A Primer on Dam Design

Design and Construction of Earth Dams

Darren Doherty

THE CHEAPEST WAY to store large volumes of open water is in a water storage dam or pond. The potential function and aesthetics of a dam are realized through good design, thorough planning and investigation, and appropriate construction techniques. This article addresses these outcomes by outlining the process we go through when designing and constructing a dam or series of dams on a client's property. "We" is Australia Felix Permaculture, my landscape design firm in Bendigo, Central Victoria, Australia. Australia Felix works throughout the southeastern part of Australia in temperate, cool temperate, semi-arid and Mediterranean climates, and has designed and developed over 700 properties large and small since we started in 1993.

In projects where the dam wall is higher than five meters, where dam failure could result in loss of life or serious damage to property, or where the developer's expertise is limited, a civil engineer should be definitely be involved. As a guide, however, the following information will guide the designer/developer on the issues to be considered in designing and constructing an earthen water storage dam.

Why Build a Dam

The sight of water storage dams is common in Australian rural farming landscapes. Dam construction allows us to store large volumes of water for a multiplicity of integrated uses, such as aquaculture, erosion control, gravity irrigation, stock and domestic water storage, solar passive effects, wildlife habitat, aesthetics and recreation. A well-designed dam can be used for all these things at once!

If you need to store anything less than around 100,000 liters of water or if potable water is needed then a water storage tank, constructed of concrete, metal, plastic, or other materials, may be a cheaper and better option. Also, if the site design process indicates that dam construction is inefficient and therefore uneconomic, a tank is preferable. Tanks can be used by themselves or as a source of effective gravity storage in conjunction with a lower level dam, stream, or ground water source.

Until relatively recently the low cost, ease of construction, and lack of regulation in dam construction have often resulted in a lack of permanence, effectiveness, and aesthetic appeal. P.A. Yeomans was the first to capture the true potential of dams on rural landscapes through his integrated Keyline farm design system which he and his sons developed in the post-war years in southeastern Australia. Keyline has been adopted by permaculture designers as the best technique for broad landscape design layout. This process starts with the use of the Keyline Scale of Permanence in conjunction with permaculture design ethics and principles. The key current reference for the Yeomans Keyline System is the book *Water for Every Farm*, available through the Keyline Designs website, www.keyline.com.au

Legal Planning Requirements

The first part of the process in the construction of a dam is to address the appropriate government regulations controlling dam construction and the use of the water stored in the proposed storage(s). The purpose of these regulations is to protect the community from poorly constructed dams and to ensure that regional water resources are not unfairly distributed. Contact your state or local government authority to obtain the necessary legal and permit advice. They may also be a source of useful regional and general information. Getting in touch with a local civil engineer experienced with dam construction is very useful and may be a requirement of a planning or building permit being issued.

A farm pond built by Australia Felix.

KEYLINE SCALE OF PERMANENCE
(in decreasing order of permanence; items lower down are more easily changed)

- Climate
- Land Shape
- Water
- Roads
- Trees
- Buildings
- Subdivision
- Soil

Dam Site Identification

Dam site identification should be a result of a holistic property planning process using permaculture design principles with an emphasis on the use of the Keyline Scale of Permanence. For the purposes of this article, however, we will look primarily at the parameters of assessing the potential siting of dams in the landscape.

The first issues to address are: What are the water resources available to the property, how they flow, how can they be captured, what is the most cost effective way of storing them, and how much is actually needed to be stored?

We always start with a catchment analysis, which identifies how much water flows through a property. Understanding the land patterns as shown on topographical maps is crucial for the effective calculation of catchments. This is achieved by recognizing the way the map's contour lines define ridges, saddles and valleys or gullies.

Begin by defining the water divide lines (or center lines) on the ridges of the particular catchment area as the boundaries of that catchment. Once this is done, use grid paper transparency (grid paper photocopied onto clear transparency) to determine the size of the area enclosed in the catchment. This number is called the area statement. If you're lucky like us then you'll have a GIS (Geographic Information System, e.g. MapInfo or ArcView) software that makes the area statement just a click away. Once you've worked out this number then use Table 1 and the formula in the next column to generate the total average run-off figures for the catchment. An engineer would also ascertain this as part of his or her investigation.

For irrigation schemes a reliability of eight years out of ten is acceptable, for domestic and stock schemes the aim is nine years out of ten.

