
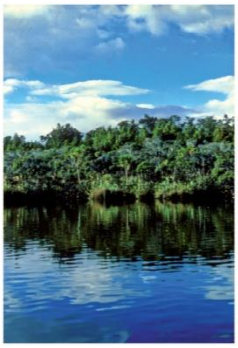

Guidelines for mine rehabilitation in Westland

Envirolink Advice Grant: 937-WCRC83





Landcare Research
Manaaki Whenua

Guidelines for mine rehabilitation in Westland

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Contents

List of Figures

List of Tables

Summary

Project and Client

- This report was contracted by West Coast Regional Council (WCRC) through an Envirolink Fund Advice Grant (937-WCRC83) with support from MBIE Minerals and Environment.

Objective

- The report tailors information and experience on mine rehabilitation to West Coast mines, with a focus on methods readily applicable to small and medium mine sites. Such sites generally have limited funds and equipment for rehabilitation.

Methods

- Two workshops were held with WCRC staff. After the first in December 2010, mine sites were visited with Council field staff. Sites included alluvial gold mines rehabilitated to pasture or native forest, coal mines rehabilitated to native forest, and several small mines typical of abandoned mines. A draft report sent to Council and Minerals West Coast was distributed in 2012 to industry in and the Department of Conservation. The report was extensively revised to focus on recommended methods, particularly rehabilitation using natural succession. Flow charts were included to further summarise information. Past rehabilitation practices and literature have been moved to an Appendix, as has a discussion on administration of mine rehabilitation. Photographs do not reference specific sites.

Results

- The report identifies general principles, objectives and rehabilitation methods for West Coast mine sites in forests and lowlands. Text is supported by photographs of West Coast mines and flow charts for pasture and native forests. An Appendix summarising research and experience underpinning the recommendations includes rehabilitation to plantation forests, as these are not a major post-mining land use.

Recommendations

- This report could be separated into two stand-alone booklets for miners and land owners or managers: chapter 3 (pasture rehabilitation), with the flow charts on planning, identifying rehabilitation resources, and rehabilitation method, would form one booklet; chapters 4 and 5 (rehabilitation to native vegetation), with flow charts on rehabilitation resource identification and methods, could form the second booklet. These would provide an information base to help all parties (miners, WCRC, and DOC), helping improve expertise, relationships and rehabilitation outcomes.
- Flow charts in the report and supporting text will be taken into the mine assessment framework by September 2014 and could be publicised using fact sheets.
- Administrative methods to enhance rehabilitation outcomes include joint bonding and joint site visits by agencies as appropriate, e.g. DOC, WCRC, and District Council.

1 Introduction and background

The West Coast Regional Council needs to ensure that effects of mining are minimised. Rehabilitation of mined sites can improve water quality, land stability, biodiversity, and amenity values of an area. Pasture productions can be increased when land is raised above flood levels and drainage improved. Miners at small sites in particular lack the tools, experience, and environmental staff of large national and multinational mining companies to develop and oversee land rehabilitation operations.[1]

'The Council became responsible for aspects of the administration of the mining licences for gold and coal mines under the Crown Minerals Act 1991, in particular for the administration of licence conditions in relation to soil conservation, water quality and site rehabilitation. The Council has also been granting land-use consents for mining operations since 1991. As old mining licences and land-use consents expire or are surrendered, the Council needs to check compliance with licence/consent conditions relating to site rehabilitation. The Council has had to deal with sites where land rehabilitation has been inadequate and that are having ongoing adverse environmental effects. The rehabilitation of these sites is problematic for a range of reasons, including climatic, soil quantity and fertility constraints, steep topography and cost, including insufficient bonds to achieve acceptable land rehabilitation. This is further exacerbated where the miner no longer exists, effectively leaving the Council to manage site rehabilitation. Although there is substantial information available on land and mine site rehabilitation, it is not necessarily applicable to the West Coast environment or tailored in a way that is readily applicable to small mine sites with limited funds available for land rehabilitation. The West Coast has more of these small sites to deal with than any other region in New Zealand.'

This report presents guidelines for council, land owners and miners in four sections. First, guidelines for rehabilitation to pasture are given; second, guidelines for rehabilitation to native forest. In each of these two sections the most effective and least-cost rehabilitation methods are identified. At all sites, rehabilitation options are heavily influenced by what can be salvaged, stored or directly (immediately) re-used during the overburden stripping process. Appendix 1 contains a generic flow chart that shows both the common resources available for rehabilitation and what influences their salvage and re-use. Both pasture and native forest sections conclude with photographs of mine sites to illustrate key points. Some of these sites could be used as examples of best practice that may be particularly useful sites to visit for land owners or miners who have little experience of mine rehabilitation. Rehabilitation to plantation forestry is not specifically covered, although West Coast experience is summarised in Appendix 3.

The section on native ecosystem rehabilitation is divided into two parts: the first part (Chapter 4) describes methods to deliberately establish native ecosystems using salvaged plants, seed or nursery plants section; the second part (Chapter 5) is 'natural regeneration: minimal cost rehabilitation' and describes how to facilitate regeneration, including where an intermediate phase in gorse, broom, Himalayan honeysuckle or other non-native woody plants is acceptable. Flow charts in the Appendices for pasture and native rehabilitation

[1] Abridged from the West Coast Regional Council Envirolink Advice Grant application 2011.

present the information in an alternative format. The flow charts aim to clarify the decisions and steps to follow to agree on rehabilitation outcomes, and to achieve the outcomes.

Mining is different from most developments. It is rare to have full knowledge of the geology of resource or overburden characteristics before mining, and the cut-off grade or overburden ratio depends on resource value and input costs (diesel, labour) that may rapidly change. Consequently, mine footprints may extend or contract. This means mine plans and rehabilitation plans need to be flexible. In larger, longer-term developments it is not unusual for personnel, contractors, and companies to change. In such cases written records of rehabilitation principles, priorities, and success criteria are vital. Short-term monitoring, even simple photo records (with information on treatment), is a useful way of tracking progress, and allows adaptive management that gives miners the flexibility they need to achieve agreed outcomes in the most cost-effective manner.

Deciding on the post-mining land use, and translating this to understood, measurable criteria is an important first step in the mine rehabilitation process. Indicators or measures of success are important to agree on. Both short-term (e.g. the year final landforms are created and plants are established) and closure criteria should be discussed. Short-term measures are useful way-points, as they can indicate the likely success of the rehabilitation, and trigger remedial intervention if needed. Early intervention is important while access to areas is easy and large machinery is on-site. Pasture and native ecosystems rehabilitation guides, therefore, provide principles for successful rehabilitation, and encourage site-specific methods to be selected. For long-term mines, site-specific methods should be based on adaptive management – keeping records of rehabilitation methods, and adjusting the methods based on monitoring results.

Appendix 3 reviews West Coast mine rehabilitation literature as this provides the background experiences that inform the guidelines in the body of the report. The final Appendix (4) was written to be useful for administrators of mine sites. It includes early indicators of favourable post-mining outcomes when assessing sites, and methods to increase the likelihood of favourable outcomes.

2 Objectives

The West Coast Regional Council gained Envirolink Funding for a report that presents guidelines that could form a ‘working manual to aid Council decision-making, assign priorities with restricted budget, and set work plans for individual mine site improvements’. ‘The guidelines will also help improve resource consent decisions made by Council on mining operations, help Council staff to work with miners on land rehabilitation and up-skill miners on how to improve land rehabilitation at their mine sites. Guidelines on low cost methods for rehabilitating disturbed land within mine sites on the West Coast will help manage mine site rehabilitation and avoid or mitigate environmental effects of those mine sites. The guidelines will be available on the Council’s web site, provided in hardcopy or electronic form to Minerals West Coast, existing miners, and mining consent applicants.

3 Mine rehabilitation to pasture

3.1 Purpose

Often rehabilitation aims to establish land with similar qualities to those occurring prior to mining. This is sometimes described as restoring land-use capability, and this term is used in some older consents or mining licences. For farming, this can be stated as growing the same pasture or crops at the same carrying capacity or yields, with similar inputs. However, on the West Coast, rehabilitation after dredging of alluvial gravels may offer enhanced farm productivity and efficiency, and an increase in land capability, particularly where pre-mining production is limited by poor drainage or regular flooding. This guideline describes key objectives and management that achieve high quality rehabilitated pasture.

Pasture has been established and managed on rehabilitated, mined land on the West Coast since the late 1970s, starting at a large scale with the Kaniere Gold and Grey River Gold Dredges. The greatest success is linked to separate salvage of topsoils, sands and fine gravels that are then used to form a freely-draining growth medium on top of gently contoured gravels. Substantial fertiliser applications (liming is not always needed) are then used to support growth of vigorous grass/legume pastures or a forage crop, with early weed control to suppress gorse and other species that are either blown in or are in the topsoil seed bank. Rehabilitated pastures with topsoil and adequate fertilisation should achieve the 13 T Dry Matter/ha that is average for dairy pastures on the West Coast (David et al. 1998), but <10 T DM/ha should be expected for areas with thin or absent topsoils, very droughty (coarse) or very poorly drained plant growth media. In general a stock unit (su) requires 520 kg DM per year and a dairy cow is 8 su, so 10 400 kg DM/ha/yr is equivalent to about 2.5 cows/ha.

Rehabilitation of pasture after alluvial gold mining is similar in some ways to humping and hollowing or flipping.[2] The former overcomes poor drainage by recontouring land into 2–3-m-tall ridge and hollows repeated over 40–50 m. Flipping breaks up iron pans by inverting the upper 1 to 2 m of soil (Horrocks et al. 2010). Both practices[3] can result in areas of lower organic matter level in the root zone, so soils are unable to store or supply adequate nutrients for pasture growth. The new soils are typically also acid. This means recommended capital (initial) and maintenance fertiliser and lime/dolomite rates are high. For example, capital applications of 500 kg N and 120 kg P (>1000 kg super phosphate/ha with trace elements copper, selenium and molybdenum) in preparation for dairy farming (Thomas et al. 2007). Alluvial mined sites are unlikely to need high rates of lime unless topsoils are peaty or patches of wetland or native forest are being converted to pasture as part of mining. If topsoil is salvaged and replaced, lower fertiliser rates should achieve adequate pasture growth. The

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[2] Westland Cooperative Dairy Limited has produced ‘Hump and Hollow. A guide for West Coast Farmers (40 pp)’ and West Coast Regional Council also produced a report in 2004 ‘Review of humping and hollowing on the West Coast’ by Opus International Consultants Ltd.
http://www.wcrc.govt.nz/environmental_management/earthmoving.htm

[3] Flipping dilutes and spreads the topsoil deeper throughout the soil profile. In hump and hollowing, topsoil is stripped, stockpiled, then re-spread over humped and hollowed subsoil, and the dilution may be minimal. When the topsoil is used to form the humps and hollows, the humps have deeper topsoils while the topsoil is scalped and may be completely removed in the hollows.

least-risk approach is to base fertiliser strategy on site-specific soil tests and agreed target soil test objectives.

