Gully Structures & Pole Planting

Gully Control Structures

11.1 Flumes & Chutes

11.1.1 Description/Purpose

Flumes and chutes are structures that convey stormwater over a gully head or scarp slope to discharge at a point sufficiently downstream so that the plunge pool does not migrate upstream to undermine the gully head. In many situations, flumes are used as a short to medium term measure to control active headward erosion, until associated protection planting has stabilised the gully head.

11.1.2 Application

The design of the flumes and chutes is critical to ensure that they are able to convey peak flows. Flumes were normally designed to convey (at least) a 10 year storm event where the storm duration is equivalent to the time of concentration. Many of the runoff control systems described below are covered in detail by Eyles (1993), using design practices developed by Mr Ian Cairns and other soil conservators in the Central Volcanic Plateau Region. When siting the runoff control structures, alternative flow paths were often incorporated into the design so that when design flows were exceeded, the stormwater flows discharged to alternative outlet points where damage would be minimised as far as practicable. Most failures relating to flumes were due to incorrect sizing for the design storm, or failure at the inlet of the flume by undermining or scouring around sides of the wingwalls.

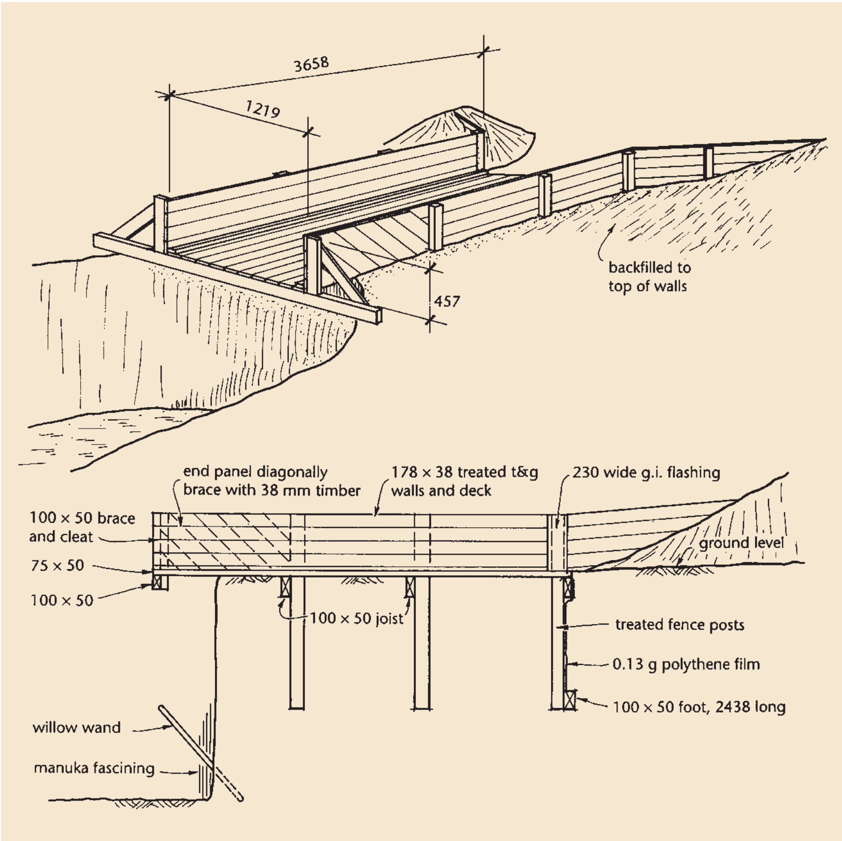
The design of flumes and chutes has changed over the years. While all flumes and chutes in the past were designed and constructed for specific sites, different products to convey small to medium flows are now available commercially, and can be bought 'off the shelf'. As these products have become available, designs have adapted to incorporate some detention of stormwater above the gully heads with the discharge into the newer types of flumes, chutes or pipes.

When constructing any gully control works where storm water is going to be directed to a pick up point and then safely conveyed past the critical gully head, water should not be directed into the flume or chute until downstream works have been completed. Consider the consequences of a storm half way through the job. It is often a good idea to divert stormwater away from the works site until the project has been completed. Alternatively, if the job is going to take two or three days, wait for a spell of good weather, and then try and complete the downstream part of the job before building the bunds and stopbanks to divert water into the runoff control structure.

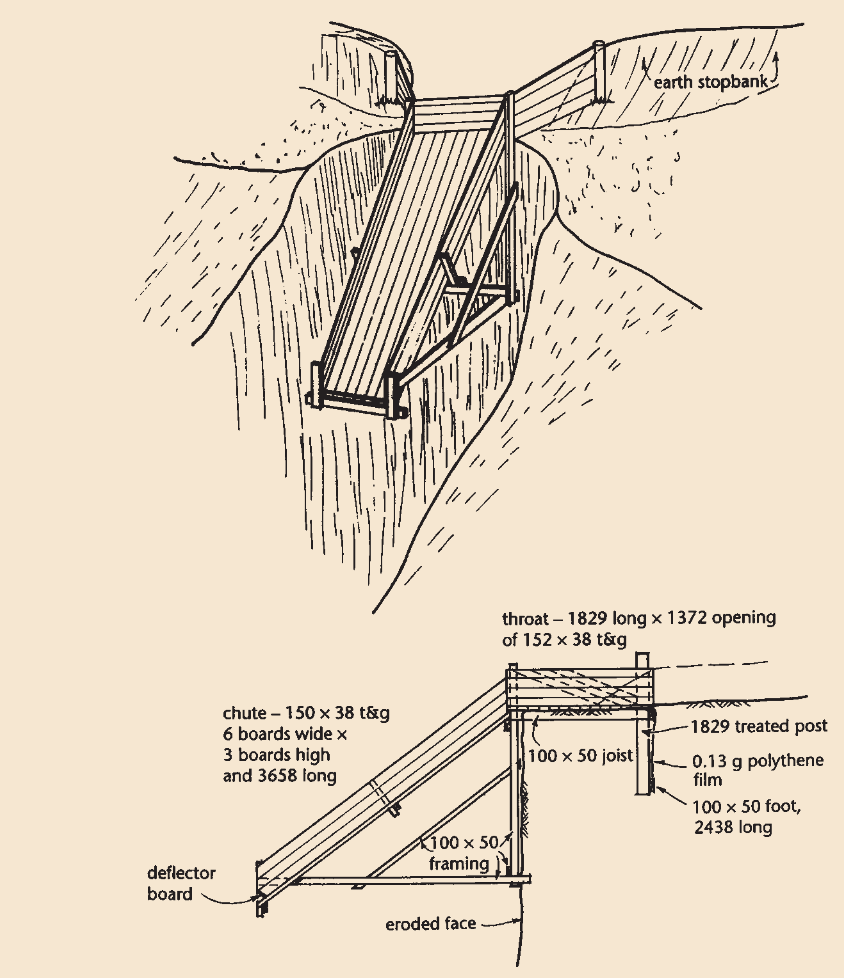
11.1.3 Types of Flumes and Chutes

Lip Flumes

These are wooden structures that concentrate the surface flow and discharge it safely over a gully head or scarp slope.



Plan of lip flume, 0.56m^3/s capacity.
All measurements are in millimetres.
Source: Environment Waikato.



Plan of a typical cantilever flume.
All measurements are in millimetres.
Source: Environment Waikato.

They need to be constructed using from either ground treated tongue and groove timber or H4 marine plywood. It should be dry, tightly jointed and double nailed with galvanised treaded flathead nails at all bearers and joints. The structure needs to be well footed, and sealed carefully at the inlet using .005mm polythene or equivalent. Wing walls at the inlet need to be well founded and sealed where they join with the sidewalls of the flume. Bunds (stopbanks) controlling the flow of water into the inlet also need to be well founded and compacted.

Cantilever & Escarpment Flumes

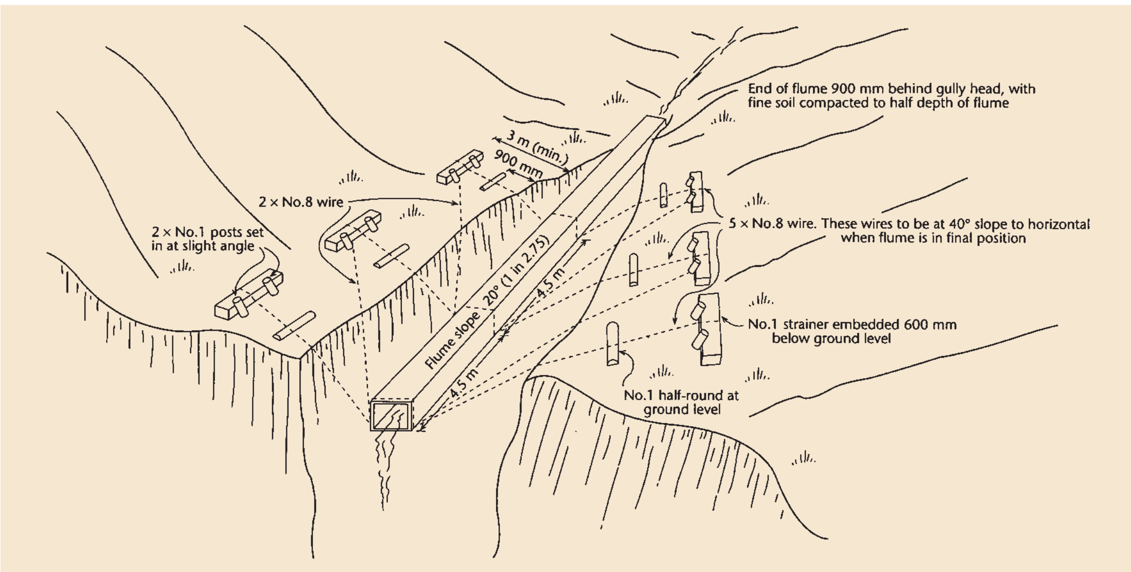
Cantilever and escarpment chutes are wooden flume structures designed to be built upslope of a gully head and cantilevered into place.

These structures have the same function as the lip flumes. They are used only in situations where the gully heads are more than 3 metres deep, and often 10 metres or more, or where all work has to be undertaken from above the gully head and cantilevered into place.

The same principles and construction methods apply as for lip flumes. However, construction needs to be lighter to allow for the difficulty of levering the structure into place. Neither cantilever nor escarpment flumes are currently used because they are expensive and difficult to construct. They have been superseded by the use of small detention bunds or ring bank discharging into drainage coil piping.

Suspended Flumes or pipes

Suspended flumes are supported by wires out over gully heads. They are used only in locations where it is not possible to



Plan of a suspended flume designed to drop surface flows safely over a 30m head in a difficult hill environment. This was one of a series of measures that included diversion banking to concentrate flows into detention bunds, retirement and planting of the gully head and outflow areas. This flume, constructed in the early 1960s, has disappeared but the gully system remains stable.

build conventional drop structures because of access, difficulty.

The suspended flumes are used to convey the stormwater flows far enough away from the gully head so that the discharge drops and forms a plunge pool that dissipates the energy without migrating back up slope to undermine the structure.

The design of suspended flumes varies depending on site conditions. The wooden constructions are expensive to build and difficult to maintain. The availability of plastic pipes in a range of lengths and diameter has meant that the principle of suspended flumes can be used with pipes as an alternative. However, their use is restricted to a few sites only, and often in conjunction with other practices such as detention bunds.

Wooden Chutes

Wooden chutes are used to convey stormwater flows down steep slopes, or escarpments. They sit on the ground surface and need to be anchored at regular intervals. They discharge at the toe of the slope or escarpment into a dissipating chamber.

Wooden chutes are constructed out of either ground treated timber or H4 marine plywood. The actual designs vary depending on how critical the site may be. They are often used to take the discharge from a culvert pipe safely down a steep slope. While Armco fluming, plastic piping or other products have largely superseded them, they are still used in some locations as they can be constructed on site, and can be sized to accommodate the design flow.

Butyl Rubber Flumes:

Butyl rubber flumes are used to convey stormwater down slopes or escarpments, in locations where the slopes are not too steep (less than 20°) and the flume is dug partially into the ground for support. The discharge point needs to be protected to avoid scour problems.

Butyl rubber flumes were used in situations where water control was required for the medium term, and the volumes of water or length of discharge was too great for wooden chutes. They were often manufactured to suit specific jobs and were considered to be a costly option to employ. Butyl rubber fluming is not used often now as there are a wide range of alternative cheaper products that can be used with equal success.

Butyl rubber flume. ***Photo: Gisborne DC.***

Corrugated Armco or Steel Flumes:

These flumes act as chutes to convey flows safely down steep slopes or escarpments. They may be partially dug into the slope so that they are supported, or can sit on the ground surface and be anchored at regular intervals. The discharge point at the toe of the slope needs to be adequately protected to avoid scouring problems.

These flumes are used very widely, particularly in association with conveyance of runoff from roads and tracks taking discharge from culvert pipes safely down steep slopes below the road.

Alternatively, they can be used in a similar fashion to lip flumes and extend over the edge of a gully head.

11.2 Pipe Drop Structures

11.2.1 Description/Purpose

Pipe drop structures transport surface stormwater from above a gully head to the gully floor, bypassing the gully head.

Application

Pipe drop structures have largely replaced wooden flumes and chutes, especially where design flows are relatively low. They have a number of advantages over wooden structures:

- They have a lower cost compared to wooden structures;
- They are more versatile and have lower maintenance requirements;
- Inlet systems for pipes are often prefabricated, which reduces the risk of failure;
- More pipes can be added if required;
- They have a degree of flexibility and can move if the gully changes shape.

Pipe drop structures are often used in conjunction with bunds or diversion banks, as well as detention banks or dams. They vary markedly in design and construction, but essentially there are two main types:

- Rigid pipes carrying surface stormwater over or away from the gully head to a safe disposal point;
- Flexible pipes following the gully head or side wall contours down to a safe disposal point. The flexible pipes can be of collapsible form, which expand to take design flows.

All pipe drop structures need to be firmly anchored throughout their length and at the discharge point. When they are running full, they have to cope with the weight of water as well as the energy of water. Pipe structures that drop water to considerable depths will need to cope with high water velocities, and need to be sufficiently robust to withstand the pressure changes. Specialised engineering design may be required to ensure that the structure is sound and well founded.

11.2.2 Types of Pipe Drop Structures

Drop Man Hole Inlet

The drop man hole inlet structure has an inlet into a man hole that allows the surface stormwater to descend safely to the required depth, before discharging out of an outlet pipe to a safe disposal point. The drop man hole inlet requires careful design to ensure that the structure is able to convey the design flow. The design also needs to ensure that the structure is able to cope with the forces exerted by the energy of the water dropping down the man hole, and the high pressure from the head of water.

The structure is commonly used where the gully head is not excessive (less than 3 metres depth) as a substantial amount of earthwork may be required for installation. These structures are used to provide long term protection with relatively low maintenance requirements.

Rigid Pipe Drop Structure

These structures involve the use of rigid pipe either discharging out over the gully head into a plunge pool, or conveying surface stormwater around the gully head and down the side of the gully to a safe disposal point. Where the pipes are run down the slope, they need to be well anchored at regular intervals.

In the past, costly steel or concrete pipes were used for protection of valuable assets. More recently, plastic or PVC pipes have become available, and are more cost effective.

Flexible Pipe Drop Structures

Drainage coil is a non-collapsible flexible pipe e.g. Nova-flo. When used with a bund or ring bank around the top of the gully head, it has proven very successful for treating small gullies (less than 5 metres high). The drainage coil is used to convey surface stormwater around the gully head to a safe disposal point on the gully floor.

The drainage coil pipe used should always be the non-perforated pipe that does not have drainage holes in the pipe wall. The pipe should be either anchored or dug in to ensure that it is stable. Inlet systems vary in design, but often incorporate a small drop man hole buried so that the inlet is at ground level. Alternatively, a simple culvert inlet with a small head wall can be used to drain stormwater from diversion bunds or detention banks. For remote sites, sandbags filled with a dry cement/soil mix can be used to construct small inlet headwalls. Sandbags should be filled to no more than one third full. The ends are folded back to seal the sandbag, and the headwall is constructed using the sandbags in a manner similar to laying bricks, but allowing for a slight batter slope on the headwall. Following rain, the headwall hardens and becomes a permanent structure.

Collapsible tubing such as Pyvac, Structure-flex, or UV stable lay-flat piping can be laid to remove surface stormwater from gully heads. The collapsible tubing can be factory prepared to cope with specified volume of runoff, and is sufficiently flexible to follow the contour of the scarp face. Operates in a similar fashion to drainage coil pipe, in that it is often used in conjunction with a ring bank or diversion bund that protects the top of the gully head, and directs water into the pipe inlet.

The collapsible tubing needs to be well anchored at regular intervals to prevent the pipe from twisting and blocking. Also, the collapsible pipe needs to be firmly attached to the inlet pipe as the weight of water over the gully drop off can exert enough force to split or break the material. Pyvac tubing is produced in rolls 30 metres by 1500 millimetres with a full width fitting over a 457 mm diameter pipe. Sheets can be welded to fit larger pipes.

Collapsible tubing has been largely superseded by drainage coil pipe because drainage coil is cheaper, more versatile and requires less maintenance.