METRIC CONVERSIONS

Length	25 millimeters (mm) = 1 inch 3 meters (m) = 10 feet 1.6 kilometers = 1 mile
Area	5 square meters (m2) = 6 square yards 1 hectares (ha) = 2.5 acres (1 ha = 10,000 m^2 or 100m x 100m)
Volume	4.5 liters (l) = 1 gallon 1.25 megaliters (Ml) = 1 acre foot 1000 liters = 1 cubic meter (m^3) 1 cubic meter = 0.75 cubic yards
Discharge	1 cubic meter per second (cumec) = 35 cubic feet per second

To estimate the annual runoff from a catchment, use the following formula:

Catchment runoff = 100 x A x R x Y liters

where:

A is the catchment area in hectares (ha)

R is the average annual rainfall in millimeters (mm)

Y is the runoff as a percentage of annual rainfall

I'll use an example to do these calculations, and then continue the same example through the rest of the article:

A small catchment of 100 hectares is forested and the soil is sandy clay. It receives an average annual rainfall of 750 mm and has an annual evaporation of 1000 mm. What would the estimated yield be for an irrigation scheme?

Table 1 RUNOFF FROM CATCHMENTS

Average annual rainfall (R) (mm)	Total annual evaporation	Reliability (years out of 10)	Runoff as a % of average annual rainfall (Y): Shallow sand or loam soils (%)	Sandy clays (%)	Elastic clays (%)	Clay pans, inelastic clays or shales (%)
> 1100		8	10 to 15	10 to 15	15 to 20	15 to 25
		9	6.5 to 10	6.5 to 10	10 to 13	10 to 16.5
901 to 1100		8	10 to 12.5	10 to 15	12.5 to 20	15 to 20
		9	6.5 to 8	6.5 to 10	8 to 13	10 to 13
501 to 900	less than 1300	8	7.5 to 10	7.5 to 15	7.5 to 15	10 to 15
		9	5 to 6.5	5 to 10	5 to 10	6.5 to 10
	1300 to 1800	8	5 to 7.5	5 to 12.5	5 to 10	10 to 15
		9	3 to 5	3 to 8	3 to 6.5	6.5 to 10
401 to 500	1300 to 1800	8	2.5 to 5	5 to 10	2.5 to 5 7	7.5 to 12.5
		9	1.5 to 3	3 to 6.5	1.5 to 3	5 to 8
250 to 400	<1800	8	0 to 2.5	0 to 5	0 to 2.5	2.5 to 7.5
		9	0 to 1.5	0 to 3	0 to 1.5	1.5 to 5
	>1800	8	0	0 to 2.5	0	2.5 to 5
		9	0	0 to 1.5	0	1.5 to 3

