Chapter 7

WATER

Water is the driving force of all nature.
(Leonardo da Vinci)

In an animal or a plant, 99 molecules in 100 are water... An organism is a pool in a stream of water along which metabolites and energy move through ecosystems.
(W.V. Macfarlane)

The sustained flow of rivers is truly remarkable, considering that precipitation is an unusual event in most areas of the earth. Localisation of precipitation in space or time is striking {e.g. at Paris, it rains for 577 hours a year, or only 7% of the time. *B.Mollison*}. Few storms last more than a few hours, so that even storm days are mainly rainless. Yet rivers flow throughout the year. The sustaining source of flow is effluent groundwater... The amount of soil water is about fifteen times the amount in channel storage in rivers.
(Nace *in* Chorley, 1969)

7.1 INTRODUCTION

Very little of the world's total water reserves are actually available for present human needs. Many areas of earth, particularly dryland areas, over–developed cities, and towns or cities surrounded by polluting industry and agriculture, face an absolute shortage of useable water. Millions of city–dwellers now purchase water, at prices (from 1984 on) equivalent to or greater than that of refined petroleum. This is why the value of land must, in future, be assessed on its yield of potable water. Those property–owners with a constant source of pure water already have an economically–valuable "product" from their land, and need look no further for a source of income. Water as a commodity is already being transported by sea on a global scale.

The PRIMARY SELECTION FACTOR, when choosing a cropland property to develop, should be an adequate, preferably well–distributed, and above all reliable rainfall. "Adequate" here is about a minimum of 80 cm (31 inches) and upwards. An equally important factor is the ability of the area to hold water as dams in clay or clay–loam storages; any stream flow within the boundaries is a bonus. All other factors (soil type, present uses, number of titles, market potential, access, and forested areas) are secondary to water availability.

Little of the lands now used for crop agriculture have such fortunate characteristics. Few farmers have invested in "drought–proofing" their land by creating gravity–fed irrigation systems of **Keyline systems**[5]. Specific strategies of water conservation and control are given in this book under their appropriate climatic and landform sections.

While there are no economically–feasible strategies or technologies for freshwater creation from the sea or from polluted sources, there are several currently neglected strategies for recycling, purification, conservation, and increased storages of rainwater. In particular, the construction of tanks and dams have been neglected in built–up areas, as have earth storages on farms and in rural areas. Waste usage ranging from over–irrigation, non–recycling in industry, inappropriate domestic appliances, and unnecessary uses (on lawns and car washes) have not as yet been adequately costed by legislators or by householders.

Tables 7.1 and **7.2** show abstract figures of the global and local water cycles. These should not be regarded as fixed or even sufficient representations of water in relation to actively designed or rehabilitated landscapes. There are ways in which we can constructively reverse past trends in water deficits, waste, pollution, and misuse. There is plenty of water for the world if we define the ways in which we store and use it carefully.

7.2

REGIONAL INTERVENTION IN THE WATER CYCLE

CLOUD SEEDING

Silver iodide, and no doubt other ice nucleii such as tea dust can be "seeded" into cumulus, cumulonimbus, or nimbostratus clouds (by plane, ground burners, or rocket) in order to initiate local precipitation.

Until recently these attempts to make rain were assessed as ineffective because no one had, at the time, realised how far and for how long the seeding effects spread and persisted. More recent analysis show that rain in fact increases over a very wide area, and that secondary effects last for months, so that varying wind directions and speeds carry the induced rain effects for hundreds or thousands of square kilometres (*Ecos*, 45, Spring 1985). It also seems probable that ground burners or ground release of ice nucleii could have a similar effect. On the ground, silver iodide is absorbed into coal dust, and this is then burnt when clouds form on hill crests. Strategic downwind hills can generate clouds and rain over large areas of land.

Once initiated, however, such effects cannot quickly be stopped, and even in places like India or Ethiopia may create a little too much rain if ground storage systems are not previously developed to cope with the extra water. In arid or semi–arid areas, flood retardation basins, oversized swales, large sand dams, water spreading systems, pelleted seed of fast–growing plants, and in fact any sensible civil strategy to preserve soil and people from any effect of increased precipitation is a necessary prelude to cloud–seeding.

Initial precipitation (due to increased bacterial or ice nucleii stimulus) increases can be as much as 30%, and subsequently averaged in Australia at 19% (17% in Israel) over weeks, falling to 8% in months. The cloud–seeding system promises to help increase monsoon or frontal rains in areas where suitable clouds occur without sufficient precipitation. This system can be very cheap for large land areas. For more data or references, contact the Cloud Physics Laboratory,

TABLE 7.2
FRESHWATER LOCATION.
Freshwater is only 3% of all water on earth, and very little is in circulation, most being locked up in storages.

STORAGE	% OF FRESHWATER
Ice and glaciers*	75.0
Groundwater more than 800 m deep	13.5
Groudwater less than 800 m deep	11.0
Lakes	0.3
Soils	0.06
Atmosphere (in circulation at any one time)	0.035
Rivers	0.03

*Frozen ground or permafrost is not assessed in this table. It represents a considerable storage (about 40% of the landmasses of Canada and the Soviet Union.

TABLE 7.1
RENEWAL TIMES OF ALL WATER IN BASIC STORAGES (seawater and freshwater) [From: Southwick, C.H., *Ecology and the Quality of our Environment*, Van Nostrand Reinhold, NY, 1976.]

LOCATION IN STORAGES	DISTRIBUTION (% of total water)	RENEWAL TIME (Turnover rates, cycles)
Ocean	93.8	37,000 years
Glaciers and permanent snow	1.986	16,000 years
Groundwater (to 5 km depth)	4.1	4,600 years
(Actively exchanged)	0.274	300 years
Lakes	0.0051	13 years
Atmosphere	0.000959	9 days
Rivers	0.00008	13 days
Biological water	0.000005	3.4 days

Division of Atmospheric Research, CSIRO, Canberra, Australia.

As similar effects (thunderstorms, rain) have been noted for tea leaf dust downwind of Kenya plantations, more homely strategies may also be developed if the underlying nucleation causes can be established. It may even be that the fires and dances of the old "rain makers" on a high hill were, in truth, effective. Certainly, fires of specific vegetation and dances with the "right" dust plume could help seed ice nucleii in clouds; quite local rain falls near some factory smoke emissions.

Windward slope forests, cross–wind tree lines, and even slight earth rises of a modest 4–6 m have been observed to induce air humidity, cloud formation, and even rain, by orographic (uplift) effects on windstreams. Thus, we are not powerless in the matter of increasing local moisture by a series of sensible ground strategies based on providing trees, mounds, and cloud ice nucleii, and perhaps a serious attempt to induce these changes will in the near future bring relief to areas such as the Indian Deccan, the Sahel, and large areas of Australia and the USA subject to rainless cloud masses.

OROGRAPHIC AND FOREST EFFECTS

Strategically–selected cross–wind ridges of even modest height [3–20 m (10–65 feet)] are ideal sites for the planting of known tree "condensers" and cross–wind tree–lines. These ridges are most useful when lying in the path of the summer afternoon sea breezes that flow inland, or located where the air drifts in at night, such as on the Californian and sub–tropical trade–wind coasts. The clearing of trees from such sites may well induce long–term drought and create a drying effect for hundreds of kilometres inland.

It is long past time that we also assessed vegetation for some of the following effects:

- Ability to provide rain nucleii, as bacteria and natural sulphur particles, and also to effectively condense water from air at night.
- The rainfall effects from forested ridges, where forests exceed 6–10 m (19–32 feet) in height, on rainfall induced by streamline compression effects. This effect is credited with up to 40% of rainfall where now assessed in Sweden and Australia (Tasmania and Victoria).
- The total effect of forested catchment area. Historical and recent evidence suggests that rainfall, streamflow, and cloud may all be seriously depleted by upland deforestation. Such effects are never assessed or costed against deforestation or wood–chipping. The soil erosion and salted land effects are, however, well known in deforested areas.

Any conservationist policies of future effective and informed regional governments would first research

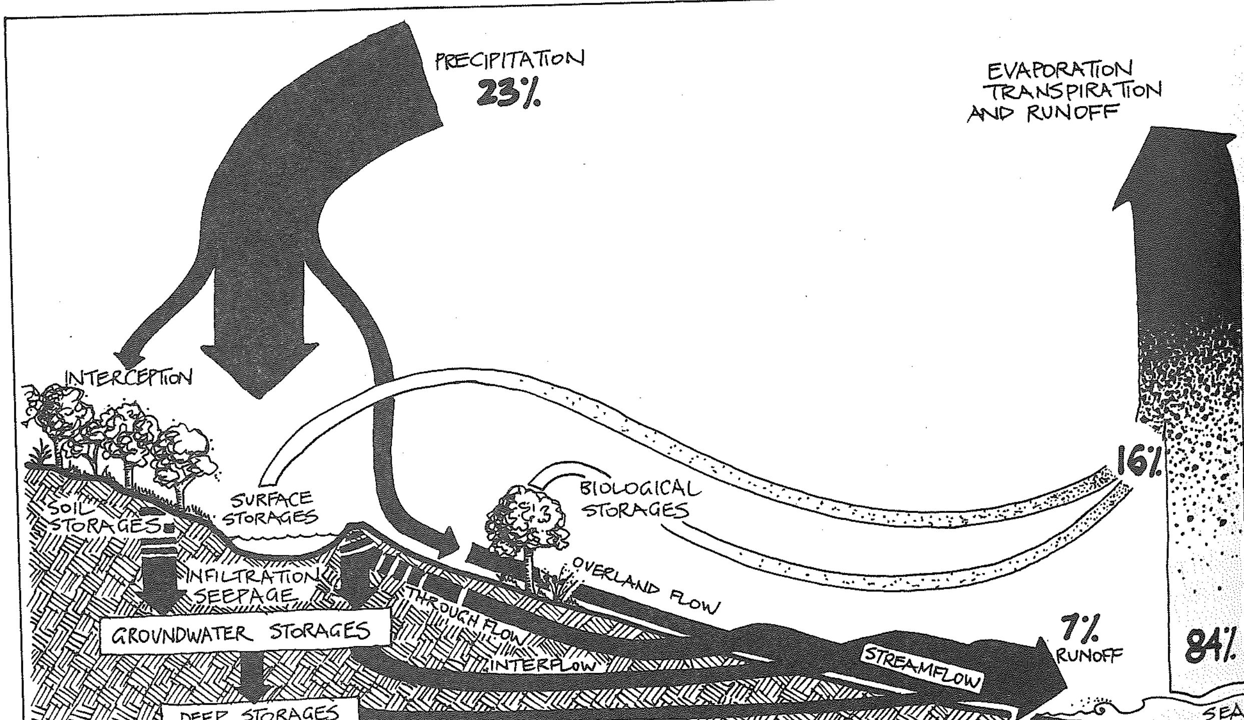


FIGURE 7.1
THE GLOBAL WATER CYCLE (Land and sea)
Omits most of the biological effects but gives the broad schematic of the water cycle. We can affect all parts of this cycle in adverse or beneficial ways.

such effects, then quickly establish national forest and watershed management or restoration policies based on such research. For ourselves, as designers, the proper approach to land planning infers that we recommend permanent forests and the preservation of older forests on cross-wind ridges, and on steep (18° slope or more) sea-facing slopes. The preservation of alpine or upland absorption areas is also essential.

SOIL STORAGES

Soil conditioning or "ripping" (see Chapter 8), providing it is followed by tree plantation, trace element additions, and a non-destructive agriculture of well-managed natural yields, sparse grazing, and conservation farming certainly increases (by factors of up to 70–85%) the ability of soils to hold and infiltrate water. Areas of up to 85% run-off can be converted to zero overland flow by a combination of soil conditioning, swales, and water spreading to forests.

As soils can contain many times the water of open storages or streams, then both the throughflow, baseflow, and water available for plants also increases. It follows that the CYCLING of water via evapotranspiration and rainfall also increases. Soil treatments now need to precede tree planting over almost every area that has been used by contemporary agriculture. In particular the barren areas used for constant cropping in dryland areas need soil treatment to initiate water absorption. Trees are essential to prevent water-logging of soils and soil salting in the long term.

INFILTRATION VIA EARTHWORKS

Cheap broadscale earthwork systems, and many minor forms of earthworks can aid the infiltration of overland water flow. PITTING, SWALES and WATER SPREADING are the main aids to getting fresh water to deeper storages for long-term use, and also to increase base flow. Diversion of surface flow to sand basins, dune fields, swamps, and soakage beds in earth-bermed fields all ensure resident water reserves for crop and trees, and longer-term storages for use in dry seasons.

Diversion drains and their associated valves, slides, cross-walls, intakes, and irrigation systems enable effective water harvesting, dependable storage, and fast emergency use in normal rolling lowlands, hill country, and drylands. They can also recharge sand basins and swales from otherwise wasted overland flow, and damp our wildfires.

POND AND FARM DAM STORAGES

Wherever precipitation exceeds the demands of transpiration and evaporation, small dams, wetlands, and swamps can proliferate. All of these act as long-term water and wildlife reserves in the total landscape, and many Australian farms are now "drought-proof" due to sensible investment in Keyline or similar water conservation systems by the owners. Excellent technical manuals exist (see references at the end of this chapter).

Dams and ponds are potential aquaculture sites, and the production of a diverse plant and fish or waterfowl protein product should also be considered during their construction. In humid areas, therefore, these water storages can occupy up to 20% of the landscape with great benefit in providing fish and a great variety of aquatic product, while at the same time moderating the effects of drought and flood.

BIOLOGICAL STORAGES

The great forests and the biological water storages in the form of fruits and nuts (such as the coconut) are the basis for the proliferation of life forms where no "free" water otherwise exists. In particular, browsers, insects and fungi draw on these biological tree reserves year-round, and perform a host of useful functions in any ecosystem. On atolls and arid islands of free-draining sands, the biological reserves are the main water reserves. This is often overlooked, except by those inhabitants dependent on the waters contained in fruits or nuts. Many plants such as cactus, palms, and agaves have specific tissues or organs to store water.

In the local microclimate, the water in vegetation greatly moderates heat and cold excesses, and both releases to, and absorbs water from passing air streams. Essential crops such as cassava will produce crop as a result of the humidity provided by surrounding vegetation, so that even this side effect of vegetation is of productive use (*New Scientist* 29 May '86).

TANK STORAGES

Water can be captured off roof areas, roads, and other paved areas, and used for both drinking water and shower or garden water, providing it can be stored. Roof water is least polluted, or most easily treated for drinking and cooking in houses, while absorption beds are sufficient for the muddy or polluted run-off from roads and parking areas.

7.3 EARTHWORKS FOR WATER CONSERVATION AND STORAGE

For the serious small dam and earth tank builder, there is no substitute for such comprehensive texts as that recently compiled by Kenneth D. Nelson (1985). This small classic deals with catchment treatments, run-off calculations, soils, construction, outlets, volume and cost estimates, and includes detailed drawings for most adjunct structures.

However, like most engineers, Nelson concentrates mostly on valley dams (barrier or embankment dams), and less on the placement of dams in the total designed landscape. Few dam builders consider the biological uses of dams, and the necessary modifications that create biological productivity in water systems.

A second essential book for water planning in landscape is P. A. Yeomans' *Water for Every Farm/The Keyline Plan* (1981)[5]. This very important book, written in 1954, is without doubt the pioneering modern text on landscape design for water conservation and gravity–fed flow irrigation. As it also involves patterning, tree planting, soil treatment, and fencing alignment, it is the first book on functional landscape design in modern times.

There are two basic strategies of water conservation in run–off areas: the diversion of surface water to impoundments (dams, tanks) for later use, and the storage of water in soils. Both result in a recharge of groundwater. As with all technologies, earthworks have quite specifically appropriate and inappropriate uses. Some of the main productive earthwork features we create are as follows:

- Dams and tanks (storages);
- Swales (absorption beds);
- Diversion systems or channels; and
- Irrigation layouts, and in particular those for flood or sheet irrigation.

SMALL DAMS AND EARTH TANKS.

Small dams and earth tanks have two primary uses. The minor use is to provide watering points for rangelands, wildlife, and domestic stock; such tanks or waterholes can therefore be modest systems, widely dispersed and static. The second and major use is to contain or store surplus run–off water for use over dry

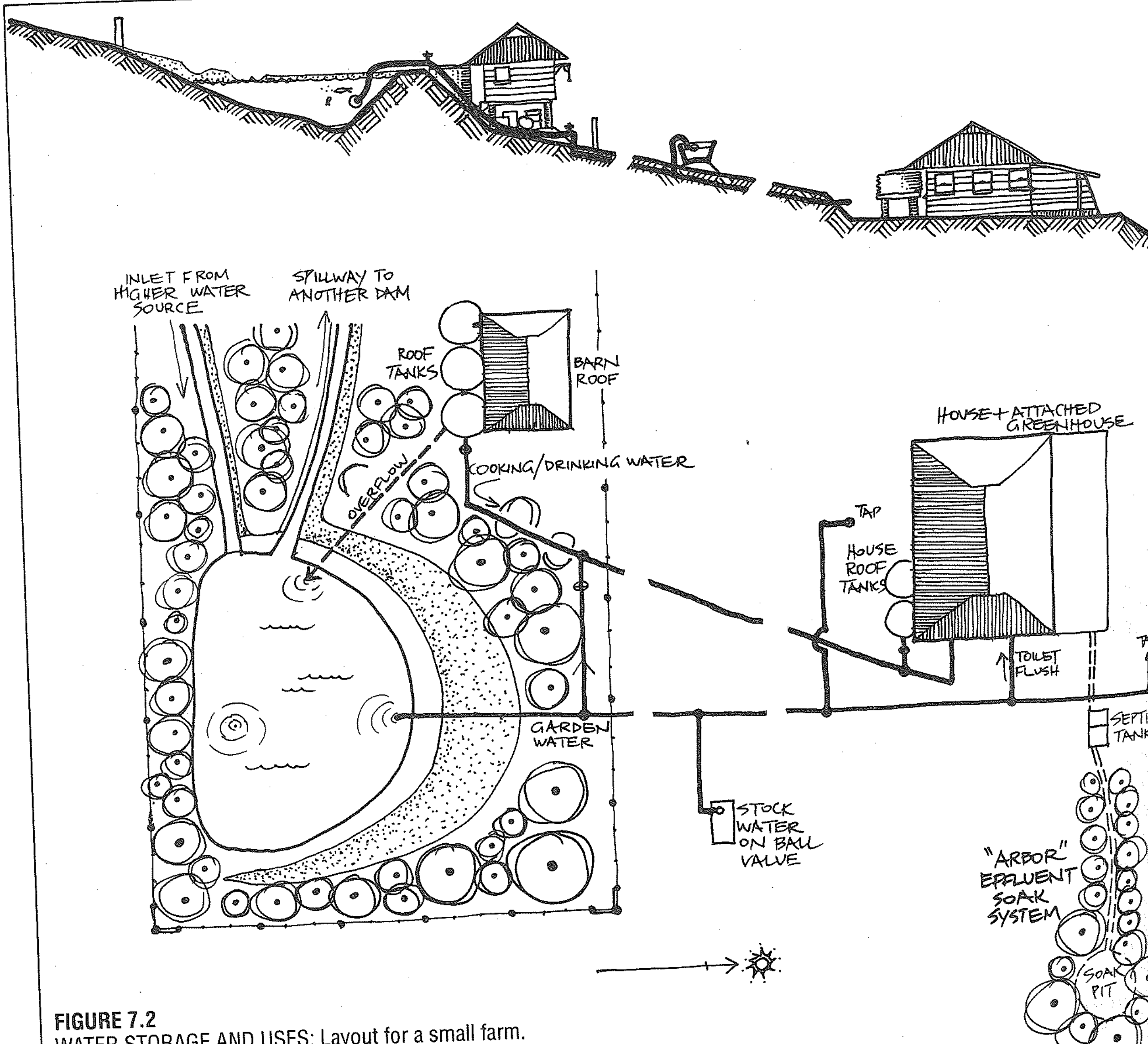


FIGURE 7.2
WATER STORAGE AND USES; Layout for a small farm.
Schematic of gravity–flow systems in relationship to farn buildings (dams and roof tanks).

periods for domestic use or irrigation. The latter storages, therefore, need to be carefully designed with respect to such factors as safety, water harvesting, total landscape layout, outlet systems, draw–down, and placement relative to the usage area (preferably providing gravity flow).