Some common objectives of establishing grazed pasture are given in Table 1. In summary, the two highest priorities are a fully productive pasture (within 2–5 years) and consistent erosion control to avoid sediment entering surface waters, particularly streams or rivers. These objectives mean pasture management in the short term should develop a dense sward with deep root systems supported by high post-grazing (residual) pasture dry mass and high tolerance to pugging.[4]

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[4] Damage to soils by animal treading, seen as rough surfaces where hooves have created 'holes'.

Table 1 Typical objectives for rehabilitating mined land to grazed pasture

Objective	Key Actions
Develop a stable soil that resists erosion and pugging	Establish favourable landform (slopes and lengths). Establish and maintain dense, vigorous pasture. Help soil structure recover by 'campaign grazing' when soils are not wet, removing stock during wet periods, and avoiding grazing with heavy stock classes (mature cattle, horses) in the first few years. Build a wet weather or winter feeding pads with a well-drained (gravel) surface on the mined area if adjacent pastures are susceptible to pugging. Avoid cultivation once pasture is established – cultivation decreases organic matter content and bare soils are vulnerable to erosion at any time on the West Coast. Direct drilling reduces losses of organic matter. Drain and/or fence any seepage zones that develop. Fencing seepage zones to exclude stock reduces pugging and sediment runoff.
Achieve water quality standards and riparian management guidelines See WCRC 2004 'Clean Streams' guide WCRC stock crossing policy, and WCRC 2004a earthmoving report[5]	Rapidly establish and maintain a stable, vegetated surface. Stage earthworks and topsoiling so only small areas are bare at one time. Manage areas with high stock activity (gateways, races and water troughs) to avoid bare soil, (e.g. use gravels) and disperse runoff from these areas to grassed areas. Establish set-backs and exclude stock from riparian areas. Encourage a dense riparian vegetation buffer to develop to trap sediment. Bridge or culvert dairy crossings used more than 10–20 times in any month to prevent animal effluent entering waterways. Use other sediment control devices such as settling ponds, silt fences, filtration 'socks' or 'tubes', etc. Install cut-off drains to divert clean run-off away from disturbed areas.
Develop productive pasture (and shelter belts)	Establish free-draining landform and soil profile. Apply adequate Nitrogen and Phosphorus fertilisers, and lime if pH <5.5. Higher than usual annual fertiliser applications are likely needed for at least 3–5 years until organic matter rebuilds. Monitor pasture production and test soil to guide fertiliser and lime applications that will enable pasture growth targets to be reached.
Ensure undesirable weeds are absent or controlled, particularly gorse, ragwort, pampas and broom See WCRC Pest Plant Management Strategy[6]	Identify weeds that are present, particularly boundary control and total control plants. Remove weeds prior to mining if possible; if weeds are confined to small areas – strip these areas separately, stockpile separately, and place in small areas away from watercourses so weeds are not spread over the whole site. Do not let weeds invade weed-free stockpiles of soils and other root-zone materials (sand/fine gravel). Ensuring machinery coming on site is clean and free of weeds Establish a dense pasture as soon as possible after topsoiling and manage to minimise unwanted weeds. Gorse regrowth is a common problem and limits successful pasture rehabilitation. It requires ongoing control during establishment, as does blackberry in riparian zones.

[5] http://www.wcrc.govt.nz/environmental_management/clean_streams.htm and …/earthmoving.htm

[6] http://www.wcrc.govt.nz/environmental_management/pest_plants/

Establishing productive pasture on mined land has a moderate establishment cost and high short-to medium-term maintenance cost, as soils usually need moderate to high fertiliser applications[7] annually, particularly if topsoils are diluted or not replaced. Intensive, regular weed control will be needed if a gorse, ragwort or broom seed bank is present or pasture cover is inadequate. Rushes can be controlled by mowing or herbicide weed-wiping. Pest control may also be required. For example, some flipped soils have been affected by manuka beetle. Grazing must be carefully managed if respread soils are susceptible to pugging, particularly if cattle are grazed.

Figure 1. Rehabilitated pasture after alluvial gold dredging.
Left: 4-year-old pasture, new race, fencing and milking shed, all on tailings. The rush-dominated pasture in the background is unmined higher terrace land, February 2002. Right: 1-year-old pasture with sheep grazing, February 1991.

Figure 2 Productive pasture with patch of remnant native forest on dredged river valley, December 2010.

[7] At least 500 kg/ha of superphosphate equivalent, nitrogen to support grass dominance, and lime to maintain soil pH within the range that promotes clover growth.

The NZ Landcare Trust has produced a free, web-available guide ‘Benefits of biodiversity for Farmers[8] (Fukuda 2012) with six farming case studies and a section on useful tools for the farm (p. 35 of the guide).

3.2 Design guide for pasture rehabilitation

Some short-term effects of mining farmland are similar to those of humping and hollowing alluvial gravels as both activities strip soil from the entire surface and reshape the upper metres of a soil profile. In both cases the new, bare surfaces are highly vulnerable to erosion and sedimentation. Erosion of fine material removes the most valuable part of the root zone (the part that stores nutrients for plant growth) and may degrade streams and rivers. A WCRC (2004) report recommended the five methods listed below to reduce adverse effects of humping and hollowing. All are equally valid to mined sites.

- Apply fenced buffer and setbacks along waterways with dense vegetation
- Stage earthworks so only small areas of bare soils are open at any one time.
- Use cut-off drains to divert clean runoff away from earth worked areas
- Control slope height and steepness by minimising gradient of hollows
- Use sediment control devices

A sixth way to reduce adverse effects is to time spreading of topsoil or fines when pasture establishment is rapid, i.e. spring or early autumn, i.e. not winter or mid-summer.

3.2.1 Landform

Dredging alluvial gravels raises the ground surface as gravels ‘swell’ between 10 to 25% when removed, depending on the size and packing of gravels and method of extraction.[9]

- A rolling landscape is preferred to help shed water, reduce the risk of poor drainage, and blend the landscape with adjacent natural areas. However, slopes should generally not be more than about 20 degrees to minimise erosion. Slopes over about 15 degrees restrict movement of some vehicles by reducing their stability. Abrupt changes in slope may also restrict vehicle movement, particularly trailers. Mined surfaces usually settle to some extent after mining, so slopes should take this into account to minimise boggy areas appearing. Where rehabilitated land is humped and hollowed, connect the hollows to drains so that shed water is taken away to waterways (these may include wetlands to reduce nutrient loads).

[8] Free to download from the NZ Landcare Trust website, http://www.landcare.org.nz/Biodiversity-for-Farmers

[9] The swelling effect is greater with deeper mining. When gravels were being mined to depth of approx. 25m at Ngahere, there was approximately 30% swell factor, which lifted this land post mining well above the flood hazard zone (Rob Harrison, pers. comm 2013).

- Consider the efficient location of farm infrastructure: gateways and races are often located along higher areas to enhance stock and vehicle movement, reduce potential for pugging in these high-use zones, and increase protection of watercourses.
- In hilly terrain, paddock boundaries should keep similar aspects, slopes and substrates together to help efficient management (this is not applicable to 'hump and hollow' topography).
- Ensure pastures adjacent to streams, wetlands or lakes are separated with fenced riparian zones. WCRC (2004a) 'Clean Streams: A guide to managing waterways on West Coast farms' gives examples of permanent and temporary fencing, culverts and bridges for stream crossings, stock watering options, how to manage wetlands, drains, weeds and pests, and riparian planting
- Design paddocks to avoid animal movement through water courses, and install culverts or bridges where animals cross watercourses to prevent animal effluent entering watercourses. WCRC requires culverts or bridges for stock crossings used for more than 10 to 20 dairy herd movements in any month (depending on herd size). WCRC provides guidance and farm bridge examples in a report.[10]
- Where high-walls or steep drops (especially into water) are present, cut-off ditches and fencing can be used to exclude vehicles and stock, and warn people of danger. Silt ponds can develop a plant cover that hides the unstable, potentially treacherous ground, and so should be filled in, or planted with wetland vegetation and fenced.
- Slopes into dredge ponds should be shaped to reduce danger (i.e. even slopes, particularly 5 m above and 2–5 m below the water's edge). Pond edges, outlines and depths can be shaped with wetland plantings if appropriate, to enhance production, and for recreational, aesthetic, and ecological values. All values are usually improved with low to moderate (<12 degrees) slopes along the water-line.

3.2.2 Root zone, growing media or soil

- Identify weeds present, where weeds are in relation to site boundaries and watercourses, and the level of control likely to be needed when topsoil is respread. If weed growth (especially gorse or broom) is likely to be abundant, consider starting with a bare sand/fine gravel substrate only. This seems a popular option.
- Target a water table below 300 mm depth and total rooting depth of at least 300 mm. This will be made from replaced topsoil (preferably 100 mm minimum depth) over 200 mm of fines or free-draining subsoils for dredged areas. Silty or clayey subsoils of poorly drained 'pakihi' and alluvial soils are usually best buried with the tailings in the West Coast environment, where poor drainage typically limits productivity more than summer drought. In coal-mined areas, ensure root-zone materials are not-acid-generating. Mining will break up impeding iron/humus pans in gravels and sands, the same action as 'flipping'.

[10] Free to download from the West Coast Regional Council http://www.wcrc.govt.nz/Resources/Documents/Publications/Environmental%20Management/Information%20Sheet%20-%20Farm%20Bridge%20Examples.pdf.

- Apply basal lime and molybdic superphosphate to ensure minimum pH >6.0, Olsen P>15 ug/kg for 0–75 mm depth for low to medium-producing pasture and 20–25 ug/g for high-producing (dairy) pasture. Additional potassium, and trace elements may be required for dairy pastures.
- Additional nitrogen (at least 50 kg N/ha[11]) will be needed initially to achieve adequate pasture establishment. Higher and more frequent fertiliser applications will be needed where the root zone has low organic matter levels.

3.3 Model rehabilitation procedure for pasture

- Plan location of races, shelter belts, paddocks (fencing), reticulated water supply, ponds and other infrastructure such as feed pads and sheds. Similar considerations are listed in more detail in Westland Cooperative Dairy Ltd (undated) booklet on humping and hollowing.
- Assess topsoil volume; assess subsoil quality and alternatives if the natural subsoils are fine textured (poorly drained). Where poor drainage is due to iron/humus pans or high water table then subsoils may be suitable for using.
- Ensure the final, agreed land-forms with adequate soil depth and drainage are created *before* heavy earth-moving machines leaving the site
- Check weed germination and growth in stored topsoils, and presence of woody or stony material that may damage farm machinery, or stock. If stone or wood ‘picking’ is required before drilling, ensure equipment is available.
- On respreading, deep cultivate where there are sharp texture contrasts between materials before topsoiling (e.g. silty soils over coarse sands or gravels).
- On respreading, the soil surface should be the maximum roughness that allows direct drilling of pasture to reduce vulnerability to erosion. Use a minimum number of machine passes to reduce re-compaction and generally avoid working up and down slopes as this increases risk of rill erosion and topsoil loss.
- Establish dense pasture cover using a range of inoculated clovers and high fertility grass species at 30–40 kg (ryegrass equivalent)/ha as soon as possible after topsoil is spread to minimise risk of erosion and to quickly supress weed seeds. Plantain and chicory are increasingly included in dairy pastures.
- Install fences, gates and reticulated water supply (if agreed) so grazing can be started as soon as grass is suitable height and root stability, so it is resistant to being pulled out by stock, particularly cattle. ‘Mob’ or short-rotation grazing encourages a dense pasture, reduces selective removal of palatable species, and avoids less palatable species (which are often weeds). Alternatively pasture can be topped (mown at a high setting) to maintain rapid grass growth (by encouraging grass tillering and preventing grass flowering).