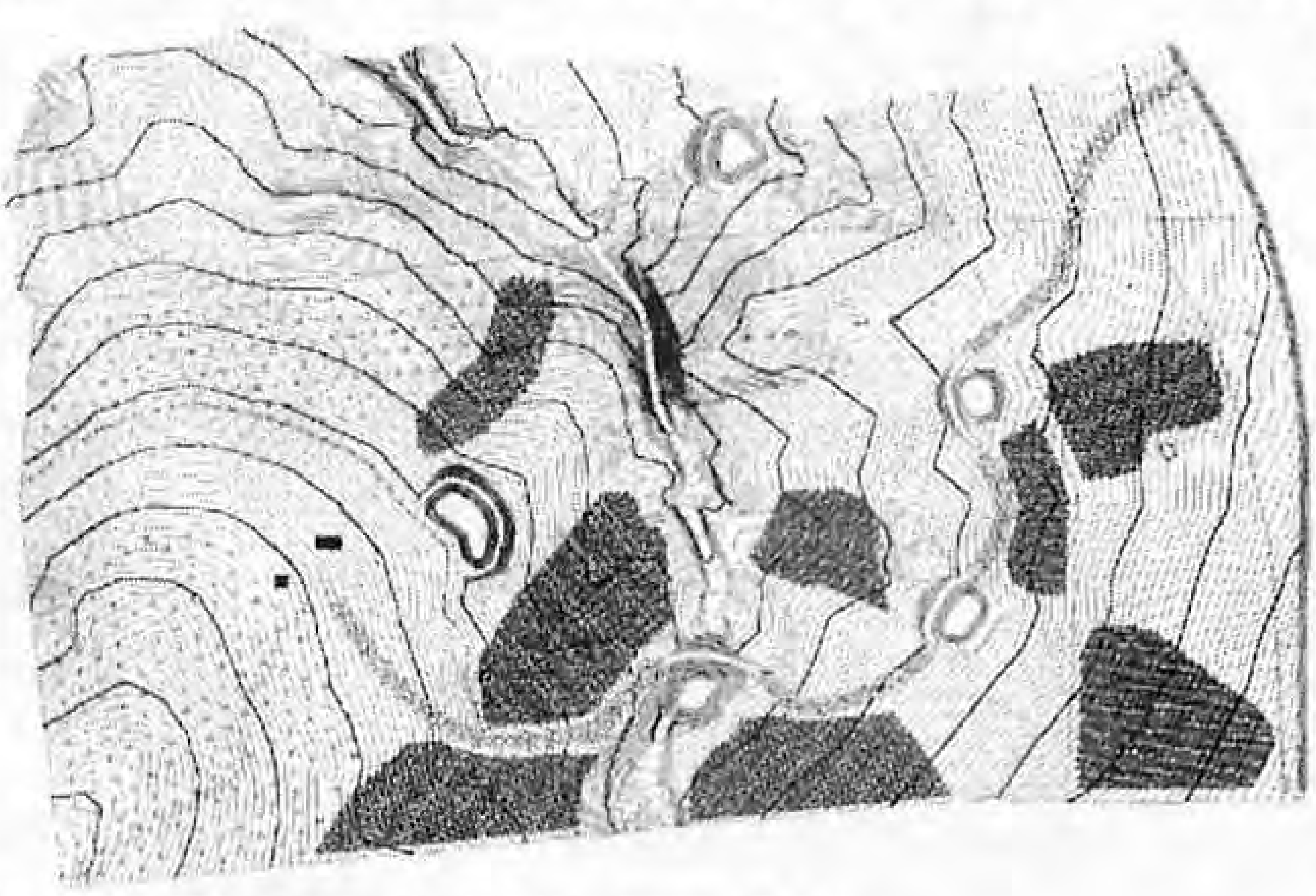
Elastic clays when dry develop pronounced surface cracking, which reduces runoff. Inelastic clays are identified, when dry, by a fine dust cover; this dust prevents seepage into the ground and so increases runoff.

A = 100 ha
R = 750 mm
Y = 7.5 % (reliability of 8 in Table 1)

Therefore runoff = 100 x 100 x 750 x 7.5
= 56,250,000 liters
= 56.25 megaliters (Ml)

A major component of the engineering of a dam is to design the overflow or spillway of a dam so that it can cope with the one in a hundred chance of the highest possible flood volume passing through the dam site. Consulting with your local water authority or engineer will enable you to calculate the amount of flood flow in cubic meters per second and design a spillway and/or trickle pipe setup to cope with these potentially hazardous occurrences. An engineer will calculate the flood flow using a method that considers the rainfall intensity, catchment characteristics and size, average slope of the watercourse, and the length from the head of the catchment source to the dam site.

Several different methods are available to increase the amount of available catchment to a dam where the catchment of a hillside or offstream storage, for example, may be too small for the amount of storage you're after. One way is to design and develop a system of earthen drains that intercept overland runoff and divert water to a water storage—we call these diversion drains. These are cheaply constructed using a grader or even better with a rotary drainer (see photo). These drains can also be integrated with road drains, as we often use the dam wall as an all weather access across wet gullies and drainage depressions. Drains can be placed so that they link two or more in a chain of dams by running overflow water from a higher dam to the next lower dam, and so on. Water reuse drains can also catch excess flood-irrigation water and divert it to a storage. Drains need to be designed and constructed considering similar flood flow volumes to those used in designing the dam itself. Again the use of an experienced engineer will assist in this element of the design.



Plan of one of Australia Felix's landscape designs.

Soil Suitability

An important aspect of the design process is to complete a borehole investigation of the proposed site. We use the services of local geotechnical engineers for this task. These engineers use a drilling rig at the site to take core samples to some depth and then perform laboratory tests. These tests determine the suitability of the site material for the construction of a dam and also what the soil profile consists of. They examine the depth of topsoil, clay/sand/silt composition, depth to water table/rock, and so on. From this the engineer will make recommendations as to how the dam should be constructed, and whether or not some amending or sealing material such as bentonite or gypsum is required.