A separate category of water storages, akin to fields for crop or browse production, are those ponds or wet terraces created specifically for *water crop* (vegetation or mixed polycultural systems of aquatic animal species).

Open–water (free water surface area) storages are *most appropriate in humid climates*, where the potential for evaporation is exceeded by average annual rainfall. There is a very real danger that similar storages created in arid to subhumid areas will have adverse effects, as evaporation from open water storages inevitably concentrates dissolved salts. Firstly, such salty water can affect animal health. Secondly, the inevitable seepage from earth dams can and does create areas of salted or collapsed soils downhill from such storages. And in the case of large barrier dams, so little water may be allowed to bypass them in flood time that agricultural soils, productive lakes, and estuaries may lose more productive capacity by deprivation of flush–water and silt deposits than can be made up (at greater cost) by irrigation derived from such lakes.

Dryland storage strategies are discussed in Chapter 11. What I have to say here is *specifically addressed to humid areas and small dams* unless otherwise noted.

Earth dams or weirs where retaining walls are 6 m (19 feet) high or less, and which have a large or over–sized stable spillway, are no threat to life or property if well–made. They need not displace populations, stop flow in streams, create health problems, fill with silt, or block fish migrations. In fact, dams or storages made anywhere *but* as barriers on streams effectively add to stream flow in the long term.

Low barrier dams of 1–4 m (3–13 feet) high can assist stream oxygenation, provide permanent pools, be "stepped" to allow fish ladders or bypasses, and also provide local sites for modest power generation. While almost all modern assessments would condemn or ban large–scale dams (and large–scale power schemes) on the record of past and continuing fiascos, a sober assessment of small water storages shows multiple benefits.

Given the range of excellent texts on small dams (often available from local water authorities, and by mail order from good bookstores), I have therefore avoided specific and well–published construction details, and have here elaborated more on the types, placement, links to and from, and function of small dams in the total landscape. Yeomans (*pers. comm.*, 1978) has stated that he believes that if from 10–15% of a normal, humid, lowland or foothill landscape were fitted with small earth storages, floods and drought or fire threat could be eliminated.

Not all landscapes can cost–effectively store this

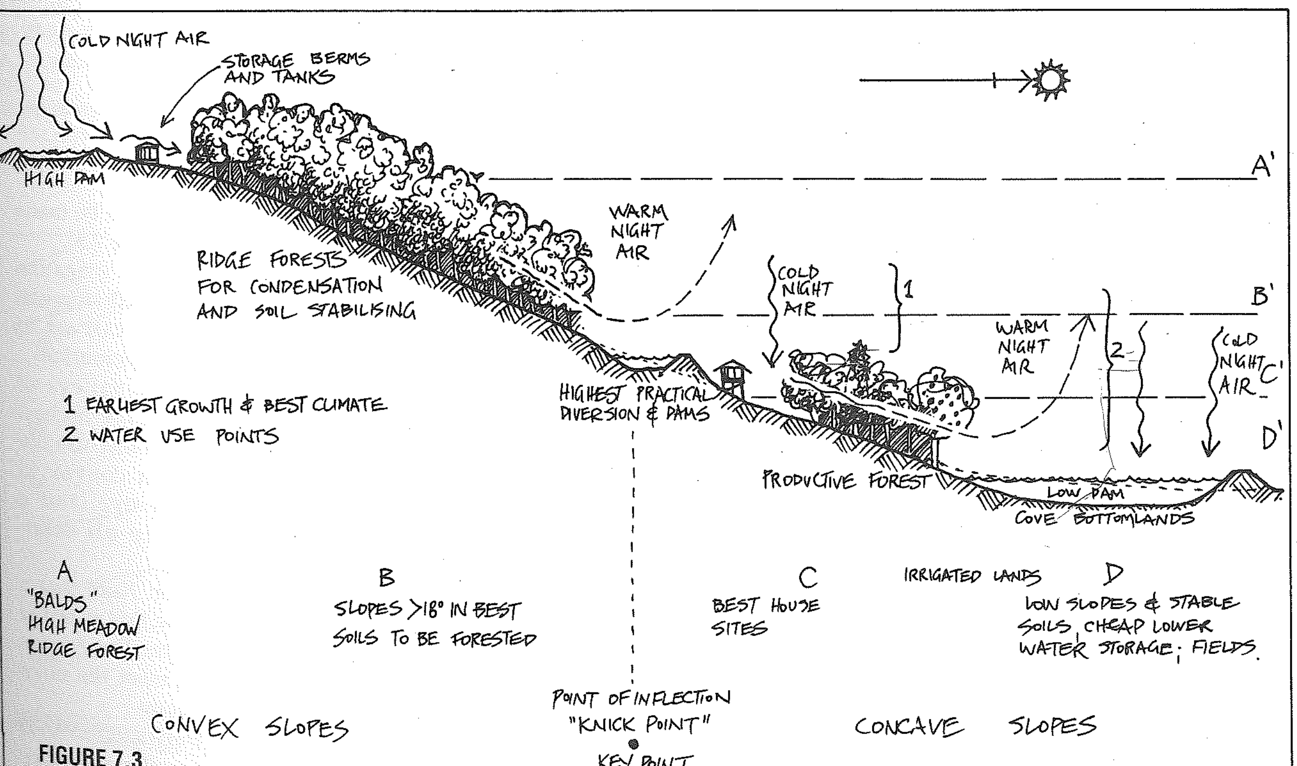


FIGURE 7.3
HUMID LANDSCAPE DAM PLACEMENT ON SLOPE
Schematic of water storages with respect to slope, forests, and dwellings.

proportion of free surface water; some because of free–draining soils or deep or coarse sands. Other areas are too rocky, or of fissured limestone, and yet others are too steep or unstable. But a great many productive areas of clay–fraction subsoils (40% or more clay fraction) will hold water behind earth dams, below grade levels as earth tanks, or perched above grade as "turkey's nest" or ring dams. There are very few landscapes, however, that will not store more soil water if humus, soil treatment, or swales are tried; the soil itself is our largest water storage system in landscape if we allow it to absorb.

Almost every type of dam is cost–effective if it is located to pen water in an area of 5% or less slope. However, many essential dams, if well–made and durable, can be built at higher slopes or grades, made of concrete, rock–walled, or excavated if water for a house or small settlement is the limiting factor. Each and every dam needs careful soil and level surveys and planning for local construction methods.

DAM TYPES AND LOCATIONS

There are at least these common dam sites in every extensive landscape:

SADDLE DAMS are usually *the highest available storages*, on saddles or hollows in the skyline profile of hills. Saddle dams can be fully excavated below ground (grade) or walled on either side of, or both sides of, the saddle. They can be circular, oblong, or "shark egg" shaped with horns or extensions at either end (**Figure 7.4**).

Uses: wildlife, stock, high storage.

RIDGEPOINT DAMS or "horseshoe" dams are built on the sub–plateaus of flattened ridges, usually on a descending ridgeline, and below saddle dams. The shape is typically that of a horse's hoof. It can be made below grade, or walled by earth banks (**Figure 7.5**).

Uses: As for saddle dams. Only of limited irrigation use, but very useful for run–off and pumped storages. Note that both saddle and ridge dams can act as storages for *pumped* water used for energy generation.

KEYPOINT DAMS are located in the valleys of secondary streams, humid landscapes, at the highest practical construction point in the hill profile, usually where the *stream* profile changes from convex to concave; this place can be judged by eye, and a descending contour will then pick up all other keypoints on the main valley (**Figure 7.6**).

Uses: Primarily to store irrigation water. Note that a second or third series can be run below this primary series of dams, and that the spillway of the last dam in a series can be returned "upstream" to meet the main valley, effectively spilling surplus to streams.

CONTOUR DAM walls can be built on contour wherever the slope is 8% or less, or sufficiently flat. Contours (and dam walls) can be concave or convex to the fall line across the slope (**Figure 7.7**).

Uses: Irrigation, aquaculture, or flood–flow basins in

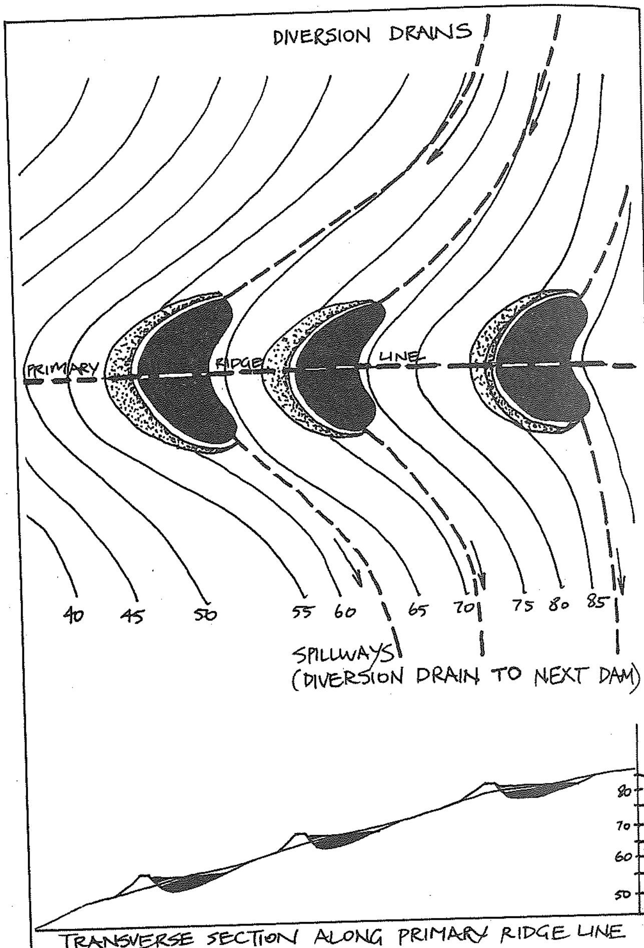


FIGURE 7.5
RIDGEPOINT DAM
or "horseshoe" dam, built on plateau areas of ridges. Uses as for saddle dams.

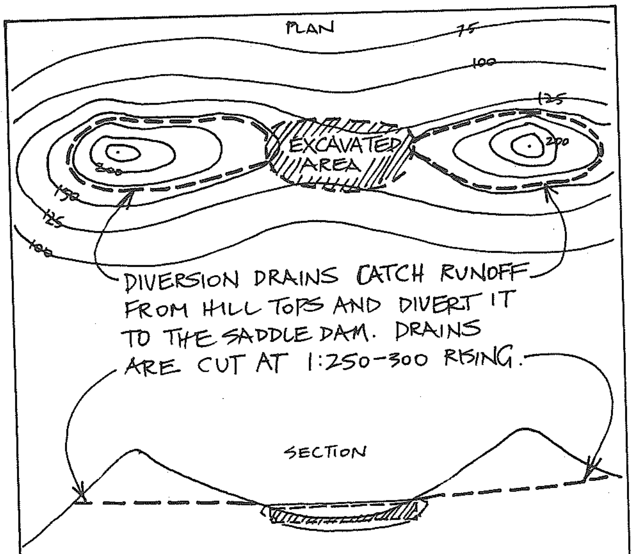


FIGURE 7.4
SADDLE DAM
Very useful for fire control, wildlife, limited irrigation. The "highest" type of dam in the landscape that fills from hill runoff.

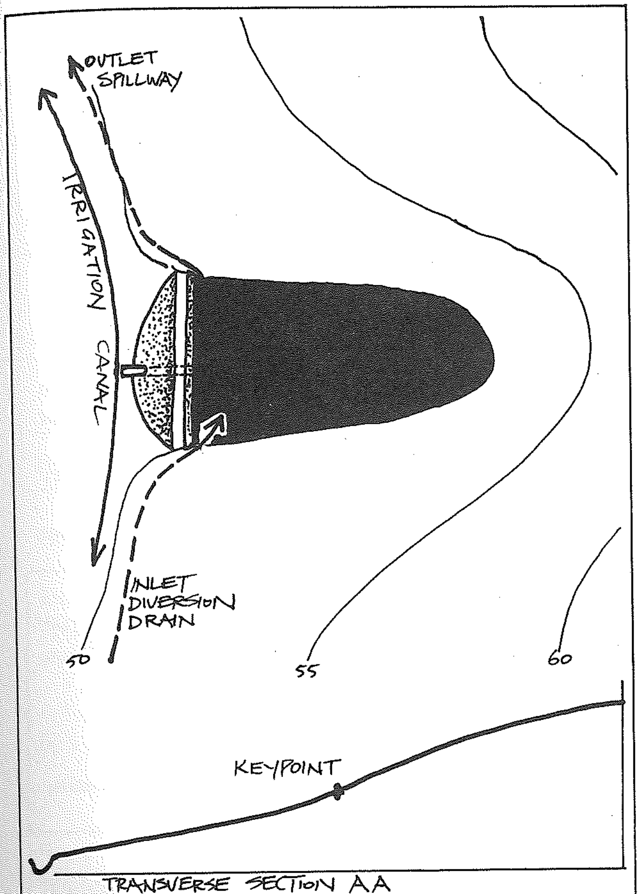


FIGURE 7.6
KEYPOINT DAM
A. If used in series, no spillway is built and the overflow goes to the next dam, and eventually to a stream. Fitted for irrigation on lower slopes.
B. The keyline (heavy dashes) links keypoints in primary valleys.

semi–arid areas.

BARRIER DAMS are always constructed across a flowing or intermittent stream bed. These dams therefore need ample spillways, careful construction, fish ladders on biologically important streams, and are made most frequently as energy systems, but are also used for irrigation if they are constructed well above the main valley floors where crops are grown (**Figure 7.8**).

TURKEY'S NEST DAMS or above–grade tanks; water has to be pumped in to these, often by windmill or solar pump. They are common in flatlands as stock water tanks or for low–head irrigation (**Figure 7.9**).

CHECK DAMS. There are many forms of barrier dams not intended to create water storages, but to

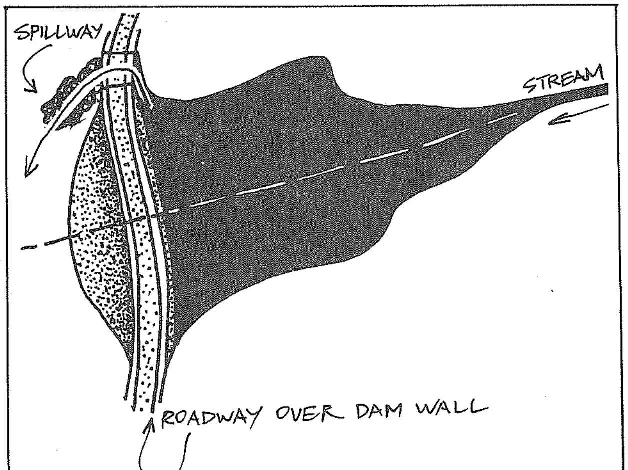


FIGURE 7.8
BARRIER DAM
"The engineer's dam." Can affect fish, migration, and be difficult to spill; works well as part of a keyline series only.

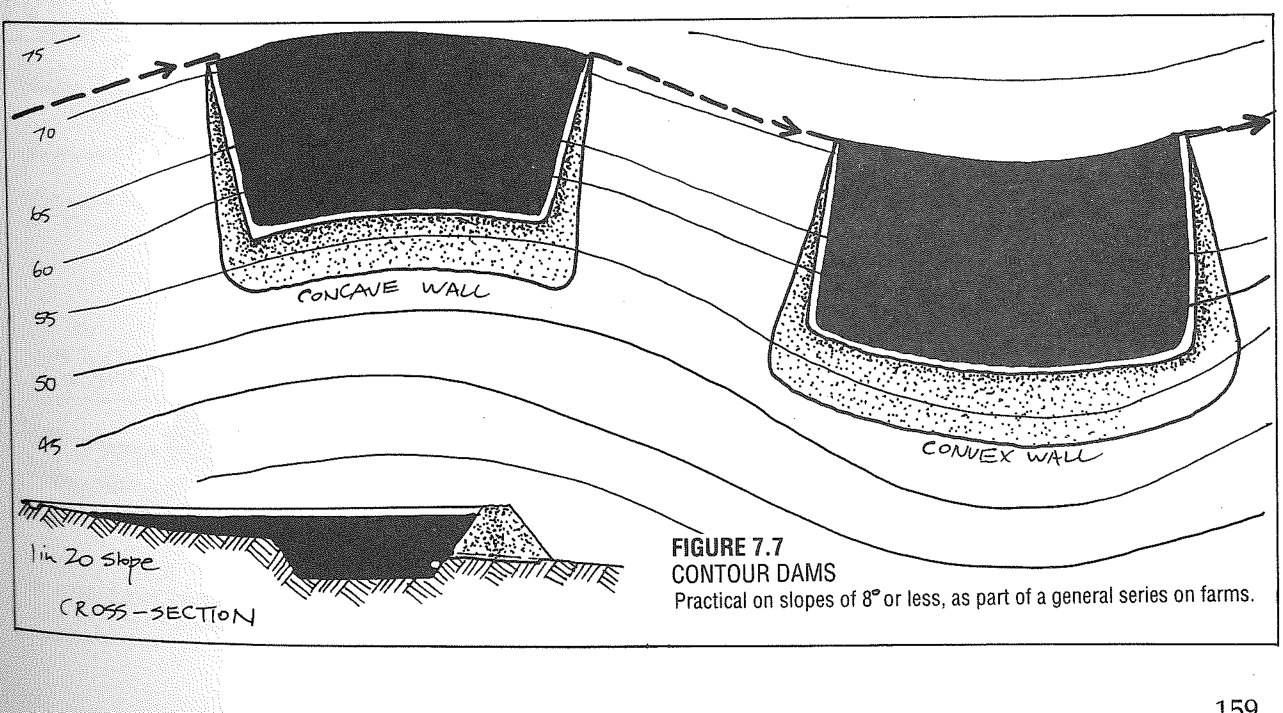


FIGURE 7.7
CONTOUR DAMS
Practical on slopes of 8° or less, as part of a general series on farms.

regulate or direct stream flow. Even a 1–3 m (3–10 foot) wall across a small stream gives enough head to drive an hydraulic ram, to fit a waterwheel, to divert the stream itself to a contoured canal for irrigation, or to buffer sudden floods. Dams intended to regulate flood crests may have a base pipe or fixed opening in the streambed which allows a manageable flow of water downstream while banking up the flood crest behind the dam itself, so spreading the rush of water over time. The base opening allows silt scour and so keeps the dam free of siltation (**Figure 7.10–13**).