[11] For dairy farms, 200–300 kgN/ha/yr in 4–6, 50-kgN/ha applications is increasingly common.

- Plant and protect (from grazing animals) shelter belts, amenity trees, wetland and riparian vegetation.
- Graze to maximise pasture density, minimise damage to soil structure, and maintain highly productive grass and clover species. This means leaving a higher-than-usual residual pasture in the first 2–5 years.
- If large areas are rehabilitated, reintroducing (seeding) earthworms is likely to speed recovery of soil structure and fertility by encouraging breakdown and recycling of organic matter. Earthworm seeding, by placing upside-down sods of pasture cut from areas with high earthworm densities onto rehabilitated areas, has been used on Southland lignite mines and North Island gold mines rehabilitated to pasture.

Pasture Dry Matter production and stock carrying capacities on the West Coast

David et al. (1998) monitored 10 Dairy Farm pastures in 1994–97 at Whataroa, Harihari, Waitaha, Kokatahi/Kowhitirangi, Taramakau, Rotomanu, Grey Valley, Inangahua, Westport, & Karamea. Average dry matter (DM) production over the 4 years ranged from 9640 to 16120 kg DM/ha/yr with the average 13200 kg DM/ha/yr. Morton and Paterson (1982) reported mean DM production of 8100 and 9370 kg/ha over 6 years for Ahaura and Kowhitirangi (Table 1). A guide to carrying capacity is 520 kg DM per year per stock unit (su), e.g. a target for rehabilitated pasture production of 8000 kg DM/ha/yr is equivalent to a carrying capacity of 15 su/ha or 2 dairy cows/ha. Where pre-mining pasture production or carrying capacity is known or can be estimated, the mine closure aim should be to achieve the same level of productivity by 5 years post rehabilitation.

Annual pasture yields for Ahaura and Kowhitirangi in kg DM/ha/yr

Year	Kowhitirangi	Ahaura
1974–75	8830	8570
1975–76	9010	7730
1976–77	11 000	8570
1977–78	7960	10 650
1978–79	6180	11 620
1979–80	5610	9100
Mean	8100	9370

Sources

David KL, Thompson NA, McLean NR, McCallum DA, Hainsworth RJ, Wards AJ, Barton RG 1998. Pasture growth on dairy farms in the Golden Bay and West Coast of the South Island. Proceedings of the Grassland Conference 60: 9–14.

Morton JD, Paterson DJ 1982. Seasonal distribution of pasture production in New Zealand Kowhitirangi and Ahaura, West Coast, South Island. New Zealand Journal of Experimental Agriculture 10(2): 245–252

3.4 Measuring success of rehabilitation to pasture

The landscape and soil indicators (previous page) can be used to predict success of rehabilitation prior to vegetation establishment. The vegetation indicators and following indicators help quantify the success of the rehabilitation once pasture has been established:

- Areas with less than 10% bare ground cover 3 months after pasture establishment.
- Little evidence of animal and insect pests or browsing damage. Porina, grass grub, and mānuka beetle larvae should initially be largely absent as they are destroyed during soil removal, stockpiling and spreading, but rabbits, hares, and geese may be attracted to fresh pasture.
- Absence of flowering weeds, particularly targeting plants requiring control under the WCRC Pest Plant Management Strategy. The strategy describes how particular pest plants identified within the West Coast region are to be controlled. Boundary control plants (broom, gorse, giant buttercup, and yellow ragwort) must be controlled within a specified distance of a boundary where a neighbour is controlling the same plant. Total control plants must be reported to a West Coast Weedbusters coordinator when seen and destroyed by the land owner. Progressive control plants must be destroyed in specified areas by occupiers of Crown land, while private landowners are asked to either kill the plants or allow Conservation staff access to do it for them.
- More than 50% legume coverage, especially when grasses were initially dominant, usually indicates the soil is likely deficient in nitrogen.
- Achievement of target pasture production, high utilisation and high residual dry matter (measured via standard feed budgets).
- Minimal seepage zones with pugging damage evident.
- Build-up in soil fertility shown in annual or 2-yearly soil testing (0–75 mm depth). Interpretation is more useful if samples are grouped by pasture age and/or growing media. Separate sampling of particularly good and/or particularly ‘poor’ areas will help identify reasons for differential performance and allow incremental improvement in management. Measure pH, total C, N, Olsen P, Sulphate-S, exchangeable Mg, and K.
- Stone picking during seedbed preparation or heavy rolling following pasture establishment may be required as stones or boulders adversely impact stock or farm management.

3.5 Post-revegetation maintenance of pasture

Managing rehabilitated pasture to build-up soil organic matter levels is important. As organic matter level increase so does dry matter production and resilience of pasture to drought or reduced fertiliser applications. On humped and hollow pasture, Horrocks et al. (2010) showed the build-up of organic matter allowed more dry matter to be produced with lower nitrogen inputs. Annual fertiliser applications are most effective when best based on soil test results or foliar analyses and nutrient budgeting. Higher producing pasture and more intensive grazing generally means higher fertiliser rates are needed to maintain pasture production. Maintenance may include the following actions:

- Pest plant control and pest animal control.
- Pasture renovation in areas with inadequate cover or productivity, after identification of underlying reason for poor performance, e.g. inadequate drainage/pugging, weed incursion, infertility, lack of moisture, shallow topsoil, and erosion.
- Soil renovation using cultivation if structure is very badly compacted. Silt caps can be disrupted using tines to break the surface but protect underlying soils. Sharp textural contrasting layers can be broken up by subsoiling or deep ripping.
- Identification and treatment of seepage zones, and subsequent drainage or retirement and fencing.
- Fence maintenance to ensure livestock continues to be excluded from watercourses, seepage zones and dangerous areas.

3.6 Photographs of rehabilitation to pasture

The following photographs illustrate outcomes of rehabilitation to pasture for grazing.

Figure 3 Poorly drained alluvial pastures can be substantially improved following dredging as a result of improved drainage, reduced flooding risk and new fertilised pastures.
Left: Dredge rehabilitation with a remaining dredge pond (partly obscured), November 1993. Right: Dredged, 1-year-old pasture with well-formed, gravelled access race and new fencing, May 1991.

Figure 4 Topsoil replaced on alluvial, dredged land.
Freely draining gravels and deep water table allow very gentle slopes to be used successfully, December 2010.

Figure 5 Dredged, 2-year-old pasture rehabilitation in the foreground and contoured tailings in the right background, March 1995.

Figure 6 Gorse, rushes and foxgloves in rehabilitated 'pasture' after alluvial gold mining indicates inadequate drainage and weed control.
At this small alluvial gold extraction operation the land owner wanted to establish house-sites within cleared native shrubland, December 2010.

4 Mine rehabilitation to native vegetation

4.1 Purpose and use

Rehabilitation may aim to establish similar conditions to those occurring before mining. Where this pre-mining condition is native forest or shrubland (ecosystem), rehabilitation will generally take decades to centuries. The absence of a tall canopy and the time taken for trees to grow means understorey plants and animals needing high humidity and shade are usually absent from young rehabilitated sites. Where soils are not replaced, the build-up of topsoil and leaf litter also takes decades. Achieving the conditions for native forest that existed before mining is therefore an aim met long after the mining company has left. Establishing suitable short-term aims is therefore vital for forest and shrubland rehabilitation. These aims are typically to establish vegetation and erosion-resistant surfaces that support natural regeneration and succession to native shrubland / forest with minimal maintenance, including animal and weed control. Another aim is often to construct landforms that support vegetation patterns that blend the site into the surrounding landscape as vegetation develops. Flows of plants and animals into and across the mined area may also be deliberately managed as part of landscape integration.

Methods for rehabilitating native shrubland and forest ecosystems on the West Coast have been trialled and developed since the late 1970s. Trials have typically focused on identifying plant species with the highest survival and growth rates in different growing media, with and without fertiliser or other amendments. Although plant species, overburdens, and climate differ from site to site, and few trials have been monitored for longer than 15 years, most have shown the value of topsoil, appropriate drainage, and rough surfaces with protected microsites. The detrimental impact of weed competition and/or highly acidic (pH<4) or compacted growth media and inappropriate drainage are also evident. Long-term rehabilitation results from initial seeding of pasture species (primarily ryegrasses, browntop, Yorkshire fog, and relatively acid-tolerant lotus species) have been inconsistent. Pasture species are generally very effective at stabilising loose soil against erosion, and building up new soil structure and organic matter. However, pasture can supress native plant growth and natural regeneration, particularly of herbs. Rehabilitation techniques for native vegetation described in this section, therefore, focus on maximising the quantity and quality of viable plants, seeds and soils salvaged, stored and re-used in rehabilitation.

Table 2 Key objectives for rehabilitating mined land to native vegetation

Objective	Key Actions
Support natural regeneration and succession to native shrubland / forest	Establish a variety of stable surfaces and favourable growth media for native vegetation. Establish vegetation that allows regeneration of resilient native ecosystems in an agreed timeframe. Maximise the health of adjacent un-mined land that can provide seeds, birds, insects, and fungi to help recovery.
Recover ecological and biodiversity values	Use plants with local genetic provenance; include plants with nectar and fruit to attract and sustain native birds and insects; return salvaged topsoil and logs to recover the insects and fungi that depend on these. Avoid stockpiling wherever possible. Transfer intact plant-soil sods from stripping sites directly to areas ready for rehabilitation.
Ensure water quality meets resource consent standards	Rapidly establish and maintain stable surfaces using a combination of suitable landforms (slopes, slope lengths), surface character (rough), and covers: plants, rock, wood, and/or mulches. Prioritise dense vegetation buffers along watercourses.
Develop a stable soil	Separately strip and replace topsoil. Create growth media with suitable rooting depth and drainage regimes. Include plants with fast-growing, extensive root systems.
Minimise medium–term maintenance	Maintain rehabilitated areas until dense native cover develops that can exclude and resist weed invasion. Minimise weeds or their spread by controlling weeds on boundaries and eradicating new populations before they spread. Minimise impacts of pest animals by selecting a high proportion of resistant plants and applying pest control.

