are worth 10 times more than those yielding paper pulp or fuel wood.
- In a low energy future the value of mature forests capable of sustained yield of a diverse range of wood products will be very high. As in the past the wealth of nations will be measured by the quantity and quality of their forests.

The dependence of European nations on their forests for the building of wooden warships is the great example from history but the breadth and depth of dependence on forests is far greater this particular example. In the same way that steel replaced wood for ships and other uses, as fossil fuel based energy increased, wood will progressively replace steel, concrete, aluminium, plastics and other energy intensive composite materials as fossil fuel energy declines. But this will only be possible if we grow those forests at least a generation in advance.

Without any particular focus on Greenhouse gas amelioration, the principle of catching and storing energy to build natural capital suggests we should grow long rotation mixed species forests for multiple values.

The greenhouse outcomes of this approach would be more useful than the knee jerk industrial monocultural mentality driving much of the current design and investment in plantation forestry.

Some of greenhouse gas advantages of such forests include.

- The best way to establish most long lived timber species is to grow them with fast growing soil improving nurse species (eg acacias) which also have the effect at increasing uptake of carbon in the early years.
- Continuous careful thinning of long rotation forests can maintain good growth rates in some of our most useful timber species for at least 100 years (see discussion of forestry in *Principles and Pathways: Use Small and Slow Solutions*), after which time fossil fuel use should have dramatically reduced.
- Well managed forests of long lived high quality timber trees protected from fire can last for hundreds of years before their timbers values and carbon storage begin to decline.
- Houses and other high quality products made from this type of timber can last for hundreds more.
- Some of decomposition of leaves, bark and wood from older trees accumulated as soil humus is capable of lasting for thousands of years.

- Regeneration of such forests can be done without the massive release of carbon dioxide associated with clear felling and burning.

These are the types of forests which we should be growing for all reasons, with the greenhouse gas sink function being simply one more reason to get on with the job. Permaculture has contributed to the now widespread notion "that reforesting the earth is one of the few tasks left to us to express our humanity"[8]. While it is appropriate to focus on the often invisible environmental services (such as catchment protection) which forests provide, few people recognise that it will be the capacity of forests to store carbon as structural timber and fuel which may allow humanity to be sustained by renewable resources in a low energy future.

SOIL HUMUS AS CARBON STORAGE

While the value of carbon rich plant materials to directly provide for future human needs cannot be overestimated, perhaps an equally valuable storage of carbon is achieved when we simply allow plant materials to rot back into the soil. Organic matter, especially carbon rich bulky plant materials is the fuel for soil micro-organism which in turn, are the key to plant nutrient cycling and availability. After processing by worms and other soil organisms, organic matter is converted into polysaccharides, proteins and other fast turnover products which support soil microorganisms and plant life. Consequently much of the carbon cycles back to the atmosphere as carbon dioxide within a season or so, from respiration by the teaming microbial life in healthy soil. Some of the carbon in organic material is distilled into more stable complex organic compounds such as humic and fulvic acids which increase the nutrient, water and oxygen holding capacity of soils. Under favourable conditions these humus storages can be stable for hundreds and even thousands of years. Wes Jackson of the Land Institute in Kansas[9] has referred to the loss of this ancient humus from American prairie cropping soils as "the mining of young coal". The rebuilding of humus in the world's cropping soils should be seen as the other great task for humanity alongside reforestation of our catchments and degraded range lands.

The loss of organic matter from cropping soils is now recognised by mainstream agricultural scientists as one of the greatest threats to sustainability. Strategies and techniques to increase soil organic matter are no longer regarded as the peculiar obsession of organic farmers, but the problem of how to describe, measure and value differing forms of soil organic matter leads to much confusion. Most soil testing laboratories measure total organic matter rather than attempt to distinguish differing forms and their relative age and turnover time.

8 Bill Mollison from the video ***In Grave Danger of Falling Food***

9 Researching the development of perennial grain crops

Soils with a build up of partially decomposed mulch and compost may indicate a mineral imbalance[10] while soils with no visible compost layer but a very dark and well structured mineral layer may have a high humus content reflecting past "digestion" of large amounts of organic matter.

Where supplies of organic materials are abundant (eg gardens supplied by surrounding urban or rural landscapes), favourable mineral balance and microbial populations are the critical factors in soils being able to digest organic matter.

Where supplies of organic matter are limited to what can be grown on site (broad acre farms) appropriate crop rotations, pastures and tree and shrub systems, are as important as the mineral and microbial factors.

It is often stated that crop waste especially grain straw from farmland could provide a huge renewable source of carbon for fuel and fibre board products in the future. Although such schemes might be better than the practise of burning grain stubble, they amount to "robbing Peter to pay Paul", since crop land everywhere needs full recycling of crop waste through grazing animals and/or directly by soil microbes, if they are to maintain, let along increase the level of soil humus.