The most important tests a geotechnical engineer would undertake would include:

Emerson Test

The Emerson test determines the behavior of clays in contact with water and to what extent, how fast, and under what conditions they break down in water. This test determines the suitability of the site material for dam construction.

Profile Texture

Determines the proportion of clay, silt, sand, and gravel through the soil profile of the test. Once tested you can get an idea of how much suitable/unsuitable material is in the proposed site.

Atterberg Limits

These are limits established by two tests. The *plastic limit* is defined as the moisture content at which soil begins to behave as a plastic material. A plastic material can be molded into a shape and then will retain that shape. If the moisture content is below the plastic limit, it is considered to behave as a solid, or a nonplastic material. As the moisture content increases past the plastic limit, the *liquid limit* will be approached. The liquid limit is defined as the moisture content at which the soil behaves like a liquid.

Sieve Analysis

Soil is put through a #200-mesh sieve to wash away clays and silts attached to sands and gravels to determine accurately where in the 15-group Unified Soil Classification (USC) the sample falls. This describes the proportions of gravel, sand, silt, clay, organic soil, and peat in the sample. When formally classified this provides the engineer/designer with the basis for designing the dam wall.

Permeability Test

This tests the moisture holding capacity of the soil. The laboratory test determines the rate of permeability of moisture per centimeter per minute. This is at once the most useful and the most expensive of the geotechnical tests. A very simple field/home test called the "bottle test" can give a fairly accurate approximation. This is done as follows:

1) Remove the bottom of a 750ml soft drink bottle.

2) Invert the bottle and fill 1/3 with the soil to be tested. The soil should be compacted to roughly the same degree achievable in the dam.

3)Fill the bottle with water.

If no water seeps through the soil within 24 hours then the soil has good water holding properties.

We use a soil log for our own field analysis in conjunction with other tests taken by others.

When the dam is full of water, a significant proportion of the dam wall is saturated. It is important to realize that no dam is completely watertight, as some seepage will always occur. To reduce the potential of failure as a result of this phenomenon the dam must have flat slopes (or batters) and the soils must be adequately compacted.

Types of Dam Walls (Embankments)

There are three types of dam walls in use on farms: homogenous, zoned, and diaphragm.

A *homogenous dam* is built of a single material and generally is made up of 20-30% clay, with the balance made up of silt, sand, and some gravel. This is also the simplest dam to construct. The height of the wall of a homogenous dam should not exceed five or six meters. Where the clays prove to be dispersive then the application of gypsum or bentonite may be required to provide additional sealing.

A *zoned dam* is the most stable of the farm dams, and is built where the required materials are available. A selected high-quality clay core is constructed in the center of the embankment, with the outer and inner slopes constructed of lesser material. As a rule of thumb the bottom width of the clay core should be no less than the height of the wall and should be joined to an impervious core trench.

A *diaphragm dam* is used where suitable dam construction material is limited. A layer of the most suitable clay available is used on the internal batter to act as an impervious section in the wall and again must be connected to the core trench. Again the application of gypsum or bentonite may be required.

Core Trench and Foundations

The construction of an adequate embankment foundation is vital to the success of the storage. The dam wall must support the weight of water and wall itself without substantial settlement and be relatively impervious to excess seepage. Sites that have landslips, and to a lesser extent springs and soaks, need to be avoided due to inherent soil instability. Professional site investigation and advice will be required in these areas.

The construction core trench (also called the dam key or cutoff excavation) is used to prevent excessive seepage under the dam wall over the natural land surface. It is a trench dug under the dam site, constructed to a dimension relative to the size and width of the wall, and should extend beyond the excavated bank to prevent outward seepage. The core trench, which locks the dam into the surrounding earth, is only effective where it is cut into relatively impervious material. Where deep layers of sand or gravel exist it may be necessary to use a horizontal blanket of 35m or more in length from the base of the embankment and 600mm thick up the base of the reservoir. This treatment is often very costly and causes some sites to be nonviable. Most farm dams will only need a core trench of relatively small dimensions in comparison with the wall base width. We generally only make it a bulldozer blade's width (2.5m+) and around 600mm to 1 meter deep.