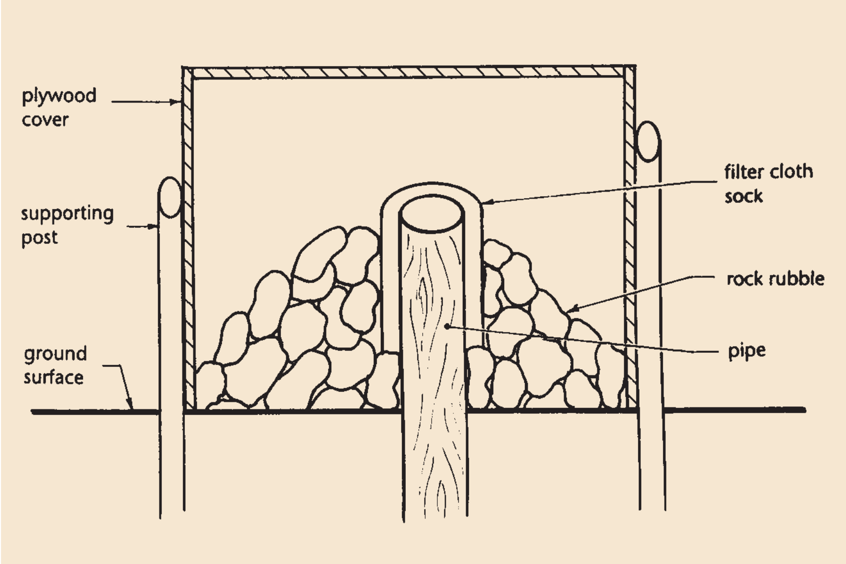
11.3 Sink Holes

11.3.1 Description/Purpose

A sink hole is a drill hole usually with a diameter of 1-1.2 m, and a depth in excess of 6 m, filled with rock rubble. It is located immediately upslope from a bund on low angle terraces in an ephemeral drainage line. The practice is similar to normal soak holes used for the discharge of stormwater from houses, except the soak hole is extremely deep.

Application

The downstream sink hole and bund should be located no closer than 150 metres from the gully head or terrace edge to ensure that groundwater recharge via the sink hole does not weaken the scarp face and cause collapse. The holes are normally used in series to provide for continuous drainage directly into the ground. Their use has been confined to deep gravel/sands river terraces in the Waikato region. The inlet system should be fenced to prevent stock and machinery from going too close to the structure. Careful attention should be given to ensuring an efficient filter system is put in place to prevent sealing and failure of the system. The practice is described in detail by Eyles (1993).



Sink hole cover for heavily stocked locations.
Source: Environment Waikato.

11.4 Detention bunds/dams

11.4.1 Description/Purpose

Detention bunds are up to 1 m high with a 150mm or similar-sized discharge pipe through the base. They are usually used in series along a valley floor or upslope from a gully head and are often used when limited storage is required.

Detention dams are larger structures up to 2.5 m to 3m high and provide a greater storage volume than detention bunds. They are often located close enough to the gully head so that the drainage coil discharge pipe is able to convey water over the gully head to a safe disposal point on the gully floor. Sometimes two or three detention dams may be constructed in series down an ephemeral valley, with the downstream structure conveying stormwater over the scarp face/gully head.

There is provision made for an emergency spillway around the side of the structure (at 2 m height), with the overflow directed to a safe alternative outlet as far as practicable.

Application

Both detention bunds and dams detain stormwater so that flood peaks are attenuated. They are normally used in conjunction with other works involving fencing, retirement from grazing and planting of the gully head and associated steep escarpment area. The detention structures are normally designed to provide for a minimum of 100 cubic metres of storage for each hectare of contributing catchment. The method is used primarily for small catchments of up to 40 hectares only.

Care needs to be taken with both the detention bunds and dams, so that discharge from the outlet pipe does not cause scour.

The detention bunds and dams can only be used if the site is appropriate, and they provide protection for small to medium storms (5 to 10 year return period) if used in conjunction with other works as described above. The practices are described in detail by Eyles (1993) and Environment BOP Fact sheet 10/98.

11.5 Diversion Banks = diversion bunds on earthworks

Description/Purpose

Diversion banks are earth banks that guide surface flows across a slope to a safe or controlled outlet. They are used either to protect a gully head, by diverting surface stormwater flows to a safe outlet, or to collect surface stormwater and move it to a particular spot for safe disposal or detention.

Application

Diversion banks are often used in conjunction with a controlled outlet pipe or flume system. They should be designed for the 1 in 20 year storm event and constructed on a grade that does not exceed the scour velocity of the particular soils on site. This may be as low as 1.25%, so a survey grade line will be required. Diversion banks need to be well compacted and grassed as soon as possible following completion. If the batters are not too steep, the diversion bank will blend in with a paddock and become part of the landscape.

This practice is described in more detail by Eyles (1993) and is similar to the diversion channels/bunds described in the chapter on earthworks.

11.6 Graded Waterways=grassed waterways in pasture & cropland

11.6.1 Description/Purpose

A graded waterway is a mechanically constructed grassed waterway that intercepts and transports surface runoff to a safe outlet. The function of a graded waterway is to regain the natural drainage grade in a gullying drainage system, enabling flows to be managed without scour or further gully formation.

Application

As with diversion banks, it is essential that the waterway grade keeps runoff to less than the scour velocity. All graded waterways should be well compacted, and grassed as soon as possible after construction. Alternatively, natural stable ground can be used.

Maximum erosion proof grades of waterways depends on factors such as the design flow, the shape of the waterway, frequency of peak flow etc. Instead of slope angles, maximum flow velocities are generally recommended beyond which erosion of channel will start to occur. For grassed channels, a conservative estimate of this velocity is about 2m/s (ref: Hydraulic Design manual, Humes Industries Ltd). This value will vary depending on the types and state of the vegetation, e.g. type of vegetation, height, density, stiffness etc.

The following table indicates acceptable velocities of flow within various grass lined channels on a range of slopes.

Table 11.1 Permissible Velocities for Grass Lined Channels

Channel slope	Lining	Velocity* (m/s)
0-5%	Grass/legume	1.25
	Kikuyu	1.85
5-10%	Grass	0.91
	Kikuyu	1.5
>10%	Grass	n/a
	Kikuyu	1.25

*For highly erodible soils decrease permissible velocities by 25%

(Modified from Soil and Water Conservation Engineering; Schwab et al).

Simple engineering formulas can be used to work out the design flow and channel size and shape. Channels that will have velocities greater than about 2 m/s may need to be reinforced or armoured (using fabric, rock etc).

The graded waterways can be installed in situations where the eroding gully head is not excessively high. The site needs to be excavated to provide a firm foundation prior to filling to correct grade. The fill material should be formed in layers and firmly compacted as filling proceeds. Different geotextiles are now available with which to reinforce and grass the graded waterways. Reinforced waterways can withstand significantly higher velocities i.e. can be installed at steeper grades without erosion occurring.

Graded waterways are suitable for grassed spillways at detention dam sites. Care should be taken when grazing stock on grassed waterways, as any exposure of the ground surface can initiate further erosion.

11.7 Drop structures

11.7.1 Description/Purpose

A range of drop structures are used to convey surface water safely over a gully head. Most of the structures are capable of controlling a gully head drop of up to 3 metres in height. However, many are only used on short gully head drops of 1 to 1.5 metres.

Application

While many of the drop structures are expensive to construct, they are also relatively permanent. Generally there is less reliance on planting for long term stabilisation. Some of the drop structures described below can also be used in permanent streams.

All drop structures should be carefully designed to ensure that they are able to convey the design flow. Provision needs to be made for storm flows in excess of the design storm, when the structure is overtopped. Drop structures are designed to be site specific. Sometimes, the ideal structure may be a combination of two or more of the generic structures outlined below.

Drop structures generally have two components:

- The 'drop' section where the water is conveyed from one level down to a lower level; and
- The 'energy dissipator' which may be a plunge pool or a flexible structure such as a tyre mattress.

The wide range of construction materials and geotextiles now available means that many different types and combinations of drop structure can be built.

11.7.2 Types of Drop Structure

Concrete Drop Structures

These are constructed entirely of concrete, concentrate the surface

Concrete drop structure – spillway over dam.
Photo: horizons.mw.

stormwater at the top of the gully head, and discharge the water over a constructed chute to dissipate safely at the toe.

The inlet needs to carefully designed and constructed so that the structure is not outflanked. These types of drop structure are expensive, but will last for decades. They have been used to protect valuable assets and are often used as spillways for dams. The structure requires careful engineering design to ensure that the design storm can be conveyed, and that the energy is dissipated at the toe of the structure.

Geotextile/Interlocking Concrete Block Structures:

These structures are similar in principle to the concrete drop structures except they are built using geotextile cloth with interlocking concrete blocks laid on the surface of the cloth to hold it in place.

Geotextile interlocking concrete blocks.
Photo: Wellington RC.

Sheet piling drop structures.
Photo: Gisborne DC.

The structure is designed to be site specific and is built completely on site.

This type of structure is expensive, but effective and permanent. The site needs to be carefully prepared with experienced staff carrying out the construction.

Rock Rip-rap Drop Structures

These drop structures use rock rip-rap to convey surface stormwater from the top of a gully head safely down to the bottom of the drop. The median diameter size of the rock rip-rap should be calculated to ensure that it is able to lock together and withstand the forces generated by the stormwater.

These structures have proven to be successful, as the rip-rap provides a structure which is flexible, and can adjust to any changes in the shape of the gully head over time. The inlet to the drop structure is often formed from gabion mattress or concrete to ensure it is not outflanked. The rip-rap may need to be topped up after a few years, as the structure settles. Geotextile cloth should always be laid underneath the rip-rap. During construction, the channel slope is shaped first. Geotextile cloth is then laid down, the inlet constructed, and rock rip-rap placed. Depending on the site, the inlet may be constructed last.

Rock gabion drop structure.
Photo: Wellington RC.

Sheet Piling Drop Structures

Sheet piling is sometimes used to control small gully heads (up to 1.5 metres in height) particularly in difficult situations such as permanently flowing streams. Sheet piles are lengths of channelled steel that are driven in as piles but interlock so that the completed structure forms a continuous wall. The sheet piling is driven (or vibrated) into position with heavy machinery and provides a permanent gradient control.

The sheet piling needs to be long enough so that the plunge pool formed at the toe of the drop structure does not undermine the sheet pile walls. This method is an option that can be used for river training works.

Rock Gabion Drop Structures

Rock gabion drop structures are normally used to control small gully heads up to 1 metre in height. They can be used in both ephemeral gullies and permanently flowing watercourses. The structure comprises a rock mattress (rock inside a wire mesh) that forms the downstream energy dissipator, with a rock basket on the upstream end. The stormwater flows over the rock basket to land on the rock mattress. The rock mattress needs to be long enough, that any plunge pool forming at its toe does not undermine the structure. Engineering design will be necessary to ensure that the structure works.

These structures will require machine work to construct. They should be carefully designed so that the size and weight of rock used in the structure is able to stay in place. The mattress is flexible and will drop if a plunge pool starts to form at the downstream end. Also, it is important that the rock basket and sides of the rock mattress are carried up the sides of the channel and fitted into the natural ground contours in a hydraulically smooth fashion. Geotextile cloth should be laid underneath the structure to ensure that fine material is not scoured out. When these structures are used in rocky streams, tyres are sometimes wired onto the top of the mattress to protect the wire mesh from being broken by the moving rock bedload during major floods.

Normally these structures have a life of 15 to 25 years, and are supported by planting.

Boulder/Tyre Drop Structures

These structures are similar in principle to the rock gabion/mattress drop structures except they are constructed out of boulders and tyres, with the tyres wired together and laid over the downstream part of the structure. They are normally used in permanently flowing streams where a substantial structure is required to control channel gullying.

These structures have been used in the Wairarapa by the Wellington Regional Council and require experienced people to ensure they are designed and constructed properly.

Geotextile Reinforced Grass Drop Structures:

These structures are used in ephemeral gullies to safely convey the surface stormwater over a gully head or steep slope. They comprise a shaped grass chute that has been reinforced by geotextile so that the roots of the grass are bound together and are able to resist normal scour velocities during flood flows. The site is shaped and the geotextile is laid down. Topsoil is then spread over the geotextile and grassed. The grass should be firmly established before the drop structure is used. Some form of energy dissipater such as rock or gabion basket is required at the downstream end of the structure.

These structures have only become possible with the advent of a range of geotextiles in recent years. The appropriate geotextiles should be chosen following careful design to ensure that the velocities will not scour out the structure.

11.8 Debris Dams

11.8.1 Description/Purpose

Debris dams are structural controls that are built in the floors of eroding gullies. Their purpose is to stabilise the gully floor so that trees can be established to stabilise the gully sides. While trees are the main long term tool for V-shaped gully control, they can be difficult to establish if water channels continually undermine the toes of the hill slopes.

Application

Debris dams are largely confined to the control of V shaped gullies. They are normally built in series over time, with the base of the upstream debris dam level with the top of the debris dam below. However, locating a suitable site to commence debris dam construction is an important part of ensuring their success. It is important that the site is able to give sufficient support to the sides of the dam.

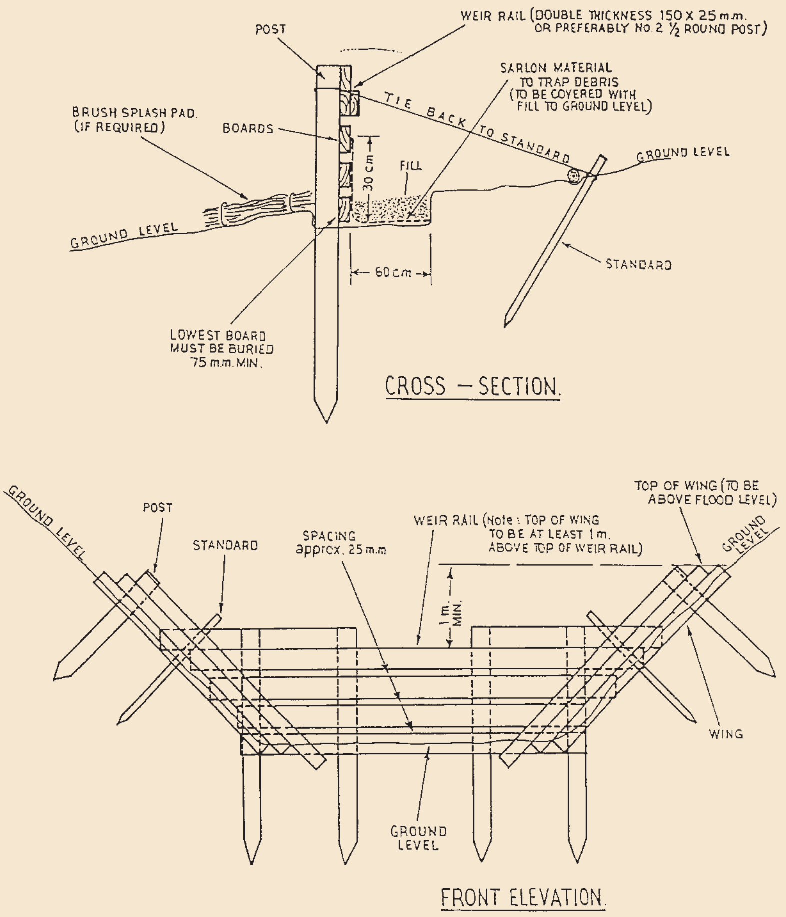
Debris dams can be used for a number of purposes (Gair 1973):

- To provide a stable area in an eroding gully, thus facilitating the establishment of trees or other vegetative control measures;
- To effect grade control, by eliminating bed level fluctuations;
- To reduce channel slope angle;
- To raise bed height, thereby supporting the base of gully walls;
- To increase bed width, and with it reduce water velocity;
- To centralise water flow in the channel;
- To trap and hold debris. This not only gives associated tree planting a better growing medium, but also helps reduce deposition downstream.

The height of debris dams (where the water flows over the centre of the structure) should be approximately 600mm on completion of construction. Following the formation of a plunge pool, this height may increase to 750-800mm. It is important that debris dams are not built higher than this, as they will become prone to failure. Over the years, many different types of debris dam

Timber debris dams. ***Photo: Gisborne DC.***

design have been built. A common factor in all types of construction is the need for the structure to be stable when the downstream scour hole has formed.



Material specifications for an average sized dam.

- 50m of 150mm x 25mm Merch Grade Pinus Radiata (ground treated).
- 6 posts 1.8m long (No 2; 1/2 rounds or No 3 rounds) for dam and wings.
- No 2, 1/2 round post with at minimum a 100mm face for weir rail or double thickness 150mm x 25mm.
- 4 standards for tie backs and wings.
- 2kg galvanised 100mm nails.
- 8m sarlon mesh.
- 20m No 8 galvanised wire.

Timber dam construction guidelines.

In the Gisborne – East Coast region of the North Island, early dam construction made use of manuka brush, which was often in plentiful supply. The brush was used for fascines, acting as an energy dissipator below the debris dams. The most successful design was the Timber Debris Dam. The Timber Debris Dam was based on an earlier Pole and Netting Dam designed by J Gair, but used ground treated timber as suggested by H Pearce. OM Borlase of the Poverty Bay Catchment Board, and WR Howie, Water and Soil Division, Ministry of Works undertook early design work on debris dams. During the 1960s and 1970s, thousands of debris dams were constructed, particularly in the Gisborne / East Coast area. However, very few have been built since loss of Government subsidies for soil conservation work, in 1988.

11.8.2 Types of Debris Dams

Timber Debris Dam

The timber debris dam is built out of ground treated timber and comprises a dam wall across the gully floor 0.9 m high with a lower centre section 0.6 m high. The dam has wing walls that extend up the side slopes of the gully so that the top of the wing wall is above flood level (at least 1 m above the top of the dam face). The dam is anchored with 1.8 m long fence posts, as well as tiebacks to warratah standards. The dam wall and wing walls are constructed from ground treated 150mm x 25mm rails spaced approximately 25mm apart. The lowest board on the dam face is dug into the gully floor at least 75 mm deep, with geotextile cloth anchored and laid part way up the inside face of the dam wall.