In north Germany grain straw is burnt in high efficiency furnaces for heating buildings, a "renewable energy" replacing fossil fuel. Traditionally this straw would have been used as feed and bedding for livestock contained in large barns over winter. The resulting compost was then returned to the fields in spring, thus maintaining the humus content and fertility of the predominantly sandy soils. Today the slurry washings from the barns are stored in large tanks over the winter and then sprayed onto the fields. Although this slurry provides some organic matter it is not enough to maintain soil humus levels and prevent leaching of nutrients into the ground water which supplies all local towns and cities.

Concerns about nitrate pollution have led to slurry quotas, which in turn have led to slurry quota trading, and even slurry marriages between farming families trying to maximise their production. The next step could be to follow the Dutch solution of exporting animal manure to Spain which would use much more fossil fuel than that saved by burning straw for heating. This story illustrates the complex interconnected nature of environmental problems and the need for a holistic framework for moving towards real solutions. Understanding and applying the permaculture principle "Catch and Store Energy" may help prevent similar absurd circular problems.

BROWN COAL AS NEW SOIL HUMUS

Ironically brown coal, with appropriate processing, is emerging as one of the most valuable resources for building long term humic acid content of agricultural soils. The air pollution

10 Acidity is well recognised as slowing the breakdown of organic matter but this is more the symptom than the cause. Low calcium to potassium ratio is the more fundamental cause.

causing high sulphur brown coals are especially valuable because of the plant nutritional value of sulphur. Coal based fertilisers are increasingly being used in the conversion of conventional agriculture to organic methods.

SOIL HUMUS AS CARBON SINK

The focus on the greenhouse effect has produced some research and policy discussion of the agricultural soils as carbon sinks although this has not received as much publicity as the role of vegetation clearing and tree plantations. This research is providing quantitative evidence to support the long articulated claim of the organic agricultural movement that rebuilding agricultural soil humus levels is the greatest contribution to the survival of humanity.

Alan Yeoman's who markets the famous Yeoman's soil conditioning plough originally developed by his father P.A. Yeomans has argued[11] that loss of humus from agricultural soils is as large a contributor to greenhouse gas emissions as motor cars and that achievable increases in humus across the world's farming soils could reabsorb the whole of the damaging imbalance of carbon dioxide in the atmosphere. Working through his remarkably simple "back of the envelop" calculations suggests we are at least talking about quantities in the same order of magnitude.

While more research about the actual and potential carbon cycle (storages and fluxes) in agricultural soil, and debates over complexity of verification and monitoring, will no doubt continue, the greenhouse issue simply gives us another good reason to get on with the job of rebuilding natural capital of soil humus as essential for humanities, survival in the post fossil fuel era.

We can do this in many ways both directly and by supporting farmers and land managers who are doing so (largely but not exclusively organic and biodynamic farmers);

- returning all organic wastes to productive garden and agricultural soils.
- eliminating all intensive forms of livestock husbandry (which consume excessive fossil fuels and reduce soil humus by increasing the demand for field crops).
- provide for (reduced) meat consumption in rich countries from conservative management of natural range lands (mostly native animals such as kangaroos) and more intensive management of grazing animals to build soil humus through perennial pastures.
- use rotations of leguminous pastures to build arable soil humus rather than continuous cropping supported by herbicides.
- replacement of soluble fertilisers aimed at crop feeding with rock mineral fertilisers and coal humus for soil feeding. (see below)

11 See book downloadable from Yeomans web site www.yeomansplow.com.au/

- large scale establishment of tree systems as an integral part in all farm landscapes, especially in high rainfall areas with a strong emphasis on soil building fodder shrubs, tree crop species and long lived timber trees with a lesser role for soil depleting and fire encouraging species such as eucalypts and conifers.

When the earth beneath our feet is less like a dead concrete slab and more like a dark, moist living sponge then we know we are on the right track.

HEPBURN PERMACULTURE GARDENS

The principle of catching water, mineral nutrients and carbon in useful landscape storages has been central in developing our property Melliodora (Hepburn Permaculture Gardens) in central Victoria[12].

For example we have built two dams on the gully which flows through the property to intercept a small proportion of the total seasonal catchment runoff. Some of the catchment is semi-urbanised so we are contributing to slowing the fast and at times destructive rapid flow from paved and roofed areas. This water flows through a silt trap/ reed bed which partly filters it before entering the dams. We also capture some roof runoff for use in the house and for animal needs. Roof runoff and other site runoff is also directed to parts of the garden where possible while minimising the risk of winter water waterlogging and nutrient leaching.

While these built systems contribute to landscape storage, it is the development of a well structured soil and a multi layered perennial vegetation system which has been the major opportunities to increase storage of water at Hepburn Permaculture Gardens.