GABION DAMS. In drylands, permeable barriers of rock–filled mesh "baskets" (**gabions**) will create silt fields and water–spreading across eroding valleys. The scale of these dams varies, but for farm construction, walls 0.5–2 m (2–6.5 feet) high are usual. As with **Figure 7.12**, the purpose is not to store free surface water, but to create a flat area where silt loads can usefully deposit, and so form absorption beds in flood conditions.

We can see the landscape (as though sliced into layers through contours) as a set of catchment, storage, usage, and revitalisation zones. (**Figure 7.15**)

BUILDING DAMS

Although we can build dams or tanks on *any* site, given enough material resources, commonsense dictates that storage dams be carefully located with respect to:

- Earth type (core out a sample pit for assessing clay fractions);
- Grade behind wall (lower slopes give greatest

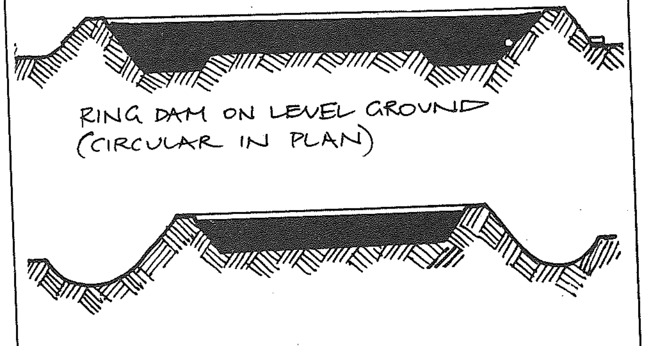


FIGURE 7.9
RING AND TURKEY'S NEST DAM.
Hold water pumped in by a windmill and provides a low head in flat landscapes; can be pipe–filled from a large roof or from parking areas.

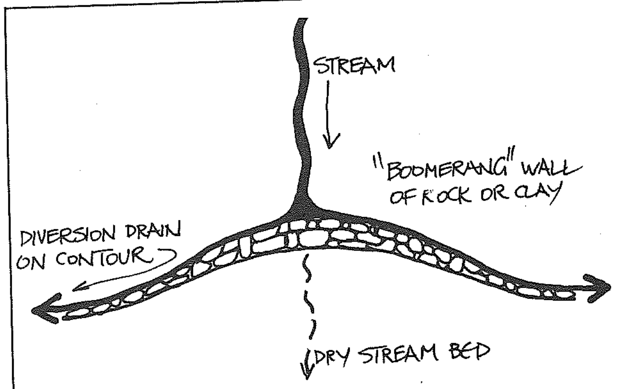


FIGURE 7.10
DIVERSION CHECK DAM
Diverts intermittent flow to ridges, storages , or canals on contour.

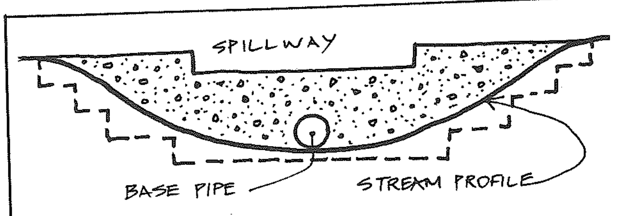


FIGURE 7.11
CONCRETE FLOOD CHECK DAM
Allows normal flow to pass, retards floods, and prevents rapid flood discharge.

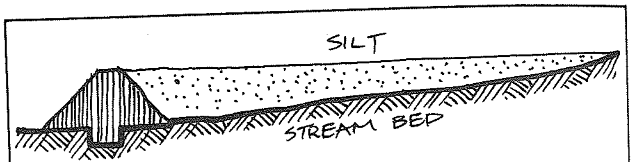


FIGURE 7.12
SILT CHECK DAM
Earth or concrete walls or gabions hold silt fields, spread water, reduce silt load in streams.

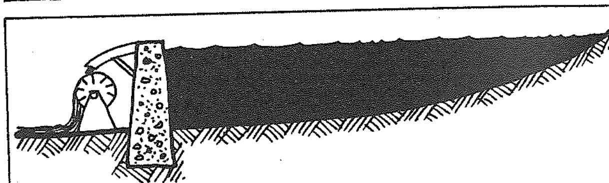


FIGURE 7.13
CHECK DAM FOR RAM PUMP OR WATER WHEEL
Only 1–3 m of head enables modest energy use for mechanical power, lift pumps, or diversion to canals.

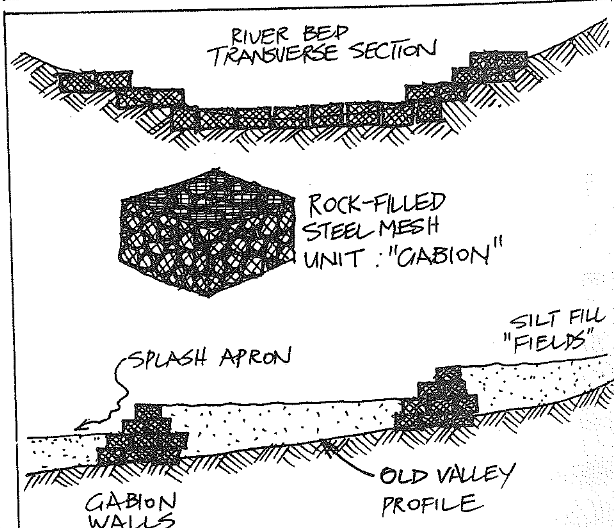


FIGURE 7.14
Eroding gullies are best stabilised using strong wire baskets to contain stones or shingle; these resist floods well.

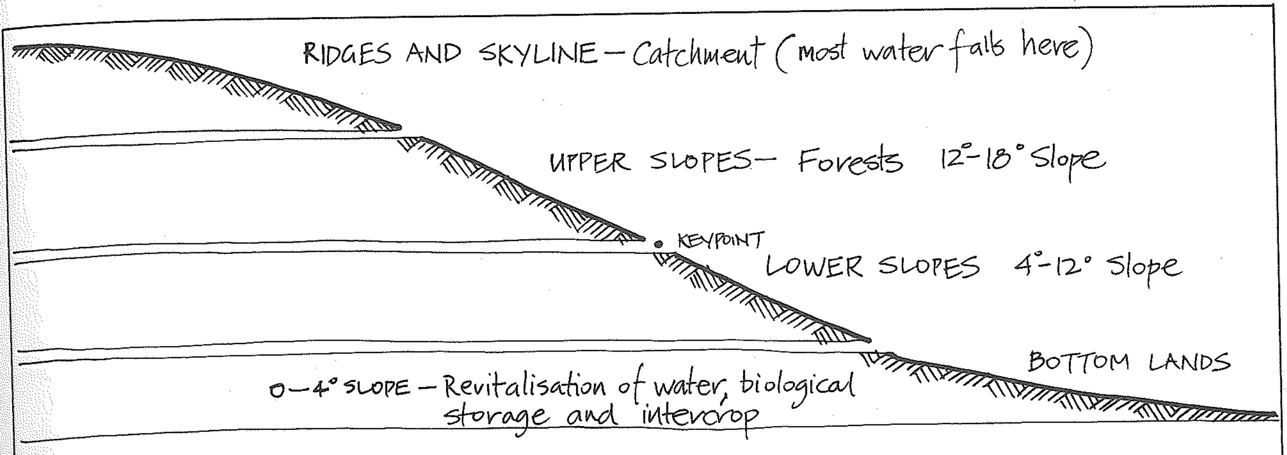


FIGURE 7.15

capacity);

- Downstream safety of structures and houses (a key factor in large dams);
- Height above use points (gravity flow is desirable); and
- Available catchment or diversion.

Tamped earth with some clay fractions of better than 50% is a waterproof barrier up to heights of 3.6 m (12 feet), not counting the holes behind such walls caused by their excavation. Therefore we speak of depths of 4.5–6 m (15–20 feet) for small earth dams. Few of us will want to build farm dams higher, and we must get good advice if we wish to do so.

Slopes to crest should be concave, and every 25 cm (10 inches) a machine such as a roller, or the bulldozer tracks themselves, should ride along and tamp down

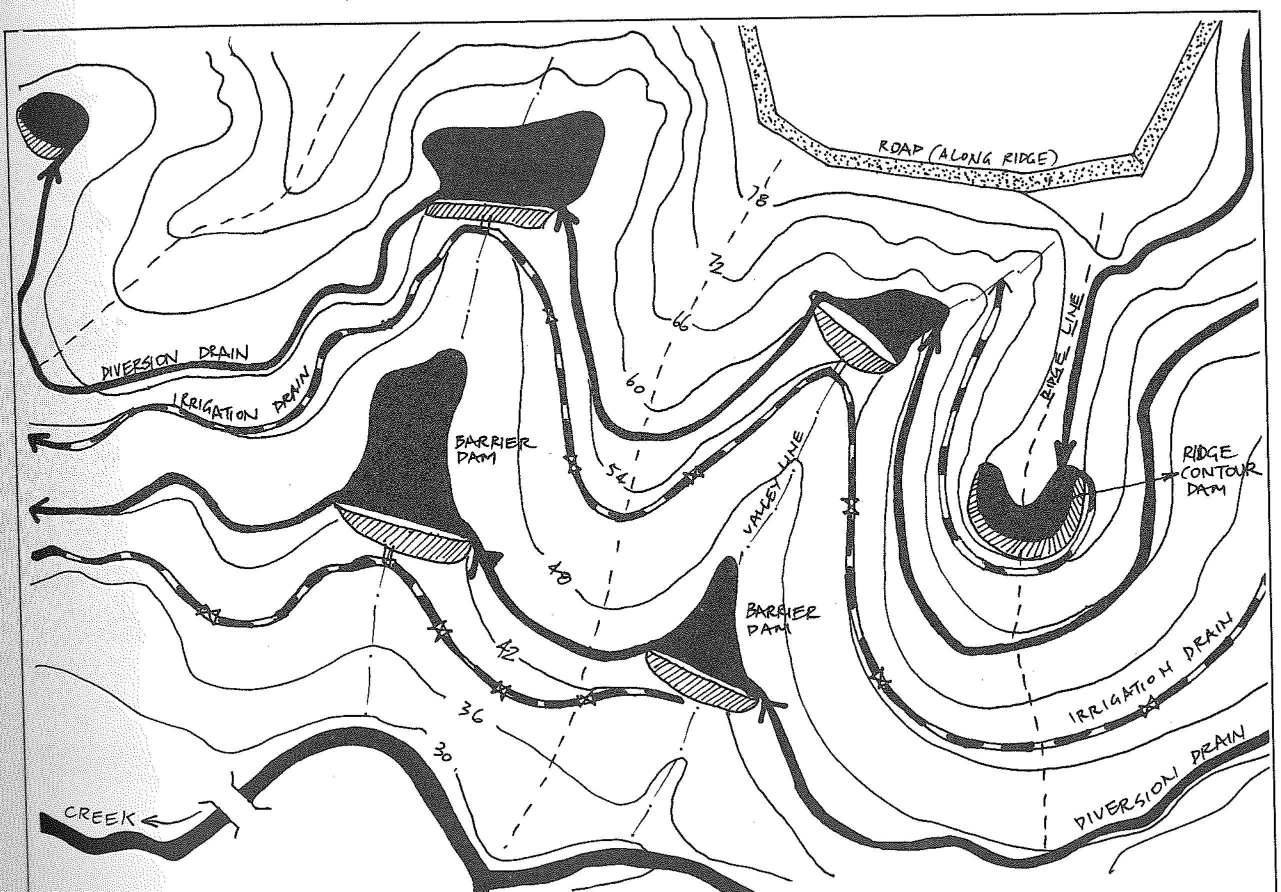
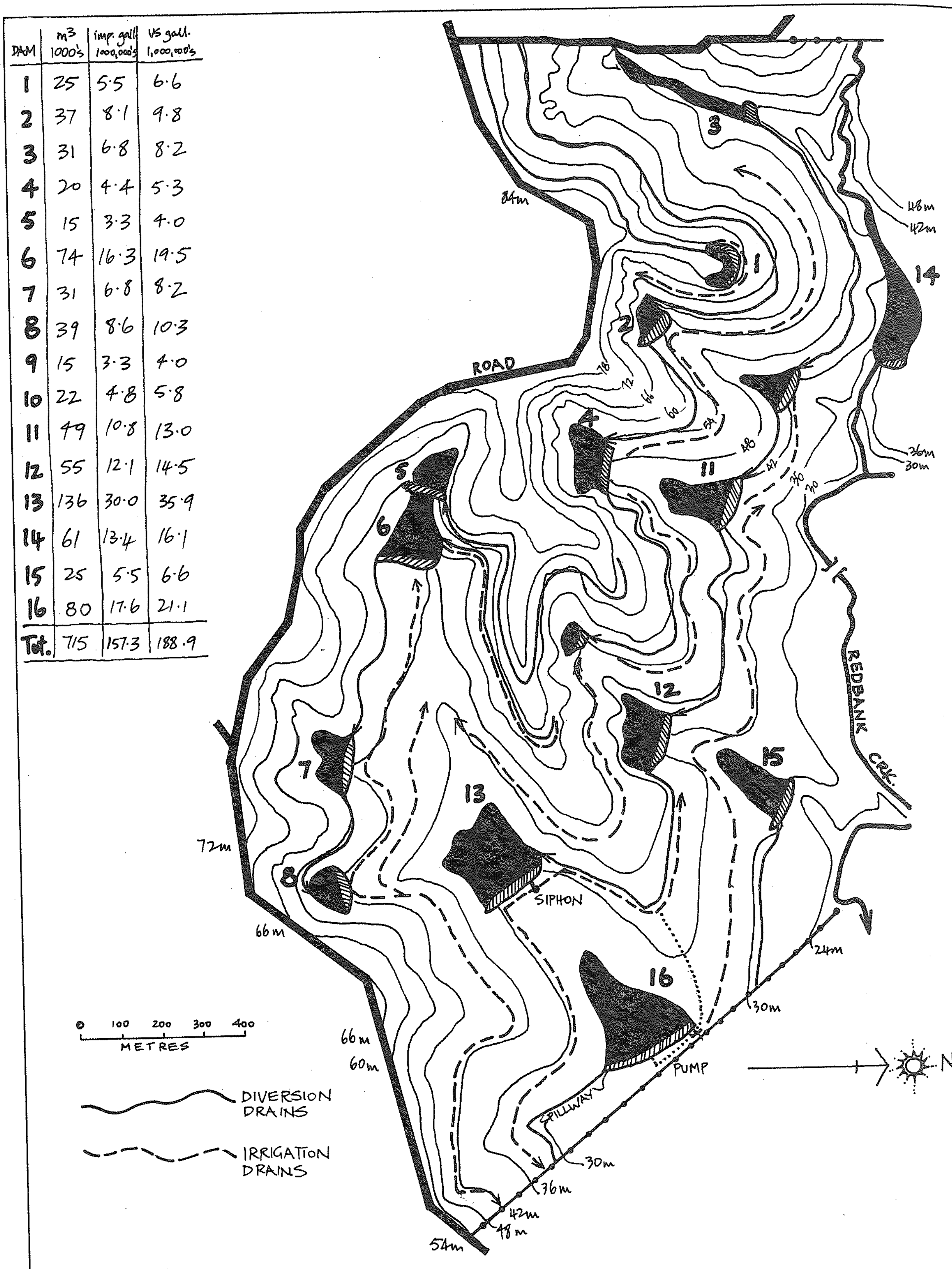


FIGURE 7.16.A
P. A. Yeomans' "Keyline" system provides drought–proofing for farms with very low maintenance and operating costs; his was the first book in English on total water design for foothill farms, access, tree belts, soil creation, low tillage, and creative water storage.



DAM	m³ 1000's	imp. gall 1,000,000's	US gall. 1,000,000's
1	25	5·5	6·6
2	37	8·1	9·8
3	31	6·8	8·2
4	20	4·4	5·3
5	15	3·3	4·0
6	74	16·3	19·5
7	31	6·8	8·2
8	39	8·6	10·3
9	15	3·3	4·0
10	22	4·8	5·8
11	49	10·8	13·0
12	55	12·1	14·5
13	136	30·0	35·9
14	61	13·4	16·1
15	25	5·5	6·6
16	80	17·6	21·1
Tot.	715	157·3	188·9

FIGURE 7.16.B
A MAP OF ONE OF P.A. YEOMANS' PROPERTIES.
P. A. Yeomans' former property "Yobarnie", after 17 years of keyline irrigation development, covering about 307 ha (758a.). The road on the southern edge of Yobarnie is located along a main ridge. Note the primary valleys and primary ridges falling to Redbank Creek to the North. For further information and photographs see Yeomans[5].

the earth. This, like the exclusion of boulders and logs, grass clumps and topsoil, is critical to earth stability (shrinkage of well–compacted dams is less than 1%). Earth so rolled should be neither so dry as to crumble nor so wet as to slump or squash out under the roller.

A key should be cut to prevent shear and cut off any base seepage. This is needed on all walls 1.8 m (6 feet) or more high, otherwise the base should be on a shallow clay–filled ditch. Slopes are safe at a ratio of 3:1 (inner) and 2 or 2.5:1 (outer), freeboard at 0.9 m (3 feet), key at 0.6–0.9 m (2–3 feet) deep. In suspect soils, the whole core can be of carted clay (**Figure 7.17**).

The wall can curve (out or in), but if carefully made as diagrammed and provided with a broad spillway, should be stable and safe forever, barring explosions or severe earthquakes.

The SPILLWAY base should be carefully surveyed at 1 m below crest and away from the wall or fill itself (don't try to judge this, measure it), and a SIPHON or BASE OUTLET pipe fitted with baffle plates placed to draw off water (**Figure 7.18**).

The efficiency in capacity of dams depends on the flatness of the area behind the wall. A "V" valley or "U" valley, plateau, or field should be as level as can be chosen for greatest efficiency. The key to efficiency is the length of the dam wall, compared with the "length" of water dammed. If the back–up is greater than wall length, then this is a measure of increasing efficiency of energy used or earth moved for water obtained. A careful survey of grade plus dam length gives this data before starting the wall. Some dam sites are very cost–effective, especially those short dams at constricted sites where the valley behind them is flattish.