The following have been noted as important tips for construction:

- If posts are not driven in, make sure they slope up-stream.
- Where posts cannot be used (because of rocky ground) standards can be used. They must, however, be tied back.
- The bottom board must be level otherwise it will be difficult to line up the other boards. It is essential that the weir rail is level, or else the water will be channelled to one side.

- All bottom boards must be hard against the ground to prevent undercutting.
- Wings must extend above flood level.
- Geotextile should be spread out evenly before backfilling.
- Backfilling is essential; otherwise the dam will blow out.
- Do not place successive dams closer than 3m apart. This is because a scour pool forms at the base of the dam, and could undermine another dam downstream.
- Where possible, place the debris dam upstream of an existing strong point, such as a tree, or rock face.

Pole and Netting Debris Dams

The pole and netting debris dam was designed in the 1960s, by trying different designs and modifying them over time. The pole and netting dam is similar to the timber debris dam except it is constructed using netting, warratah standards, polythene and manuka poles. The manuka poles were used for the rails on the wing walls and weir rail. If manuka was not available, polar or willow poles were used instead.

The pole and netting dam was largely superseded by the timber debris dam in the 1970s.

Brush Debris Dams

Brush debris dams were comprised of manuka brush laid 0.5-0.6m thick across the gully floor after rough shaping of the channel. The brush is laid so that the ends overlap, in alternate layers with butts upstream, then butts downstream. Two rows of standards are then driven through the brush in a line across the channel. No.8 wire is then threaded through the top of the warratahs and tightened to pull the brush down firmly. The weir is formed from the brush material with two wings up the sides of the gully. At least 12 poplar or willow poles were planted on the edge of the structure in a pair pole planting pattern.

By the 1970s brush dams were seldom used. However, they did prove useful where there was some degradation in the gully floor, but the sides of the gully were still stable. The brush acted in a similar manner to mulch and helped prevent the mudstone gully floor from drying out and flaking. The dams were cheap, trapped moving bedload (rubble) efficiently, and the manuka brush lasted well. However, the dams did not cope with any erosion of the valley sides, and were not used if brush was not readily available to the site.

‘Bag’ Debris Dams

The ‘bag’ debris dam was developed to help collect debris as it moved down the gully, and the collected debris was used as an energy dissipater. The dam was comprised of angle iron either bolted/wired together or driven in a line across the gully floor. Wire netting mesh was then attached to the structure and folded back so that it formed a bag downstream of the angle iron that collected debris. As the bag filled, it tended to settle and act as a mattress downstream of the supporting structure.

In the Manawatu and Rangitikei-Wanganui areas, this technique was developed and used successfully. In other areas, where there was more risk of lateral movement, they required a lot of maintenance and were not used extensively.

Log and Slab Dams

Some of the first dams used boulders, logs or other debris already trapped in the gully floor. These later evolved into using split logs (slabs) or poles placed vertically across the gully floor or horizontally across the gully with lateral support.

‘Spider’ Dams

Some dams used pre-fabricated angle irons that were then placed as a debris dam structure across the gully floor. Ranges of different materials were used to form a mattress below the dam.

Various Designs

Various other designs were used throughout New Zealand, incorporating aspects of the designs outlined above. Often, the designs were “one-off”. At times, they were constructed off-site, then brought in and installed in the gully.

11.9 Surface Protection in Gullies

Surface protection is occasionally used for gully control. The appropriate techniques are described in Section 16.2 (Mulches, coatings and tackifiers). This page merely gives a few additional observations specific to their use in gullies.

11.9.1 General

Surface protection in gullies can involve grassing (the most common measure), mulching, fabric and all manner of coating substances such as aggregate, chemicals. Surface protection helps to protect the soil against raindrop, sheet and rill erosion, which can aggravate existing gullies. (Also see Earthworks – stabilisation)

Surface protection will not control erosion from concentrated flows, so appropriate runoff control measures should be applied first. Vegetative surface protection such as grassing or hydroseeding will establish more successfully if there is adequate moisture, suitable soil medium, and fertiliser. Non vegetative surface protection such as mulches, or geotextile fabrics will give instant cover, but may need follow up maintenance or establishment of vegetation in the longer term. Some surface protection measures (such as, geotextile fabrics, aggregate etc) can be applied to the flow paths of surface stormwater runoff.

Types of Surface Protection used in gullies:

- Grassing
- Hydroseeding
- Mulching
- Geotextile Cloth
- Erosion Control Blankets
- Aggregate

11.10 Mechanical Infilling of Gullies

Description/Purpose

This involves the contouring of the ground surface with earthmoving machinery to infill small U shaped gullies or tunnel gullies. It is carried out in association with surface stormwater runoff control and follow-up surface revegetation. The gully infilling is normally part of the surface contouring to change drainage patterns, and provides for a more productive land use on eroded ground without any productive potential.

Application

Mechanical infilling of gullies is an expensive option that can be undertaken to address small U shaped gullies, and tunnel gullying problems. Mechanical infilling is usually carried out in conjunction with reconstructing drainage patterns, and establishing stabilising ground vegetation. Where small U shaped gullies occur on short terrace faces, gully infilling, contouring of the face to an easier grade, controlling stormwater runoff to reduce velocities, and follow up topsoil and grassing can control the active gully erosion and substantially reduce the risk of further gullying.

Infilling of severe tunnel gullies was carried out at the Wither Hills, Marlborough with diversion banks installed to direct water back to ridges, and follow-up planting and surface revegetation.

Mechanical infilling of gullies is not carried out to any great degree in New Zealand because of the large costs involved. However, following infilling operations at Wither Hills, studies have shown that although the costs are high, increased returns from production alone following treatment can pay for the work over a period of time. Furthermore, increased production costs do not take into account other benefits such as easier management, more versatile land use etc.

Mechanical infilling of gullies should only be considered on small scale gully erosion problems. The costs for infilling large gullies will generally be prohibitively expensive, and potentially prone to failure

Pole Planting

12.1 Description/Purpose

Tree planting is the traditional long-term control measure for gully erosion in many parts of New Zealand. In particular, tree planting is used (in conjunction with other measures) for the control of V shaped gullies. The main purpose of planting is to stabilise the sides of gullies. However, planting also stabilises the gully floor in the long term as tree roots extend beneath the channel. Well planned planting stabilises the soil through the binding of roots, as well as dropping soil pore water pressure by evapotranspiration. Planting of trees in a gully's catchment will also help to modify and attenuate peak runoff for small to medium sized storms.

12.2 Application

Normally specific planting for gully control is confined to willows and poplar species only. Specialised planting may be used in particular regions e.g. Erythrina in Northland or native planting adjacent to ecologically important areas. Willows and poplars are normally planted as stakes or poles for specific gully control works where there is a potential gully erosion problem. This is carried out by pair planting or staggered planting along either side of the gully floor or eroding channel. Alternatively, poles can be space planted on the sides of gullies to help control associated erosion which can aggravate the gully erosion. Willow poles are also used for control of tunnel gully erosion. Extra long poles (up to 5 m long) may be necessary in some places and these are planted directly in the holes formed by the tunnel gully erosion, or by pair planting if the tunnel has collapsed. Polar poles may also be used, although willow poles perform better on wetter sites. The poles should have protectors fitted. Poplars and willows are ideally suited to gully control as they have a strong fibrous root system that helps to stabilise gully floors., Because they are deciduous, they do not shade out grasses and other ground cover, providing they are not planted too close to each other. Initial pair pole plantings of poplar or willows at 5 or 8 m spacing, has proven to be too close after two or three decades. Ideally pair pole planting should have final spacings of 10 to 15 m between pairs. On very small gullies, staggered planting is preferable to pair pole planting.

If willows or poplars are planted out as stakes, the plantings will need to be protected from stock.

12.3 Practice

This involves the planting of unrooted poplar and willow poles into land which is susceptible to slips. The aim is to have a surface spread of roots through the ground which holds the soil together while also drawing water from the ground. Pole length can range from 1 – 305metres, depending on whether stock are excluded while they establish.

Poles, like all living plants require careful handling and care must be taken to prevent them drying out prior to planting. Studies show that standing the poles in fresh water for 48 hours immediately after cutting will improve their establishment in the field. Initial root growth draws on moisture reserves in the pole. In some areas it is the practice to expose fresh wood at the base of the pole shortly before planting. This is done by pointing the pole with a sharp cutting tool prior to planting.

12.1.1 Pole dimensions

Pole length and small end diameter (SED) will vary according to site conditions, where they are to be planted, and the class of animal that will be grazing the paddock.

All animals will rub against poles as well as chewing the bark where it is not protected, so a bigger stronger pole, well rammed into the ground, will resist movement better than lighter ones.

Table 12.1 Classes of pole (giving typical dimensions)

Class of Pole	Length	SED
Cattle	2.5–3.5,	25mm
Sheep	2.0–2.5m	25mm
Retirement pole(stake)	1.0-2.0m	15 to 20mm

12.3.2 Planting poles

Poles should be in the ground before shoots start to appear, generally before the end of August, although some species have a later bud break.

There are many ways to plant poles, but the most effective ways are driving or digging. For driving, the pole big end needs to sharpened using an axe or slasher. In some areas poles are slice cut in the nursery which eliminates the need to point the pole on site. If the ground is dry and hard, a pilot hole is made with a crowbar, the sharpened end is placed in the hole and then driven into the ground not less than 60cm, with a pole driver. This is a length of pipe, larger in diameter than the pole, about 800mm long and fitted with two handles. A spike may be fixed to the driver in order to make a pilot hole. If the ground is moist and soft, poles can be driven without the need for a pilot hole.

Widespread gully (above) and spaced (below) planting of poplars to control erosion on mudstone soils, Kanakanaia Valley. ***Photo: Don Miller.***

When digging a hole, use a spade to dig a hole 60cm deep. Place the pole in the centre of the hole and ram the earth with a rammer from the bottom to the top, taking care to avoid damaging the bark.

It is necessary for the pole to be firm in the ground while roots are developing. Any movement caused by animals rubbing or by wind will cause the roots to break. If a space develops between the bark and the earth the pole will dry out. In some soils, poles may work loose as the soil dries and shrinks. Re ramming may be necessary and farmers should be made aware of this requirement.

12.3.3 Pole placement and spacing

Poles will struggle to grow in thin or dry soil. So sites where there is moisture, and a sufficient depth of soil to allow the pole to penetrate 60cm are essential. Poles will eventually grow into large trees, so spacing should be carefully considered. Trials have shown that a 10m spacing will develop a full root mat between trees at five to ten years age. Between ten and twenty years age, roots will spread more than five metres from the trunk, so the stand may be thinned by removing every second tree i.e. a final spacing of 20m. However this should not be done on particularly unstable sites, where root density at five to ten metres radius may be insufficient to bind the soil.

Poles need only be planted on the unstable parts of a slope, identifiable by micro-relief which indicates past failure (regrasses slip scars and debris hummocks). So actual planting density in a paddock will vary, and average out at less than the theoretical 100 poles per hectare. Establishing a pole in a harsh environment will result in losses, so closer spacings may be required initially, with thinning carried out later. Alternatively, plant replacement poles in the gaps.

Willow poles form a fibrous root mat and do better in wet conditions, such as along stream beds and gully floors. Poplar poles are better on drier sites, although large leafed varieties should not be planted in windy sites. Poles are planted to prevent erosion, so it is preferable to site them where erosion could occur sometime in the future. Planting them in eroded sites (which is common) is worth doing, as it will stabilise remaining subsoil. However, it is much harder to establish poles once the damage has been done.

12.3.4 Pole protection

All poles that are planted in paddocks where animals will graze must have protectors fitted to them. Ideally cattle should be kept out of the paddocks where the poles have been planted for 18 months to 2 years to allow the poles to establish. Other animals such as goats and deer should also be kept out for the same length of time. In practice this rarely happens, so protectors are fitted instead.

Pole protectors, or plastic sleeves, are commonly used where grazing animals are presents. There are two types, 'Netlon' and 'Dynex' and both are slid over the poles at the time of planting. They are 1.7m long for use with cattle poles and slightly shorter for sheep poles. Netlon sleeves need to be stapled at the bottom to the pole.

If stock can be excluded for two years, 1-2m stakes may be planted, a substantial cost saving, compared with the larger poles.

12.3.5 Other benefits

Willows and poplars are deciduous, and this is a great benefit to pasture and animal production. Firstly the trees will provide shade for animals from spring to autumn. Then, in winter the trees have shed their leaves, so pasture growth is not suppressed. Even in summer, enough light filters through the trees for pasture to keep growing. Field trials have demonstrated that annual dry matter production is depressed by about 15-25% beneath growing trees (Gilchrist et al 1993, McElwee 1998, Parminter and Dodds pers. Comms.). The canopy shading loss is roughly counterbalanced by pasture growth between the trees, on ground that otherwise would have been lost to erosion (Gilchrist et al 1993, Hicks et al 1995, Hicks pers. Comm.). The leaves are high in nutrient and are excellent food value in times of drought or other feed shortages, dropping about 500kg of dry matter a hectare in autumn.

Poplars are recognised in other countries as having a high value for timber, fibre and match production. In New Zealand this value has not really been appreciated by growers or industry. Unpruned and inaccessible trees are of no value to anyone, including the farmer. Occasional silviculture is recommended to:

- prevent trees from splitting and falling (which can damage fences and block tracks)
- maintain good growth form (which minimises pasture suppression by the canopy)
- ensure a defect-free trunk, if harvest for timber is envisaged.

Specific recommendations for matching poplar and willow cultivar to sites, planting techniques, and silviculture, are given in a series of pamphlets recently published by HBRC and TRC.

12.4 References

Hathaway, R. & Van Kraayenoord, C, (eds) 1987. Plant Materials Handbook, Water and Soil Division MWD

Wilkinson, A. G. FRI Bulletin No. 124, 17 The poplars, Forest Research Institute 2000

Hawkes Bay Regional Council, Environment Topics – Planting Poplars and Willows 1995

Forestry & Shelterbelts

Chapter

Erosion Control Forestry

13.1 Earthflow stabilisation with erosion control pole planting

13.1.1 Shallow Earthflows

The trigger for renewed movement of an established earthflow is an excessive amount of infiltrating water causing swelling of the clay and raising pore water pressure. Control is obtained by either reinforcing the soil with tree roots or by reducing the pore water pressure (either by de-watering or evapotranspiration by trees).

Tree species that will establish from poles are almost without exception deciduous and so soil moisture removal during the winter months will be virtually zero. There will certainly be moisture removed when they are in leaf but the value of the moisture deficit that will be carried into winter has not as yet been adequately established. The stabilising impact of deciduous trees is mainly through the reinforcing effect of their roots and it is necessary that they be planted at close spacings.

The depth of penetration of tree roots will have a significant impact on their effectiveness but may be limited by soil conditions. The lower surface of the shear plane may have fine grained material and water may be perched there, both conditions that will restrict root growth.

Planting patterns: Five approaches have been used successfully:

- Very close planting of Salix matsudana on a regular 3 metre by 3 metre spacing with no surface drainage. With 7 year old trees this successfully held a small, previously active, earthflow near Gisborne during cyclone Bola. The only other earthflow at that site that did not fail was afforested with P radiata.

- A wider spacing (approx. 6 metre by 6 metre) of poplars and willows planted after a long period of de-watering. A very active earthflow affected area of bentonite clay, planted in this fashion survived 600mm of rain in 3 days during Cyclone Bola (photos) with minimal damage, but the works were very expensive to install.

- Willow poles closely planted in rows adjacent to graded drainage banks in association with a comprehensive de-watering program. Poles were also planted wherever scour could have been a problem in other surface drains. The works, on a number of properties, were spread over several years to allow gradual drying out of the saturated soil. Both slope stability and pasture production were greatly improved.

- Planting of poles in pasture on a wide spacing (greater than 10 metres) with no de-watering. These generally reduce erosion by 50% or more compared with unplanted ground. A key factor may be the absence of exceptionally wet winters in the following 5 to 7 years, which could give the trees a chance to establish, and to reinforce the soil mass. This lower cost method may be most effective where earthflow movement is sporadic.

- The planting of small gullies within the earthflow, may prevent worsening earthflow movement as gully enlargement is a major destabilising factor.

13.1.2 Deep Earthflow

The forces involved in deep seated movements are such that even if the roots of trees could penetrate to the shear plane the relative proportion of shear strength they could provide would be minimal. Stabilisation of deep-seated movements relies on de-watering and the most effective trees to lower the water table will be fast growing evergreen species.

If poles of deciduous species are close planted (within a 10 metre spacing) the general increase in shear strength of the soil mass may have a slight benefit, but a combination of de-watering and afforestation will give the most effective low cost treatment.

Full stabilisation of a deep-seated movement, even if it is possible, will usually involve a full civil engineering investigation and subsequent works.

13.2 Erosion control forestry for gully stabilisation

Large scale planting or afforestation with Pinus radiata, Eucalyptus or other species is often used for catchment planting. However, pines should not be used too close to eroding gully channels as they do not have the secondary fine root system necessary for gully control, and they will shade out the willows and poplars. Normal distances back from the eroding gully is at least the height of a mature pine tree. If production trees such as pines are planted, consideration should be given to proposed harvesting options in the future, and whether planting boundaries are appropriate to allow for sustainable production forestry. Trees are normally planted out as open rooted seedlings, and stock are excluded from the planted area. Seedling trees can be planted out with protectors, but careful grazing management is required, and the cost is higher.

Planting for long term control on U shaped gullies is only carried out if the gully head is not too deep (less than 2 m). Normally, planting is undertaken on U shaped gullies to provide a vegetative regime that is easy to maintain, or to provide an income when trees are harvested. Normally, willows and native species are planted within the purely protection areas, while other species such as pines, or special purpose production species are planted in areas that can be safely harvested without compromising the gully control works.