The first step in this "revegetation strategy" was fencing to exclude rabbits, wallabies and stray livestock, to allow maximum growth of pasture grasses, brambles and other wild existing vegetation which could most efficiently use natural rainfall and be seasonally slashed to form mulch for recycling to soil humus.

In our plantings we catch and store mineral nutrients as well as nitrogen in a variety of ways:

1. First of all we grow an abundance of legumes and other species which host microorganisms which fix atmospheric nitrogen.

2. In the vegetable garden we use sawdust from a local sawmill as garden paths which slowly absorb nutrients which may leach from intensively watered and composted garden beds. As it decomposes, the old sawdust is used as mulch around trees.

12 Holmgren, D. ***Hepburn Permaculture Gardens: 10 Years of Sustainable Living,*** Holmgren Design Services 1996

3. We also use sawdust in the compost toilet to absorb very soluble nutrients in urine and faeces. In the chook deep litter yard we use crop wastes, pampas grass and pasture grass to absorb the concentrated nutrients in chook manure and we turn the yard in winter to avoid anaerobic conditions to avoid odours and loss of nitrogen. In the goat's milking stall we use straw, spilled hay and tree fodder waste to absorb nutrients in urine.

4. In the orchard we grow many large and nutrient demanding fruit, nut and fodder trees which themselves become large storages of nutrients.

5. Along the gully we use willows and other species to absorb soluble nutrients in catchment runoff which flows through and past the property. These nutrients are then recycled to the land by pollarding the tops of the trees for animal fodder and compost.

Our planting strategies have created carbon storage in forms specifically appropriate to the site and situation. Because of the intensive, semi-urban nature of the site we have minimised the planting of large competing and fire hazardous forest trees such as eucalypts and conifers, but included many deciduous food and fodder bearing trees as well as nitrogen fixing animal fodder, shelter and timber trees. We have pruned our trees to develop good timber form so, if and when they are harvested more of the wood will be in a form which can be useful as round and/or sawn timber rather than fuel. We feel it is better to transport firewood short distances from sustainably managed local native forests than devoting a large part of our relatively fertile and well serviced urban fringe land to growing our firewood. Nevertheless, we produce about 10% of our annual firewood consumption as a by-product of managing the trees for multiple values.

Our pastures include long lived perennial grasses and other deep rooted species which maintain a significant permanent biomass as well as producing a large surplus in spring.

By slashing and mulching pastures, lopping fodder trees and use of grazing and browsing animals we have recycled much of the annual production of biomass to organic matter which has, over time substantially increased the soil humus content of our soils.

Where we hold animals in yards and pens, we use fibrous organic matter to absorb concentrated manures and urine to form balanced composts for growing our most nutrient demanding annual crops.

In recent years as the system matures we have put more focus on the recycling of much the nutrients stored in perennial pasture and tree biomass into more available forms through animal grazing and browsing. At the same time we have attempted to better balance mineral fertility which has also improved the structure of the soil and its capacity to hold larger quantities of nutrients[13]. As the capacity of our soil to store water, nutrients and carbon increases we have the flexibility to reduce storage in perennial plant biomass if it suits, without compromising the overall resilience of the system.

PERMACULTURE AS GREENHOUSE STRATEGY

The greenhouse effect is the problem industrial civilisation "had to have" before the limitations of reductionist and symptomatic thinking would become self evident.

Unfortunately rather than a complete revolution in thinking and societal response, the old ways of thinking continue to dominate the formal structure of research and official strategies for dealing with the problem. Research agendas, budgets and debate is still largely determined by a segmented and reductionist world view which generates detail complexity across many different fields. At almost no point can anyone get a sense of the whole picture because of this detail complexity which are then filtered by economic and political structures to generate a small number of technical fixes which can be implemented by powerful government and corporate decisions.

Whether we consider fossil fuel consumption, the carbon sink side of the equation or the adaption to inevitable climatic change, permaculture principles and strategies are a predictor of appropriate greenhouse effect responses because they deal with the more fundamental causes of imbalance rather than the symptoms. Widespread adoption of permaculture principles and strategies would make greenhouse strategies unnecessary.

The holistic systems thinking which generates permaculture strategies works from design principles to recognise a pattern language of solutions which can be used to proliferate small and local solutions which co-evolve to incrementally mutually reinforce one another in an interlocking new ecosystem of human service.

13 Total Cation Exchange Capacity is the measure of a soils capacity to hold nutrients and mostly depends on the quantity and types of clay plus the quantity of humus present. Testing over recent years shows a rise in the TCEC from increasing humus. Most interestingly we think our humus levels are increasing due to the nature of its breakdown into true humus rather than greater addition of organic matter. This improved quality of humus we attribute to additions of Calcium and selected trace elements in recent years based on the Albrecht approach to soil fertility balance.