4.2 Guiding principles for rehabilitation to native ecosystems

Adopting the following seven principles forms the basis for successful rehabilitation of native ecosystems:

- Minimise the impacted area and enhance the health of adjacent ecosystems. The smaller the area disturbed, the less area needs rehabilitation. In some cases it is better to create a small area of steep cut face, even if it is difficult to revegetate, than to cut back faces to create a large, gently sloping area that is easy to vegetate (Fig. 7). Applying this principle includes avoiding movement of rock and sediment into adjacent areas, especially near watercourses, where it can affect downstream areas, and along access roads. Sites adopting this principle will have clearly defined boundaries. Control plant and animal pests in adjacent areas and restrict vehicle access beyond defined areas.

Figure 7 Steep, unvegetated slopes reduce disturbance to adjacent high value ecosystems in this Scenic Reserve, Buller District.

- Identify, salvage, conserve and re-use rehabilitation resources (see Appendix 1. Flow Path). The most valuable resources are topsoil, subsoil and vegetation; wood, rocks and soil-like, non-acid producing overburden layers can also be valuable. Miners can maximise the value of rehabilitation resources by using staged stripping which enables no-stockpiling techniques, such as direct transfer (“DT”). Soil quality is highest when topsoil is not mixed with subsoil or overburden. Mine scheduling needs to allow time and access to the vegetation ahead of bulk stripping, and mine planning allow designated stockpile space where materials are kept separate form overburden. Boulders and rock are useful to create erosion-resistant drainage paths and rip-rap.
- Create landforms with slopes that blend the site into the landscape. In native ecosystems, creating a variety of slopes and aspects helps underpin development of a variety of plants. Variation at a smaller scale, as can be achieved by creating topographic microsites such as potholes, hollows, and mounds is also valuable. Rough surfaces create sheltered, stable microsites and small differences in drainage that help plant establishment and resilience to drought or climate extremes. Rough and dimpled surfaces also limit movement of sediment into surface waters until plants establish.
- Create rooting media (growth media) that have the depth, drainage and fertility that will support the desired ecosystem(s). Use undisturbed ecosystems as a guide.
- Use naturally local, and locally-sourced native plant species, for example, ‘free’ plants from your site. Do not plant beech where beech is not naturally present (the Beech Gap). If using seedlings, include a variety of native plants. A large proportion of selected plants should be unpalatable to deer and possum (e.g. mānuka or kānuka). Bands of fire-resistant plants may be useful adjacent to public roads, or to break up larger sites (broadleaf, flax). Most plants selected will be tolerant of high light and exposure, and some grow rapidly (karamu, koromiko, flaxes and toetoe). This means forest revegetation is likely to use some plants that have low natural abundance in undisturbed areas (toetoe, tutu, koromiko). Some native trees are adapted to emerging through a closed canopy rather than open ground. The best options are either allow such trees to establish naturally, if there is a nearby seed source, or inter-plant them later when there is a shrub canopy. Non-native grasses (straw or seed) and legumes can be valuable for temporary erosion control.

- Minimise the establishment and spread of woody, non-native species if consents or access agreements specify return of a native cover within 5 to about 15 years. Gorse (*Ulex europaeus*), broom (*Cytisus scoparius*), and Himalayan honeysuckle will quickly smother small native seedlings. Dense lotus and large pasture grasses (e.g. Yorkshire fog, cocksfoot, ryegrass) can also smother native species, particularly in higher fertility sites and if sown earlier than native plants. Spread of weedy species can be limited if soil and vegetation areas with weeds are separately stripped and separately stockpiled, then replaced in areas where weeds can be easily controlled and immediately established with native plants.
- Record details of rehabilitation: what, when and where. Records and monitoring help tailor rehabilitation methods to individual sites and may be part of consent or access conditions. Photographic records are a fast and cost-effective way of recording rehabilitation progress towards 'closure'. Landcare Trust has developed 'WETmak', a guide to selecting and recording rehabilitation progress using photographs.[12]

4.3 Steps in rehabilitation to native ecosystems

The following guide to native ecosystem rehabilitation is divided into four mining stages: pre-stripping, stripping, storage, and re-use. Mine scheduling is critical for effective native rehabilitation as it governs the ability to strip, stockpile, and use topsoil and vegetation. Mine scheduling that avoids stockpiling and double-handling both reduces rehabilitation costs and increases rehabilitation quality.

Table 3 Steps for rehabilitating mined land to native ecosystems

STEP	Pre-stripping
1	Resource assessment: Identify and locate ecosystems, plant (and animal) species, topsoil, subsoil, overburden that can be salvage. Identify what methods will be used to salvage each resource, and where they will be stored or used immediately. This includes collection of seeds, propagules and plants for nursery growers. Growers will take 1–3 years to grow plants to a suitable size for planting so pre-ordering is an important part of planning. At risk or endangered species or ecosystems, and large trees generally have highest values. Reassess the mine footprint, to avoid or minimise removal or disturbance to these high-value areas. Roads, ex-pit stockpiles, sediment ponds, and site infrastructure can all be moved to some extent.
2	Erosion and water assessment: identify where any cut-off drains (to keep clean water clean) and storm water drains will be needed, where they will drain to.
3	Identify vehicle access to the stripping area and surface materials needed to ensure track trafficability.
4	Coordinate with mine plan to ensure time and machinery is available for the preferred vegetation stripping method.
5	Review specific conditions of Access Agreements, resource consents, and Wildlife Permits and ensure mine stripping and rehabilitation plan is consistent with these. Notification may be required before stripping (or drilling) activities beginning.

[12] WETmak Wetlands Monitoring and Assessment Kit, Module 2 Photopoints'
http://www.landcare.org.nz/files/file/802/Module%202%20Photopoints.pdf

STEP	Stripping
1	Ensure pre-disturbance surveys are complete. Wildlife Surveys and salvage may be required for specific plants or animals within specified times of stripping (e.g. kiwi, *Powelliphanta* snails)
2	Establish vehicle access into stripping block – light vehicles (for seed and plant salvage) and/or heavy vehicles (for general salvage of plants, soil, logs, rocks and overburden). Avoid sidecasting without pre-stripping, as this degrades adjacent vegetation and soils. Unconstrained sidecasting is particularly destructive in short vegetation.
3	Retrieve hand transplants. The cost-benefit of hand transplants depend on the species targeted, the size of plants, the reason transplants are used (e.g. at Stockton to identify vegetated areas as other plants are visually insignificant and there is little regeneration from many spread soils), and expected growth rates.
4	Fell shrubs and trees that are too large or tall to be safely picked up, transported and stockpiled or unloaded. Such trees are typically greater than 3–6 m but depend on the equipment available.
5	Remove logs after cutting them into transportable lengths. This may be efficient to do at the same time as vegetation and soil stripping if suitable machinery (e.g. a grapple head) is available. On steep, untrafficable sites, logs and vegetation may be either bulldozed down onto benches/ lower accessible areas, or back-acters used to pull slash and logs up onto ridgelines. Pulling up to ridgelines allows less handling, less damage and greater quality of soil and vegetation.
6	Cut up remaining tree heads into piece sizes that are safe to handle. Large pieces are useful for erosion control and creating sheltered sites on slopes without unduly impeding access. If rehabilitated areas are unavailable, large tree pieces may need to be mulched to reduce the storage area needed.
7	Plants and soils are ideally removed as intact sods (direct transfer). Mānuka, kānuka, hebes, and some coprosmas with ripe seed can be salvaged as branches for immediate fascining (also called layering or brush seeding). Otherwise, remove and transport vegetation and topsoil directly to areas needing vegetating or storage areas. When a new site is first opened up there may be no storage areas; however, vegetation and soils may be able to be spread on disturbed areas along access roads. Avoid burying this valuable material or placing it in areas from which it cannot be retrieved. Stripping vegetation and soil together helps protect soils from compaction and allows regeneration. Plan to salvage branches of suitable plant species that have seed for layering.
8	Boulders /Subsoils/Overburdens stripped. Where these materials are not needed to create root zones, for erosion rip-rap, road surfacing or capping, they are usually incorporated into backfill or engineered landforms. Acid or potential acid-forming (PAF) overburdens must not be placed where they may influence the root zone or surface waters. PAF should be identified early and specifically managed in engineered landforms.

STEP	Storage (ideally only applies to first stripping block)
1	Define specific storage areas for rehabilitation materials, and mark to ensure they are not covered by low-grade material or overburden, or inadvertently trafficked. Ensure storage areas have a firm, trafficable base that ensures free drainage. Create topsoil and vegetation stockpiles by back-dumping from trucks to avoid compaction and keep the surface loose and aerated. Divert clean water around the stockpiles. Runoff from stockpiles should flow to dirty water treatment area (e.g. sediment pond).
2	If storage space is limited, prioritise storage of topsoil, create temporary (short-term) storage areas 'in pit', increase stockpile height, or increase depth of soil used to rehabilitate areas rather than wasting this precious material.
3	Protect stockpiles from degradation. If vegetation cover is low, soil stockpiles can be stabilised by covering with mulch or seeding. A plant cover helps retain soil quality (and invertebrates) in the upper areas of the stockpile. Weeds should be removed to prevent them building up a seed bank. Establishing a desirable plant cover (which may be grasses or legumes) helps supress weed establishing.