Most U shaped gullies are fenced and permanently retired from grazing, because the gullies are a hazard for stock. It is advisable to provide a gate or rails (preferably wired shut) in a retirement fence to make it easy to get stock out of the retirement area if they do manage to find their way in.

Gully control planting (using willows or poplars) is sometimes carried out at strong points such as a confluence upstream above an eroding gully head. In these situations, the areas should be fenced off to ensure that the plantings become well established. Once the plantings are established, careful grazing management can be carried out, taking care that the trees are not damaged.

13.3 Erosion Control Forestry on Earthflows and Other Deep-seated Movements

Deep seated mass movements have been successfully stabilised by erosion control forestry on both large scale eg Mangatu Forest, and small scale, as with farm conservation woodlots. Research carried out at Mangatu Forest in Pinus radiata forests on argillite earthflows demonstrated the dramatic effect that the forest had on ground water levels. In addition there are significant soil reinforcing effects produced by the deep vertical sinker roots that develop about 7 years after planting.

At Mangatu the entire ground surface was covered, but where only discrete earthflows are being planted further action may be needed to ensure maximum effect on groundwater. Even at Mangatu there were areas where a combination of high groundwater (possibly due to subsurface flow) and poor soil permeability created trees with very shallow roots. These trees were subject to severe windthrow once the area was opened up by adjacent logging.

The chances of success may be improved by additional measures:

- De-watering of the earthflow before planting may increase stability in the early years after planting, before the trees are fully effective. It may also reduce windthrow problems in small blocks with a greater proportion of exposed edge trees.
- Ridge tops and areas of disturbed ground above the actual earthflow may be infiltration zones that feed groundwater into the earthflow. These may need minor earthworks to increase run-off and reduce infiltration, and should possibly also be planted to increase moisture loss. Soil water control will increase as greater proportions of a catchment are planted.
- In argillite country groundwater is known to flow between adjacent catchments, and this increases the importance of groundwater control where only discrete catchments are to be planted. If obvious infiltration zones exist in neighbouring

catchments they may need treatments as detailed above.

- Areas that are obviously wet and areas in which continuing root strength after felling is required, could be planted in water tolerant coppicing species such as redwood or suitable varieties of poplar or eucalyptus. The choice of tree may be influenced by erosion control forestry subsidy refulations.

- Roading should be carried out carefully to ensure that run-off is not concentrated or directed into critical areas, such as zones of permeable rock or gully heads, where it may increase gully instability.

- Planting densities for P radiata and Douglas Fir are recommended at 1500 stems per hectare in order to obtain root zone canopy closure for maximum early stability improvement (1250 sph under the ECFP 2001 regulations). Of equal significance is the subsequent silviculture regime as excessively zealous thinning too early can open the canopy and reduce the erosion control properties of the forest.

- The Gisborne District Council recommend thinning to 600 sph after the low prune and a final stocking of 350 to 400 sph. An alternative used by forestry companies producing un-pruned farming grade timber is to thin to 350 sph after 7 to 9 years, which is satisfactory form a soil erosion control perspective.

- Poplar may be planted at 500 stems per hectare under the ECFP regulations. An initial density of 1000 sph, using stakes rather than poles, would obtain more rapid root reinforcement.

13.4 Erosion Control Forestry of large Mudstone and Argillite Gullies (Farm Wood lots)

Standard erosion control forestry practice applies where entire catchments are being forested. Where only the gully itself, and some surrounding land, is being treated as a farm wood-lot, the limited understanding of the effects of forest on gully activity needs to be appreciated.

The reduction of groundwater flow to the gully walls, through afforestation of the gully's catchment, is almost certainly a major stabilising factor. Seepage forces and pore water pressure in a gully wall increase the incidence of the shallow slump failures that lead to gully enlargement. A reduction in the volume of groundwater that seeps from further up-slope will be beneficial and the greater the proportion of catchment planted the greater the benefit will be.

Evapotranspiration and interception by the forest will probably be of greater importance than the root strength of trees, except for those trees immediately adjacent to or on the gully walls. A reduction in surface run-off through the gully bed, is a further process by which afforestation aids gully stabilisation.

A less recognised role of the trees around the rim of a gully is their effect on the microclimate in the gully itself. Shading and wind protection of exposed faces by larger trees can greatly improve the possibility of them being revegetated.

13.4.1 Gully perimeter planting

The larger the proportion of catchment planted, the greater the reduction in run-off. A compromise on the location of the fence around the gully will occur if both grazing and stability are desired. On more unstable gullies a wide margin (at least 30 metres, but preferably much more) is required, while more stable gullies in mudstones may be fenced closer. Economies of scale will apply when harvesting takes places and a larger area may give a greater return in terms of both stability and dollars.

Fencing costs may be minimised if a reliable, well constructed, electric fence is used and if cattle-only grazing is carried out on the remainder of the paddock during critical periods of tree establishment.

Appropriate tree varieties can be best judged from other local experience or the NZ Farm Forestry Association may provide information. While P. radiata is almost universally successful for planting around gully perimeters, some varieties of Eucalyptus and Acacia are better suited to specific regions and conditions. Cypress species, in particular Cupressus macrocarpa and C. lusitanica may have limited uses but only where soils are well drained, as they cannot tolerate high water tables. Their foliage may cause abortion in cattle. Details on eucalyptus, cypresses, and other species, for specific sites are given in the Plant Materials handbook for Soil Conservation, Volume 2.

Tree planting densities will be as for normal production forestry practice (1500 stems/ha for P.radiata is typical) unless under an agro-forestry regime. One can expect a less rapid erosion control benefit from wider spaced agro-forestry trees. The silviculture regime practised on farm scale gully wood-lots may be affected by the large proportion of edge trees, the degree of exposure to winds and the need to maintain a relatively dense tree stocking for erosion control benefits.

13.4.2 In-gully planting

Planting in an active gully will often only be successful when the surrounding forest is several years old and has already reduced groundwater flow. There seems to be little point in attempting to revegetate the gully floor when fresh sediment is still being deposited and signs of improved stability, such as the establishment of pampas grass seedling, may be useful as a guide as to when tree planting should commence. Rather than having two age classes of timber trees, the use of suckering trees that will survive logging damage may have merit on gully walls. Robinia pseudo-acacia has been observed growing well in such sites and Acacia melano-xylon has also been proved useful in tough conditions, although initial establishment can be difficult. A. dealbata is an exceptionally drought tolerant tree, particularly during its establishment phase, but is has still to be proven in the acid soils found in many argillite gullies. Other Acacia varieties were tested in Mangatu Forest by FRI, who will still have information available. In acid sulphate affected gullies in Northland the Coral Tree (Erythrina x sykesii) has been found to be very easy to establish, although it is best suited to frost free areas.

Pines appear to be hardier than poplars in the tough conditions found in gully walls, but if suitable suckering poplars can be established, such as Bolleana (Populus alba "Pyramidalis") or the P.alba x glandulosa crosses; Yeogi 1 and Yeogi 2 (which require well drained sites), they may provide long term stability despite logging damage.

The walls of argillite gullies will almost certainly be more difficult to revegetate than mudstone. In either case repeated attempts may be required until benevolent weather conditions occur and the plants are able to establish. The presence of seed sources of native plants such as Tutu, will often allow natural regeneration to occur once the major gully movements have been controlled by the surrounding forest.

A technique for establishing poplars and willows on steep slopes in some soil conditions is brush layering, in which cutting sized material is laid in a crossed pattern on contour terraces across the slope, which are then back filled with material from the next terrace up-slope. Most commonly used on road cuttings, the technique would only be warranted where very good soil moisture was present and the soil had adequate fertility. Details can be found in Schiechtl, 1980.

13.4.3 Post Harvesting Management

Where suckering trees and shrubs have become established in the gully floor and walls, provision should be made to exclude stock immediately after harvesting to allow these plants to recover from damage sustained during logging, prior to forest re-planting.

13.4.4 References

Schiechtl Hugo Meinhard. 1980. Bioengineering for Land Reclamation and Conservation. (English-language translation co-ordinated by N.K. Horstmann). University of Alberta Press.

Forestry company manuals, where these are able to be accessed, may provide standard methods of forest establishment.

After 1989 when Regional Councils were formed, and Government subsidies were no longer available for soil conservation activities, financial assistance with erosion control forestry became the responsibility of each Council. Some responded with ratepayer funded grants and others set aside capital funds from the sale of assets from which dividends were invested in conservation works. Others entered into joint ventures with farmers, where eventual proceeds from the sale of logs would be shared between the Council and the landowner.

13.4.5 Application

Erosion control forestry began on the east coast of the North Island with the plantings on Mangatu in 1961. The 6,500ha area was subject to slumps and earthflows, with severe gullying and aggradation in stream channels. The land was waterlogged in winter. The only vegetation consisted of poor pasture and a scattering on titoki and manuka (Willis 1973)

Early plantings were made with radiata at 2200 stems per hectare and by 5 years canopy closure had occurred and there was a marked improvement in slope stability. Observations showed that the top 10 to 20cm was much drier and there was a noticeable reduction in sub surface flows into stream channels. Aggradation had slowed and many of the streams and gullies had degraded to a stable base.

Current practice is to plant seedlings at a density of 1250 spha in 4m rows at 2m centres, with a thinning to about 400 spha while maintaining early canopy closure. (Marden 1995) With the ECFP it is possible to plant other species of trees, including exotic species such as Douglas fir and poplar, as well as indigenous forest plant. Much more is known about the effects of radiata on slump and earthflow erosion control due to the 40 years plus experience with this particular tree. With other species it is necessary to plant to similar tree densities in order to obtain similar erosion control results.

Seedling planting requires careful handling of the seedling tree from nursery to placing in the ground. Handling, transport to the site, preparing the ground, and eliminating plant competition is essential. Factors that should be considered are:

Handling and transport

After undercutting and wrenching in the nursery, the seedlings are lifted and placed in either plastic bags or cardboard boxes. There are advantages and disadvantages with each method of packaging. In boxes the seedlings are protected from crushing and sweating that might occur in plastic bags. However, with care, the bags can be more economical to transport. In the Gisborne area helicopters are sometimes used to transport men and seedlings into remote and difficult access sites. A plywood pod has been designed that can carry up to 3000 seedlings, and be slung under the helicopter. The pod is a 1.2 metre cube which is reusable and it provides good protection for seedlings in plastic bags.

Planting

The key to planting success is placing a well rooted plant in the ground where the roots are undistorted, facing downwards and contained by a well worked soil. Planting into a single spade cut with exposed roots and poor compaction raises the odds against tree survival. In drier areas a technique has been developed with considerable success where a double cut is made and the soil between the cuts is thoroughly loosened before placing the tree in the ground.

Reducing weed competition

It is normal forestry practice to use a herbicide to eliminate plant competition. A sprayed circle of 75 to 100cm is usual, the larger size is used where there is likely to be growth of vigorous pasture species. If the new tree is heavily overgrown by other plants it can lead to deformation and shortage of soil moisture, both factors essentially killing off the chance of a useful tree eventuating.

Other species

Erosion control forestry can include species other than radiata. Site conditions and accessibility may suggest the use of alternative species. For example, willows could be used where there is active gully erosion, macrocarpas for sheltered and accessible sites, and in along stream margins indigenous plants could be encouraged, and even planted.

Where poplars are selected the tree density needs to be much closer than normal open spaced planting.

Post planting care

Trees which are planted at 1200 to 1400 spha will need to be thinned to around 400 spha. The aim is to get early canopy closure, and thin out unwanted or distorted trees, while maintaining an even spread throughout the planted area. Pruning is a choice of the owner and a regime should be selected at or about the time of planting. Many factors will influence this decision, including, access to the site, proximity to processing, severity of erosion on the site and availability of time and resources to do the work

Erosion control forestry on Class VIIe land.
Photo: I H Cairns.

13.5 Forest Management Practices – Mountain Lands

13.5.1 Introduction

The practice involves planting a range of seedling trees on mountain faces or gullies subject to erosion. The trees are normally planted as seedlings but in special cases may be planted poles or stakes

Forestry plantings have been traditionally established to control slips, gullies, debris avalanches and to a lesser extent for frost heave, sheet wash, wind and creep erosion. There was very little planting in the mountain lands prior to the 1950s partly due to emphasis on other forms of revegetation and farm development but also there was insufficient information about the performance tree species at high altitude.

However, the work of Forest Research Institute at Craigieburn and Kaweka has provided valuable information on appropriate tree species, planting techniques, growth rates and other management details.

13.6 Protection Forestry

This applies where forestry plantings are carried out with the objective of controlling soil erosion. The trees may in time have other benefits such as timber production, weed suppression, recreational uses, water quality enhancement and carbon storage.

13.6.1 Species

Many species have been tried in the 130 years of European settlement. The most successful are the conifers. Other species e.g. Poplars, Willows, Silver birch (Betula verrucosa) and sycamore (Acer pseudoplatanus) are less common in the high country.

The most common species recommended today are as follows:

Mountain pine: (Pinus mugo) very hardy, multiple leaders, shrubby. Most suitable for the severe high altitude sites up to say 1600m depending on the site.

Lodgepole pine: (Pinus contorta) very hardy and seeds well but not recommended today because of wilding spread.

Scots pine: (Pinus sylvestris) not used so much today, may be prone to possum damage.

Corsican pine: (Pinus nigra) a hardy species (up to 800m) best on drier sites.

Ponderosa pine: (Pinus ponderosa) often grouped with P.nigra as a species for hard sites but is more prone to pests and diseases when stressed.

Radiata pine: (Pinus radiata) the most versatile quick growing species but is limited to the lower altitude or warmer sites below 540 m above sea level.

Douglas fir: (Pseudotsuga menziesii) species well suited to the more moist areas of the high country.

European larch: (Larix decidua) was used in the past but site tolerance and slow growth make it not as popular, deciduous, also potential wilding spread.

Alders: (Alnus spp) still useful on moist sites esp on scree slopes and streambanks. Deciduous but can grow at altitudes up to say 1600m.

Other species are available such as the natives (normally slow and difficult to establish unless self seeded) and some hardy eucalypts (subject to frosting and pest problems).

13.6.2 Planting regimes

Generally for erosion control purposes seedling trees need to be planted at 1200-1600 stems/ha i.e. 2.5m x 2.5m to 3 x 3 m spacing. Follow up grass control is essential once the seedlings are planted but on many of the high country sites competitive grass and weeds may not be an issue.

On heavy rainfall areas where soil fertility status is low the addition of fertiliser tablets for each tree is recommended (trace element deficiencies occur in this environment). On the easier slopes that are readily accessible, follow up weed and pest control is essential. Silvicultural management needs to be considered, depending on the objective of erosion control.

Where frost heave is active severe difficulties may arise with seedling tree stock, so an alternative is to aerial oversow Pinus species seed with fertiliser and a small quantity of suitable grass-clover mix to reduce the frost lift. Otherwise, use Maku lotus, which is a species that adapts well to low fertility sites. Time sowing when moisture is present and stock have been removed from the block.

Where the trees listed above have been planted for erosion control purposes on areas with slight to moderate sheet, wind and creep erosion, they can be managed to enable harvest for income. Harvesting must be carried out using cable techniques or special logging equipment (e.g. Wyssen Hauler) for sensitive areas. The need for a detailed harvesting plan is paramount. Refer to chapter on slips for more information on harvest of trees from erosion-prone land.

Shelterbelts

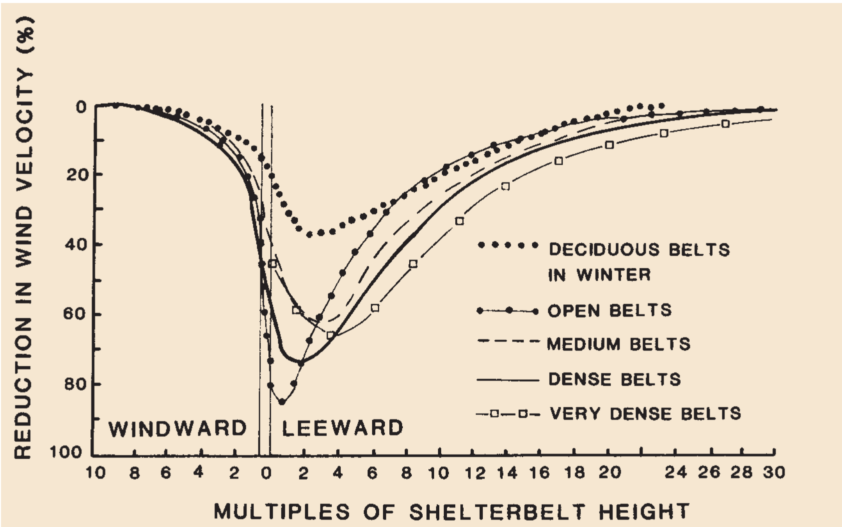
Field shelter by planting windbreaks is widely practised on both agricultural and horticultural croplands and pastoral farmland. Many windbreaks were planted and fenced for grazing control and were often planted as part of regional wind erosion control schemes, which could attract a subsidy of up to 70% (Stringer 1978; Wethey 1984). By 1984, wind erosion control schemes protected 1.9 million hectares of land susceptible to wind erosion (Salter 1984). Windbreaks have been multipurpose, providing livestock shelter and enhanced crop growth (Sturrock 1981), in addition to mitigating wind erosion. Considerable research has been directed at windbreak design and performance, suitable species, the advantages of shelter, and its costs and benefits (Gilchrist 1984, Sturrock 1984).

In the "Plant Materials Handbook for Soil Conservation" 1986, Volume 1, p. 125-138, Allan Wilkinson gives a brief but comprehensive summary of windbreak siting, design, establishment and management, and examples of windbreak designs, both for shelter only, and as "timberbelts" for wood production. He emphasises the need for an integrated shelter system for a farm property. His format is followed here. Section 14 of the "Radiata Pine Growers' Manual" (McLaren 1994) contains additional information specific to pine timber belts.