Table 2 Storage Periods for Various Rainfalls

Average Annual Rainfall (mm)	Duration of Storage Period Required (months)
>650	12
451 – 650	18
250 - 450	24
<250	30 - 36

Types of Dams

There are several types of dams, the design and placement of which depends largely on the topography of the property and how the water stored is to be used. As a result of the whole farm-plan exercise, one should be able to answer the questions of what goes where and where supportive elements need to be placed. The storage ratio of different dam types and sites differs, and this ratio determines the economy of each site in terms of the volume of excavation versus the volume of storage. For example, a hillside dam on a slope or in a steep gully (i.e. above a keypoint) will have a poor storage ratio, whereas a tank dam or lower-drainage depression gully dam will have much greater capacity for every cubic meter of earth moved during construction.

The type and dimensions of the dam will also depend upon the climate and the amount of average evaporation losses. In semi-arid and arid zones the amount of evaporation will be quite large compared to cooler climates. Dams in the hotter zones need to be deep in order to overcome annual evaporation losses, which are a significant threat to stored capacity in prolonged droughts. In cold climates where soil freezing occurs an engineer's involvement will be needed due to the effects of seasonal freezing/thawing on the bank's structure and stability.

The effects of sedimentation (silting) may cause a dam failure through lost capacity. Some small sedimentation will always occur particularly after construction, and this can be beneficial in forming a watertight seal on the base of the reservoir. The timing of construction to match local rainfall patterns will reduce the risk of the dam filling too quickly, which can bring with it increased sediment loads. The construction of small sediment pond(s) above the storage or at the ends of diversion drains will reduce flow velocities, catch sediment and nutrients, and can—where creatively designed—act as a wetland for riparian vegetation and wildlife.

Gully (Embankment) Dams

These are the commonest of all dams, constructed across a gully or drainage depression where water is most likely to flow. This makes them the easiest storage option. Gully dams have a good storage ratio where they are not positioned above the keypoint (where the gully slope section changes from a concave to convex profile), and are normally constructed with a bulldozer and/or scraper. Trickle pipes sized relative to catchment flood flow volumes are usually required to reduce the amount of pressure on the spillway. Lockpipes through the base of the wall can make large volumes of water available for gravity irrigation supply, as in a Keyline system).

Hillside/Contour Dams

These dams are built on the side of hills and usually have a three-sided or curved bank. Diversion or overflow drains are the primary source of water for this style of storage. These dams have a relatively poor storage ratio and are therefore expensive to build compared with gully or tank dams. They do have a clear advantage in providing gravity storage. Bulldozers and/or scrapers are the preferred construction machinery.

Ring Tanks and Turkey's Nest Dams

These circular dams are fairly limited in their application. Constructed with excavators, their low storage ratio makes them expensive for the amount of water stored. Their best application is as an earthen stock trough filled with underground water by pumps or windmills. This type of dam has the highest evaporation losses. I have seen one very functional turkey's nest dam that was built on a small flat-topped ridge for flood irrigation. It had very low walls and was filled by gravity via a Keyline irrigation system, and overflowed when filled to irrigate about 300 degrees of the ridge that provided supplementary summer fodder in a winter-rainfall district.

Tank Dams

This type of dam is usually a square or rectangular excavation cut below the natural surface. This is the second commonest type of dam as it has the highest storage ratio of any of the dam types and is well suited to areas with flatter and gently undulating topography. We have constructed several of these on the plains country in western and northern Victoria and achieved significant water volumes for the relative cost of construction. One valuable feature of tank dams is they can be extended without much trouble, when time or budget allows a larger dam to be built. Their only downside is that gravel or sand seams may render them leaky, or shallow groundwater tables may create a salinity problem.

Making the dust fly: Cutting a drainage ditch with a channeler.

Spillways, Overflows, and Freeboard

The first guiding consideration with overflows is that no more than 2.5 cubic meters per second (2500 liters/second) should flow through a well-grassed spillway or erosion is likely. Calculation of the one-chance-in-a-hundred flood flow volume is the key to designing a spillway capable of taking overflow water with the lowest risk to the embankment. Inlet and outlet widths vary according to the flow volumes available (see Table 3).

As the spillway determines the ultimate water level in a dam, it is important to design its level so that there is adequate freeboard (distance from top of the bank to the water level). Freeboard depth is determined by the amount of fetch (longest exposed water surface on the storage) and should be at least 750mm; 1m for dams where the fetch is under 600m. Otherwise erosive wave action and overtopping (water going over the embankment) may occur, causing dam failure and potential damage to life and property. Give consideration to settling of the dam wall after its consolidation by increasing the construction height of the wall above the needed amount by around 5%. This is particularly important if the wall is to be used as a road.