Small dams of this nature are a jewel in the landscape. Fenced and planted to 30–60 m of forest and fruit surround, they will provide biologicially clean, if sometimes muddy, water, and if the topsoil is returned,

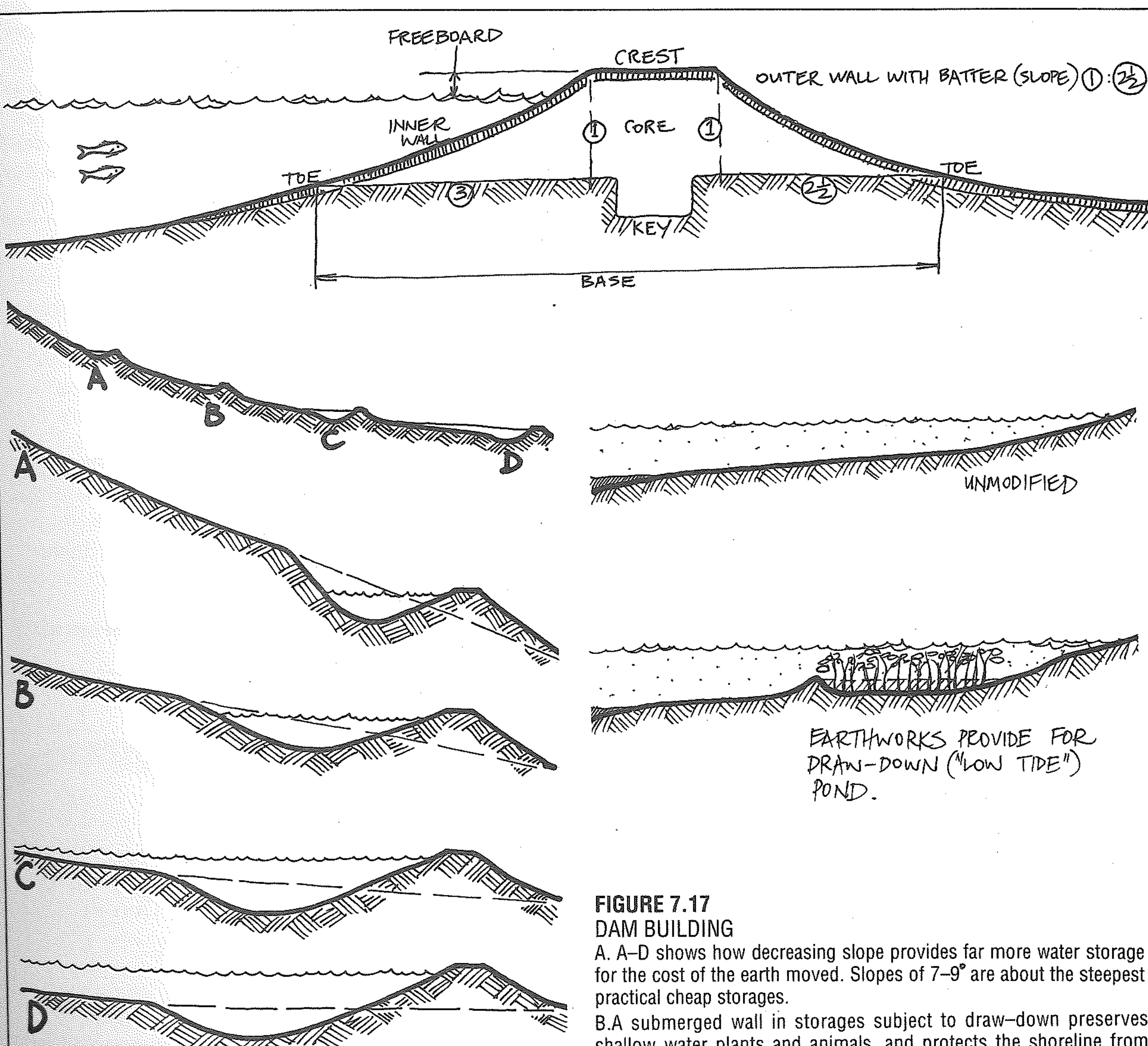


FIGURE 7.17
DAM BUILDING
A. A–D shows how decreasing slope provides far more water storage for the cost of the earth moved. Slopes of 7–9° are about the steepest practical cheap storages.
B.A submerged wall in storages subject to draw–down preserves shallow water plants and animals, and protects the shoreline from wave attack at low levels.

lime used, and edges planted, mud will decrease and eventually clear. For water cleanliness and parasite control, cattle, sheep, and other animals should be watered at spigots or troughs, not directly at the dam. Troughs are easily treated with a few crystals of copper sulphate to kill snails and parasitic hosts; dams stocked with fish will do the same job.

Crests can be gravelled and safely used as roads to cross valleys or bogs, and special deep areas, islands, peninsulas, and shelves or benches made inside the dam for birds, plants, and wild–fire–immune houses.

SEALING LEAKY DAMS

There are several ways to seal leaking dams:

- Gley;
- Bentonite;
- Explosives;
- Clay; and
- Impermeable membranes.

GLEY is a layer of mashed, wet, green, sappy plant material sealed off from air. Although the very green manure of cattle is preferred, shredded, sappy vegetation will also work. It is carefully laid as a continuous 15–23 cm (6–9 inch) layer over the base and *gently* sloping sides (ratio of 1:4) of a pond, and is covered *completely* with earth, cardboard, thick wet paper, plastic sheets, or rolled clay, and allowed to ferment anaerobically. This produces a bacterial slime which permanently seals soil, sand, or small gravels. Once ferment occurs, the pond is pumped or hosed full of water, and the paper or plastic can be later removed. I have used carpets and odd pieces of plastic sheets overlapped with good results. In cold areas, ferment can take a week or two, in tropics a day or so. Lawn or second–cut grasses, papaya and banana leaves, vegetable tops or green manure all serve as the base layer. I believe that in very good soils, especially in the tropics, it may be possible to grow the gley as a mass of *Dolichos* bean and just roll it flat before sealing it (**Figure 7.19**).

Modifications are:

- To pen and feed a herd of cattle in the dry dam until the bottom is a manurial pug; occasional watering assists this process.
- To strew bales of green hay and manure on ponds that leak slightly, producing algae which seal minor cracks.
- To sow down green crop in the dry dam, spray irrigate and feed it off regularly with cattle.

BENTONITE is a slippery clay–powder derived from volcanic ash. It swells when watered and will seal

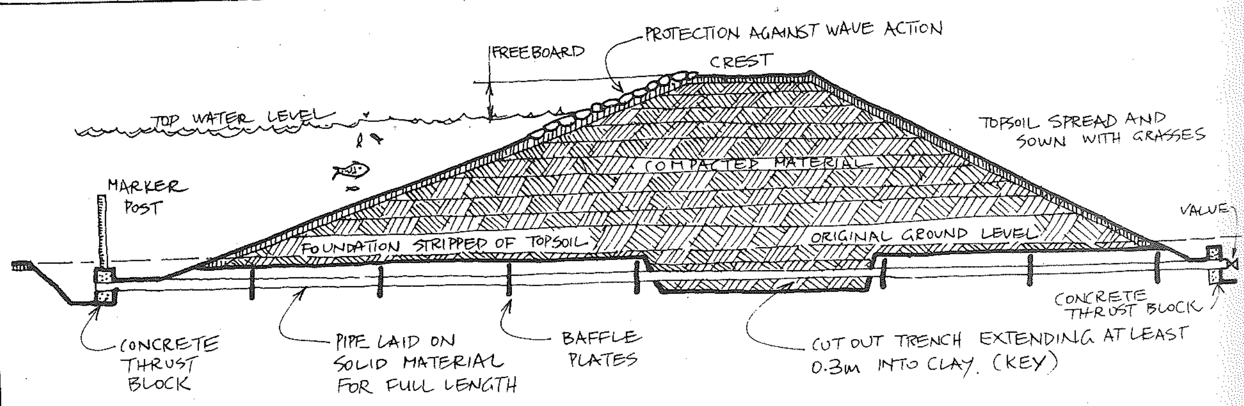


FIGURE 7.18
DAM WITH LOCK PIPES.
A large earth dam feeding irrigation canals in the Keyline system can be fitted with a base pipe. Smaller dams use siphon over the dam wall to gardens and houses.

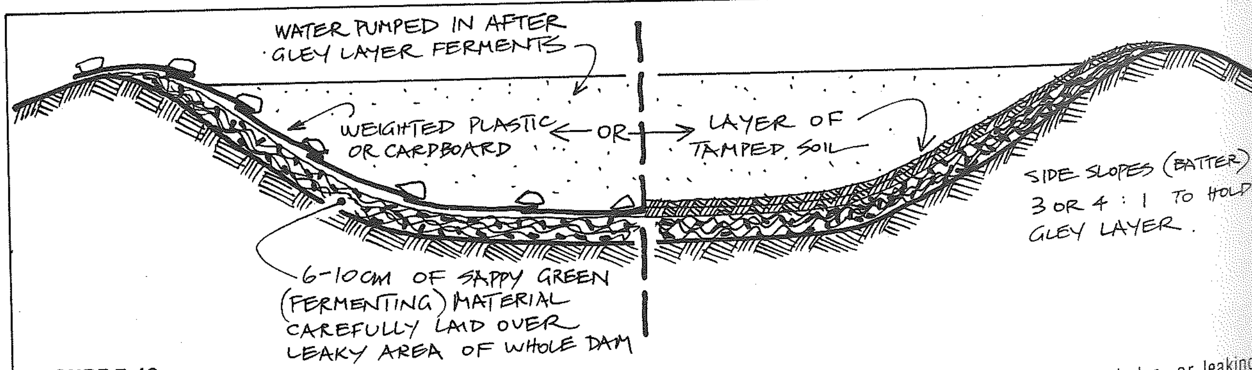


FIGURE 7.19
GLEYING A POND
With great care taken to slope side and place ferment material, this technique will seal ponds in sands, gravels, shales, or leaking substrates.

clay–loams if rototilled in at 5–7 cm (2–3 inches) deep and rolled down. However, it is expensive and doesn't always work. Cement and tamping plus sprinkling might be preferable, or a bituminous spray can be rolled in after tilling. In clay soils, salt or sodium carbonate can have the same effect.

EXPLOSIVES are sometimes used to compact the sides of full dams, and consists of throwing in a 3–5 stick charge of dynamite. This works well at times, but is dangerous if you own a retriever, or if the dam wall is poorly compacted to start with.

CLAY is expensive if it has to be carted in, but it is often used to seal dams near a clay pocket. The clay is spread and rolled 23–30 cm (9–12 inches) thick over suspect areas.

IMPERMEABLE MEMBRANES can be of welded plastic, neoprene, or even poured concrete. Impermeable membranes are too expensive to use on any but critical dams, which may mean a guaranteed water supply to a house or garden in very porous areas. Using membranes enables banks to be steeper than in any other earth–compaction or gley system, so that more water can be fitted into smaller space. It is not "biological" unless a sand or topsoil floor is also added over the sealing layer, when fish or plants can be added.

Earth storage is now the cheapest, easiest, and most locally self–reliant method of water conservation. Unless both cities and farms use such methods, clean water will deservedly become known as the world's rarest mineral, ill–health will be perpetuated, and droughts and floods alike become commonplace. None of these are necessary.

Costs vary greatly; as a rough guide, water stored in soil and humus is the cheapest and of greatest volume, surface dams next cheapest, and tanks dear, but still much less expensive than piped water from mains supply. I can only urge all people of goodwill to promote, fund, and investigate water and water storage, water energy and water cleanliness, as the chlorinated, metallic, asbestos–fibred, poisonous water of modern centralised systems is producing such epidemic disease and illness as cancer, bone marrow failure, and gastrointestinal disorder.

If a 22,500 l tank costs 20 units of money, the same units in a sensible eath storage pays for 2,500,00 l, or about 100 times as much water. Up to 135,000–2,500,000 l tanks get cheaper, as less concrete is used for more water. That is, a large tank is relatively cheaper than a small tank. Above 22,500 l, such tanks are usually poured on site; below this, they are carted from a central manufacturing site.

Dams, in contrast, begin to cost more as the height of the wall rises. About 3 m (10 feet) of retaining wall is the limit of cheap dams. Above this, costs rise rapidly as greater skills, more expensive and massive materials, more complex controls of levels, and much greater environmental risks take their toll.

As noted, "cheap" water in dams depends on the choice of site, so that very low dams on well–selected sites impound 20–100 times more water than the same earth used on steeper sites, where every unit of earth moved equals a unit of water. However, even earth tanks excavated below grade are at one–tenth the price of concrete tanks above grade.

Where are tanks, modest dams, and massive dams appropriate? Tanks are appropriate on isolated dwellings, in flatlands, and everywhere in cities and urbanised areas. Dams of from 22,500 to 4.5 Ml are best built on any good site in country and parkland areas. Massive dams are appropriate hardly anywhere but the the rock–bermed or glaciated uplands of solid and forested hills, subject to low earthquake risk and then only for modest domestic (not dirty industrial) power generation.

TANKS

Cultural and historical precedent may determine how earth is moved and used, or even if it can be moved at all. Thus, an Australian, accustomed to a great variety of surface storage, is astounded that there are no

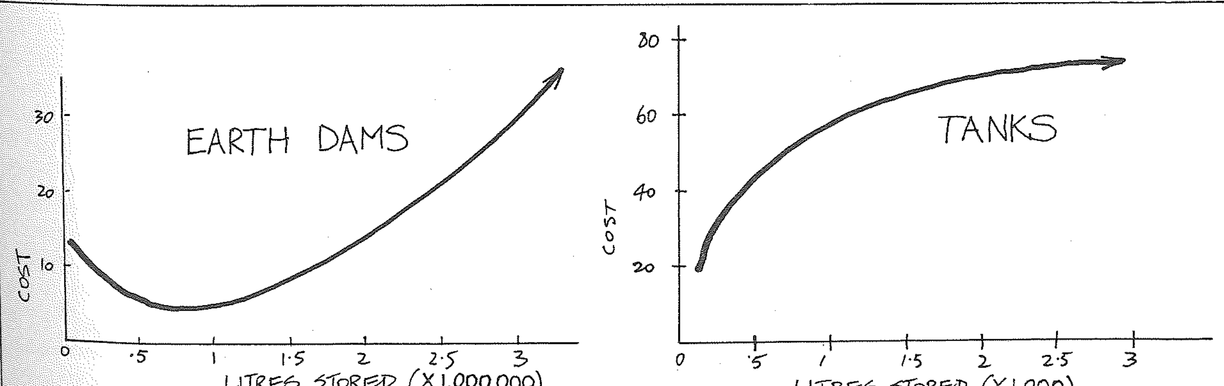


FIGURE 7.20
SCHEMATIC OF COSTS FOR DAMS AND TANKS
Storage tanks cost about 100 times the cost of dams for the same amount of water stored; cost–size schematics for both are given.

significant domestic rainwater tanks in Europe, the USA, or India (where clean drinking water is rare), that British, American, and Brazilian farmers rarely use multiple earth storages of water, and that expensive pipelines and bores are the preferred "alternative", even where local rainfall often exceeds local needs.

The simple forms for making concrete tanks cost a few hundred dollars, and may be used hundreds of times. About 22,500 l provides a family with all needed water (drinking, showers, cooking, modest garden water on trickle) for a year; tank water is renewed by rain at any time of year. Every roof, whether domestic or industrial, would fill many such tanks, and simple calculations (roof area x average rainfall in millimetres or inches) and conversion to litres or gallons gives the expected yield.

Granted that roof areas themselves can be contaminated by birds, dust, or industry, the first precaution is to reject the first flow–off of water, and use it on gardens or in swales. Two methods for doing this are shown in **Figure 7.21**.

As for the entry of insects, birds, or rodents to tanks (and this includes mosquitoes), a "U" pipe entry and exit, a sealed tank roof, and an overflow pipe emptying to a gravel–filled swale all effectively exclude these potential nuisances. If birds persistently perch on roof ridges, a few very fine wires or thread stretched along the ridge as a 10 cm (4 inch) high "fence" will discourage them.

Gutters on roofing can be cleaned out regularly, or "leaf–free" gutters or downpipes fitted (about 3 or 4 types are commercially manufactured; some systems are illustrated in **Figure 7.22**).

Given that most dust and leaves are removed, residual organics are usually harmless. These "fix" as an active biological velvety film on tank walls and bases. Taps or outlet pipes are normally fitted 15–20 cm (6–8 inches) above any tank floor to allow such a film to remain.

Finally, a net or bag of limestone, shell, or marble chips is suspended in the tank. This creates hard (alkaline) water, preventing heavy metal uptake from the water and decreasing the incidence of heart attacks in those using the tank. Washing and shower water can be soft (acid) but the water we drink is best made alkaline for the sake of health.

It makes far more sense to legislate *for* such tanks on every roof than to bring exotic water for miles to towns; it will also ensure that clean air regulations are better observed locally, that every house has a strategic water reserve, and that householders are conservative in their use of water.

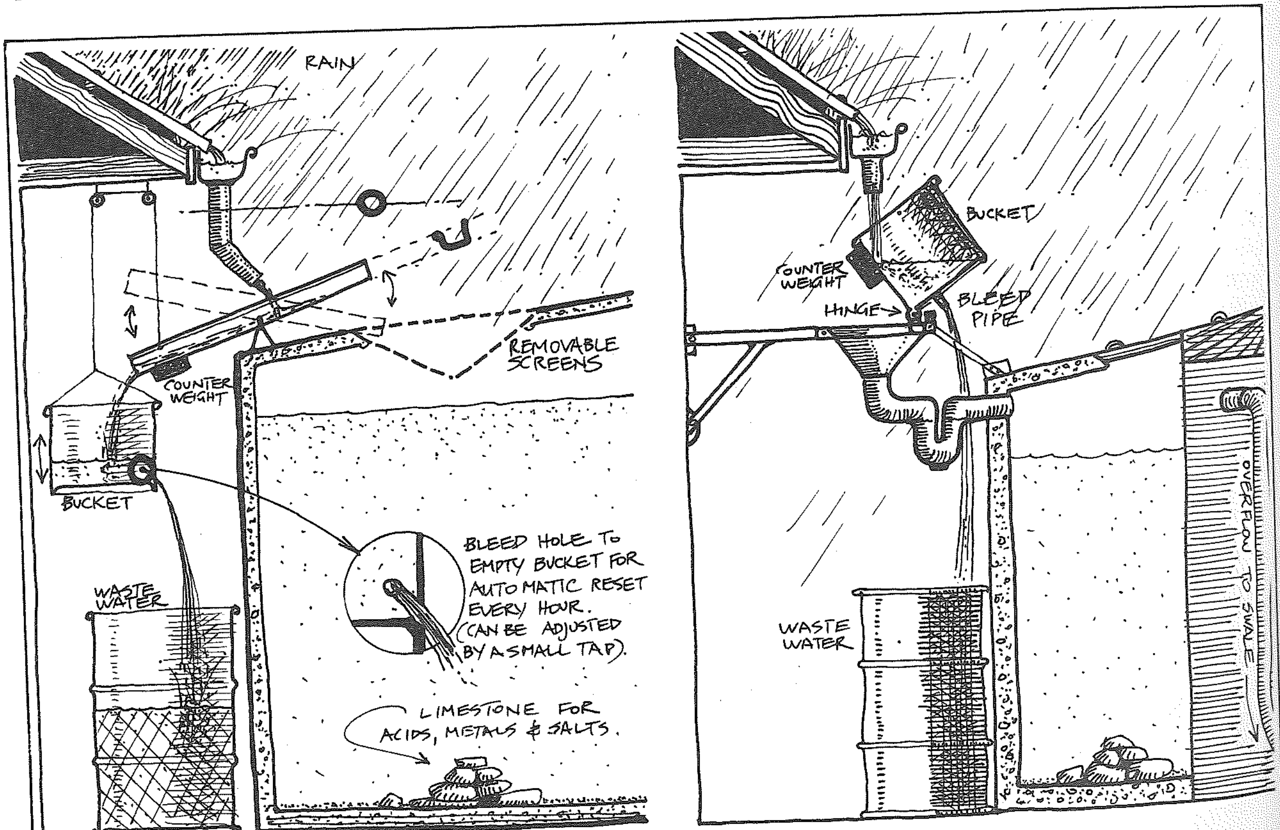


FIGURE 7.21
METHODS OF REJECTION OF FIRST WATER FLOW OFF A ROOF.
The first rains wash the roof, and are rejected; these systems automatically reset when empty.