14.1 Siting

The following are the major factors to be taken into account:

- Orientation should be as near as possible to 90º from the harmful wind direction.
- Windbreaks should be as long as possible, connect with existing shelter to obtain continuity, and gaps should be avoided where possible, because wind velocity is increased by up to 25% around ends and through gaps.
- The interval between windbreaks depends on the expected maximum height and degree of shelter required.
- Physical restrictions need to be taken into consideration, including property boundaries and roads, power and telephone lines, microwave and cellphone towers, water races, irrigation systems (especially border dyking), filed drainage systems such as tile drains and perforated pipes (novaflo), and existing fence lines.
- Existing natural shelter. On hill country, windbreaks should be complementary to natural shelter.
- Aesthetic considerations. Where possible, windbreaks should follow natural boundaries, and should include designs and species that enhance the existing local character; they should form part of an overall shelter system for the farm which includes hedges, woodlots and wide-spaced tree plantings.
- The farmer's objectives. These may be many, including minimising width of windbreaks, provision of shelter at a specified time of year (e.g. lambing, spring flowering, autumn crop and fruit harvest), minimising winter shading, minimising competition with adjacent crops or pasture, maximising the return from timber sales, increasing the pollen and nectar supply for honey bees, and providing food and shelter for desirable bird species [and insect predators].



Patterns of wind abatement in the vicinity of shelterbelts of different density (after Caborn 1965).

14.2 Design

Some weighting of objectives is necessary to produce designs that meet the needs of the farmer and the rural community. In the past, lack of perception and insufficient effort devoted to design has resulted in a limited number of species being planted throughout New Zealand without due regard to the local conditions and the visual landscape. Unreasoned antagonism to shelter has arisen in many areas. Single purpose designs such as radiata pine hedges have evolved and the contribution which shelter can make, both in increased production and the quality of rural life, has not been fully recognised.

The requirements for each windbreak site within a designed shelter system should be carefully examined. The resulting windbreak design should incorporate experience resulting from previous designs, the best local knowledge of species performance, and consideration of the following factors:

Height of windbreak

A significant reduction in wind velocity is obtained for a distance of 10-15 times the height of the windbreak. The maximum reduction occurs at a distance of 1-4 times the height, depending on the permeability.

Permeability (density)

Very dense impenetrable windbreaks can result in severe turbulence in the lee of the shelterbelt and a resumption of unhindered wind velocity at a relatively short distance form the shelterbelt. Permeable shelterbelts provide a greater reduction in wind velocity further out from the shelterbelt but less reduction very close to the shelterbelt. The optimum density for a permeable windbreak is between 40% and 50%. This may be obtained by:

- Planting trees of the appropriate natural density, e.g. pines have a dense crown, gums and poplars have light crowns;
- Varying the spacing of trees within the row;
- Varying the number of rows of trees [multiple rows];
- Tending, including side trimming, pruning, and thinning.

Continuity of shelter

All species have a limited life and must be replaced before they become over-mature. Continuity can be obtained by planting at least two rows of trees, each row having a different rotation length, or by replacing alternate shelterbelts at different time, as part of an overall management plan for the property.

Stability of windbreaks

Windthrow occurs in areas with shallow soils, which experience high velocity winds. The risk of windthrow can be decreased by:

- Good design, e.g. two rows of species which have different growth rates are combined to give additional stability to the windbreak: the slower growing species is established on the windward side to reduce movement of the root plate of the fast growing species;
- Good establishment techniques, e.g. the use of high quality tree stocks with some form of deep cultivation and careful planting;
- Good management: the milling and replacement of trees nearing the end of a rotation is the most significant step that can be taken to reduce future windthrow.

14.3 Establishment

For the establishment of shelterbelts, it is extremely desirable that 100% survival be obtained. Thus the greatest possible attention must be paid to site preparation, planting techniques, tree stock quality, fertiliser requirements, release spraying, protection form animal damage, and irrigation. The following are key points to note. (See Chapter 2 of the Plant Materials Handbook for more detail.)

14.3.1 Site preparation

Some form of cultivation is recommended prior to planting. The site can be cultivated well in advance (including deep ripping) and sown down in a covercrop such as oats or ryegrass to provide initial shelter for trees planted in sprayed spots or lines, and to suppress weeds. Shallow line ripping can be carried out in winter with at least two or three rips per line to avoid any possibility of root runs down single ripped lines. The tractor wheels can be run back over the rips to consolidate the soil and improve the surface for pre-plant herbicide application.

14.3.2 Time of planting

On sites where frost and waterlogging are not a problem, autumn planting is often very successful, especially if summer droughts are common. Wet or frosty sites are best planted in September-October if a period of stagnation in growth is to be avoided. Many North Island sites can be planted any time from May until late August. Many sites in the South Island and some in the central North Island cannot be planted until after the danger of severe frost damage is past.

14.3.3 Planting stock quality

Planting stock quality has a major effect on survival, early growth rate, root system configuration and resistance to windthrow. Container grown stock generally shows a higher survival and faster early growth rate than bare-rooted stock. However, where adequate survival and growth of bare-rooted stock can be obtained, this is preferred.

14.3.4 Weed control

Although good weed control can be obtained short-term by cultivation prior to plantings, more encouraging long-term control can be obtained by the use of herbicides. Only a limited range of herbicides is suitable for use in windbreak establishment because of the susceptibility of many of the species used (particularly hardwoods) and the need for 100% survival of good healthy trees. Accurate calibration of spraying equipment is essential to obtain successful weed control without damage to the trees. Residual herbicides commonly used include hexazinone, simazine, and terbumeton/terbuthylazine (see Appendix 2 of the Plant Materials Handbook, Vol 1).

Those farmers who do not wish to use herbicides, should consider various mulches, including black plastic mulches, or spraying with hot water or even silage leachate, or cultivation with the old push hoe.

14.3.5 Damage from rabbits, hares, and possums

The susceptibility of young trees to animal damage necessitates the use of individual protection devices, rabbit netting, or electric fencing (see Section 2.10.2 of the Plant Materials Handbook). Damage can also be reduced by:

- A programme of eradication of animal pests in conjunction with the regional council;
- Good establishment to enable trees to attain a size out of reach of animal pests as quickly as possible;
- Spot spraying well in advance of planting to allow the growth of tall grass around the planting spots before planting. (All three pests are less likely to run through rank grass than along clear-sprayed lines).
- Several Regional Councils also suggest pest repellent made by mixing together 5 fresh eggs, 150 ml of white acrylic paint, and 600 ml of water. Apply to seedlings with a paintbrush.

14.3.6 Windbreaks

Windbreaks should always be protected from grazing animals. The distance from fence to trees for areas carrying only sheep should not be less than 1 metre. Where cattle are present, the minimum recommended distance from the fence to the trees is 2.5 m. Where this distance to the windbreak is not acceptable, electrified top wires are recommended, but the farmer should ensure that this is a fail-safe electric fence. Animals have an uncanny knack of getting into a shelterbelt as soon as the power is off where they can do a lot of damage

14.3.7 Irrigation

Trickle irrigation is recommended on dry sites to ensure 100% survival and optimum growth rates. The amount of water to be applied depends to a large extent on the plant species, weather and soil type. Average application rates vary from 10-25 litres per tree every 7-10 days; light sandy soils require more frequent application than loam or clay soils. Additional advice may be sought from regional councils' irrigation officers or companies supplying the equipment.

14.3.8 Management & Maintenance

While some species for shelterbelts require little maintenance once well established, shelterbelts do require some maintenance to prevent them from:

- Spreading out beyond the boundary fence;
- Becoming too tall and casting excessive shade;
- Becoming too dense, causing excessive turbulence behind the shelterbelt.

Thinning may be applied, but grazing of the vegetation inside the fence is not recommended. This is to prevent the formation of a browse line under which windspeed could increase, or loss of beneficial insect predators

14.4 Windbreak design and plant species for different sites

Wilkinson l.c. describes in considerable detail, a range of shelter designs from one row to multiple rows hardwoods which can be deciduous or evergreens, with or without underplanting; also rows of conifers, again with a range of variations. The conifers may or may not be used for timber. He also describes shelter for coastal situations. The shelter designs are described in terms of shelter height, spacing, management, site selection and applications. The site tolerances of the suggested shelter species are indicated in Appendix 1 of the Plant Materials Handbook for Soil Conservation, Volume 1. Additional information may be found in the Fact Sheets of the New Zealand Plant Materials Research Collective. Advice about locally suitable species can be sought from Regional Councils, Landcare Groups and members of the Farm Forestry Association.

In all following figures, the wind direction is always from the left in the profile diagrams.

14.4.1 Shelterbelt, medium-tall hardwood, one row

Medium height species	Tall species
Alnus cordata glutinosa incana rubra Phebalium squameum (syn. P. billardieri) Salix discolor	Populus alba 'Pyramidalis' (suckers) P. X euramericana 'Tasman' or 'Veronese' or 'Crow's Nest' P. nigra 'Italica'* Salix matsudana** S. matsudana X alba hybrids** S. matsudana X pentandra hybrids**

* P. nigra 'Italica' is rust-susceptible; use only in inland Canterbury, Marlborough and Otago.

** Salix matsudana and its hybrids may be defoliated by larvae of the willow sayfly.

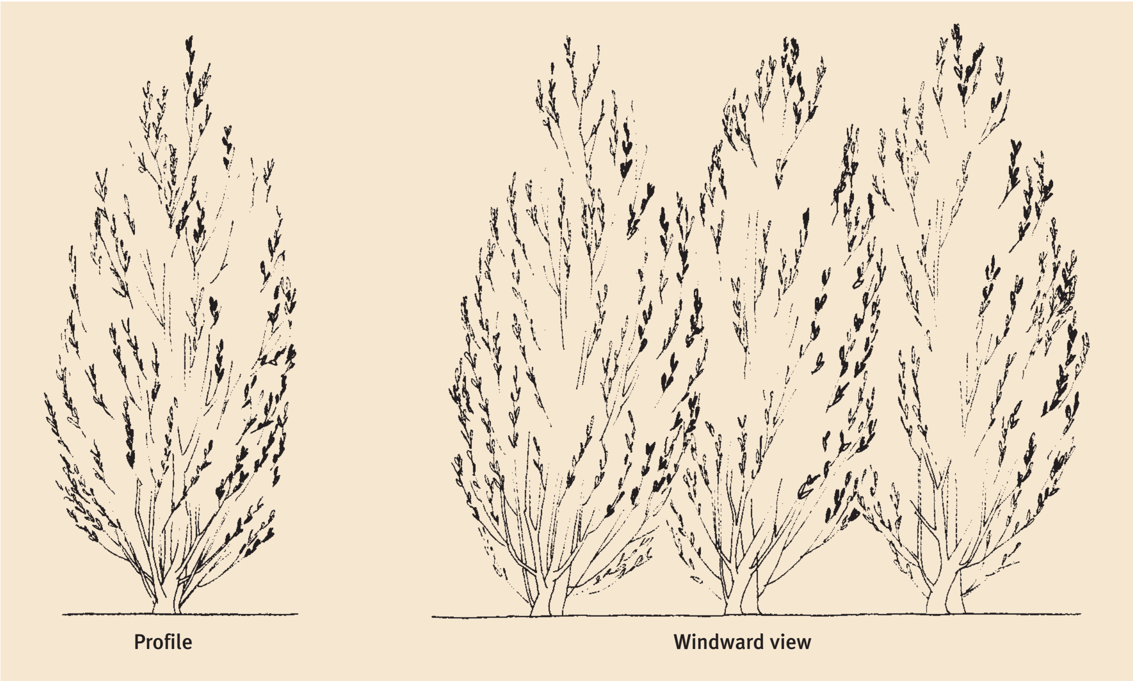
Initial Spacing

1-2 m between trees for horticultural shelter

2-3 m between trees for farm shelter

Management

Low maintenance. Optional side trimming to reduce width of belts and retain live green branches on the lower portion of the stem.



Medium-tall hardwood, one row.

Site selection/applications

Moist, reasonably fertile soils and irrigated cropland. Branch trimmings can provide supplementary stock fodder during mid-summer.

Use deciduous shelter for east-west windbreaks where winter shading is a problem.

Preference is now for perimeter belts to be of poplars and willows; internal belts of alder; in milder climates, the semi-evergreen Alnus acuminata.

14.4.2 Shelterbelt, medium-tall hardwood, one row, underplanted

Low- or slow-growing evergreen species	Tall, fast-growing species
Acacia spp.	Tall species listed in 14.4.4 or Eucalyptus spp. Listed in 14.4.4
Bambusa oldhamii	
Callistemon spp.	
Chamaecytisus palmensis	
Corokia spp.	
Cortaderia spp.	
Cryptomeria japonica	
X Cupressocyparis leylandii	
Olearia spp.	
Phormium cookianum	
P. tenax	
Pittosporum spp.	
Thuja plicata	

Initial planting

2-3 m between tall-growing species

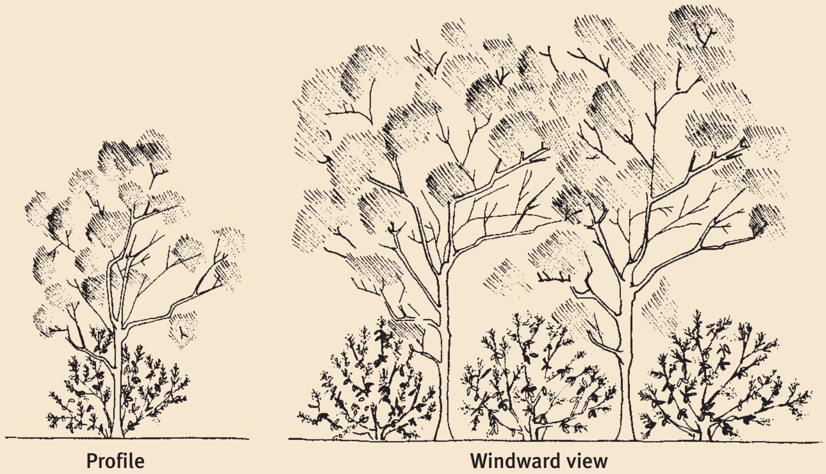
1 m between low-growing species

Management

Low maintenance. Occasionally side trim to reduce fence overhang.

Site selection/applications

Deciduous hardwoods should be used in east-west belts on naturally moist or irrigated soil types. Most of the above low-growing species can be used with the deciduous hardwoods but care should be taken to select Acacia spp. tolerant of moist sites, e.g., Acacia floribunda, A. melanoxylon, A. retinodes.



Medium-tall hardwood, one row, underplanted.

On drier sites use eucalypts combined with drought-tolerant, low-growing hardwoods or slow-growing conifers.

Hardwood shelterbelts can provide firewood, visual amenity, nectar and pollen for honey bees, and branch trimmings for supplementary fodder (deciduous species and Chamaecytisus). In milder climates fruit or nut-bearing shrubs such as feijoas, guavas and hazelnuts can be used for underplanting.

14.4.3 Shelterbelt, medium-tall hardwood, deciduous, two row

Low- or slow-growing species	Medium-tall growing species
Abelia grandiflora	Alnus cordata
Acacia floribunda	glutinosa
A. melanoxylon	incana
A. retinodes	rubra
Callistemon spp.	Populus alba 'Pyramidalis' (suckers)
Chamaecytisus palmensis	P. X euramericana 'Tasman'* or 'Veronese'* or Crows Nest
Cortaderia spp.	P. nigra 'Italica'**
Cryptomeria japonica	Salix matsudana***
Cupressus lusitanica	S. matsudana X alba hybrids***
X Cupressocyparis leylandii	S. matsudana X pentandra hybrids***
Melaleuca spp.	
Olearia spp.	
Phormium cookianum	
P. tenax	
Pittosporum spp.	
Thuja plicata	

*'Tasman' and 'Veronese' can be pruned for veneer logs. If this is done, prune annually to restrict stem diameter over stubs to 100 mm.

**P. nigra 'Italica' is rust-susceptible; use only in inland Canterbury, Marlborough and Otago

*** Salix matsudana and its hybrids may be defoliated by larvae of the willow sawfly

Medium-tall hardwood, deciduous, two row.

Initial spacing

2-3 m between tall-growing species within the leeward row

1-1.5 m between low-growing species in the windward row

1-1.5 m between rows

Management

Wider-crowned species may require occasional side trimming.

Site selection/applications

Moist, reasonably fertile sites and irrigated cropland. Provides low winter shelter for stock; high permeable shelter for pasture and crops during the growing season. Use as east-west windbreaks where winter shading is a problem. Low-growing species and Salix spp. provide food sources for honey bees. Branches of Chamaecytisus palmensis and poplar and willow tree species can be used as supplementary fodder.

14.4.4 Shelterbelt, medium-tall hardwood, evergreen, two row

Low- or slow-growing species	Fast-growing species
Moderate to high rainfall areas. Low- or slow-growing species listed in 14.4.3	Moderate to high rainfall areas. Eucalyptus botryoides* E. delegatensis* E. fastigata* E. fraxinoides* E. globoidea * E. muellerana* E. nitens* E. obliqua* E. ovata E. regnans* E. saligna*
Low rainfall areas Abies pinsapo Cupressus arizonica C. torulosa X Cupressocyparis leylandii Pinus ponderosa P. nigra subsp. Laricio Sequoiadendron giganteum	Low rainfall areas Eucalyptus amygdalina E. cordata E. gunnii E. nicholii E. pulchella E. viminalis

Species marked * are timber production species.

Medium-tall hardwood, evergreen, two row.

Initial spacing

4 m between trees in the leeward row

1.5-2 m between trees in the windward row

2 m between rows

If fast initial shelter is required, plant the leeward row at 2 m between trees; thin to 4 m apart at age 4-6.