A trickle pipe is often used to reduce the movement of lower-level flood flows through the overflow. This is often a requirement, as you should never allow even small flows to go through a spillway longer than several days, as this can cause more erosion than short-term higher-volume flows. We install high-density polyethylene (HDPE) trickle pipes of 150-300mm diameter to just below the maximum water level. Inlet and outlets consist of either prefabricated cement collars or endwalls, or they may be 1m-diameter pipe upturned, buried to expose the top, with the trickle pipe inserted through the side and sealed. If well sealed the volume of water flowing though the pipe will be quite substantial. A collar or baffle plate will need to be placed around the pipe in the middle of the wall to restrict moisture seepage along the pipe, which could lead to tunnel erosion and wall failure. A mesh cover should be placed over the inlet to remove the risk of blockages in the trickle pipe, which are sometimes difficult to clear effectively.

To provide a smooth flow of flood waters through the spillway, immediately after construction it should be covered with topsoil and seeded with grasses such as kikuyu, couch, para grass or others. Mechanical finishing or smoothing of all excavated surfaces can be done by a four wheel drive car or tractor dragging a section of reinforcing mesh weighed down with old tires. This will provide an excellent smooth finish to the dam and assist in the preparation of a seedbed for sowing and regrowth. In tighter areas, particularly around the overflow, further hand finishing of the dam can be done with a shovel and rake. This extra effort is always

Table 3 Spillway Inlet/Outlet Widths

Flood Flow (cumecs)	Inlet Width (m)	Outlet width @ 24% (m)	Outlet width @ 14% (m)	Outlet width @ 4% (m)
3	5.5	20	13	6
4	7.5	27	18	8
5	9.0	34	22	10
6	11.0	40	27	12
7	12.5	47	31	14
8	14.5	54	36	16
9	16.5	60	40	17
10	18.5	67	45	19
11	20.0	74	49	22
12	22.0	80	54	24
13	23.5	87	58	26
14	25.5	94	62	28
15	27.5	100	67	30

Outlet slopes calculated for return slopes of 24%, 14%, and 4% - Seek references or professional advice for further information on different slopes.

worthwhile and you will thank yourself for doing it in the years to come, such is the effect.

Outlet Pipes

Outlet pipes are installed for the following purposes:

- Gravity supply of water for downstream/downslope uses
- Suction pipe water supply for pumping
- Emptying the dam for repairs, including silt removal and leak location
- Environmentally necessary flows in sensitive catchments or where required by local authorities.

Outlet pipes present some difficulties in the construction phase and are expensive to install. However, their applications makes them such a useful item that they should be considered where possible.

Collars or baffles are required along the length of the pipe to prevent seepage along the length of the pipe, and are generally made of steel plate, each of around 75cm to 1.2m square. At least three are needed for pipe lengths of up to 20m. Pipes 25m long will need 4 baffles, 40m pipes need 7, and 50m will need 8. The pipe, made of HDPE, rubber-jointed concrete or galvanized iron, is installed by hand into a prepared trench. Soil is compacted around the pipe and then covered carefully with the machinery available (traxcavator, backhoe, or bulldozer are best) and then carefully built up and track rolled. We place star pickets around the inlet and outlets and put an upturned oil drum over them to protect them from damage for the remainder of the construction process. Again, a mesh cover is recommended to cover the inlet with both the inlet and outlet secured in an anchor block relative in volume to the diameter of the pipe. The Keyline Designs website and books have some excellent pictures of pipe baffles and inlet mesh guards.

Outlets use gate valves to control the amount of flow out of the dam. Valves are placed either downstream or upstream of the wall. Downstream valves are more popular, although they are likely to leak more due to constant pressure applied to them, and also are more difficult to repair. Upstream valves are more difficult to access, as they are submerged, and a remote winding spindle will be need to operate it. However, they have less pressure on them and make it easier to repair the pipe.

Siphons are another common way of piping water out of dams. Prefabricated HDPE siphons are now available and they remove some of the natural difficulties faced by many who have made siphons themselves. Compared to outlet pipes using equivalent diameter pipes, however, the volume of water able to be discharged is very small and this often limits their use. But where applicable, a small siphon can be a cheap and effective means of discharging small volumes of stored water.