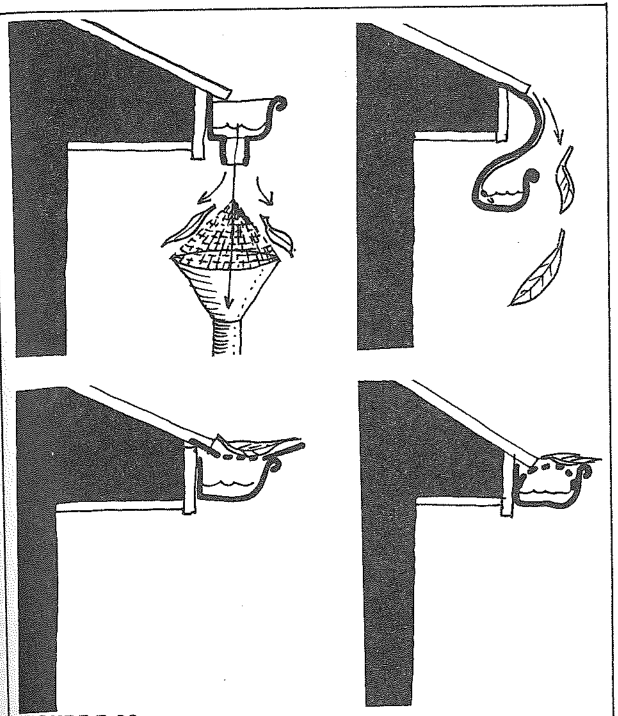


FIGURE 7.22
TYPES OF GUTTERS
Self–cleaning and leaf–free gutters or downpipes are useful where trees overhang a house; cone to pipe is also useful to collect water from rock domes.

SWALES

Swales are long, level excavations, which can vary greatly in width and treatment from small ridges in gardens, rock–piles across slope, or deliberately–excavated hollows in flatlands and low–slope landscapes (**Figure 7.23**).

Like soil conditioning or soil loosening systems, swales are intended to store water in the underlying soils or sediments. They are, simply, cross–flow dry channels or basins intended to totally intercept overland flow, to hold it for a few hours or days, and to let it infiltrate as GROUNDWATER RECHARGE into soils and tree root systems. *Trees* are the essential components of swale planting systems, or we risk soil waterlogging and a subsequent local rainfall deficit caused by lack of evapotranspiration of the stored water. Thus, tree planting *must* accompany swaling in arid areas.

Swales should ideally not exceed in width the total crown spread of the fringing trees planted to use the stored water absorbed into the swale sediments. Trees overshade and cool the soils of swales, further reducing the risk of evaporation and dissolved salt concnetration, or water loss. Although swales can also be grazed, few grasses can effectively remove the absorbed water to re–humidify airstreams.

Swales are therefore widely used in arid to sub–humid, even humid areas, on both fairly steep slopes and flatlands, and in both urban and rural areas. They are appropriate to road and other silty or contaminated run–off harvest (where the dust or tar oils washed off have no adverse effect on tree growth).

The essentials of swale construction are simple: they are all built on contour or dead level survey lines, and are neither intended nor permitted for water flow. Their function is just to *hold* water. Unlike dams, swale banks and bases are never compacted or sealed (although small tanks can be sunk in swale bases for watering livestock or trees). Conversely, the swale soils can be gravelled, ripped, or loosened to assist water infiltration. The swale depth and width can be varied to cope with the speed of infiltration locally, so that wider and shallower swales are made in sands, narrower and deeper swales in clay–fraction soils.

After an initial series of rains that soak in a metre or more of water, trees are seeded or planted on either bank or side slopes of the swales. This can take two wet periods. Thereafter, it takes about 3–5 years for tree belts to overshade the swale base, and to start humus accumulation from leaf tissue. (Humus will accumulate, however, by wash–down and wind movement from bare or uphill areas.)

Early in the life of an unplanted swale, water absorption can be slow, but the efficiency of absorption increases with age due to tree root and humus effects. As this happens, it is possible to admit water to swales from other areas, leading it in via DIVERSION DRAINS DRAINS. This "exotic" water from unused road or rock surfaces or overland flow can enable the planting of high–value trees of higher water demand or a new set of swales to be constructed.

Every sub–humid and arid townscape can, with great energy gain and much reduced cost for roading and water use, fit all roads and paved areas with swales, along which tree lines shade pavement and reduce heat oases while they produce fuel, mulch, and food products. Every roof tank overflow, and some greywater wastes can be led to swales (if boron detergents are not used).

Swales interpenetrating the suburban development of Village Homes in Davis, California (Michael Corbett, designer) accept all road and excess roof run–off, and

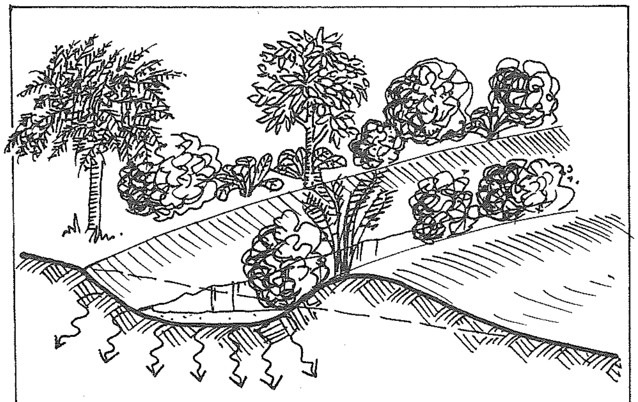


FIGURE 7.23
Swales on contour do not flow; they first stop and then infiltrate overland flow. Swales on hillsides are part of access or production systems.

support hundreds of productive trees in settlement. Water penetrated soils to 6 m (19 feet) deep after a few years of operation, and swales were self–shaded after 3–4 years of tree growth. In Hawaii and in central Australia, swales I have designed produced fast growth in trees in volcanic cinder and sandy soils.

Swales in Australian drylands have consistently grown larger and healthier water run–off fed trees than have open plantings. In arid areas, it is imperative to plant trees on swales, or we risk salt concentration and soil collapse downhill. All swales are therefore temporary events, as trees supplant their function; they are precursors to rehabilitation of normal forests in their region. Natural swales in humid forests (Tasmania) not only generate much larger trees and provide level access ways, but support a thick humus and specialised plants on the swale floors. Orchids, fungi, and ginseng do better in swales.

Most swales should be adjusted (by widening, gravelling, or ripping) to absorb or infiltrate all water caught in from 3 hours to 3 days. Fast absorption will not harm most tree species, although trees such as chestnuts and citrus may need to be planted on nearby spoil banks for adequate root drainage. I believe swales to be a valuable and greatly under–used earth form in most climates, including upland and plains areas of snow–drift in winter.

In summary, a swale is a large hollow or broad drain intended to first pool, then absorb all surplus water flow. Thus, the base is ripped, gravelled, sanded, loosened, or dressed with gypsum to allow water INFILTRATION. Trees ideally overshade the swale. The base can be uneven, vary in width, and treated differently depending on the soil type. The spoil is normally mounded downhill or (in flat areas) spread. Water enters from roads, roof areas, tank overflows, greywater systems, or diversion drains.

The distance between swales (the run–off or mulch–planted surface) can be from three to twenty times the average swale width (depending on rainfall). Given a useful swale base of 1–2 m (4–6 feet), the interswale space should be 3–18 m (12–60 feet). In the former case, rainfall would exceed 127 cm (50 inches), and in the latter it would be 25 cm (10 inches) or less. In humid areas, the interswale is fully planted with hardy or mulch–producing species. In very dry areas, it may be fairly bare and exist mainly to run water into swales.

Mulch blows into, can be carried to, or is grown and mown in swales. Fine dust and silts build up in swale bases, and domestic wastes can be buried here as a mulch–pit for hungry plants. The swale and its spoil–bank make a very sheltered starting place for plants on windy sites, and the lower slope swales can be planted mainly to *Casuarina* or leguminous trees to prevent upslope winds. Ridges should always have windbreak and condensation plants of hardy and useful species (*Casuarina, Acacia, Leucaena,* silky oak, pine, cypress). Windbreaks can occupy every sixth to tenth swale on sites where wind is a limiting factor. It is better to plant on the downslope side to allow mulch collection in the swale base for use elsewhere.

Swale sections can be over–deepened, so that although the swale lip is surveyed level, its floor may rise and fall. Deepening is most effective in clay–fraction soils, and may result in shallow ponds for water–needy crop. Widening is most effective in sand or volcanic–fraction soils, and readily admits water to the ground table.

Two other pit systems are useful in swales: one mulch and manure–filled for heavy nutrient feeders (yams, bananas, etc.) and the other to hold oil drums, plastic liners, or tyre ponds as a sealed water reserve for watering young plants. These can be planted with lotus, kangkong, watercress, Chinese water chestnut, or like crop.

Keeping the swale width to the tractor, donkey cart, foot track or wheelbarrow access width that one has planned, sections can be widened at regular intervals to take assemblies of plants, to dig ponds or mulch pits, and to plant trees of higher water need. This leaves access open and enables many assemblies, species, and constructs to be built along the swale as need dictates.

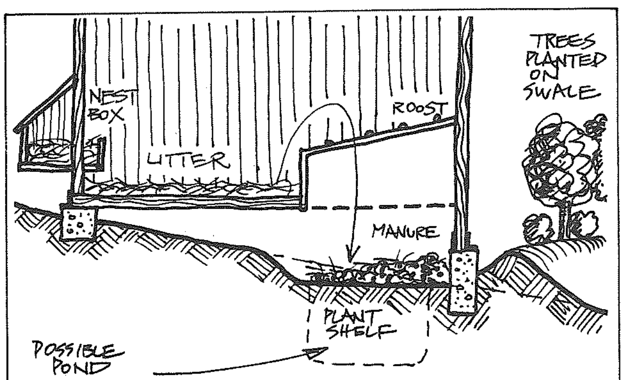


FIGURE 7.24
CHICKEN HOUSE OVER SWALE
Manures from animals placed in swales, or canals feeding wet terraces, provide nutrients via water transport for swale crops, and associated trees.

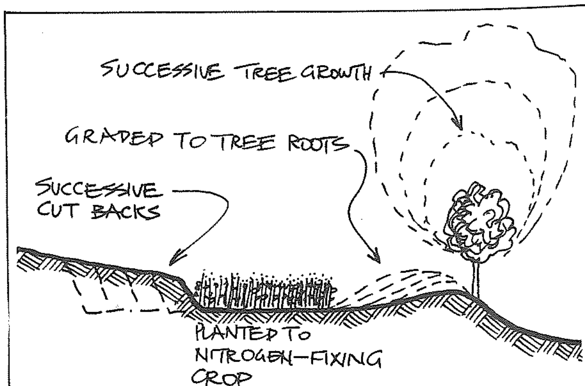


FIGURE 7.25
REGRADING SWALES TO REMOVE SILT
Silt from swales is graded out or shovelled up to tree lines on downslope side. Swales can be widened over time to create a terrace.

DIVERSON BANKS AND DRAINS

Diversion drains are gently sloping drains used to lead water away from valleys and streams and into storages and irrigation systems, or into sand beds or swales for absorption. If low earth–walls are raised across the flow channels of larger diversion drains, these then act as a series of mini–swales for specific tree sites, while surplus water flows on to storages. Diversion drains differ from swales in that they are built to *flow* after rain (from overland flow or from feeder streams). They are the normal and essential connectors of dam series built on the Keyline systems, so that the overflow of one dam enters the feeder channel of the next.

Such diversion systems need careful planning and survey, with drain bases sloping as little as 1:6000 in fine sands. Dam crests and irrigation drains need equally careful placement. Even without a stream intake, diversion drains will gather water from overland flow in as little as 1–1.5 cm (1/2 inch) of rain over 24 hours, so that isolated dams are normally fitted with diversion drains even in quite dry country. Diversion drains can be led to broad level swales in drylands, or made of simple concrete or stone walls across solid rock faces. In the Canary Islands, these gather rock run–off which is led to underground cave storages or large open tanks. Simple sliding gates across or in the downhill banks of such drains allow controlled flow, controlled irrigation, and (in floods) by–passing of dams.

Spill gates can be FIXED (concrete slide holders and aprons) or MOVEABLE (plastic sheets weighted with a chain sewn into the foot, and supported across the drain by a light pipe sleeved into the top). These latter are called "flags" (**Figure 7.27**).

Slide gates can open on to ridge lines, and water then spreads downhill, while plastic flags can be placed and taken up at any point along a drain. This enables one or two people to water 200–240 ha (400–600 acres) in a morning. It is also an effective wildfire control system in forested areas. For sophisticated wildfire or irrigation control, both slide gates and dam–base gate valves can be remotely operated, by radio signal and storage batteries or buried electrical conduits, to power small motors or hydraulic slides. A complete wildfire control can be achieved by dams and sheet irrigation, and using infrared sensers and automatic spill–gates. Such systems remove the risk for fire–fighters, and allow forests to regenerate in semi–arid areas.

Interceptor drains. These drains–or rather, sealed interceptors—act in the opposite tense to diversion drains. These earthworks are specifically designed (by Harry Whittington of West Australia) to prevent overland waterflow and waterlogging, which has the effect of collapsing the dryland valley or downslope soils of a desert soil catena. Thus, they ideally totally intercept overland flow, and direct it to streams or valley run–offs. They can be cross–slope as are swales, but they differ from diversion drains and swales in that their construction always involves the ramming (by bulldozer blade) of subsoil layers hard against the downhill bank. This effectively prevents or impedes water seepage through the downhill wall of the interceptor bank. Moreover, they are always 1.5–2.5 m (5–8') deep, carefully spaced, and effectively stop not only overland flow but also salt water seepages in shallow sand seams. In effect, they isolate large blocks of soil from waterlogging and salt seepage.

After this preparation, trees can be planted in previously desertified soils.

Where deeper sand seams carrying salty water are located, these can be trenched out and stopped with a vertical plastic barrier, backed by compacted clay on the uphill side.

Made to flow at 1:600 to 1:1500 cross–slope interceptors effectively cut up incipient or degraded croplands subject to desertification into blocks of 100 m (330 feet) to a maximum of 300 m (985 feet) wide, isolating each block from flooding and the salty "cascade" flow from uphill. Surplus water is carried off in streams. Interceptor banks also cut off seepage from salt lakes, and can divert early (salted) overland flow around saltpans, letting later fresh floodwater fill the pans or shallow lakes.

Spreader drains or banks are intended to spill a thin sheet of surplus (overflow) water down a broad grassy slope, either for irrigation or (in deserts) to prevent channel scour and gullying. They are normally made to

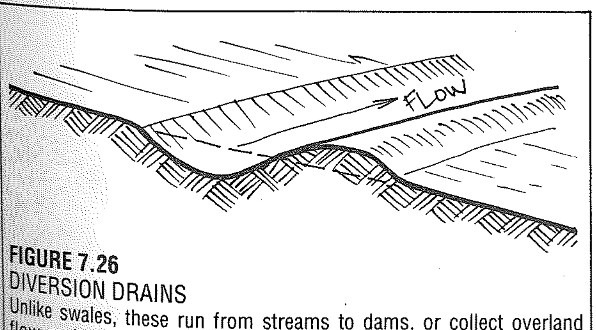


FIGURE 7.26
DIVERSION DRAINS
Unlike swales, these run from streams to dams, or collect overland flow and convey it to storages. They are part of any rainwater harvesting system.

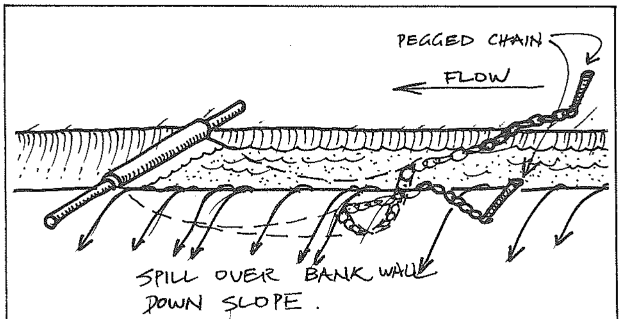


FIGURE 7.27
FLAG
A plastic sheet, one end supported by the channel banks, the other wighted by a chain, forms a temporary dam, causing the channel to flood out and irrigate land downhill.

take any overflow from swales and dams, and may be tens or hundreds of metres long. Spreader banks have the lower side dead level, and compacted or even concreted. Water enters from a dam, swale, or minor stream and leaves as a thin sheet flow downslope. Spoil is piled *uphill*, preferably in mounds, or removed to allow downhill sheet flow to enter the spreader ditch (**Figure 7.28**).

For irrigation areas of flatlands, the bank is often pierced by a series of dead–level pipe outlets, each feeding an irrigation bay (itself planed flat), to which water is confined by low side walls (STEERING BANKS). At the lower end of that bay, a TAIL DRAIN—a surplus water drain—leads off excess water to a stream or secondary storage dam. In such cases, the uphill or primary feeder drain is called the HEAD RACE, and has cross–slides that block flow; this causes the levelled pipes to flood out into the bays. Sometimes the pipes are replaced with level concrete sills and in old–established spreader banks, the whole of the lower lip may be concreted to give a permanent level spill immune to breakage by cattle or vehicles.

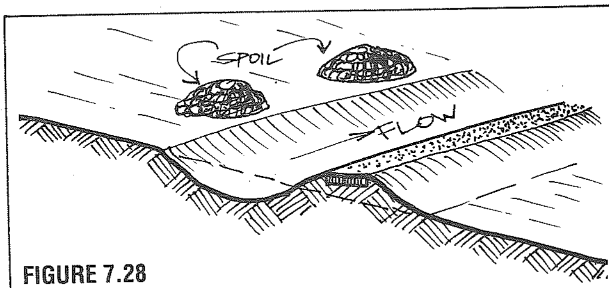


FIGURE 7.28
SPREADER BANK
Water overflow is evenly spread by carefully levelling the downhill bank as a sill.

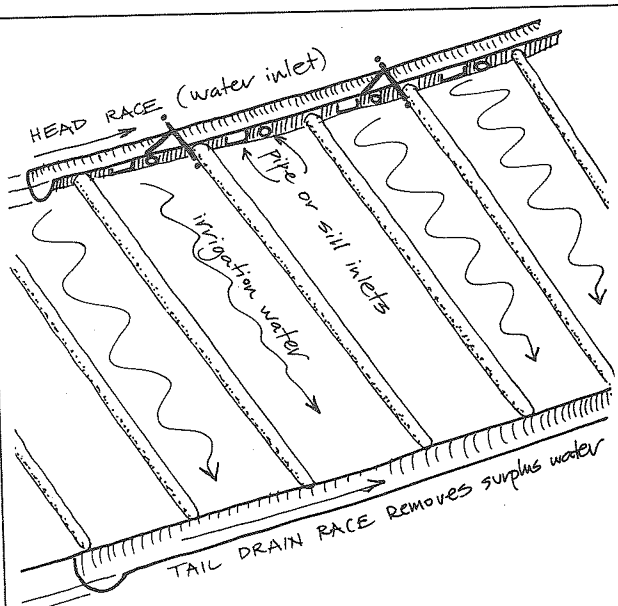
Spoil lines uphill from spreader banks are best piled or at least broken by frequent openings to allow downhill overland flow to enter the drain without carrying silt loads.

In *any* landscape, a subtle and well–planned combination of dams, drains, spreader banks, swales, and appropriate pipes, gate–valves, spill gates, flags, or culverts will harvest, store, and use surplus flood or overland flow waters. These are used to flush out salts from soils, spread water evenly over crop, put out wildfires, and modestly irrigate land. It is a matter of first deciding on, then surveying any or all these systems, and above all of considering the long–term effects on the immediate landscape and the soils.

All earthworks can be regarded as REHABILITIVE and remedial if they replace salted and eroded lands with perennial browse or forests. They can be seen as DAMAGING and exploitative if used to irrigate high water–demand crop (like lucerne/alfalfa) in drylands, to cut off flow to dry areas, or to run water for unessential uses to large urban centres devoted to lawns and car washes.