Management

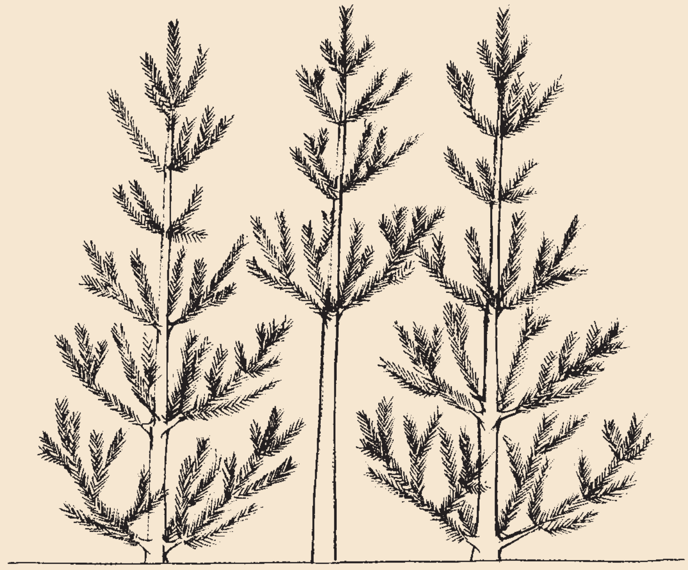
Low maintenance. Side trim occasionally to restrict width of belt. In shelterbelts the timber species require annual pruning to restrict stem diameter over stubs to 100 mm and to remove multiple leaders.

Applications

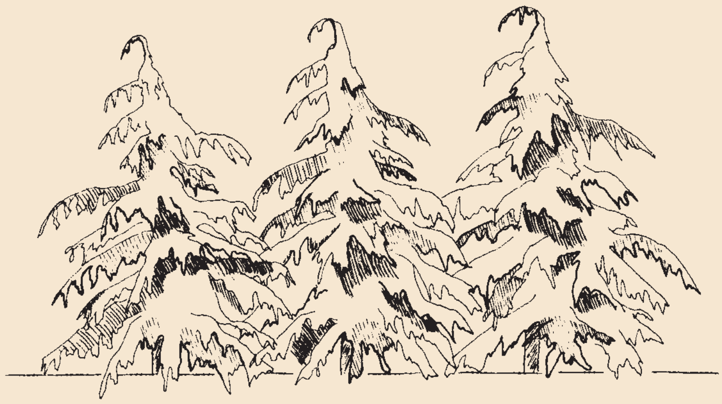
Timber, firewood, visual amenity, and nectar and pollen for honey bees and birds. Low-growing species can provide supplementary stock fodder from branch trimmings. It is essential to select the species and seed sources suited to particular sites.

14.4.5 Shelterbelt, conifer, one row

Fast-growing species
Pinus radiata
P. muricata (blue strain)
Medium-growing species
Cryptomeria japonica
Cupressus lusitanica
C. macrocarpa
X Cupressocyparz s. leylandii
Pinus nigra subsp. laricio
Pseudotsuga menziesii
Slow-growing species
Abies pinsapo
Cedrus atlantica
C. deodara
Cupressus arizonica
C. torulosa
Sequoiadendron giganteum
Thuja plicata



A. Pruned for Timber, Windward view



B. Unpruned, Windward view

Conifer, one row.

Initial spacing

2-3 m between trees

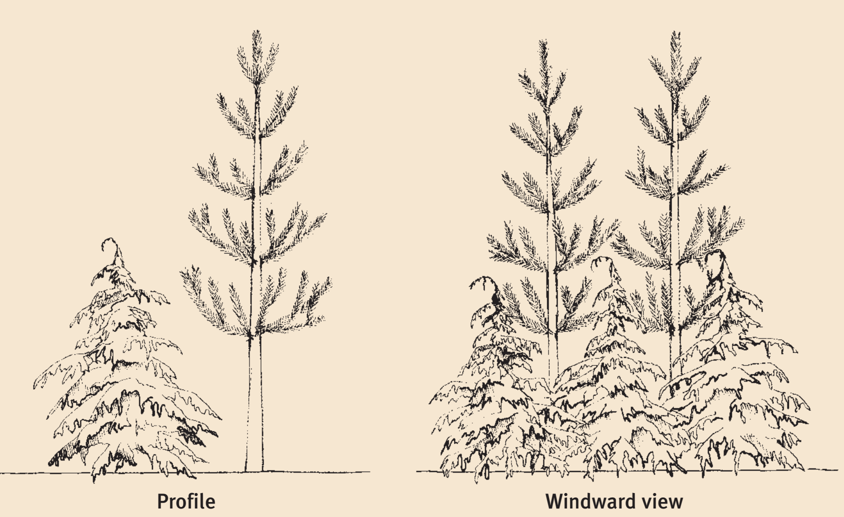
Management

High maintenance: Clear prune alternate trees (annually); pruning lifts should concentrate on restricting stem diameter over pruned branch stubs to 100 mm. Fan prune and/or side trim remaining trees. Fan pruning entails removing branches that grow at 30-90' to the windbreak. Prune logs to at least 6 m above ground.

Low maintenance: Optional side trimming to reduce the width of the windbreak.

Site selection/applications

One-row pruned belts are not suitable for primary shelter in very exposed coastal or inland South Island locations.



Tall conifer, two row, timber.

14.4.6 Shelterbelt, conifer, two row, timber

Slow-growing species	Fast-growing species
Low rainfall areas Abies pinsapo Cedrus deodara Cupressus arizonica C. torulosa (2) Medium-high rainfall areas Cryptomeria japonica Pseudotsuga menziesii Thuja plicata X Cupressocyparis leylandii Hardwood species listed in 14.4.3	Pinus nigra subsp. Laricio P. ponderosa P. radiata

Initial spacing

2-3 m between trees and rows

Management

Clear prune all trees in the leeward row to restrict stem diameter over pruned branch stubs to 100 mm. This may require annual pruning until the desired log length is attained (6 m is the currently recommended height for pruning).

The windward row may be trimmed mechanically to confine branch growth between the windbreak fences.

Site selection/applications

The windward row provides added stability (resistance to windthrow) thus this design is recommended for shallow soils. If desired, evergreen hardwoods capable of growing up to 6 m tall can be substituted for conifers in the windward row.

14.4.7 Shelterbelt, conifer, multiple row, timber

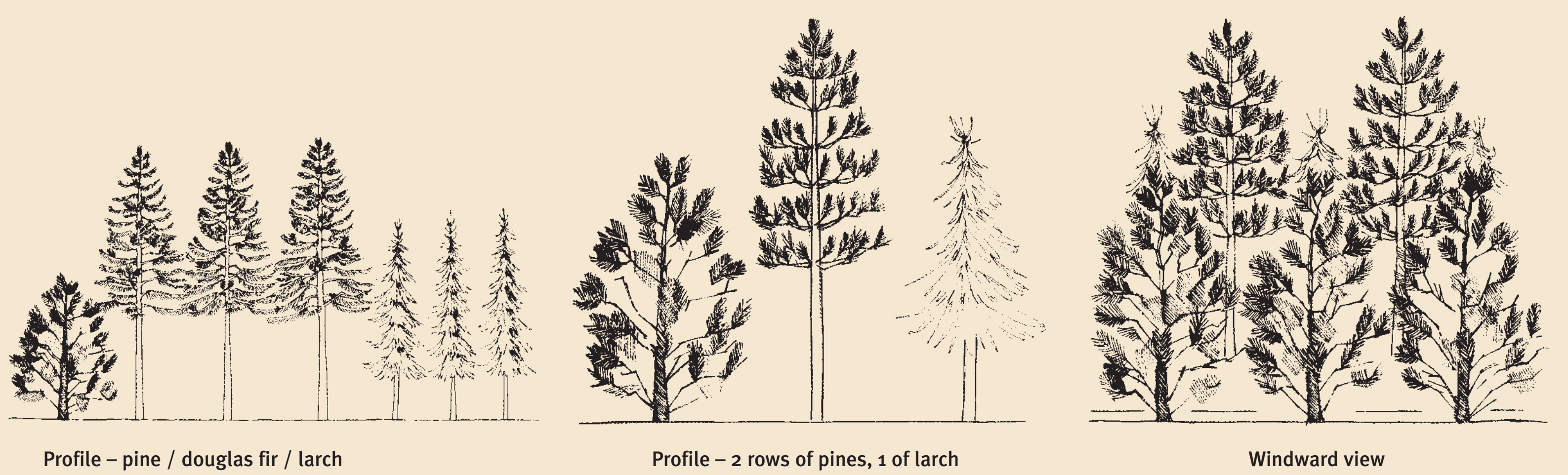
Initial spacing

2-3 m between trees and rows

Rows should be staggered to overlap gaps in preceding rows. Delay establishment of slow-growing leeward rows until sufficient shelter is provided by the two primary rows.

Management

Clear prune second (and subsequent rows if desired) to restrict stem diameter over stubs to 100 mm. Multiple row timber plantings should be pruned and thinned as woodlots. Amenity rows can be pruned to 3-4 m to allow underplanting with shade tolerant shrubs



Tall conifer, multiple row, timber, cold inland areas of the South Island.

for fodder, pollen, nectar and fruit production.

Application

Cold areas of the inland South Island where drifting snow is a major problem. Homestead shelter.

14.4.8 Shelterbelt, low-medium coastal, two row

Windward species
Acacia sophorae*
Coprosma repens
Cortaderia spp.
Phormium cookianum
P. tenax
Senecio reinoldii
Tamarix chinensis
Teucrium fruticans

Leeward species
Albizzia lophantha
Araucaria heterophylla
Banksia integrifolia
Cordyline australis
Corynocarpus laevigatus
Dodonaea viscosa
Erythrina sykesii
Lagunaria patersonii
Metrosideros excelsa
Myoporum laetum
M. insulare
Olearia paniculata
O. traversii
Pittosporum crassifolium
P. ralphii
Pomaderris apetala
Quercus ilex

*In many regions, this species is an invasive weed. Check with Regional Council staff before planting.

Initial spacing/site selection

1-2 m between rows and between plants within rows

Spacings need not be rigid. Species can be grouped together in clumps to vary the width of the windbreak. Use the flax (Phormium) or toetoe/pampas (Cortaderia) with cabbage trees (Cordyline) on poorly drained heavy

Low-medium coastal shelter, two row.

soils. In frost-fee areas Norfolk Island pine (Araucaria heterophylla) can be planted at 5-8 m intervals in the leeward row. Species for the South Island should be selected for greater cold tolerance.

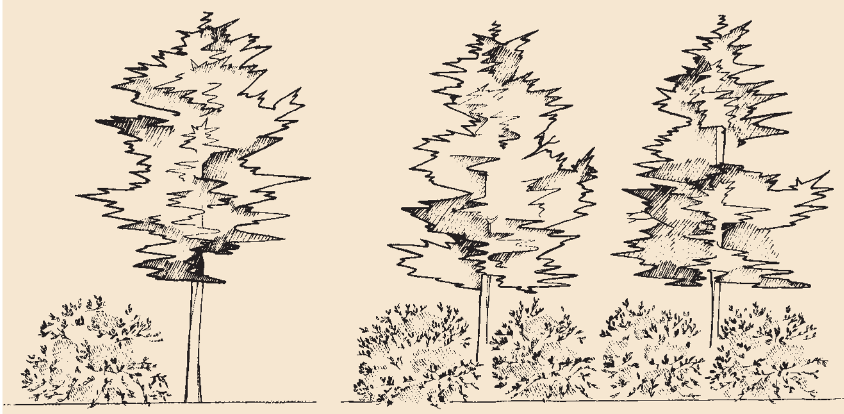
Establishment and management

It may be advantageous to provide initial shelter for the plants by erecting a brush fence or commercial windbreak cloth barrier along the windward boundary of the shelterbelts. Maintain stockproof fences.

Applications

Low shelter for stock, visual amenity, shelter and food sources for birds and bees.

14.4.9 Shelterbelt, tall coastal, two row



Tall coastal shelter, two row.

Windward species
Acacia sophorae*
Coprosma repens
Cortaderia spp.
Phormium tenax
Senecio reinoldii
Tamarix chinensis

Leeward species
Cupressus macrocarpa
X Cupressocyparis leylandii
Eucalyptus botryoides
Pinus muricata
P. radiata

*In many regions, this species is an invasive weed. Check with Regional Council staff before planting.

Initial spacing

2.5-3 m between trees

2 m between rows

Management

Low maintenance. Occasionally side trim to restrict overhang on leeward side of windbreak.

Applications

Coastal areas of both islands. For primary shelterbelts, it may be necessary to precede the tall tree belt with low to medium height shelter species as in 14.4.8 and increase the number of leeward rows to two or more.

Earthworks

Chapter

Runoff Control Practices for Earthworks

15.1 Diversion Channels and Bunds

15.1.1 Description/Purpose

Diversion channels are shallow open drains which intercept and convey runoff to stable outlets at non-erosive velocities. They are used to protect work areas from upslope runoff and to divert sediment laden runoff to appropriate sediment retention systems. Bunds are compacted ridges of soil which intercept runoff and convey it to diversion channels.

15.1.2 Installation

Diversion channels and bunds need to be designed to ensure that they have sufficient capacity to convey the runoff from the required storm. They must have a positive grade to a stable outlet. Grade should be less than 2 % otherwise the channel itself will erode and will then need to be stabilised (with rock, timber or fabric). The outfall may need to be protected against erosion rock, a flume. Because of the small room for error, these channels should be surveyed to obtain an even grade.

They should be constructed with a trapezoidal cross section with internal side slopes no steeper than 3 horizontal: 1 vertical. Earth bunds should be constructed in layers no greater than 200 mm in thickness and be well compacted as construction proceeds. As a general principle, any excavated channel or bund wall should be sown with grass seed or hydroseeded to prevent scouring.

Design requirements will vary from region to region and can be found in planning documents, erosion and sediment control guidelines etc. If there is no guidance, it is suggested that design be for the 1 in 20 year storm event.

Because of their low grade, deposition of sediment will often occur in diversion channels quickly compromising their capacity. Channels will need to be sited so deposited sediment can be removed. Care is therefore needed in their placement. If the channel/bund is constructed on a steeper grade to avoid deposition, the channel itself will generally erode (if constructed in earth) and will require specific measures to control this i.e. rock armour or fabric lining. A common problem is inadequate compaction of bund walls, or channels/bunds put in by eye, which breach or overtop at weak areas or low spots.

15.1.3 Maintenance

Diversion channels need to be inspected during and immediately after heavy rain, to ensure the diversion is working correctly and is not blocked or its function otherwise impaired. Any necessary repairs need to be undertaken. The outfall should be checked to ensure that it is free from erosion. Check that machinery movement through the site hasn't damaged the channel/bund.

15.2 Check Dams

15.2.1 Description/Purpose

Check dams are small structures constructed across a drainage way or channel. Their purpose is to reduce erosion of the channel by reducing the velocity of flow. Although these measures also trap sediment, this is generally a secondary function.

15.2.2 Installation

The catchment of individual check dams should be limited to four hectares. They can be constructed from rock, logs, fabric, or sandbags and must have sufficient mass to withstand the energy of a concentrated flow. A check dam should be no more than 1000mm in height and have sides that are at least 300mm higher to ensure that any flow passes over the centre of the structure and not around the sides (which will usually wash it out). The toe and sides of the structure should be well protected against undercutting or outflanking. They should be constructed so that the crest of one structure is level with the toe of the next upstream (this can be hard to achieve in practice).

Fabric structures should be not more than 0.6 metres high, anchored well at the toe and well tied back. They are less robust and their catchment should be less than 2 hectares.

15.2.3 Limitations

Check dams are often undercut or outflanked and the failure of one can affect the integrity of other structures.

Diversion band.

Contour drains.

These are not commonly found on temporary earthwork sites because they take time to implement and can be difficult to construct correctly. They can be costly.

15.2.4 Maintenance

Check dams need to be inspected regularly after every storm. The inspection should check that the integrity of the structure is not impaired by erosion or piping. Sediment must be removed sufficiently often to ensure drainage channels behind each dam retain their flow capacity.

15.3 Contour Drains

15.3.1 Description/Purpose

These are temporary drains constructed at the end of work or when rain is imminent to reduce slope length and convey runoff safely off an earthwork site. They are removed/obliterated once work recommences.

15.3.2 Installation

They should be as short in length as possible and constructed at no more than a 2% grade (to avoid scour of the channel). As a rule of thumb they should be about 500 mm deep and constructed at about 30 metre intervals. They should be closer together on steep sites whereas spacing can be increased on flatter sites. They should be as short as possible and constructed at no more than 2% longitudinal grade (to avoid scour of the channel). The position of these measures should be determined by the presence (or otherwise) of an erosion proof outfall. They must never discharge over areas of fill (install a flume).

15.3.3 Limitations

Care is needed with cut-off drains because they concentrate site runoff. Each drain must discharge to an outfall that is stable against erosion. Common problems include insufficient capacity, erosion prone outfalls, constructed on too steep a grade (so they erode) or too shallow a grade (so they don't flow).

15.3.4 Maintenance

They should be inspected during periods of prolonged rainfall to ensure they are functioning. Immediately after each heavy rainfall, any necessary repairs should be undertaken.

15.4 Flumes

15.4.1 Description/Purpose

Flumes convey runoff down a bank or over an erodible site without causing erosion. Pipes, polythene, geotextiles, fabric flumes, sheets of iron, concrete lined chutes, rock etc can all be used for this purpose. Fabric flumes can be bought "off the shelf" (made to order from 200 – 600 mm diameter).