STEP	Stockpile use and revegetation
1	Confirm required number and quality of nursery-raised plants are available, if planned, and these will be 'hardened off' before arrival, or prepare an area where this can occur on site. Hardening off means reducing fertiliser, and increasing exposure to wind, sun-light, and frost so plants have tough leaves (not soft, lush growth).
2	Confirm final landform meets design requirements, e.g. maximum and minimum slopes and slope lengths, heights above water table, and the specified Non-Acid-Forming (NAF) capping if overburden contains acid-generating rock. Designed storm water controls such as water tables along benches and sediment traps should be installed before revegetation to minimise damage to revegetated areas. Efficient revegetation requires adequate access, vehicle turnaround, and safe parking areas at suitable spacing or density. Ripping of the root zone may be beneficial if surfaces are heavily compacted. The rough surface created by ripping also helps soil lock into steeper slopes.
3	If final topsoiling /vegetating are delayed and landforms are prone to erosion, apply a temporary cover of straw or grass-seed or wood-chip or rock. This approach may only be needed on parts of the site that are vulnerable to erosion, such as steep slopes and the lower third of moderate slopes, and areas where eroded sediment will degrade water bodies, such as slopes adjacent to riparian zones or drainage controls. Rock rip-rap is generally the preferred erosion control method within flood zones. Straw, wood-chips, and small branches may be washed into watercourses where it risks impeding flows or degrading water quality.
4	Place rock, boulders, and/or logs to define edges of rehabilitated areas, sudden changes in slope, and control subsequent access. If small areas of vegetation sods or small number of individual VDT stumps will be used for rehabilitation, it is usually effective to place these first, then add bulk mixed soil and vegetation to reduce compaction to the mixed soil.
5	Vegetation/topsoil mix from stockpiles spread on final landform, working from bottom to top and edge to access point, to avoid trafficking and damaging soils and vegetation once spread. Back-acters are slower, but leave a less compacted soil, with many more surviving plants than bulldozers.
6	Plant seedlings salvaged from un-mined areas (wildings) and /or hardened-off, nursery-raised seedlings, if required; fertiliser should usually be placed in the planting hole (if slow release) or in a slit upslope of the planting hole (if concentrated fertiliser such as superphosphate, DAP or nitrophoska) to avoid stimulating growth of competing plants, especially if pasture or woody weeds are present.
7	Rehabilitated areas may be seeded before or after planting to minimise soil erosion on some sites. Fascining, hydroseeding, hydromulching, and broadcast seeding are all methods that use seed and plant fragments to establish vegetation, particularly on high walls and steep batters where other methods are not practical. Bird perches (e.g. tree spars and logs) will assist bird dispersal of seed for some native plants (particularly fleshy-fruited species such as coprosmas and native pines). Fascining is a labour-intensive process in which branches carrying ripe seeds are spread over bare ground. Hydroseeding and hydromossing involve spraying a water-based slurry of seeds, plant fragments (mosses, lichens, and herbs), adhesive, a mulch of wood fibre, paper mulch or straw, and fertiliser onto areas needing stabilisation. Soil may also be applied. The mulch gives some immediate erosion control and improves conditions for seed germination. Hydroseeding is commonly used on road batters and steep pit walls, but only a few mines are using this technique. High rates of grasses or legumes are usually used in hydroseeding; these provide superior short-term stabilisation but usually prevent growth of native seeds (which are slower to grow). Hydromossing is suited to shady, south-facing rock faces.
8	Audit within 1 month of planting to confirm the required density and placement of stumps and/or seedlings; audit after 3–12 months to confirm adequate survival so that in the case of poor results, replanting can occur the following season if the cause of the failure can be established and amended. For example, if plants have been browsed, replanting will be done with unpalatable species and/or with increased pest control. If plants have been smothered with weeds, then a pre-plant herbicide may be used, or if this is not practicable, release native plants by hand but this is more time consuming and expensive.

9	Establish photo points at sites that will not be grown out, as a minimum record of rehabilitation performance over time. A regular record should be kept, taken at the same time of year, at not more than 12 month intervals.

STEP	Maintenance and closure
1	Maintenance as required to meet rehabilitation targets. Poorly managed control of plant and animal pests is the most common cause of native plant failure in the first 2–4 years after establishment. If native shrub or forest seedlings are planted, their growth will usually be fastest if adjacent plants are lower than the seedlings. Check weed contractors can differentiate the weed species from native species before beginning spraying. In all cases, comply with requirements of the West Coast Regional Council Plant Pest Management Plan. It is generally much more cost effective to remove first occurrences of invasive weeds before they flower. Early identification and control prevents widespread establishment (and future expense in control). Control is particularly important for wind-blown weeds such as pampas and pine, and bird-dispersed plants such as Himalayan honeysuckle or cotoneaster. Weeds that spread from cuttings or seeds along water-ways, such as willow and *Juncus squarrosus* need to be controlled beginning at upstream areas to reduce re-invasion. Heavy-seeded weeds such as gorse and broom can often be successfully boundary controlled if absent from the site to start with. Pampas (non-native *Cortaderia*), the native *Cortaderia* toetoe and Gahnia look superficially similar.
2	Monitoring is an important part of maintenance activities. Severe climatic events (drought, cold winds or unseasonal frosts, and individual storms) can create widespread damage to young rehabilitated areas. Damage needs to be identified, and this requires at least an annual walk-over of rehabilitated areas. Such events may require additional planting, seeding or other vegetation establishment. Maintain photopoints.
3	Specific monitoring may be required to demonstrate bond criteria are met. This may involve a site visit with agencies holding bonds.

4.4 Guidelines for selecting density of planted or wilding native seedlings

Planting nursery-raised or salvaged native seedlings (<1 m height) is generally restricted to mine sites that operate for more than 3 years and/or have few weeds. Seedlings usually need at least 3 years of weed control to prevent smothering of seedlings by faster-growing plants such as gorse, broom, and Himalayan honeysuckle. Some sites are largely free of weeds. If competition from short-term groundcover can be managed, native seedlings may require little maintenance post-planting. Where dense weed or pasture growth is expected, the competitiveness of native seedlings can be encouraged by planting taller seedlings, direct transfer of root plates (stumps) containing native seedlings, or clustering intact sods (direct transfer, DT) with minimal gaps between sods in clusters.

The density of seedlings planted depends on the following factors.

- Initial soil stabilization method, in particular the contribution of the method to site stability. Common stabilisation methods include spreading mulch, spreading logs and wood (salvaged vegetation), and sowing pasture. High pasture sowing rates and high fertility increase competition with planted seedlings.

- Natural establishment of native plants from seed produced by planted nursery-raised seedlings or extent of 'free' regeneration. Natural plant regeneration and recruitment can be high if salvaged soils and/or vegetation are handled with minimal disturbance. The high plant regeneration from direct transferred sods means additional planting is not usually needed if sods are placed close enough together. Wetlands may naturally revegetate if suitable substrates and slopes are provided and prevented from eroding.
- Growth rate of plants. Faster growth rates generally allow a lower planting density. However, dense planting on weedy sites helps quickly suppress weeds, leading to faster canopy closure. Growth rates on topsoil are typically 2–10 times faster than growth rates on overburden, depending on plant species (see Section 4.5 for more information).
- Weed species at the site; how fast weeds establish and grow relative to native plants. This is influenced by the timing, intensity, and duration of weed control. Weeds such as gorse, Himalayan honeysuckle, and butterfly bush are common along older roads and may be brought into the site on machinery and in road aggregate. Both site-led and weed-led control approaches may be adopted. A site-led approach aims to prevent new weeds becoming established by monitoring rehabilitated areas and areas prone to weed colonisation (roads, sediment ponds and watercourses). A weed-led approach develops strategies for specific weeds known to be present. Weed prevention and control protects investment in native plantings. In areas with low weed abundance and diversity, weed control also helps protect adjacent areas.
- Purpose of planting. Low densities of larger plants (e.g. salvaged flax or direct transfer tree root plates with attached seedlings at 500 units /ha) are useful to clearly identify rehabilitated areas. Low densities of specific species may also be used to enrich plant diversity of areas with natural regeneration. For example, long-lived trees may be introduced to an area, particularly trees with poor natural dispersal such as beech, despite contributing little to cover in the short term. Effective erosion control may influence planting density as well as species. For example, at sites with favourable growing conditions toetoe planted at 5000 plants/ha can be expected achieve full site coverage after 12–18 months. Closure conditions may specify a minimum density of long-lived trees per hectare that are tall enough to avoid being smothered by the weeds expected at the site. In this case planting density should be high enough to achieve closure taking into account expected mortality and variation in growth rates.
- Plant availability, e.g. the density of wilding plants and direct transfer clumps will be low when only small areas are stripped or mine development is complete.

The timing of rehabilitation with respect to mine closure and committed active maintenance period may also influence planting density. In mines with a 10-year life, early plantings may be sparser and use smaller plants to reduce up-front costs, but allow for more intensive weed and pest control. Later plantings may use higher densities and faster-growing plants to reduce maintenance costs when the mine is no longer generating revenue. Closure usually requires vegetation to be established to a condition that ongoing maintenance is minimal. A high planting density usually speeds development of native plant cover with shorter time to closure than a low planting density. The following Table 4 summarises the factors that influence planting density.

Table 4 Factors influencing density of planting

Factors requiring high initial plant density	Factors favouring low initial plant density
High plant mortality or year to year variation in mortality	Low plant mortality, consistent across seasons
Low plant growth rate	High plant growth rate
Low natural regeneration	High natural regeneration (from direct transfer, slash or topsoils, etc.)
Slow natural seeding and spread	Fast natural seeding, spread or establishment of cuttings leading to many new plants (depends on plant species, soil conditions and suitable micro-climates)
Low likelihood of detecting, and replanting due to difficult access, lack of suitable plants, completion of mining, inadequate monitoring, etc.	High likelihood of detecting and replanting any gaps
High erosion potential	Low erosion potential
Short time until closure	Long time to closure
Highly variable climate and/or growth rates	Relatively even growth rates across years
High weed competition	Low weed competition

4.5 Predicting growth rates of plants

Predicting the growth rates of plants, including the relative growth rates of desirable and undesirable plants is important when considering alternative rehabilitation methods, plant species and planting density. Achieving a dense plant cover is fundamental to controlling erosion and reducing the visual and ecological impacts of mining. The factors in Table 5 predict plant growth and most can be manipulated to enhance plant growth rates.

Table 5 Factors influencing growth rates of plants

Factors that increase plant growth	Factors that slow plant growth
Topsoils present. Topsoils are generally the most favourable root zone as they have organic matter that supplies nitrogen and stores moisture. Relatively good fertility for native species	Topsoil absent. Root zone with low levels of organic matter and/or low water holding (coarse), highly acidic media or other low fertility issues in the planting media
Deep root zone	Shallow or compacted root zone – plants have restricted root systems and soils hold less water and nutrients
Sheltered sites. Shelter can be created by increasing surface roughness using contouring, mulch, logs, and boulders. Plants that are close together shelter each other once established	Exposed sites
Low transplant shock Plants that are tolerant to transplanting include flaxes, red tussock, coal measures tussock	High transplant shock. Occurs with adverse climate (drought), poor plant storage and/or planting technique, slow extension of roots from potting mix. Some plant species are much more susceptible to transplant shock than others
High genetic potential – plants like manuka, kanuka and *Hebe salicifolia* grow quickly. Nitrogen-fixing plants such as tutu can also grow rapidly, even in infertile sites	Low genetic potential – plants that naturally grow slowly
Plants established from seeds tend to have larger root systems	Nursery-grown plants are more susceptible to transplant shock, especially if poorly hardened-off or with large top growth and small root systems
Low competition for light, water, and nutrients	High competition for water, light, and nutrients. Fine wood mulches can 'compete' with plants for nitrogen as mulches break down, especially if nitrogen levels in the underlying soil are low
Low losses of leaves and roots from browse or disease	High leaf loss from pest animals; death of roots from root diseases (e.g. phytophthera)

Note, however, that fast growth rates may not be compatible with high plant diversity in the short term. Fertilisation may be essential to achieve satisfactory cover where topsoils are absent. However, excessive nitrogen fertilisation enhances plant palatability, and may predispose plants to softer growth and developing a higher shoot to root ratio (more leafy growth). Both factors increase plants' vulnerability to frost, wind damage, and drought. Timing fertiliser applications is therefore important, both seasonally, and over the years. For example, nursery plants may be planted with slow-release fertiliser near the root ball. The slow release is less likely to promote a flush of growth and placement near the root ball reduces uptake by competing plants. Flaxes may grow quickly with an initial fertiliser supply in sites without topsoil, but will often need repeated fertilisation to prevent dieback.