7.4
REDUCTION OF WATER USED IN SEWAGE SYSTEMS

In cities, water is chlorinated and fed back into the system, sometimes mixed with seawater or "treated" waste water to give it that city taste so typical of, e.g. Las Palmas in the Canary Islands. Surplus sewage,



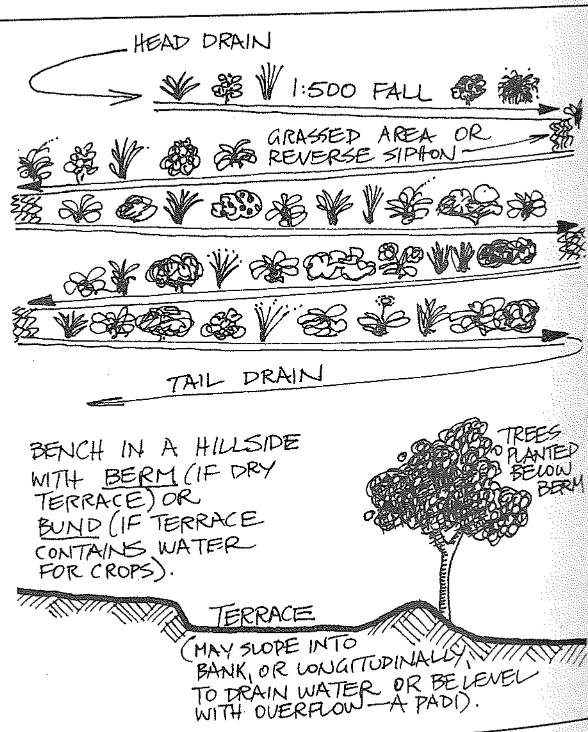


FIGURE 7.29
SCHEMATIC OF IRRIGATION BAYS
Layout for channel irrigation; bays should not exceed 100 m long or water can be wasted to evaporation. See also Figure 7.30.

untreated, is often passed to sea, with bacteria, viruses, and parasites intact for bathers to wallow in.

All of this arises from the frequent, wasteful, and unneccessary flushing of toilets by those of us living in the effluent society. In Sweden, it is compulsory to use dry toilets in remote, unsewered, or unsuitable areas. In the USA, UK, and Australia, one has to fight hard to get permission to use these, as it is the vested interest of industry and town clerks to supply and charge for sewerage systems.

However, *no* clean water need be used to flush toilets if there is a diversion from a hand–basin to the toilet tank. In Australia at least, hand–basins moulded in to toilet flush tanks are available (**Figure 7.31**). It is essential to use low–flush toilet bowls with such systems, as they otherwise flush incompletely, and build up heavy pathogenic bacteria populations.

This is a simple solution to 40% of domestic water misuse, and encourages hand cleanliness rather than the false cleanliness/tidiness of toilet flushing for its own sake.

Dry toilets are not always appropriate, except in cities and other water–critical areas. They are unnecessary on farms or in well–drained soils, or wherever sewage is used to produce methane by anaerobic digestion in tanks. In fact, dry toilets reduce the potential uses of sewage, just as compost is a reduction in the potential use of mulch. Dry toilets are quite specifically useful where:

- No methane system is used;
- Sewage is not used in the production of plants;
- Soils do not suit septic tanks; and
- Cities have critical water supply problems.

In using wastewater from kitchen, bathroom, and laundry, it is wise to establish just what chemicals, and at what concentration, are being released to gardens and soils (or waterways). A typical analysis of a powdered detergent or a soap could include: sodium or potassium salts or polysulphates, silicates, sulphates or bicarbonates, borates, residual biocides (concentrated in animal fats) e.g. DDT, Dieldren, Hexachlor from dairy cattle, additives such as resins (hardeners), scents, dyes, and brighteners, faecal bacteria and viral or worm pathogens from washing (in showers or via clothes). This data is from Kevin Handreck, CSIRO Division of Soils, (*pers. comm.* 1979).

Of these, most can be dealt with by soil organisms, but if the basic water supply is already saline, sodium and potassium salts can add to this and deflocculate soil clays or damage leaves (at >1,000 ppm), while

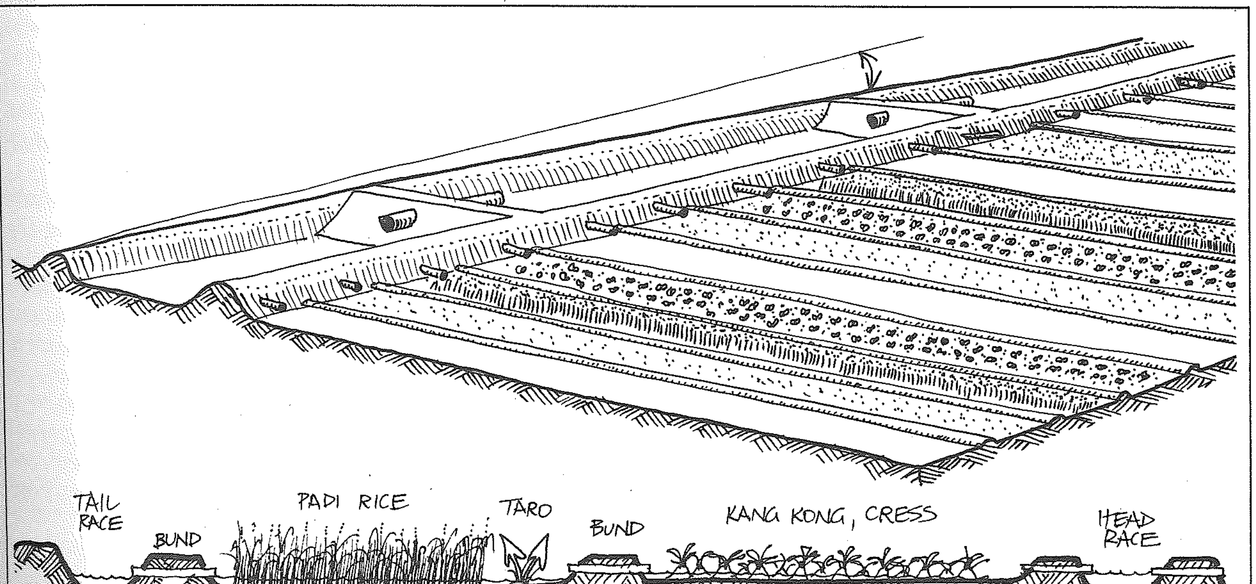


FIGURE 7.30
IRRIGATION
Slight slope on main "head" drain allow pipes to be blocked, when water spills via minor siphons or sills to irrigation bays. A "tail" drain (See Figure 7.29) takes surplus water. Bays are flooded for 60% of length; then next series is irrigated.

borates at >0.5 ppm can create excessive boron concentration in soils, and above 1.0 ppm is harmful to soil life and plants. Thus, we need to use plain soaps on crop if possible, and route more complex pollutants to tree systems (well–monitored), as woody perennials can cope better than garden vegetables, and allow more time for decomposition of long–term pollutants.

In critical areas, and especially in arid or delicate environments, we may need to create both special soaps (unpolluted oils, potash or sodium) and plant special crops which remove excesses (many water plants) before passing on greywater to the soils and streams. There is no blanket policy, only specific cases where we can expect to gain yield and also clean up water *if* we know the composition of soils and soaps.

7.5
THE PURIFICATION OF POLLUTED WATERS

The only long–term insurance of good water supply to a settlement is by rigorous control of a forested catchment, including a total ban on biocides and metallic processing. As there are few such clean areas left in the world, house roof tanks must do for the foreseeable future. The 30–40 additives commonly introduced into water supplies are often pollutants in themselves to that increasingly sensitive sector of society developing allergies to any type of modern pollutant. These additives represent the end point of the technological fix: pollution is "fixed" by further pollution.

Herein, I will stress the *biological* treatment of common contaminants; the only water safe for us is also safe for other living things. For millenia we have existed on water supplies containing healthy plants and fish, and if we keep natural waters free of faecal and industrial contaminants, we can continue to do so. This is not so much a matter of water treatment, as the prevention of polluting activities.

However, for many existing cities and towns, sewage and stormwater supplies must continue to represent a "disposal problem". As the wastewaters of upstream settlements are the drinking waters of downstream areas, our duty is to release from any settlement only water of sufficiently good quality to be safely useable by others.

The problem contaminants most likely to affect drinking water are:

- TURBIDITY: silt and fine particles suspended in the water.
- BACTERIAL or ORGANIC pollution from sewage, and as decay products, e. g. *E. coli*, disease organisms and viral or protozoan pathogens, parasitic worm eggs and so on.
- METALLIC POLLUTANTS such as chromium, cadmium, lead, mercury.
- BIOCIDES, e.g. Aldrin; Dieldrin; 2, 4–D; 2, 4, 5–T; dioxin; PCB, etc (organophosphates, halogenated hydrocarbons).
- EXCESSIVE FERTILISER, especially nitrogenous compounds, phosphates, sodium and potassium salts.
- ACIDS or acid–forming compounds (a pH less than 5.5 increases metallic pollution).

Many of these factors interact. Acid rain dissolves out of rocks and soil poisonous forms of aluminium, mercury, lead, cadmium, and selenium, or other metals such as copper, nickel, and lead from drinking tanks, tea urns, and hot water tanks. Organisms may convert inorganic mercury to organic forms (as happened in Minamata, Japan) which are readily absorbed by the body. Sewage in water aids such conversion to biologically active metals.

Mercuric fungicide dressing on seeds has not only caused direct poisoning of people who have eaten the seed, but also poisons the soil. Excessive artificial fertiliser increases aquatic biological activity, which results in further uptake of metals in acidic waters, and so on. In biocides, Aldrin prevents DDT being excreted; the combination is deadly (one can buy this mix in Australia and the third world, or farmers will achieve it by successive sprays. DDT is a stable residual poison co–distilling with water, so that distillation will not help). An additional threat to public health comes from

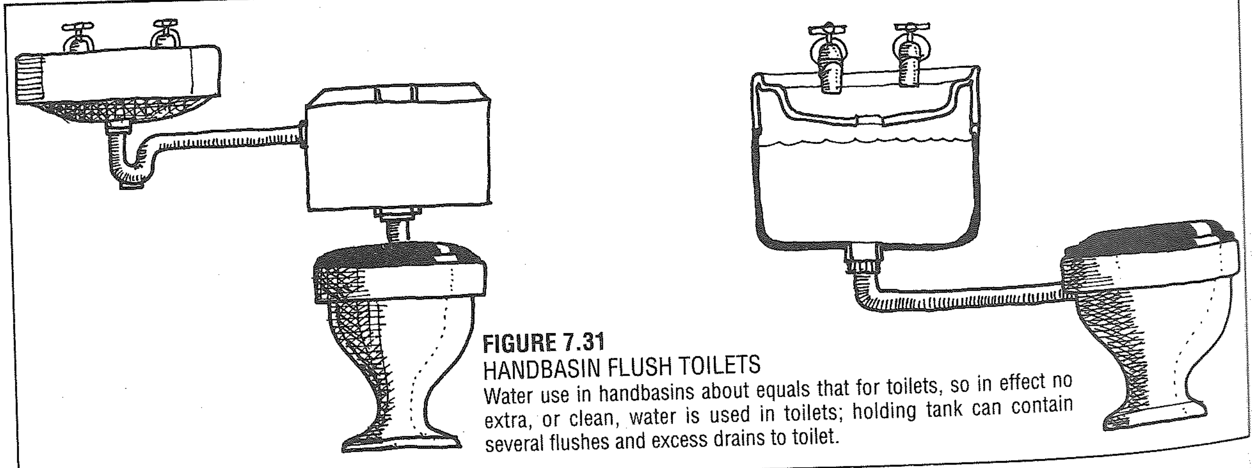


FIGURE 7.31
HANDBASIN FLUSH TOILETS
Water use in handbasins about equals that for toilets, so in effect no extra, or clean, water is used in toilets; holding tank can contain several flushes and excess drains to toilet.

the many miles of asbestos pipe used in public water supply systems; there is a definite threat of both stomach and bladder cancer from asbestos particles in water supplies.

Ferric and aluminium sulphate, salt, and lime are all added to water to cause fine particles to flocculate and settle out as clay. In England, as pH increases due to acid rain, and in fact wherever acid rain occurs, aluminium goes into solution, and with lead and cadmium may bind to protein in vegetables and meat, especially those boiled or steamed. Even if salt is added to cooking water to decrease these effects, levels far exceeding the 30 μg/l allowable for those with kidney problems are experienced. Cooking may increase the water content of metals by a factor of 5 due to this protein binding, and as well make the metals so bound easy to assimilate in the body. Cooking acidic substances in aluminium pots simply worsens the problem. Aluminium from *acidic* rain leaching is now thought to be a major cause of tree and lake death. Ferric sulphate may be safer to use, especially if water is initially or reasonably alkaline. Obviously, these effects need more study and any inorganic salt or metallic salt deserves very cautious use.

WATER TREATMENTS COMMONLY USED

- AERATION (oxygenation) by wind, mechanical aeration, or by increasing turbulence in flow. Aeration is also achieved by trickle columns and vegetation, phytoplankton, or injected air.
- SETTLING: spreading flow in still–water ponds or rush beds to allow particles to fall out, filter out, or flocculate.
- SKIMMING and SIEVING to remove large organic particles.
- FILTRATION via sand beds or charcoal–fibre columns, soils, the roots of aquatic plants.
- COAGULATION or FLOCCULATION by using chemical additives (lime, salt, ferric sulphates) or organic (bacterial) gels.
- BIOLOGICAL REMOVAL by bacteria, phytoplankton, and higher plants.
- pH ADJUSTMENT by adding calcium (as lime) or sulphur compounds as needed.

Filtration

A classical and widely–used filter is sand. Britain and many cities use sand filters followed by chlorination to clean settled and treated raw sewage water sedimentation. Filtration by slow drip through 1.2 m (4 feet) of sand (top half fine, bottom half coarse) is used even in temporary rural camps for water filtration. For cities, fixed sand beds with brick bases are used, the top 1 cm (0.5 inch) or so of sand periodically swept, removed, and dried or roasted to remove organic particles before the sand is returned.

Activated charcoal, often from bones or plants such as willow or coconut husks, is also used as a fine filter in homes and where purity is of the essence. Fine dripstone (fine–pored stone) is used in water cleaners and coolers to supply cool water in homes.

Trickle filters through sand and gravel columns actually feed resident bacteria which remove the surplus nutrient. In less polluted environments, a similar task is carried out by freshwater mussels.

Carbon is essential for the removal of nitrogen or for its conversion by bacteria to the gross composition $C_5H_7NO_2$, and it is generally added as carbohydrate, which can be liquids such as methanol, ethanol, or acetic acids, many or all of them derived from plant residues. This is a bit like "adding a little wine to the water" to encourage the bacteria to work. Surplus nitrogen is released by bacteria to air. Unless bacteria are encouraged and allowed to work, nitrates move easily through sub–soils in which no plants or bacteria can live, and can emerge in wells and streams.

In ponds intended for drinking, light exclusion and surface water stabilisation reduce both turbidity, and thus algae, to a minimal quantity. The stabilisation of banks by grasses and clump plants helps considerably. Pond surface stabilisers are water lilies, *Azolla*, and water hyacinth. Bank stabilisers are *Juncus, Scirpus,* various grasses and clovers, *Phyla nodosa (Lippia),* and bamboo and pampas grass clumps.

With turbidity much reduced, filtration loads are likewise reduced. Liming will further reduce turbidity if pH is 6.0 or less. This is as simple as placing crushed marble or limestone as a layer in a tank, or casting burnt lime over a pond before filling and (if necessary) after filling. Crushed shells or even whole shells in water tanks and ponds have the same effect. Lime flocculates particles, causing them to settle out of the water.

There are several techniques for filtration, some or all of which can be used in series. First, trickle filters of

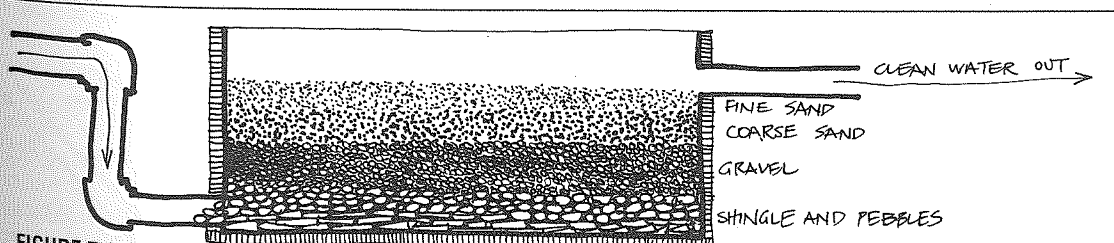


FIGURE 7.32
SAND FILTER
A basic cleanser for microbiological pollution; flow is upwards from base to surface. Surface sands can be washed or roasted for cleaning as needed usually every 12–18 months.

loose pebbles (2.5–10 cm) can be used to form an active bacterial surface layer to absorb nutrients, then a sand filter can be used to absorb bacterial pollution. Water rising through a sand column is fairly clear.

The shells of water mussels can be substituted for pebbles, and the living mussels in the pond or tank not only monitor acidity (dying at pH 5.5 or thereabouts) but filter, individually, up to 100 l/day, digesting bacteria and depositing wastes in the mud base. Mussels and crayfish are not only susceptible to low pH but are also very sensitive to biocides such as Dieldrin, so that their living presence is a constant monitor on life–threatening pollution.

Water, now fairly clean, can be passed through a bed of watercress to remove dyes and nitrates, and the cress cut and fed to animals or dried and burnt to ash. As a final process, the water can be trickled through a column (a concrete pipe on end) of active carbon (10%) and silicon dioxide (90%), otherwise known as burnt rice, oat, or wheat husks.

The results should be clear, sparkling, safe water to drink. No machinery is involved if the system is laid out downslope to permit gravity flow

Lime (freshly burnt) is often used to remove phosphorus and sludges in a primary settling lagoon, and then water is passed to a trickle tower for ammonia removal by bacteria. In towers, of course, the bacteria are not further consumed, but in open lagoons a normal food cycle takes place, with myriad insect larvae and filter–feeders removing bacteria, and frogs, fish, and waterfowl eating the insects. In small towns, the water can be passed from filter towers to sewage lagoons, which in fact may become rich waterfowl and forest sanctuaries. It can then be routed to field crop such as forest, pasture, and to crops to be distilled or burnt, which does not directly re–enter the food chain.

Sewage Treatment Using Natural Processes

Raw sewage is a mixture of nutrients, elements, heavy metals, and carbon compounds; it also contains quite dangerous levels of bacteria, viruses, and intestinal worm eggs. A typical analysis is given in **Table 7.3**. Units are as mg/l; samples are of 30% industrial, 60% domestic wastes at Werribee, Victoria, Australia (Hussainey, Melbourne Metropolitan Water Board Pubs., 1978).

Melbourne is a city of 2,700,000 people and its sewage lagoons cover 1,500 ha (3,700 a.) Thus, there is one hectare of pond (in total) to 1,800 inhabitants (or about 1 a. for 820 people). In the ponds, raw sewage is run into about 724 ha (1,790 a.), where it settles out. Each of these primary settling ponds rarely exceed 7 ha (17 a.) in area, so about 100 ponds receive and settle all raw sewage. Scaled down, this means 1 ha (2.5 a.) of settling pond to 3,800 people.