15.4.2 Installation

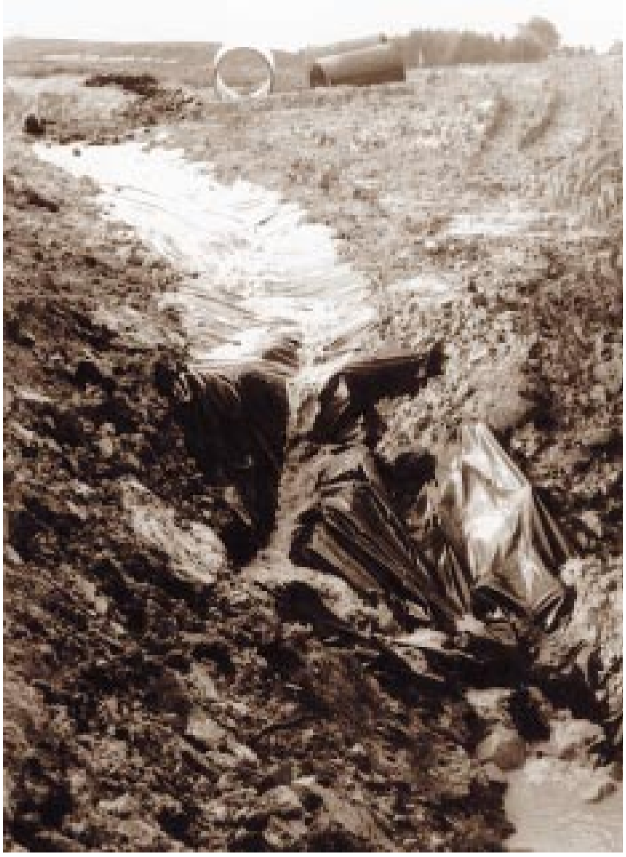
Flumes should be sized according to individual site requirements. The flume should be capable of carrying a minimum discharge equivalent to the 10% AEP (Annual Exceedence Probability) strom where the storm duration is equal to the time of concentration. Some flume dimensions for specific discharges are given in the reference "Gully erosion control techniques for pumice lands" Eyles (1993). On critical sites protecting valuable assets, the design strom can be as large as 2% AEP.

The catchment of temporary flumes should be a maximum of 2 hectares. All catchment flow needs to be directed to the flume. This is often achieved through a pipe installed through a compacted earth bund. Its invert should be laid at ground level and have a positive slope of at least 3 %. All flow needs to be directed to the flume and the flume should be securely attached to the inlet pipe. The flume needs to be water tight, and the outfall should be protected against erosion. The flume should be laid directly down the slope if possible and be well supported and anchored. It should discharge to a stable outfall (rocks armour or erosion control fabric.).

A secondary flow path may be required should the inlet become blocked or if flows exceed its capacity. Fish passage may need to be provided if a flume is to convey stream flows around temporary works in their channels.

15.4.3 Limitations

The inlet to the flume needs to be well dug in or protected (e.g. with concrete) to guard against undercutting or outflanking of flow. The wing wall, inlet and flume need to be well secured to each other. Wing walls may not direct all runoff to the flume. The flume may not be waterproof or runoff may splash out



Plastic flume.

of the flume and erode adjacent areas. Subsidence may occur on fills and this may affect the functioning and integrity of the structure.

15.4.4 Maintenance

Flumes should be inspected daily during periods of prolonged rainfall, immediately at the finish of each rainfall, and weekly during periods of no rain. Any necessary repairs should be made immediately. The flume should be retained until the area has been permanently stabilised or the flow has been removed.

Soil Management Techniques on Earthworks

Stabilisation of an earthworks site commonly involves grassing, mulching, or fabric. Less common are all manner of structural measures, aggregate, various chemicals etc. Only the first three are discussed here.

16.1 Grassing

16.1.1 Description/Purpose

Established grass protects the soil against raindrop, sheet and rill erosion.

Application

Topsoil should be spread over the site to a minimum depth of 100mm to create a suitable medium for the establishment of grass seed. Grass seed should be applied in either spring or autumn when there is enough moisture for germination and establishment but is not too cold to inhibit growth. Mulch can increase the success of grass establishment into the drier summer period. Annual grasses will generally give quicker establishment and more vigorous winter growth than will perennial grasses. Fertiliser should be added. A grass seed and fertiliser mix suggested in one region is as follows

Table 16.1 Mix of grass seed and fertiliser for Auckland

	Mix	Rate (kg/ha)
Seed	Temporary Annual rye grass (e.g. Tama) and clover	300
	Permanent Perennial rye, brown-top and red/white clover	perennial – 120 browntop – 45 clover – 45
Fertiliser	D.A.P. N.P.K.S. (18:20:0:2)	240

Ref ARC TP 90

Different seed mixes will be required for different regions. Discuss this with a local seed merchant. Hydroseed (seed, fertiliser and paper or wood pulp sprayed on as a slurry) can be used. Hydroseed can also be used in the cooler months (provided mulch is also applied), on difficult slopes, and as a temporary cover directly onto subsoil surfaces.

Limitations

Heavy rain soon after sowing can wash seed away (this particularly applies to hydroseed which is not incorporated into the soil). Grass can take a while to establish and additional measures, such as mulch, may also be required to protect the site against erosion while the seed establishes, particularly in the drier summer months. Poor grass establishment can often be attributed to insufficient fertiliser application.

Maintenance

Seed may need to be resown after heavy rain, or dry weather.

16.2 Mulching

16.2.1 Description/Purpose

This is the application of a protective layer of straw, hay, wood fibre, bark or similar to the soil surface to protect it against raindrop impact and shallow sheet flow. It will give instant protection once applied and so can be used for erosion control when grass growth is slow (winter or summer) or where immediate protection is required. Hay has its own grass seed source but can carry weed seeds. Straw lasts longer. Mulch can "nurse" the establishment of grass seed. Bare subsoil can discharge over six times as much sediment as from mulched subsoil areas (ARC 2000) and mulch on topsoil is much more effective again.

Figure 2(38) mulching Photo

Installation

Mulch can be temporary or permanent, applied with grass seed and fertiliser or without. Mulch should be applied at 30 mm loose thickness (measured at time of application) and be anchored by

Mulching.

spraying a tackifier or crimping into the soil with discs. It can be applied by hand on small areas but mechanical "blowers" will give a more even spread over larger areas. Runoff control measures need to be installed before mulching.

Limitations

Mulching will not control erosion resulting from concentrated flows so appropriate control measures should be applied first. Hay and straw will break down over time and another application may be required. Insufficient mulch may be applied. Some tackifiers can be environmentally harmful. Wind can blow mulch away, from exposed sites, unless it is anchored with wire netting.

Maintenance:

Mulched areas need to be inspected after high winds or heavy rain and mulch reapplied as necessary.

16.3 Geotextiles

16.3.1 Description/Purpose

Geotextiles are fabrics used to stabilise runoff conveyance systems. They can be used to line temporary channels, spillways, outlets to culverts, under riprap etc. An enormous variety of geotextiles is sold by manufacturers' agents. Which to choose, is dictated by cost as much as site.

Installation

The fabric must be dug in at the inlet. An anchor trench 500-mm wide by 500 mm deep needs to be excavated across the top of the channel and up the sides. The fabric should be laid in the trench leaving the top 1.5 metre extending out of the trench. The fabric should be pinned at 0.3 metre centres along the trench, and soil then backfilled and compacted over the fabric. The top 1.5 metre is then folded back over the compacted soil and pinned at 0.3 metre spacing. The fabric is rolled out down the channel and pinned on a 0.5 metre grid pattern down the sides and length of the channel. The fabric needs to be continued to an erosion proof outfall.

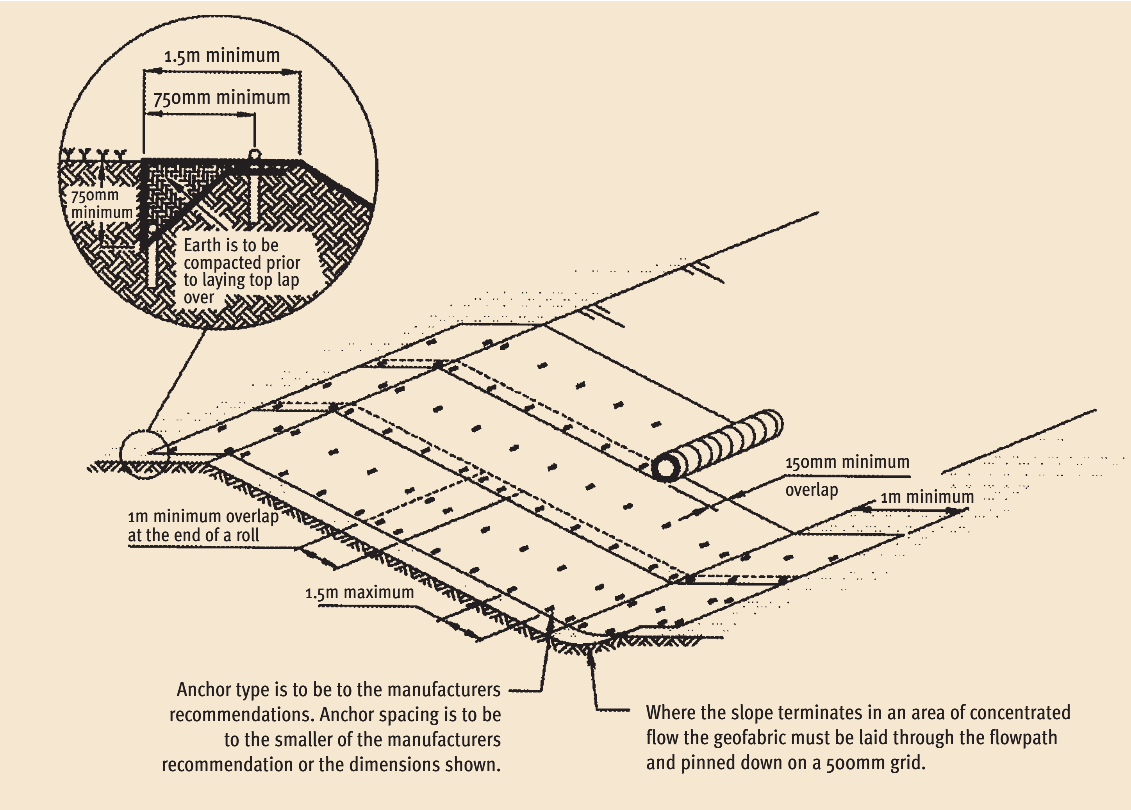
Limitations

The big drawback to most fabrics is that they allow some water through. Unless the channel is very smooth, some water can permeate and scour under the fabric. Polythene is waterproof but difficult to fasten (it rips if it is pinned). Some alternative fabrics address this problem but they are more expensive.

Pinning/fastening of fabrics is often poorly done, particularly at the inlet end. All fabrics must be securely dug in at the top of the work and well fastened. The function of the fabric liner depends entirely on the fastening. Where shear stresses are high more expensive fabrics and better fastening will be required.

Maintenance

The fabric should be inspected regularly e.g. weekly and during and after each heavy rainfall to check it is securely fastened at the inlet and down its length.



Geotextiles. ***Source: Auckland Regional Council, Technical Publication No 90.***

Structures for Runoff and Sediment Control on Earthworks

17.1 Sediment Retention Ponds

17.1.1 Description/Purpose

A sediment retention pond is designed to retain sediment on site from temporary construction and minimise off-site sedimentation. It is the most common sediment control measure utilised when the site is more than 0.3 hectares.

Installation

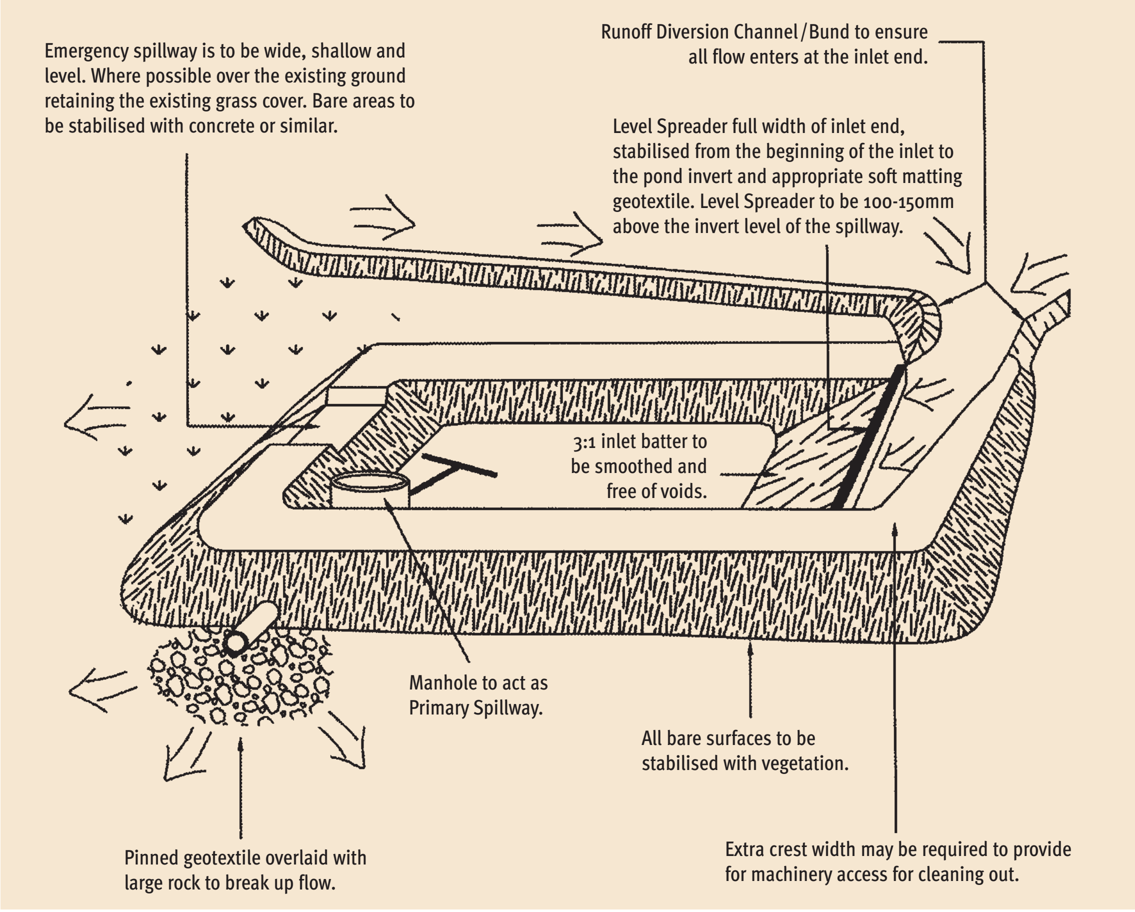
Sediment trapping efficiency is primarily a function of sediment particle size and flow velocity. To maximise the time available for sediment to settle out of suspension, a pond should retain as much storm runoff as possible, have low energy inlet flow, and low decant rate at the outlet.

The following design principles are currently promoted for clay soils. Silt or sand soils should require less pond capacity.

17.1.2 Location

These are generally constructed at the bottom of slopes, or at the lower end of a site, and in a position that allows access for sediment removal. It is usually better to locate them immediately below the works site (to optimise sediment retention), and, if possible, away from the actual works area in order not to compromise site earthworks. They should not be located in streams. Pond catchments should be kept to less than 5 hectares if possible.

- Pond capacity. The capacity of ponds should be 200 m3 for each hectare of contributing catchment for slope gradients less than 10% and less than 200 m in length. Otherwise 300 m3



Sediment retention pond. *Source: Auckland Regional Council, Technical Publication No 90.*

Sediment retention pond.

per hectare of catchment of pond capacity is required.

- Alternatively: use Pond surface area (m^2) = 1.5 peak inflow rate (l/s).
- The inflow rate is calculated using the 5% AEP rainfall event.
- Pond depth. This should be between 1 – 2 metres in depth. The pond should be a minimum 1.0m deep.
- Length to width. A pond should be at least three times longer than it is wide (baffles may be necessary to achieve this).
- Inlet. Inlets should be level, have an inlet batter of no more than 3 horizontal to 1 vertical slope, and be the same width as the pond.
- Primary Spillway. A piped outlet is required to act as the primary spillway. For ponds less than 3 hectares, the outlet pipe can be 150 mm diameter. Concrete manholes and pipes are required for larger catchments. At least two antiseep collars should be installed along the pipe through the pond embankment and the soil needs to be well compacted to guard against possible failure along the pipe.
- Emergency spillway. This should cater for the 1 % AEP rainfall event and be constructed in solid ground (not fill). Lining to protect it against erosion will be necessary. It should be at least 6 metres wide or the width of the pond (whichever is the greater).
- Permanent water storage. This is the component that remains in the pond to dissipate inflow energy and should be 30 % of the pond capacity.
- Operating volume. This is the volume between the lowest decant level and the primary spillway invert and should be 70 % of the pond capacity.
- Outlet decants. These should allow the removal of the relatively clean water only. The current recommended rate is 3 litres/sec/ha of contributing catchment and is achieved by a perforated floating decant pipe. This pipe is generally 100 mm in diameter and has a series of 10-mm holes drilled at 60 mm spacing along its length. This is attached to the primary spillway. One decant is required for each 1.5 hectare of catchment. A single decant should extend through the operating volume of a pond. If more than one decant is required, then the additional decants should be positioned so they "kick in" proportionally through the operating volume of the pond.
- Pond Cleaning. Ponds should be cleaned out when they are 20 % full of sediment.
- Pond efficiency. Ponds constructed in accordance with the above criteria are about 70-80 % efficient in retaining sediment (from trials on clay based soils in the Auckland region). Increasing the pond size does not significantly increase the efficiency of sediment retention.
- Chemical treatment. Some trials with poly aluminium phosphate (PAC), alum and polyacrylamide have been undertaken to promote flocculation of suspended sediment particles and aid sediment retention. While results look promising, further investigation is being undertaken.