4.6 Strategic use of direct transfer

Direct transfer is the most effective method of rehabilitating ecosystems (plants and insects and soil with its biota) in most circumstances. When intact plants are extracted with minimally-disturbed root systems and placed onto suitable backfill sites, dieback can be minimal and recovery rapid. The area of direct transfer is typically limited by the availability of rehabilitated backfill on which to place excavated sods, and accessibility of suitable material. This means there is almost always a deficit of material to use for direct transfer. Direct transfer enhances a range of environmental outcomes.

The main use of direct transfer is to establish vegetation cover that closely resembles that existing prior to mining.

Common secondary uses are listed below, from highest to lowest priority:

- Maintaining populations of large-bodied, slow-mowing invertebrates such as earthworms, weta and flightless beetles. This benefit is effective when plants will experience minimal dieback. Such direct transfer has very small gaps between adjacent sods and is placed to minimise edge area and achieve a large sheltered 'core' (Figure 8a)
- Providing sources of plant and invertebrate diversity within larger conventionally-rehabilitated areas (using seedlings or natural colonization). Direct transfer sods should be relatively close together over reasonably large areas to reduce the short term losses of invertebrates into adjoining, more hostile areas. A rule of thumb is that the taller the vegetation and the more exposed the site, the larger the direct transfer 'islands' need to be. The effectiveness of these islands is enhanced when surrounded by slash on high-quality soils, as this helps buffer the direct transfer, and contains many protected sites into which seeds can establish. Such islands would be devalued if placed within a matrix of coarse, mixed overburden with few sheltered microsites
- Establishing a target density of long-lived tree species such as beeches and podocarps with their associated fungal communities. In this case clumps are likely to be spaced relatively evenly across an area. Survival and stability are improved if the surface of the clumps is about the same height as the surrounding matrix. These 'even' surfaces are achieved by spreading salvaged, re-spread soils, and slash around the clumps, and/or preparing shallow trenches or hollows in which to place the clumps. Coverage may be as low as 10–20% of the area (Figure 8b)
- Connecting ecosystems on either side of a mine site or buffering high-value ecosystems on the edge of a mine site (Figure 8c)
- Visual screening. High quality direct transfer can relocate shrubs and trees 3–5 m high, providing effective screening and visual buffering of mine entrances and operational areas if land contour is also favourable
- Controlling erosion. This is listed as a low priority use because ecologically lower-value resources such as mulch or slash are effective alternatives. However, where direct transfer is used as continuous strips along small watercourses or around ponds, it has a high value. In such cases direct transfer sods act as a

protective filter and can contribute shade, a food source of and for invertebrates (Figure 8d)

- Identifying boundaries of rehabilitated areas

These secondary values are likely to change across a site, and be influenced by properties of the direct transfer material, as shown in Figure 8.

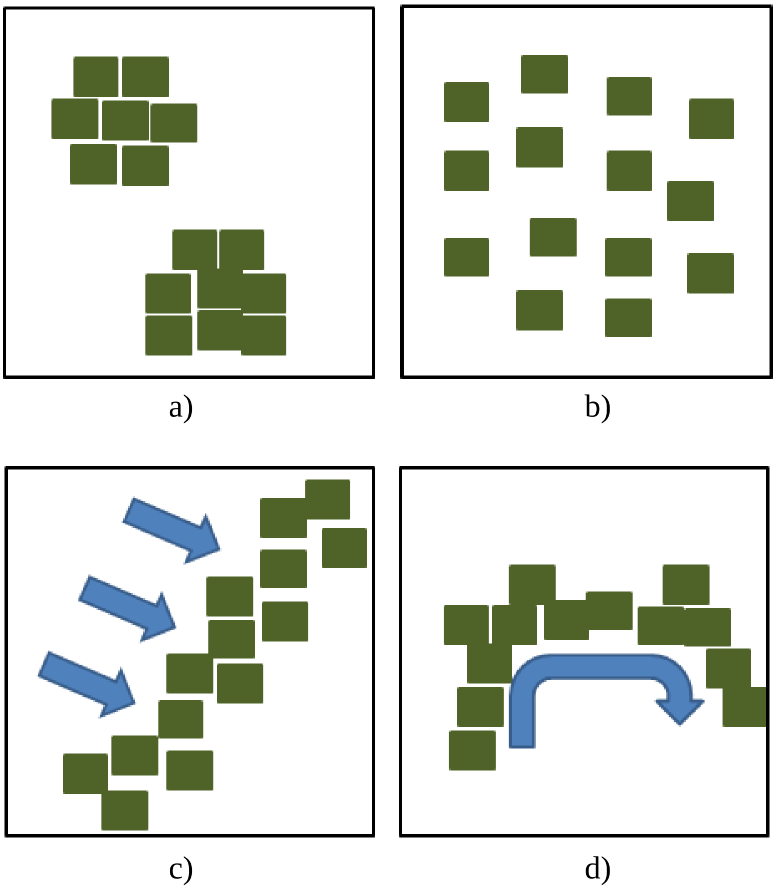

Figure 8 Direct transfer placed in four patterns to achieve alternative goals.
(a) to create islands as sources of plant and insect diversity; (b) to establish a target density of trees; (c) for erosion control (arrows showing the direction if surface flow); and (d) to protect the edge, and shade, a pond or small watercourse.

4.7 Strategic use of mulch and slash

This section identifies uses for mulch, including slash, branches, and larger wood. It explains where to use these materials for maximum benefit and minimum cost. All are valuable resources, salvaged from areas being stripped, and are best used fresh. They are most commonly used to control erosion, preserve topsoils and rooting material, and create protected microsites for seedling germination. Some are also valuable as sources of plants and vegetative propagules: roots, rhizomes, cuttings, and fragments of herbs and mosses.

Mulches can be defined by the size of individual pieces, the proportion of soils and fines that are mixed with the material, and proportion of live plants and pieces of plants that are likely to sprout. Mulches can be grouped into three general types:

- Smaller branches and plants with or without seed with moderate to high proportion of leafy material that may have a low to moderate amount of soil intermixed
- Relatively intact branches, logs and stumps, large piece sizes that are stable
- Woody material that has been mulched, ground, or crushed so it takes up less space in storage and is unlikely (especially beech mulch) to be suitable habitat for wood-eating beetles

Four characteristics influence the use and values of mulch: the percentage of fines (soil and fines, erodible material), the piece size (coarseness), proportion of viable desirable plants, and the weeds that are present or likely to sprout. The following give examples of how these characteristics influence uses of mulch:

- As the percentage of fines increases the mulch contributes more to seedling establishment but may be less effective at mitigating erosion.
- As the individual piece size of mulch increases the mulch is likely to last longer and hence contribute more to erosion control and formation of sheltered micro-habitats in the long term. However, larger mulch also tends to divert water flows rather than filter flow. Larger mulch also tends to be more stable (heavier). Mulches more than about 100 mm diameter enhance habitats for insects, as do logs with loose bark, under which insects can shelter. However, a dense mulch of large piece sizes is difficult to plant through, and more difficult to walk or drive over safely.
- As the proportion of plants likely to sprout increases, the importance of minimal handling, i.e. avoiding stockpiling and not using bull dozers, increases. If a high proportion of the plants have ripe seed, fascining (or layering) becomes efficient. This is where a thin layer of branches is placed (by hand) across surfaces with favourable rooting media, i.e. media as soil-like as possible.
- As the proportion of weeds likely to sprout from transferred plants or the soil seed bank increases, the value of the mulch decreases. The locations highly weed-infested mulch can be used are restricted to areas that are accessible (for weed control) and where weeds are less likely to spread over larger areas, i.e. away from watercourses where water can spread seeds downstream. Spreading soil and mulch that contains weeds may be acceptable if natural regeneration through gorse is an appropriate approach, and the sites are likely to be stable.

Where to apply mulch

Apply mulch where it is most valuable. The values of mulch will change across a site, and be influenced by the properties of the mulches available. Mulches are likely to have a variety of uses at any individual site. Common priorities, from highest to lowest priority, are listed below:

- Establishing native seedlings, where competitive weeds are absent, controlled or non-competitive by using mulches with viable seed or propagules of suitable native species (this is most likely when soils are fresh, i.e. weeds do not have a ‘head start)
- Protecting erosion-prone surfaces, except floodplains. These include the steeper slopes (as long as mulches will stay on the slopes), the bottom third of batters, the finest, most erosion-prone root zones, and overburdens (subject to temporary erosion). Larger, heavier wood (logs) can be used to reduce wave erosion around the edges of ponds, and may be buried or tied into the banks of small watercourses. When used in these roles logs enrich habitat for aquatic invertebrates by providing shelter and substrate. Tree heads (i.e. more complex, taller) may be particularly valuable around small ponds, as the dying leaves provide a food source, the taller structure is more attractive as bird perches, and more complex structure provides more invertebrate habitat
- Mulching areas where conditions for establishment and growth of plants are poorest. These sites are often more exposed to winds, drought, frost, and poor soils or no soils are present. Coarse mulch with large wood is most valuable for creating protected microsites. It is also less likely to create nitrogen stress in the short term (because it breaks down slowly), and will increase the amount of water held in the soil by slowing water (allowing more infiltration) and reducing evaporation from the soil surface
- Mulching areas where ecological linkages are valuable. Mulch enhances conditions for colonisation of rehabilitated areas by insects by increasing moisture at the surface. Large wood and branches with logs are particularly valuable as they last a long time, create complex habitat, and, where bark is present, provides hiding places for invertebrates. Fresh slash containing soil may contain insects and fungi that help establish nutrient cycling and soil formation. The insects and fungi may also provide food for birds, other vertebrates, and insects. Logs also become places on which some plants are adapted to establish, reducing competition with plants on the ground
- Controlling access to areas, and defining rehabilitated areas. Only larger wood and logs are useful to control access. Finer slash containing live plants that will sprout relatively quickly can be very useful to define rehabilitated blocks visually. When used for this purpose, the slash will usually be back-dumped or placed in small mounds for greater visual effect.