All these settling ponds are anaerobic, and give off biogas, a mixture of methane (CH_4), carbon dioxide (CO_2) and ammonia gas (NH_3), with traces of nitrous sulphide or marsh gas (NO_2). Biogas is, of course, a useful fuel gas for engines, or a cooking gas for homes. However, it is also a gaseous component of the atmosphere that is creating the "greenhouse effect" and thus should be used, not released to air.

The next set of ponds is faculative (as described below) and the last set aerobic. These, in total, slightly exceed the area of the anaerobic or settling ponds. Most

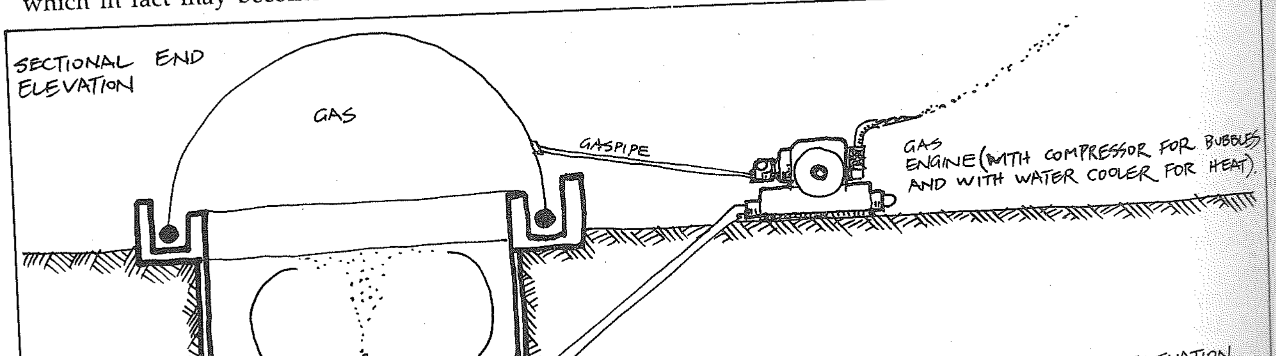


FIGURE 7.33
SCHEMATIC OF SEWAGE PONDS TO CROP
via various energy–producing systems.

are 7–10 ha (17–25 a.) in size.

Ponds can be built (as they are at Werribee) to fall by gravity flow from one to the other. In the first series of (settling) ponds, the sludge creates an ANAEROBIC condition. In the next series of ponds, some sludge passes over and becomes anaerobic at the pond base, while the surface water in the pond (due to wind or algae) is AEROBIC (oxygen–producing). The final series of ponds is totally aerobic. Thus, from intake to outlet, we have the terms:

- ANAEROBIC, or methane–producing (digester ponds).
- FACULATIVE, or part methane, part oxygen–producing.
- AEROBIC, or oxygen–producing ponds.

Ponds at Werribee are only an average of 1 m (3 feet) deep. Deeper, and the sludge breakdown and wind aeration effects are less.

One thousand townspeople and their associated industries therefore need as little as 270 metres square of settling pond 1 m deep. We could, in fact, achieve this as a "long" pond (or series of ponds) 3 m wide x 90 m long, or 3 side–by–side ponds 30 m long and 3 m wide, or any such combination. We can halve the length by doubling the depth to 2 m, and get a pond 3 m x 45 m long; or treble the depth and condense the pond area to a 3 m deep x 3 m wide x 30 m long "digester" pond.

Such a long and narrow pond is easily made *totally* anaerobic by fitting water seals and a weighted cover over the top (which can be of plastic, metal, butyl rubber, or fibreglass). Note that for these deeper digester ponds we would need to *artificially agitate* the sludge (using pumped biogas to stir it), otherwise it settles and becomes inactive (**Figure 7.33**).

Sludge is "active" only in contact with the semi–liquid inputs of the sewer; thus when we stir up the sludge, the better we break down the sewage to biogas. Another (critical) benefit in sealed and agitated digesters is that no scum forms on the pond surface, which can slow the breakdown process further and cause an acid condition.

Of the total dissolved solids (or influent) entering such a digester, over a period of 20 days and with a temperature of 25–30°C (77–86°F), a very high percentage of the mass is transferred into methane; a small proportion is also passed on to other ponds, some as living cells (bacteria or algae). As methane forms, so the oxygen demand of the effluent falls; about a cubic metre of methane generated removes about 2.89 kg of solids, reducing biological oxygen demand (B.O.D.) to that extent.

In the digester, 90–94% of worm eggs are destroyed, as are many harmful bacteria. Useful energy is generated, and can be used at that location to run a motor for electricity, or to compress gas for cooking or machinery (or both, as power demands vary). This motor both supplies the heat for the digester process, and also compresses the gas for digester agitation, and for energy supply.

What happens in the digester? The marsh gas produced, hydrogen sulphide (H_2S), combines with any soluble forms of heavy metals to produce sulphides, which are insoluble in water above pH 7. A little lime can also achieve or assist this result.

TABLE 7.3
ANALYSIS OF RAW SEWAGE

ANALYSIS	**MG/L**
SOLIDS	
Total dissolved solids	1,200 (TDS)
Bilogical oxygen demand	170 – 570 (BOD)
Suspended solids	160 – 620
Volatile liquids	180 – 510
Total organic carbon	110 – 360
Anionic surfactants	1.0 – 3.6
NUTRIENTS	
Nitrite as **N**	0.05
Nitrate as **N**	0.1 – 0.3
Ammonia as **N**	5 – 32
Organic **N**	7 - 24
Total N	9 – 56.2
Orthophosphate as **P**	1.5 – 6.0
Total phosphorus	1.5 – 9.0
METALS	
Copper	0.09 – 0.35
Chromium	0.25 – 0.4
Cadmium	0.015
Iron	1.6 – 3.3
Lead	0.3 – 0.4
Mercury	0.003
Nickel	0.15
Zinc	0.4 – 0.8
COLOUR	
(as Pt/Cp Units)	100 – 300
pH	6.9 ± 2.0 (near neutral)

Of the total sewage input, from 45 – 60 % of the volume builds up as sludge in settling ponds.

Hussainy found that the following result occurred in anaerobic ponds (see original metal content, **Table 7.3**):

- Copper is removed 97%, of which 78% was removed anaerobically.
- Cadmium is removed 70%, all anaerobically.
- Zinc is removed 97%, 83% removed anaerobically.
- Nickel is removed 65%, 47% aerobically.
- Lead is removed 95%, 90% anaerobically.
- Chromium is removed 87%, 47% anaerobically.
- Iron is removed 85%, 47% anaerobically. (Up to 92% of iron was removed by the faculative pond process, but some iron was partly dissolved in the aerobic pond again, to give the 85% quoted.)

The results are that solids, metals, and disease organisms are very greatly reduced by the first (anaerobic) treatment of sewage. What, in fact, happens to the sludge? It becomes methane. In an anaerobic shallow pond, or a deeper agitated pond, the more sludge, the more active the pond. Thus, *a self–regulated equilibrium condition soon establishes* where input balances gas output. If we remove the sludge, the process slows down or stops. This is a clear case of leaving well alone, of active sludge becoming its own solution; rather than being a problem, it generates a resource (methane).

In the anaerobic pond, there are few algae, but there are some specialised sulphur–loving bacteria of the genera *Thiosporallum*, *Chromatium*, and *Rhodopseudomonas*. These (in open ponds) may appear pink and give this colour to the ponds. They use hydrogen sulphide as a hydrogen source for carbon assimilation; their by–product is therefore elemental sulphur (S), which binds to the metals present. About 1.8–2.0 mg/l of heavy metals are precipitated as sulphides at 1.0 mg/l of elemental sulphur. The bacteria help in this process.

Passing now to the faculative ponds, we see both the life forms and the biochemical processes change. Here, algae blooms; four almost universal sewage lagoon algae are forms of *Euglena*, *Chlamydomonas*, *Chlorella*, and *Scenedesmus*. The total algal and bacterial flora (of many species) are called PHYTOPLANKTON (plant plankton).

Bacteria are also phytoplankton, the bacteria benefiting from the oxygen produced by the algae. Typical bacteria in the open ponds are *Cyclotella*, *Pinnularia*, *Hypnodinium*, and *Rhodomonas*. The sulphur–loving bacteria may linger on in the sludge base of faculative ponds, but are absent or rare in aerobic ponds. The algae fix carbon, releasing oxygen to the bacteria.

With such a rich algal food available, ZOOPLANKTON now thrive: most are rotifers (*Brachionus*, *Trichocerca*, *Haxarthra*, *Filinia*); cladocerans (*Daphnia*, *Moina*, *Chydorus*, *Pleuroxus*); copepods (*Mesocyclops*); and ostracods (*Candanocypris*, *Cypridopsis*). Among these are protozoan flagellates, ciliates, and some nematodes. On this rich fauna, waterfowl and fish can flourish.

Some of the remaining metals are gathered by the zooplankton. In mg/l (dry weight) they contain 1,200 of iron, 152 of zinc, 37 parts of copper, 28 of chromium, 12.2 of nickel, 10.3 of lead, 1.7 of cadmium—almost a mine in themselves. Harvested, both zooplankton and algae can be added to foodstuffs for poultry. Pumped into forests or fields, they provide manures and trace elements for growth. In rich algal growth, blooms of such forms as *Daphnia* can be as dense as 100 mg/l.

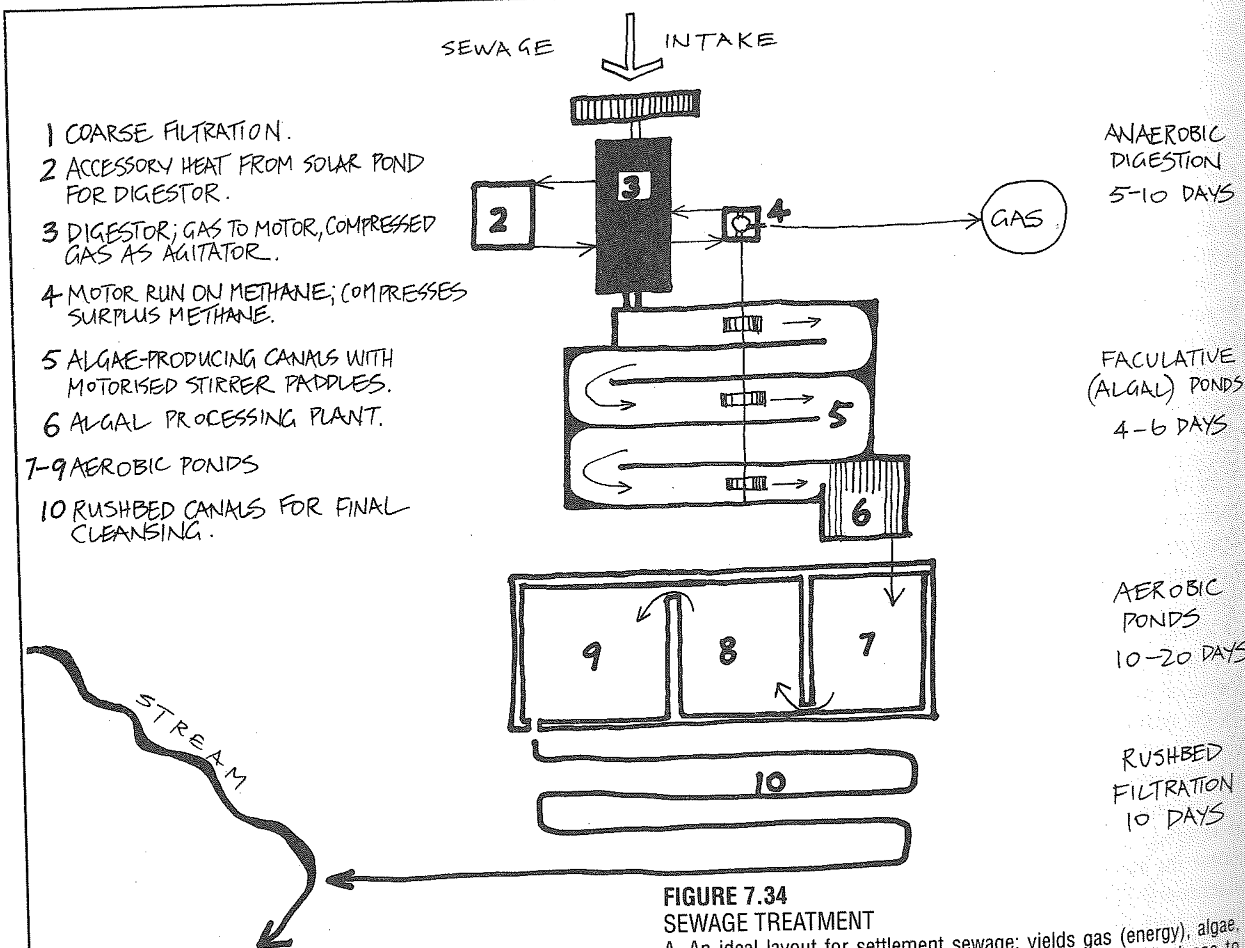


FIGURE 7.34
SEWAGE TREATMENT
A. An ideal layout for settlement sewage; yields gas (energy), algae, fish, wildlife, crop, and thoroughly cleanses water for release to streams. See notes 1–10 on illustration.

These zooplankton masses are self-controlled by eating out their algal foods, and can in their turn be eaten by fish in subsequent pond systems.

Of the pH, which varies both long-term and in 24-hour cycles, it too increases from stage to stage: anaerobic pH 6.2–7.8; faculative pH 7.5–8.2; and aerobic pH 7.5–8.5. In clogged algal waters at night, it may climb higher.

At the aerobic stage, the B.O.D. is only 3–57 mg/l, due mainly to nitrogenous compounds, the suspended solids 32–50 mg/l (now mainly algae and zooplankton). About 80% of these have been removed and incorporated into life forms, and the metal levels are now down to World Health Organisation standards. The water can be used for irrigation, or filtered via rush beds to streams.

Seasonal changes are noticeable. In winter, more hydrogen sulphide is given off by anaerobic ponds (8–15 mg/l compared with summer's 2–5 mg/l), and winds may contribute more to oxygen levels in open ponds than do algae; in winter too, more ammonia (NH_3) is released to the atmosphere.

Summer sees residues oxidised to nitrates. The oxygen being provided more by algae than by wind, less hydrogen sulphide is given off, and there are greater ranges of temperature. In winter (10–15°C), decomposition slows and sludge levels build up, only to be more actively converted in the summer warmth of 18–22°C (64–72°F). B.O.D. is 495 kg/ha/day in winter, 1034 kg/ha/day in summer (at optimum pond conditions), showing that activity almost doubles as temperature increases. Consequently, almost twice as much gas as methane is given off in summer (or in *heated* digesters). In winter, the cooling water of methane-powered engines can provide the essential heat to digesters via a closed loop pipe.

In all, this simple lagoon series produces a very beneficial effluent from heavily-polluted influent. However, there are even more sophisticated biological treatments omitted—those effected by the higher plants. As outlined below, some genera of rushes, sedges, and floating plants can greatly assist with removal of heavy metals and human pathogens, but perhaps more importantly, some plants can also break down halogenated (chlorine, bromine) hydrocarbons synthesised as herbicides and pesticides.

Israel (*New Scientist*, 22 Feb '79) leads sewage waters to long canalised ponds, agitated by slowly-revolving paddle-wheel aerators. Ponds are 0.5 m or less deep. Under bright sunlight (or under glasshouse covers) dense algal mats form, and these are broken up by the addition of aluminium sulphate (a pollutant!), skimmed off, drained, centrifuged, steam-dried, and fed to either carp or chickens (although I imagine that carp could self-feed on aquatic algae). Algal protein replaces 50% of soya bean protein in feed rations to poultry. Total treatment by these methods takes about 4 days. The water is alkaline and somewhat anaerobic, needing more agitation in winter or on cool days. Holland runs sewage to similar canals, and reaps reeds or plants as green crop or for craft supplies.

It has been found (*Ecos* 44, Winter '85) that the artificial aeration of faculative ponds is most efficient if run at intervals of two hours in six (30% of the time). The faculative bacteria follow two digestive modes, and operate best if a rush of air is supplied after a four-hour anaerobic period, excreting carbon dioxide and thus reducing the bulk of sludge. There are corresponding reductions in energy costs for aeration. Nitrogen was reduced from 20 mg/l to less than 5 mg/l, phosphorus from 8.5 mg/l to less than 1 mg/l when ferric chloride was supplied. The process has been dubbed A.A.A. (alternating aerobic and anaerobic) digestion.

Thus, *agitation* of anaerobic systems by bubbling with compressed methane, and A.A.A. of faculative ponds can be used to obtain useful yields of methane and high-protein alage from sewage. As for the aerobic ponds, such higher plants as water hyacinth removed residual metals, surplus nutrients, and the *coli* group of bacilli (*New Scientist*, 4 Oct '79, p. 29). Microwave radiation can also be effective at breaking up algal mats, and sterilising algal products, eliminating toxic aluminium salts.

As for temperatures, solar ponds used in conjunction with compact anaerobic ponds can supply the low grade heat necessary for efficient sludge digestion, and methane will drive any motors needed for both aeration and the gas compression used for the agitation of sludge. The whole processing system can be made very compact, and at the aerobic pond level, throughflow can be led to firewood or fuel forest systems, to irrigated grasslands (as at Werribee), or via trickle irrigation to crops in arid areas.

Final treatment, now in use in Holland and recommended by scientists at the Max Planck Institute in Switzerland, can be released via a sinuous, sealed canal of a variety of rushes and floating water plants.

Waters polluted with metals, biocides, or sewage can be cleaned by travelling through reed beds of *Scirpus*, *Typha*, and *Juncus*; or by harvesting off floating plants such as water hyacinth. The rushes and sedges can be mown and removed periodically for mulch or cellulose. For *untreated* sewage, a holding time of 10–12 days is necessary, or travel through a series of maze-like gravel-filter canals with floating weeds and sedges. For swimming pools and less polluted systems, a pumped "cycle" of water through ferns, rushes, and watercress suffices to remove urine and leaves. Such pools need a 23–30 cm (9–12 inch) coarse river gravel base, with intake pipes below, and a skimming notch for leaves.

Species recommended are:

- *Phragmites communis* and spp., *Typha* spp.: Flocculate colloids, dry out sludges, eliminate pathogens.
- *Schoenoplectus* spp.: Takes up copper, cobalt, nickel, manganese; exudes mould antibiotics.
- *Scirpus* spp.: Breaks down phenols, including toxic pentachlorophenol.