Limitations

The embankment and spillway can be weak areas. Careful attention should be paid to good compaction and erosion protection here. Settlement of fill may affect embankment heights. Pipes through embankments need antiseep collars and good compaction to protect against piping. Ponds are hazards and should be fenced.

Maintenance

The most common problem is decant holes blocked with floating material such as straw mulch. These should be checked daily. Ponds should be inspected on a regular basis and after every storm. Checks should be made for outflanking, scour, spillway protection structural soundness of the embankment and the operation of the decants. Repairs should be undertaken to ensure the pond remains in good working order. Sediment should be removed from the pond when it is 20 % full. The pond should be retained until the upslope area has stabilised.

17.2 Sediment Retention Bunds

17.2.1 Description/Purpose

A sediment retention bund is a compacted ridge of soil used to retain sediment from small areas of sheetflow only.

Installation

The catchment of a sediment retention bund should be less than 0.3 hectares. The bund should be well compacted for strength. Its outlet should have a perforated pipe upstand, about 100 mm below the spillway level, supported by a rigid stake/waratah and connected to a non-perforated pipe that passes through the earth bund. The spillway should be lined with an impermeable or non-woven fabric so excess flows can be safely discharged. The spillway should be the lowest point on the bund and a freeboard of 250 mm should be allowed for. The spillway should be stabilised e.g. lined with impermeable or non-woven fabric and this should be well pinned.

Limitations

They should never be used in waterways or where runoff has concentrated. Lack of compaction is often a problem, particularly if the discharge pipe is trenched through the embankment. Spillways on earth bunds are often poorly constructed.

Maintenance

They should be inspect regularly (e.g. weekly, during and after each heavy rainfall). They should be repaired or reinstated as necessary. Sediment should be cleaned out when the bund is 20 % full. The perforated upstand should be unblocked when it becomes clogged.

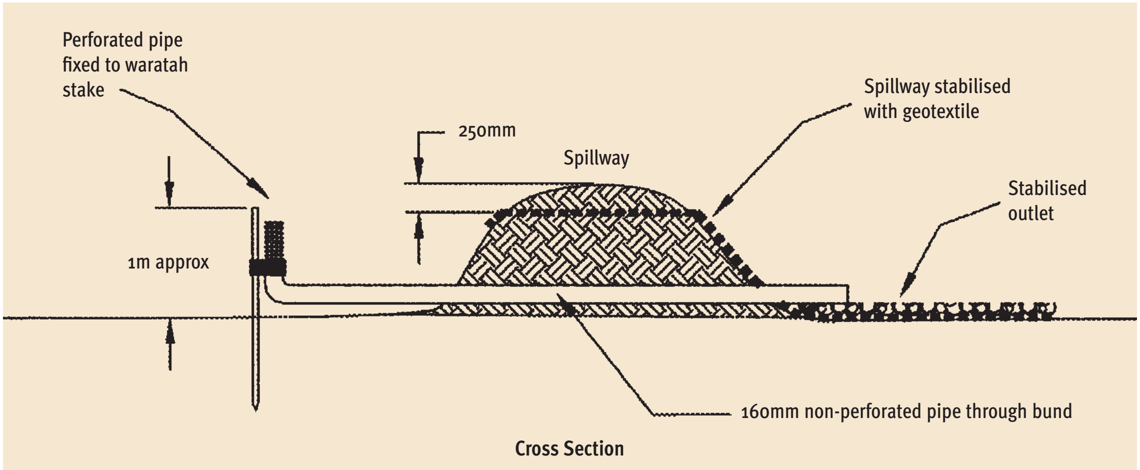
17.3 Silt Fences

Description/Purpose

A silt fence is a geotextile barrier attached to posts and used to retain sediment from small areas of sheet flow only.

Installation

They are constructed from woven geotextile fabric. The supporting post/waratah should be at two metre maximum spacing and 400 mm into ground. The fabric should be trenched 200 mm deep into the ground and upslope of the supports. Gravel filled sandbags laid end to end over the toe of the fence can be used where trenching is not practical e.g. where there is surface rock. The top of the fabric should be 400 mm above the ground and have a tensioned wire (2.5 mm HT) along the top of the silt fence. The fence should be aligned along the contour as much as possible. Ensure that the fence cannot be outflanked by flow by turning the ends up equivalent to the effective height of the fence. Returns should be constructed every 30 metres to confine sediment load. The fence should be tied back to another waratah for additional support in low points.



Sediment retention bund. ***Source: Auckland Regional Council, Technical Publication No 90.***

Silt fence.

A silt fence can be reinforced with sheep netting, chain mesh netting or similar behind it. The netting must also be dug into the ground.

Limitations

Silt fences should only be used to intercept sheet flow. They should not be used across flowing watercourses or similar areas of concentrated flow, as they do not have the strength to stand the energy of concentrated flows. The fabric quickly becomes blocked with fines and the fence then acts more like a sediment retention measure. They often fail through being undercut.

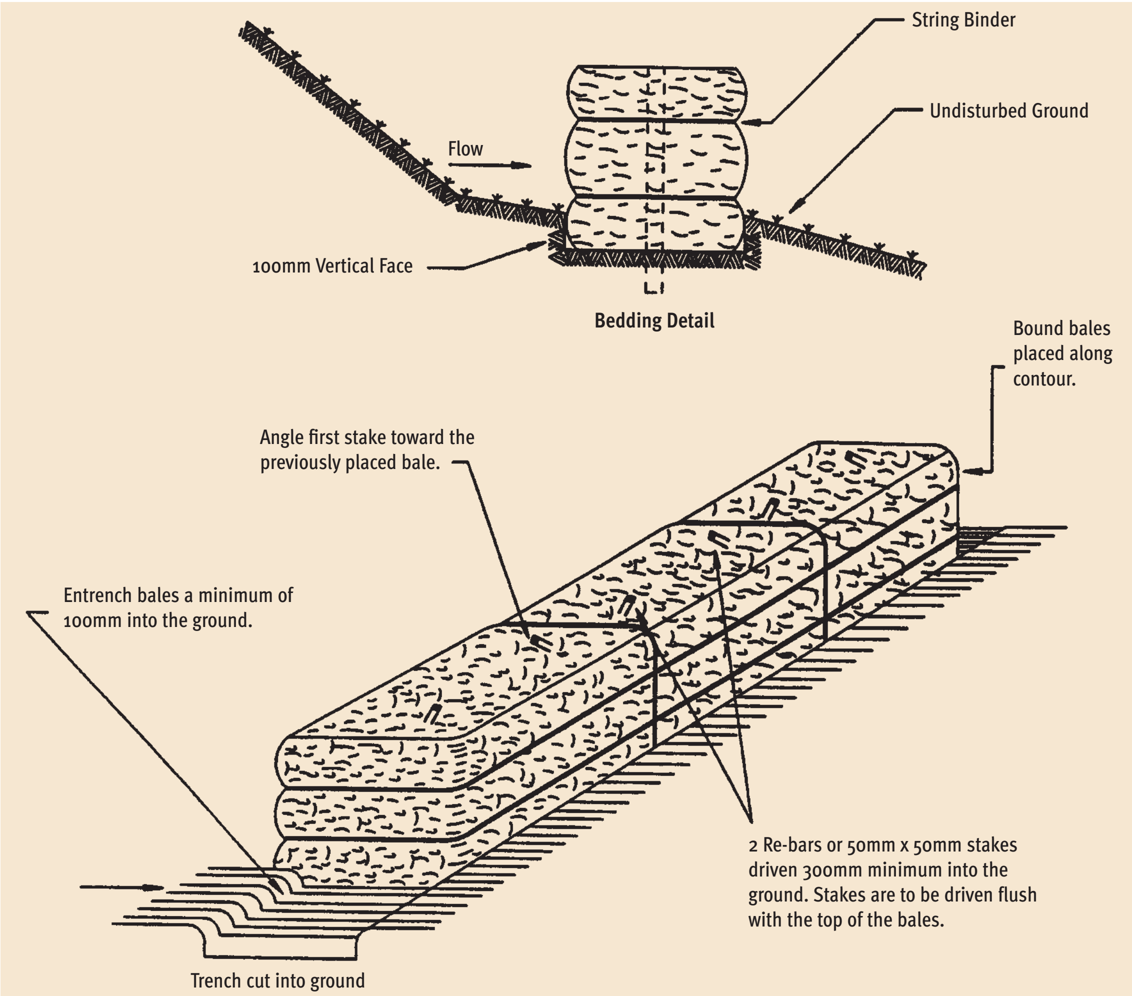
Maintenance

They should be inspected after heavy rainfall and repaired as necessary. Sediment should be removed when it creates bulges in the fence. Tiebacks should be installed at low spots. Fences generally fail by being undercut. This can be addressed by extending the fabric up slope and then digging the toe in approximately 1 metre away from the fence.

17.4 Haybale Barriers

Description/Purpose

A haybale barrier is a temporary sediment retention measure. They can also be used to intercept and divert runoff from small catchments.



Haybale barriers. ***Source: Auckland Regional Council, Technical Publication No 90.***

Installation

The catchments should be less than 0.2 hectare for sediment retention purposes and 0.5 hectares for runoff diversions. The haybales should be placed on the contour and the ends of the barrier turned up to stop runoff flowing around them. Each bale should be butted up to the previous bale and each bale staked with 2 stakes driven 300 mm into the ground. The first stake in each bale should be driven towards the previously laid bale to force the bales together. Holes under/between the bales will need to be securely plugged with clay.

For runoff diversion purposes, start from the discharge point and then install the hay bales on a maximum 2 % grade. The line needs to be surveyed (an abney level or inclinometer is sufficient – do not survey by eye), and the hay bales will normally weave around a slope as the terrain varies. Make sure that the discharge point is secure against erosion, by installing erosion control fabric or rock armour.

Limitations

Hay bales are impermeable and do not filter. They should never be used in permanently flowing waterways or where runoff has concentrated. They have a short life of only a few months. Once they get wet, they become very heavy and difficult to move around on site.

Maintenance

For "tight"(sites, they can be removed after rain provided they are replaced before the next rainfall. Otherwise, leave them in place and inspect them regularly (weekly, during and after heavy rainfall). Sediment should be removed when it is half way up the bale. The barrier should be reinstated or repaired after each heavy rain event (or if it is damaged by site machinery).

Figure 2(45) Hay bales Photo

17.5 Stormwater Inlet Protection

Description/Purpose

These are sediment retention measures installed around roadside stormwater inlets to capture eroded material, preventing its entry to stormwater systems and eventual discharge to receiving environments.

They can be constructed from sandbags, silt fences, rock/gravel barriers, or haybales. An excavated depression upslope of the measure helps retention.

Installation

The catchment of each protective measure should be less than 0.3 hectares. Individual measure should be spaced up slope of the stormwater inlet in the roadside water table. The impoundment depth should be slightly lower than the kerb to avoid redirecting the flow. Treated runoff should then flow around the outside of the sandbags and into the stormwater inlet. The stormwater inlet should not be covered with, silt fence fabric (because this will quickly block) but left open so flows can enter into the stormwater system. Consider whether ponded water will encroach on a road/private dwelling.

Rock should be 100 mm in diameter and faced with 25 mm gravel on the side away from the inlet. Side slopes should be a maximum of 3 horizontal: 1 vertical. Concrete blocks and wire mesh can be used as a support for the stone.

- Sandbags can be used as barriers – they should be half full only.
- Silt fences should be no more than 500 mm in height.
- Coarse filter fabric can be laid against wire mesh and both nailed onto a wooden frame secured by sandbags.

Limitations

Because flows have to be retarded to retain sediment, control measures can impede the entry of stormwater into stormwater inlet systems, and cause surface flooding. They should be regarded as a backup system only.

Maintenance

Control measures need to be repaired if dislodged or broken. They should be inspected, and sediment removed after each heavy rain.

Dust Control Measures for Earthworks

18.1 Introduction

Dust is generated when soil is repeatedly disturbed and broken down into fine particles. On susceptible soils (such as volcanic ash when dry, or loess) dust associated with earthworks can be severe, and difficult to control. Repeated tracking of soils with machinery not only breaks down the soil particles but also aerates them so that they become quite “fluffy” and suspended as particulate material in the air. This is similar in principle to sediment control where finer particles are more difficult to settle out. On high-risk sites, fine soil on the ground can become very dry and aerated, and roll in waves as machines pass even when there is no wind. Once the site is subject to any wind, the dust gets very difficult to control. Dust from problem sites can travel for kilometres and cause a range of problems to health and property.

18.2 Guidelines

Dust management should be considered early in the planning stages of any earthworks project. Planning and managing to minimise dust problems is the best option. If dust management is only addressed after it has become a problem, it is almost impossible to bring under control.

A Dust Management Plan should be prepared prior to any works being undertaken on a susceptible site. In the Bay of Plenty, where resource consents are required for some earthworks operations, a Dust Management Plan is a necessary part of the consent application.

The main practice used to control dust on earthworks is the application of water to keep soil moisture high enough to prevent dust generation. A Dust Management Plan should include the following elements:

- The potential effects of dust if it causes a nuisance off site.
- The soil characteristics of the site and whether the timing of operations will help or hinder dust control.
- Any methods that can reduce the dust e.g. restricting the amount of bare ground exposed, staging of works.
- If water is used, the plan should detail the water source, source capacity and availability. If the source is marginal, then on-site storage may be necessary. If the water is sourced from a municipal reticulated water supply, then written confirmation from the territorial authority will be required.
- Other types of control that may be used.
- Contingency plans (e.g. for severe wind problems). Contingency plans should outline other options if the primary method of control turns out to be ineffectual.

A Dust Management Plan normally also provides for signage at an earthworks site giving a 24 hour contact number for dealing with dust complaints that may arise from the operations. The provision of this 24 hour contact number ensures that the contractor has a management plan in operation to deal with dust control.

The timing of works can be crucial for dust management. If the earthworks can be carried out during wetter seasons, then dust control will be less of a problem.

18.3 Watering

Description/Purpose

The application of water to maintain soil moisture so that the soil does not dry out sufficiently to generate dust.

Application

Water is normally applied for dust suppression in one of two ways; by water cart or by sprinkler. Either system requires a minimum amount of water to achieve effective dust control over an open earthworks site. In the Bay of Plenty, the minimum amount of water required to control potential dust problems is 5 mm/day.

The use of water carts is the most common system of dust control. Water carts can carry from 3,000 to 10,000 litres. The use of water carts is limited by the ability of the vehicle to access the areas that require wetting down. A sprinkler system is often used on earthworks sites where there are large areas open, or where the terrain may be too steep for water carts. Sprinkler systems are also commonly used on sites where some irrigation may be useful to establish vegetation following completion of earthworks.

Water should be applied as a dust suppressant at a rate of 5mm/day before soil moisture levels start to drop. This can vary with individual sites, and prevailing weather conditions, but consideration should be given to applying water after 7 days without rain during spring/summer periods on susceptible sites, This period can be reduced markedly in windy conditions, where on-site conditions should be assessed to commence treatment. Water should continue to be applied until the next rainfall event that results in surface runoff from the site.

Limitations

The main limitation is availability of sufficient water during mid-summer. When the water cannot be taken from municipal water supplies, alternative options may be required. Sometimes, a reservoir can be used.

The use of a groundwater bore specifically for the operation is a common practice.

18.4 Dust Suppressants

Description/Purpose

Dust suppressants are polymers or chemicals applied to the exposed surface to protect it from the wind, and so reduce the dust generating capacity of the treated area.

Application

Dust suppressants are a recent alternative that has been used on some sites in New Zealand over the past two to three years. There is a range of dust suppressants available. They are normally a proprietary blend of naturally derived surfactants and acrylic polymers, provided in a aqueous emulsion form so that they dissolve readily in water for easy application. Upon application, they provide a protective surface that reduces dust emissions.

Alternatively, some dust suppressants act as a binder. These include salts (CaCl2, and MgCl2), and ligin sulfonates. Chemical suppressants include salts, lignin sulfonate, wetting agents, latexes, plastics, vegetable oils and petroleum derivatives. The use of petroleum derivatives may require a resource consent.

Limitations

Dust suppressants generally cannot withstand machinery being driven over the treated area. The cost means that they are only used in places where the treated area is not be worked for a period of time. There are questions regarding whether they have a contamination effect on the soil. The potential contamination effects are unknown at this time.

18.5 Surface Stabilisation

Description/Purpose

Protection of exposed ground surface using a range of different materials or products to reduce the potential for dust generation.

Application

Surface stabilisation is a dust control option that is normally only used as a last resort if other dust control measures are not fully effective. Hydroseeding mix, aggregate or geotextiles may be placed on to the exposed soil to reduce dust. Sometimes, aggregate just need to be applied on areas where there are a lot of vehicles travelling. Alternatively, aggregate may be applied in conjunction with a water cart as a back up.

Limitations

Surface stabilisation is normally only used as a last resort because of the its cost, and also because the surface stabilisation may then need to be removed to finish the job.

18.6 Windbreak Fencing

Description/Purpose

Windbreak fencing comprises low fences constructed from fabric to reduce wind velocities on site, and reduce dust generation.

Application

Wind break fencing using geotextile or windbreak fabric is sometimes used on small sites to help control particular areas that may be difficult to access using other methods, or to assist with the establishment of vegetation as an additional dust control measure. Windbreaks or silt fences can also be useful in keeping machinery off critical parts of the earthworks site.

Limitations

Windbreak fencing only controls dust on small areas because the fences are relatively low; no more than 1 metre high, and protect ground for no more than 10 metres to leeward. Even here, they can be ineffective due to eddies round either end of a fence. Unless well-staked and constructed out of heavy duty fabric, they will be demolished by strong winds.