Earthwork Volumes and Storage Capacities

A significant part of the design process is the calculation of earthworks volumes and storage capacities. We need to calculate these respective volumes to ascertain the cost of earthworks and the efficiency of the storage. The ultimate volume will depend upon the height of the wall, the shape of the gully/slope cross section, and the area of the storage reservoir upstream of the embankment.

The most accurate method of estimating earthworks and storage volumes is to have a high-quality electronic field survey completed, and then have the dam designed using the appropriate civil engineering CAD software. This is what we use with our team and it makes our lives a lot easier, as we can build the dam on the screen, see how much it will cost, and see if it is an efficient storage or not. To do that takes about one half to two hours per dam.

For calculating regular shapes the prismoidal formula can be used to estimate both storage and embankment volumes and is useful in all earthworks. It is generally written as follows

Gully Dam Volume Formulae:
Embankment Volume
$V = 1.05 \times W \times H \times (H+1) \times K$
Where
V = volume of earth (m^3)
H = height of embankment (m)
W = length of the dam wall along crest (m)
K= appropriate coefficient for gully shape

Water Storage Volume
$V = 0.22 \times W \times D \times L \times K$
Where
V = volume of water stored (m^3)
L = longest length of water surface (m)
W = width of water across the dam wall (m)
D = water depth at the base of the embankment (m)
K = appropriate coefficient for gully shape

Another accurate method for calculating gully embankment volumes uses the horizontal slice method. This requires a plot of the dam wall onto a survey plan of the site. For higher accuracy you can then divide the dam and storage into a series of 0.5m slices, then with the aid of a planimeter calculate the volume of each of the slices, with the total volume being the sum of all of the slices. You can also use the grid paper transparency over the survey plan and count the area contained in the squares for a similar, less accurate result.

The Queensland Water Resources Commission developed the following method which involes determining the shape of the gully slice cross section and then selecting a corresponding shape from a list, each of which has its own coefficient between 0.5 and 1.6.

To estimate embankment volume and gully storage, we can use the figures from the previous examples:

Embankment Dam Dimensions:

Embankment Volume (V)

= 1.05 x 0.5 (K) x 50 (W) x 4 (H) x 5 (H+1) = 525 m^3

Water Storage/Reservoir Dimensions

Water Storage Volume (V)

= 0.22 x 0.5 (K) x 30 (W) x 3.5 (D) x 100 (L) = 1155 m^3(1.155Ml)

Then we can decide whether the amount of water stored justifies the amount of earth moved (how economical our chosen dam is) by determining the ratio of the water stored to the total dam and reservoir volume. This is called the storage ratio, calculated as follows:

Total Storage = 525 + 1155 = 1680 m^3

Storage Ratio 1680/525 = 3.2

The table below tells us that a dam with this storage ratio is worth doing.

Dam Storage Ratio Feasibility

Storage Ratio	Rating
<2	Poor
2 – 4	Moderate
4 – 6	High
> 6	Very High

Dam Planning & Design Checklist

1. Permaculture Farm Plan – Gather map resources and develop a holistic diagnosis and design planning approach to assess the integrated need for water storage's per se, the catchments available, where dams fit into the overall landscape.

2. Why do I need a dam? Is it the most appropriate water storage choice?

3. Legal Planning Requirements—Contact local/state authorities, experienced consulting civil engineers.

4. Soil Classification—Take soil samples. Best to use Geotechnical Engineers where possible to ensure safest, best outcome.

5. Dam Design—Use climate/soil/catchment/site analysis to assess the best options. Again professional consultation wise if the experience or knowledge base is low. May be legally required anyway.

6. Outlet Systems—Do I need them? Does the cost warrant the installation? Look for suppliers, etc.

7. Earthwork and Storage Volumes—Calculate them to assess the cost/benefit ratio.

8. Contact local earth movers—What's their experience? Check out references and examples of their work. Find out how much they cost per hour or per cubic meter equivalent. How much earth can they move per hour/day. Get set price quotations and quality guarantees.

9. Construction—Finalize construction timetables, Markout, and your personal finances. And read the next issue of this magazine.

This is the first installment of a multi-part article on earth dams.

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www.keyline.com.au—Keyline Designs (Ken Yeomans) Δ

Darren J. Doherty is a fifth-generation Bendigonean committed to the sustainable development of Australia. He grew up on the land, has been a chef and certified organic market gardener. Darren has strong links to the farm forestry industry, and operates Australia Felix Permaculture, a land planning firm.

Taking a borehole soil sample with a power auger.