Depth of mulch application

The depth (ranging from less than 5 mm to 150 mm) at which mulch is best applied depends on the following factors:

- Physical stability of mulch on a slope. Deep mulches are likely to be less stable on a slope, particularly if they have a high soil component and slopes are smooth and hard (so water flows laterally over the surface). Stability of mulch can be enhanced by placing on a rough surface and/or placing on a surface with freshly-spread soils or rooting media. Larger mulch will settle into a fresh surface, as the surface settles with the first few rain events

- Particle size of the mulch/slash and drainage status of the root zone. Even fine mulch is effective at slowing drying of the underlying soil – where the underlying soil drainage is poor such mulches will exacerbate poor drainage causing anaerobic conditions, especially where >70–100 mm depth. In general, the coarser the mulch the thicker it can be before affecting drainage
- The reason why mulch or slash is being spread. When seed-bearing branches are used in facsining, only a single layer is usually applied. This thin layer may only cover 30% to 60% of the area, enough to provide enough seedlings. The depth of mulch applied for erosion control is also sometimes thin, particularly if the mulch is blown onto slopes. However, mulches used to supress weeds or propagules in underlying soil from establishing plants are usually applied at a minimum depth of 70 mm and up to 150 mm depth. Very deep, coarse mulches are difficult to plant into as small seedlings may be buried, and/or suffer stem rot. In such situations mulches are better to apply to irregular depths, or even bands. However, if the slash or mulch has a high proportion of soil it may be a favourable root zone, as long as planting depth takes account of initial settling that occurs. In this case planting is ideally delayed until initial settling has occurred
- The areas available. If mulch is in short supply apply the minimum depth and area that will achieve the primary purpose for using mulch. However, if there is a surplus of mulch that needs to be disposed of, a maximum depth can be applied. Where coarse mulches are used this may mean delaying planting in some areas until the mulch has broken down enough to create a suitable rooting medium

Safety when applying mulch or coarse slash

Mulches can be applied by blowing or placing using excavators or bull dozers with a variety of attachments. Safety is a primary concern, particularly where logs are used on slopes. Safety exclusion zones should, therefore, be established during spreading operations where logs could move onto roads or work areas. Bunds and/or boulders can also be used to restrict movement of large pieces. Reducing log length and ensuring surfaces are rough before mulch is placed also increase stability of larger mulches. Dense, coarse mulches can also present trip, slip, and fall hazards. Risks can be reduced by leaving access corridors from roads. These corridors may also enhance efficiency of planting, monitoring, and maintenance. Fascined branches are usually along slopes to maximise their contribution to sediment retention; this also reduces slip hazards for people.

4.8 Guidelines for selecting native plant species

The following factors should be considered when selecting native plant species for rehabilitating a specific site:

- Plant performance at similar sites (climate: altitude, exposure and rainfall) and on similar rooting media (soils, rooting depth, drainage and slope)
- Aim of rehabilitation. High initial plant diversity does not usually influence success of forest or shrubland rehabilitation. As few as 510 species are likely to be readily

propagated, or salvaged, and have adequate growth rates in exposed conditions typical of mine sites

- Weed pressure. In weedy areas rehabilitated to forest or shrubland, select species that quickly develop a 1–3-m high canopy that is also dense and broad. Plants with these features are effective at suppressing most common woody weeds and pastures
- Pest pressure and ability to control/duration of control, e.g. large-leafed coprosma species and broadleaf tend to be highly palatable to deer, goats, and hares. In the absence of pest control, such highly palatable species should make up a small proportion of planting, especially if plants will be fertilised (as this makes them even more palatable). A small proportion of palatable species can be included, however, as an indicator that pest animals are present, or a small area of highly palatable, fertilised species planted in an area that is easy to access and safe to shoot
- The availability of species that can be propagated and produced to planting-out size at an acceptable cost. For example, *Gahnia* are rarely produced by nurseries, while *Astelia* may be limited by availability of local seed, and some podocarps (e.g. bog, pink and yellow-silver pines (*Halocarpus* species and *Lepidothamnus intermedius*) are expensive to produce as they require up to 3 years in the nursery to achieve a plantable grade
- Ability to set seed early to create new seedlings, for example toetoe, hebe, cassinia, mānuka, with some coprosma, gaultheria, and olearia species can fruit in the first 2–3 years after planting, establishing new seedlings
- Location. Plants in riparian zones that regularly flood should lie flat when covered with water to physically protect the underlying soil, and ideally have low bulk to maximise channel flow capacity. Plants with large, dense, and strong root systems or creeping rhizomes are preferred (cabbage tree, toetoe). Single trunk trees are less prone to retaining flood debris. A high planting density helps achieve rapid groundcover in erosion-prone zones, and helps quickly screen areas
- Revegetation method. Some plants spread vegetatively so cannot be seeded; some species are highly resilient to transplanting as wildings (flax, rata, red tussock) if an adequate, undisturbed root volume is taken. Some species are likely to regenerate from the seed bank or seed blown or carried from adjacent areas (e.g. some ferns, rushes and grasses). Direct transfer often includes species poorly represented in nursery plantings, e.g. *Empodisma minus* (wire-rush), *Gleichenia dicarpa,* and herbs such as *Epilobium, Nertera*, and *Celmisia* that then spread
- Fire potential. This is likely to be where there is a high cover of gorse or pampas, or it is likely these will invade the site, or there are underground fires, or the site is likely to be accessed by the public, including zones with fire-resistant plants reduces risk of fires.[13] Fire halts natural succession and tends to favour non-native plants such as gorse, where they are present. Low flammability native species are most efficiently used as firebreaks and adjacent to areas where fires may start (roads and access points). Low flammability plants include broadleaf, tree fuschia, large-leafed coprosmas, and five-fingers. Mānuka, kānuka, akekake, and totara are high-flammability species.

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[13] Forest Research 2001. Fire Research Report. A flammability guide for some common New Zealand native tree and shrub species. http://www.fire.org.nz/Research/Published-Reports/Pages/A-Flammability-Guide-for-Some-Common-New-Zealand-Native-Tree-and-Shrub-Species.aspx

- Planting approach and on-site expertise. On-site expertise may allow species mixes to be tailored to individual parts of a site based on slope, exposure, aspect, drainage, and rooting material. Where on-site expertise is not available, a single mixture of species can be blanket planted across large areas. An efficient approach is sometimes to use mine staff for direct transfer, with short-term 'campaign' planting of nursery-grown seedlings or individual wilding plants by contractors.

Table 6 lists key advantages and disadvantages of common nursery-grown species used for forest rehabilitation on the West Coast. The table draws on information in Department of Conservation's alluvial mine rehabilitation guide (DOC, 2010).

Table 6 Common nursery-grown species for shrubland and forest rehabilitation

Species	Advantages	Disadvantages
coprosma species, C. *robusta* (karamu), *C. foetidissima, C. propinqua,*	High survival and moderate growth rates in moderate fertility sites, fruits attract birds and are produced within 1 to 3 years	Some species vulnerable to heavy browse, relatively inconspicuous
Coriaria arborea (tutu)	In sheltered sites with low moisture stress grows rapidly to 3 m height and fixes nitrogen	Poisonous to stock and restricts timing of beehives (toxic honey); can be heavily browsed
Dracophyllum longifolium, D.uniflorum	Shrub with moderate to high survival and growth rates	Upright growth and narrow leaves provides less cover than other species
Griselinia littoralis, (broadleaf)	Moderate growth rates on topsoil, forms dense bushes, easy to propagate from cuttings	Susceptible to deer browse. Coarse roots mean nursery plants susceptible to losing soil on de-potting
Hebe salicifolia,[14] (koromiko)	Very fast growth with moderate fertility, easy to propagate, seeds readily.	Vulnerable to heavy frost, relatively short lived, moderately palatable
Kunzea ericoides (kanuka)	Long-lived nurse crop, quickly propagated	Intolerant of poor drainage or very low fertility; bushy growth form needed in exposed sites
Leptospermum scoparium (manuka)	Excellent medium-term (10–20 yr.) nurse crop providing nectar and abundant seed after 2–5 years, tolerant of low fertility and poor soil drainage	Bushy growth form required to avoid stem rock in exposed sites; highly variable germination in nursery production
*Fuscospora cliffortioides, F. fusca, Lophozonia menziesii (*mountain, red and silver beech)	Long lived trees, red and silver beech have faster growth rates and respond to nitrogen and phosphorus fertiliser	Irregular seed availability; in some topsoils nursery plants are susceptible to fungal pathogens. Some sites with large volumes of dead wood may be impacted by insects
Olearia avicennifolia, O. arborescens	Moderate to fast growth rates on soil, bushy growth form, early spread as adventive seedlings	Ensure nursery-grown plants are not leggy

[14] Hebes are also called Veronicas. The lowland *Hebe salicifolia* is replaced by other species, such as *Hebe mooreae*, at higher altitudes as the former is killed by heavy frosts.

Phormium cookianum, and *P. tenax* (mountain and lowland flaxes)	Excellent short-term (5–10 yr.) nurse crop, fast growth rates if fertility is adequate	Mountain flax sets limited seed in infertile sites. Both flaxes require repeat fertiliser applications to sustain growth in infertile conditions
Podocarpus totara[15] (totara)	Tolerant of compaction and exposed conditions, long-lived tree	Can be smothered by faster-growing species
Pseudopanax species, P. colensoi (five finger)	Large bushy shrubs, high survival rates, flowers and fruit attract birds and insects	Moderate to slow growth rates, particularly in infertile sites. Some five fingers are highly palatable
Weinnmannia racemosa, kāmahi	Canopy tree with wide tolerance of soil fertility and moderate growth rates	Not suited to very exposed areas. Naturally colonises areas with soil-like, sheltered micro-sites near undisturbed kāmahi

[15] In lowland, more fertile sites cabbage tree, kahikatea, kōwhai and *Schefflera digitata* (seven finger) are also valuable species.

5 Natural Regeneration: minimum, least-cost Rehabilitation

5.1 Purpose and Use

In some cases a minimal level of rehabilitation is acceptable, with agreement of the land owner or manager. Such sites may include mines where the mining licences provide for this approach (e.g. pre-Resource Management Act 1991). Small areas in pine forests may not be feasible to re-establish in pines because the silviculture and harvesting may be inefficient as it is out-of-step with the surrounding forest. Some areas in native forests may also fall into this category of rehabilitation, particularly small areas such as drill sites, prospecting sites, access tracks, and underground mines with small above-ground disturbance. Some areas in regenerating shrubland that will initially have a dense gorse cover may also be suitable candidates for natural regeneration. Gorse is naturally replaced by native forest and shrubland species on the West Coast, as in much of New Zealand (Wotton & McAlpine 2013). Natural succession from gorse to native shrubland and forest requires an adequate and nearby source of native seeds and absence of ongoing disturbance (especially by fire). Succession is fastest in sites with favourable growing conditions, i.e. low moisture stress, low exposure, and suitable root zones.

This section also describes the objectives and prescriptons for management of abandoned sites that are safe for people, with stable surfaces unlikely to discharge sediment, acid mine drainage or other pollutants (e.g. oils) to watercourses. Such sites typically have no stockpiled topsoil or growth medium, and very small bonds (less than $10,000). These factors are key limitations to rehabilitation, combined with absence of suitable machinery and/or mining licence, or access agreements with specific (and enforceable) rehabilitation outcomes. Such sites eventually develop a ground cover of mosses and lichens and a plant cover of woody shrubs and herbaceous plants. Woody weeds such as gorse are a common cover, depending on the seed bank and adjacent vegetation. Rehabilitation of remote abandoned sites is likely to be a one-off activity; however, costs may be reduced if timing can coincide with earth-moving activities planned by the land-owner or by infrastructure companies, particularly forest harvesting or road construction companies. Forest harvesting and road construction can also generate soil and vegetation that could be useful rehabilitation resources. At least one post-rehabilitation assessment should be scheduled to confirm the planned actions have been implemented and are effective, and to allow a minimum of maintenance that focuses on ensuring watercourses are stable and assisting vegetation cover.