Low to zero populations of *E. coli*, coliform bacteria, *Salmonella*, and *Enterococci* are found after water is

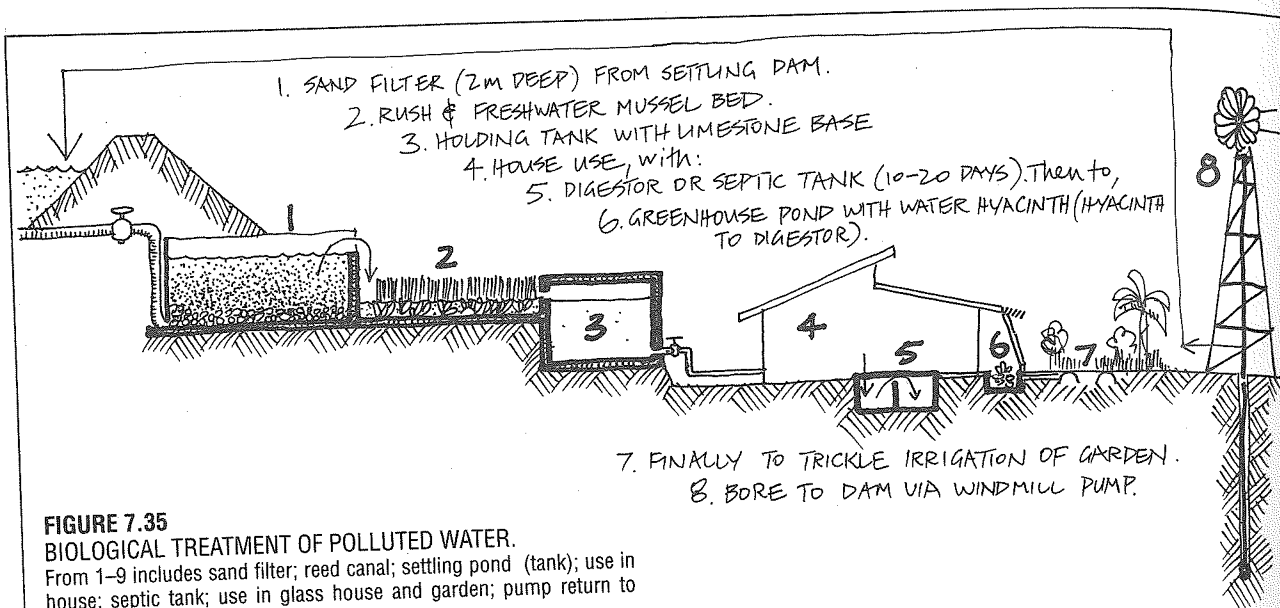


FIGURE 7.35
BIOLOGICAL TREATMENT OF POLLUTED WATER.
From 1–9 includes sand filter; reed canal; settling pond (tank); use in house; septic tank; use in glass house and garden; pump return to sand filter.

treated via the above species. Virus and worm eggs are also eliminated.

Also active in pathogen removal are (although these species must be tested and selected for specific problems): *Alisma plantago–aquatica, Mentha aquatica, Juncus effusus, Schoenoplectus lacustris, Spartina* spp., *Iris pseudocorus*.

For chlorinated hydrocarbons, use rush types with large pith cells (*Aerenchyma*), e.g. *Juncus* spp., especially *Juncus effusus; Schoenoplectus* spp.

Cyanide compounds, thiocyanates, and phenols were treated in fairly short flow times (7+ hours) with *Juncus*.

Systems must be carefully tended and monitored in field conditions. Water can flow through a gravel base planted to purifying species, or for longer rest times, passed through lagoons and ditches.

Domestically, a comfrey bed is one way to absorb the faecal products of animals, where wash–water from yards or pens is available. Comfrey can stand heavy inputs of raw faeces in solution, and the crop may then be used for fodder or trenched for "instant compost" under other species of plants such as potatoes. Flowthrough systems for methane production take little plant nutrient from faecal matter, and comfrey or algae ponds deal with the residues, while producing useful by–products for compost and stock feed.

The water from sewage lagoons has been safely used to rear beef cattle at Werribee for 35 years, and at Hegerstown (Maryland, USA), sewage waters supplied

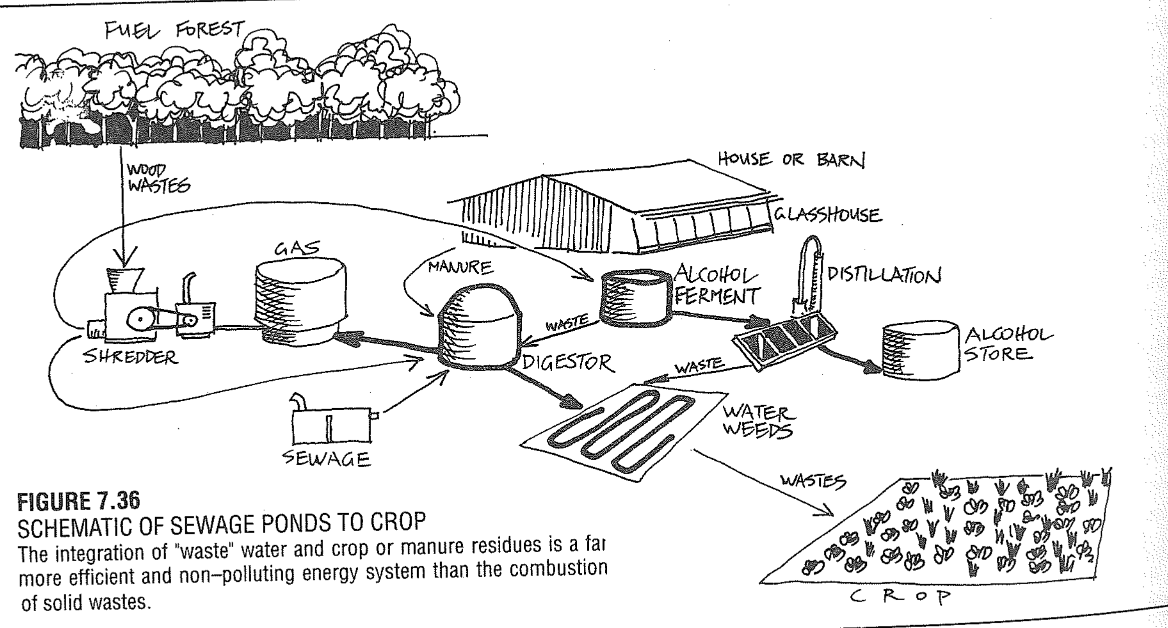


FIGURE 7.36
SCHEMATIC OF SEWAGE PONDS TO CROP
The integration of "waste" water and crop or manure residues is a far more efficient and non–polluting energy system than the combustion of solid wastes.

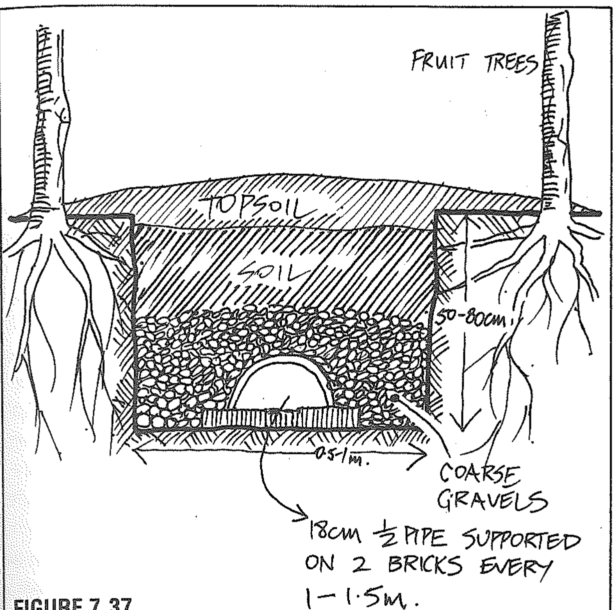


FIGURE 7.37
PITS FOR SEPTIC TANK DISPOSAL
Developed in South Australia as the "Arbor" system. Supported half-pipe never clogs with tree roots, enables trees to remove waste water from trench which has cross–supports every 1.2 m to create "pools".

to selected coppiced poplar plots can produce (as wood chips) some 60% of town energy use. Obviously, water saved from reducing the extent of urban lawn systems can supply the remaining deficit *plus* food crop for any town.

As waters pass through towns, it may gain from 300–400 ppm in salinity—a grave factor in usage in any dryland area (*New Scientist*, 13 Oct. '77). Saline waters can cause problems in irrigated systems, but algae and plant production and removal will reduce this surplus salinity. Discharge of sewage to subsoils does not remove nitrogen compounds from sewage or farm run–off. Again, it is necessary to use productive pond production of algae to reduce nitrates to safe levels for discharge to soils, or we risk pollution of wells and bores, as has occurred in Israel and the USA.

As with garbage, separation of sewage into solids and liquids at the domestic level has productive advantages; 2% urea sprayed on the foliage of rice plants in padi has increased grain protein yields to 40% (11% protein by weight; *New Scientist*, 1 Sept. '77). Such separation can also be used to recover alcohol and chemicals from urine wastes. Urine diluted with water to a 5% solution controls moulds on cucurbits, and aids garden growth or compost activity generally.

In summary, it has long been apparent that modestly–designed sewage treatment systems based on

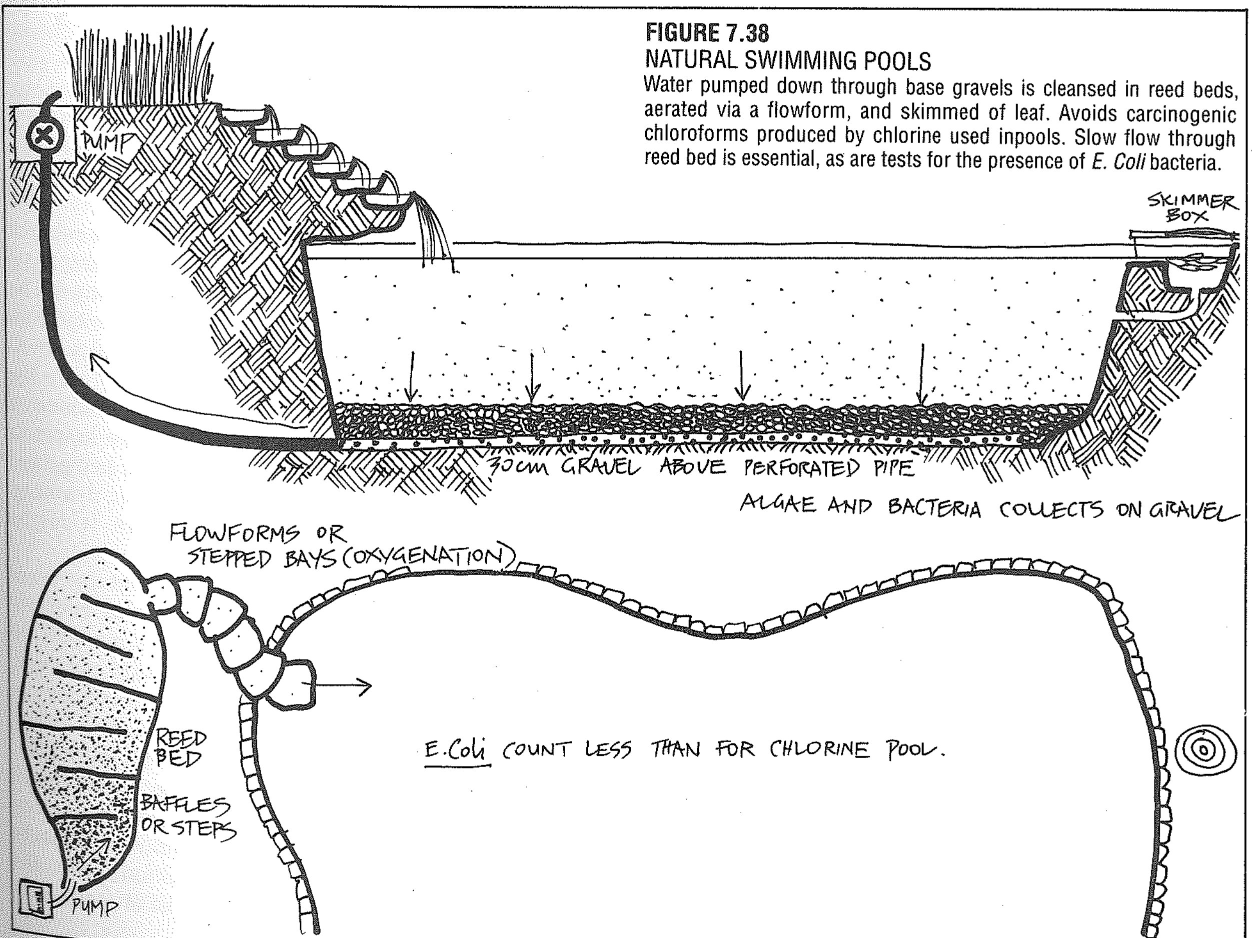


FIGURE 7.38
NATURAL SWIMMING POOLS
Water pumped down through base gravels is cleansed in reed beds, aerated via a flowform, and skimmed of leaf. Avoids carcinogenic chloroforms produced by chlorine used inpools. Slow flow through reed bed is essential, as are tests for the presence of *E. Coli* bacteria.

sealed (not leaky) lagoons and their associated biological systems not only function to recycle water efficiently, but to create a variety of yields from the 'wastes' of society. There are simply no modern excuses for continuing with the dangerous disposal of such wastes to seas and subsoils, where they inevitably turn up as pollutants in wells, streams, and on beaches, or add considerably to the greenhouse effect of atmospheric carbon dioxide. It is possible to design small and large systems of water treatment systems which are both biologically safe and productive.

Creative Disposal of Septic Tank Effluent

There are two basic productive disposal systems for septic tank effluent:

- Underground and surface leach fields around which trees are grown.
- Biogas conversion, followed by a pond growing aquatic crop for biogas feed stock, then a leach field.

A leach field is a trench or open gravelled soakage pit through which sewage wastes from a septic tank flows. In clays and clay–loams, tank water from a family home will stimulate fruit tree growth (without other irrigation) for 20 metres or more. The system follows normal procedures in that a long trench with a 1:12 ratio base slope is dug away from the septic tank outlet pipe. Topsoil is put to one side, and the trench is fitted with an 18 cm or larger half-pipe as per **Figure 7.37**. Coarse gravels or stones are placed in the trench, and over all this a strip of plastic or tarpaper is placed. The trench is then back–filled and trees planted 1–2 m off both sides as 2–6 m spacing. All fruit and nut trees benefit.

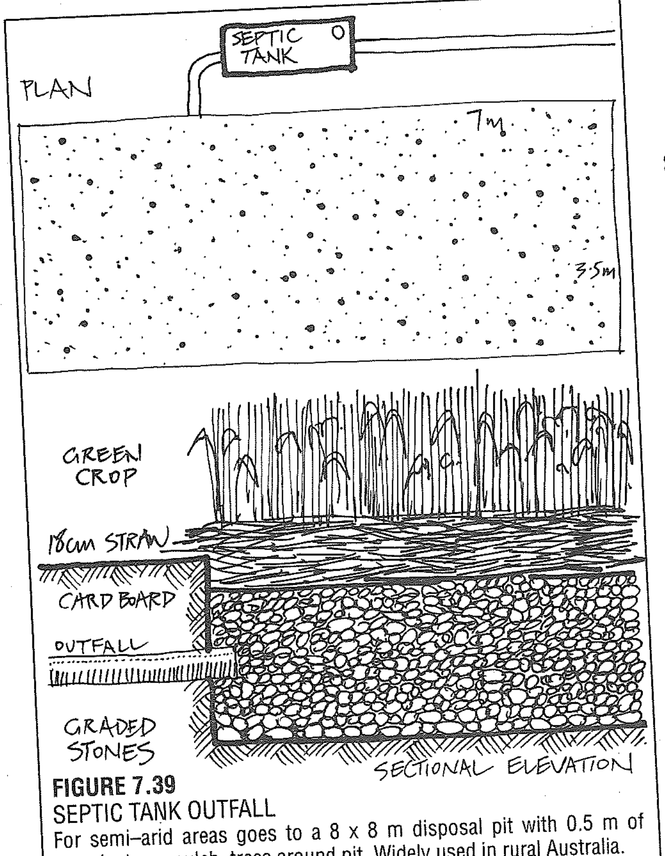


FIGURE 7.39
SEPTIC TANK OUTFALL
For semi–arid areas goes to a 8 x 8 m disposal pit with 0.5 m of gravel, straw mulch, trees around pit. Widely used in rural Australia.

Square or round pits about 25 m square can be dug out and filled with graded stone (coarse 6 cm at base to 2 cm at top). Over this, a layer of cardboard and a thick layer of straw is spread, and the latter sown to oats or green crop. Around the pit, trees can be planted.

For biogas applications, septic tank effluent, weeds, and manures are loaded into a tank 2 to 1.5 m deep and 3–4 m in diameter. A loading chute for weeds and wastes about 20 cm and 30 cm slants to the base. Septic tank effluent also enters at the base. Overflow goes to a pond with baffles, and *Pista*, watercress, or any rampant soft water weed is grown there. These are returned to the tank every week. A perforated pipe at the tank base is worked by a small gas compressor to "bubble" gas back into the tank for 1–3 hours daily on a timer. This breaks up the scum on top of the ferment. Gas caught in an inverted tank is fed to the house cooking range, lights, refrigerators. Surplus from the pond is fed to a leach field.

7.6
NATURAL SWIMMING POOLS

When thou wilt swimme in that live bath
Each fish, which every channel hath
Will amorously to thee swimme
Gladder to catch thee than thou him...
(John Donne)

Swimming pools have crept across the affluent suburbs so that, from the air, these ponds now resemble a virulent aquamarine rash on the urban fringe. The colour is artificial, like that blue dye that imitates an ocean wave obediently crashing down the toilet bowls of the overly–fastidious. Chemicals used to purify the water are biocides, and we are biological organisms; if fish can't live in our pools, we should also keep our bodies out of the water. When chlorine isn't being used as a war gas, it is being dumped into our drinking, bathing, and swimming water, where it forms carcinogenic chloroform.

Innovative pool designers now filter natural pools below a base pebble bed, using the pebbles as algal/bacterial cleaners, then cycle it through a reed–bed to remove excess nutrients before cascading it back, freshly oxygenated, into the pool. Such pools can be delightful systems with tame fish, crayfish, rock ledges, over–arching ferns, and great good health (**Figure 7.38**).

They are also reserves for fire–fighting, potential heat sources for heat pumps, barriers to fire, and emergency water supplies rechargeable from the roof, and can be recycled by photovoltaic pumps. Goodbye to the endless servicing, and perhaps hello to an occasional lobster or overgrown trout!

7.7
DESIGNER'S CHECKLIST

On any property, identify sources of water, analyse for quality and quantity, and reserve sites for tanks, swales, or dams. Wherever possible, use slope benefits (or raise tanks) to give gravity flow to use points, and detail plant lists that will grow (as mature plants or trees) unirrigated.

In the general landscape, soil samples (for 40% or more clay content) will reveal sites suited to earth–dam construction; such sites need to be reserved for future storages. A sequence of primary valleys may enable a Keyline system to be established for downhill fire control and irrigation.

Where evaporation exceeds precipitation (arid areas), make sure all water run–off is infiltrated to soil storages via soil conditioning (rip–lines), swales, pits, or sandfield soakages. In humid areas, open–surface dams dams can be used.

Define water "pathways" in use, so that water use is economical in houses, and that greywater is used in gardens (via filtration beds), forests, or (for villages) design for clean–up on site through a common effluent scheme based on maximum use (methane, plant production, irrigation).

Get good advice on (and supervise construction of) all dams. Wherever possible do not impede normal stream flow or fish migration, and site houses out of the way in case of dam failure. In particular, allow adequate stable spillway flow for "worst case" rain intensity.

Make sure that all earth storages, and in particular swales, are planted with trees, to remove infiltrated water and (in arid areas) to prevent salting problems.

Before recommending cloud–seeding, make sure that the area to be affected is warned, and that dams and swales are designed to cope with any increase (up to 30%) in rains.

Design for forested ridges, and maximise forest on strategic uplands; do not lend your skills to high–country deforestation (or any deforestation).

Windbreaks and in–crop trees are essential to reduce water loss in croplands.

7.8
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