Minimal rehabilitation is unlikely to be acceptable within pasture, or other areas where a dense cover of rushes, gorse, broom, pasture weeds, and/or other non-native plants are unacceptable. Minimal rehabilitation usually has the objectives outlined in Table 7.

Table 7 Key objectives for sites using natural regeneration

Objective	**Key Actions**
Develop stable landforms	Design and rehabilitate mined land to stable land forms/topography and drainage ways that link to and are in accord with the surrounding landscape (see Fig. 9)
Eliminate or reduce hazards to an acceptable level	Identify and rate hazards. Prioritise eliminating high risk hazards with medium to high likelihood (e.g. removal of hazardous waste). Exclude vehicles, stock and people as required
Protect waterways from sediment and contamination	Identify acid-mine or acid-rock drainage, waste chemicals or oils. Isolate by diverting water, sealing with a compacted cover or removing. Contour and/or remove erodible material from watercourses and floodplains (this is often useful as a growth medium if stabilised); re-contour landforms to create stable and rough slopes with areas to capture sediment. Create erosion resistant surfaces and stabilise erodible materials using boulders, rock, wood (logs) and mulch. Create wetlands or settling ponds for receiving runoff waters from the site
Enhance regeneration to a natural pattern that fits with adjacent areas	Ensure landforms have a variety of slopes. Provide stable, rough surfaces with many protected microsites; spread wood and logs to provide medium and long-term places for seedling establishment and enrich insect diversity colonisation. Spread forest 'slash' over replaced topsoils and root zone loosened to at least 0.5 m (where stable). Use direct transfer sods, stumps and replaced topsoils strategically to create 'islands' and peninsulas with higher native plants across larger areas. Prevent weeds spreading from road
Minimise adverse impacts on land-owner and neighbours	Ensure land-owner and neighbours are aware of hazards and weeds during site assessment; discuss options and potential for joint remediation or collaboration. 'Neighbours' can include New Zealand Transport Agency and their contractors, and power companies.

Figure 9 Minimal Rehabilitation: A favourable, soil substrate with variation in topography and stable surface after alluvial gold mining.
This is likely to develop a dense cover of mainly non-native species that will gradually be colonised by native shrubs and trees from the adjacent forested area, December 2010.

5.2 Design Guide

5.2.1 Landform and water management

The earthworks needed to create safe and stable landforms are usually the most expensive part of rehabilitation. In abandoned sites, earthworks need to be prioritised, as they will be limited by time (money), volume, and location of suitable materials, and the size of the equipment that can be taken to site. The following landform guides are listed in order of usual priority:

- Create safe, temporary access tracks and turn-around areas for machinery, and permanent tracks if required
- Exclude vehicles and warn people from areas above high-walls or steep drops, and underneath potentially unstable walls. This may involve using boulders or large tree stumps, in combination with shallow ditch/mound features, and/or fences or temporarily removing masking vegetation
- Shape slopes adjacent to ditches or water (e.g. dredge and sediment ponds) to reduce danger, making them even and low angle, particularly 5 m above and 2 to 5 m below the water edge. Sediment in ponds can be a hazard, as it can vegetate to resemble stable ground but have a low bearing strength. Pond sediment may be useful as a growth material

- Manage water flows to keep clean water clean, e.g. install cut-off drains and either divert runoff water away from loose and erodible material, or move this material away from the runoff. The latter approach is usually effective where tailings or overburden is encroaching on a floodplain and its removal will not destabilise adjacent overburden. An alternative approach may be replacing the encroaching material with large, stable rock. This is likely to require consultation with land management officers or engineers
- Manage water flows to reduce erosion potential as it flows over disturbed areas. This typically involves controlling water movement so it moves along benches, avoiding uncontrolled water spilling between benches, and limiting slope lengths so water does not concentrate to create rills or gully erosion. Small boulders (>200 mm diameter) can be used to armour areas where water is expected to concentrate and reduce its energy
- Unstable slopes should be contoured to stable angles. At abandoned sites it may only be practicable to treat slopes that may impact surface water, unsafe areas, and areas where vehicles may access
- In some cases roughening slopes and relieving compaction may be enough to create stable, favourable micro-climates and root zones that allow plants to establish. Spot mounding may be an effective method if forestry equipment is available and help establish a natural ‘dimpled’ topography of a native forest. Mounds should be offset across slopes to help slow and trap water flows.
- Add logs, mulch, slash and boulders as available.

5.2.2 Growing media (soil)

Spreading topsoil is the most cost-effective form of speeding-up revegetation as the seeds and propagules in the soil may be adequate to successfully revegetate the site. Topsoil is usually also the best substrate for seeds blown into the area to establish in. If topsoil or growing media are in short supply, prioritise their use where revegetation is most beneficial. It may be better to spread soil over parts of the site in patches or bands 100 mm deep rather than have large, contiguous areas with no growing media. Other growing media include:

- Sands and fine gravels, particularly if organic matter or limited topsoil can be roughly mixed in or placed on top
- Peats and organic materials (including wood chips, branches, logs, wood waste)

It is important to identify acid-generating materials or seepage at the surface, or within the plant rooting zone, as these can usually only be revegetated by being covered with a less acidic growing media, preferably separated from the acidic material by a compacted water and air barrier. Table 8 identifies the factors influencing the success of natural regeneration. The likelihood of minimal rehabilitation strategy being successful at a site can assessed against these factors.

Table 8 Factors influencing success of natural regeneration

Factor affecting regeneration	High probability of fast regeneration	Low probability of regeneration, slow regeneration
Size of site	Small	Large (>20 ha)
Shape of site, especially area to edge ratio and length of edge	Narrow	Square or Round
Growth rates of adjacent vegetation	High	Low
Variety of slopes and drainage status	Moderate to high	Low, particularly if flat
Surfaces present that favour propagule growth: soil-like, low moisture stress, many protected and stable sites, not overly compacted, favourable root zone	Abundant	Infrequent
Method of rehabilitation	Direct transfer, minimally-handled slash	Coarse or acidic overburdens with no slash or mulch
Probability adjacent vegetation will produce seeds every year and can establish in stressed, highly exposed sites, e.g. mānuka, kānuka, hebe, toetoe	High	Low, most species require sheltered forest floor
Contribution of birds to seed dispersal	High, perching and roosting sites present	Low
Weed species present that are likely to smother native plants in short term	Absent or sparse	Present and numerous
Weed species present that are likely to persist and regenerate long term, e.g. long-lived seed banks and unstable site, shade-tolerant weeds	Absent or sparse	Present and numerous
Use of a dense non-native grass or legume cover to quickly stabilise erodible sediments	No	Yes
Importance of establishing plant species that do not spread far from seed or seed infrequently (e.g. beech) , especially if visual integration with adjoining landscape is important	No requirement	Yes
Likelihood of browse, especially if a high proportion of regenerating plants are palatable (large-leafed)	Low	High
Maintenance (e.g. releasing or pest control) required to achieve acceptable outcomes	Low	High
Likelihood of disturbance, particularly from fire	Low	High

5.3 Suggested Minimum Rehabilitation Procedure

Table 9 below outlines the recommended steps to rehabilitate native shrubland or forest using natural regeneration. This can be combined with a range of maintenance approaches, from minimal to relatively intensive. Intensive maintenance may include 'weeding', spot-fertilising, and pest control to manipulate the seedlings that are allowed to establish.

Table 9 Steps for rehabilitating mined land using natural regeneration

STEP	Action
1	Identify boundaries and hazards
2	Identify safe access routes and turn-around areas for vehicles and people
3	Isolate, eliminate /reduce hazards, depending on their severity. Areas may become hazards when masked by trees and other vegetation. Typical hazards include: high walls, ditches, sediment ponds, dredge ponds and areas with sudden changes in slope. Abandoned equipment may also be hazardous and should be removed or buried unless of historic value
4	Identify water courses, flood plains and flows into, through and adjacent to, the site
5	Identify the volume and location of accessible rehabilitation resources on site – these include root zone materials, rock and wood. Sometimes soils can be pulled onto disturbed areas from along boundaries – this creates a larger disturbed footprint, but breaks up edges and enhances conditions in adjacent uncovered areas. This technique is particularly useful to close tracks: rip or spot-mound compacted tracks destined for closure, ideally to about 300 mm depth, if a bulldozer or digger can access the site. Not all areas need to be covered to establish enough vegetation to achieve a stable site in the medium term – even 25–30% cover of favourable plant growth medium dramatically improves medium-term outcomes, as plants that establish on these areas help shade and shelter adjacent areas. This creates conditions that allow plants to colonise les-favourable sites Where topsoil and subsoil are available, create an uneven depth of subsoil to underpin long-term diversity and resilience of naturally regenerating vegetation
6	Plan a final landform that includes water controls to isolate areas with erodible sediment from clean water (keeping clean water clean). The final landforms will identify where contouring is required to create stable slopes with controlled water runoff, and placement of growth materials in areas where vegetation is most useful (sediment control, screening, buffering streams, etc.). The plan will provide for staged access, working back to the final access point, and then blocking access as required
7	Identify areas that require fast stabilisation. These areas will be prioritised for topsoil placement and topsoil reinforced with mulch, and plants (e.g. seeding with non-native groundcover). Stable areas away from flood plains or riparian areas do not need seeding
8	Spread growing media, keeping a rough surface (100–200 mm variation) and/or logs/vegetative material. Avoid influence of acid rocks in the root zone
9	In the absence of suitable topsoil or growing media over at least 30% of the site, particularly for areas with moderate to high erosion potential, broadcast a browntop, Yorkshire fog and legume (lotus, clovers) mix. The optimum seeding rate depends on site fertility and potential for natural regeneration. On low fertility sites, where slow growth and high seedling mortality is expected, and little natural regeneration apply 10–30 kg/ha (including about 3 kg legumes and at least 10 kg/ha ryegrass) with Di-Ammonium Phosphate (minimum 150 kg/ha). Nitrogen is needed to boost establishment. Rates are higher if ryegrass is used, as the seed is much larger and heavier than browntop. Ryegrass is generally not persistent in low-fertility sites but establishes and grows quickly, providing fast stabilisation. On sites where high establishment rates are expected (low mortality) and/or natural regeneration is wanted, seeding rates can be much lower. Rates for such sites would typically be 2–3 kg/ha browntop,

	5 kg/ha ryegrass, and 0–2 kg/ha of a legume. Fertiliser is still likely to be needed
10	Locate clumps of direct transfer to create vegetation islands, and speed natural regeneration. Sometimes it is worthwhile to pull in clumps of shrubs from site edges and along roads (without blocking water tables – unless this is useful). Clumps can be used as boulders, to restrict access
11	Spread wood/logs/slash/fascining to create vegetation islands. Boulders may also be useful to create diversity of habitat. Logs are particularly valuable to enhance long- and short-term biodiversity, and for erosion control if they are short. Tall stumps may be used by birds, providing perches (and the seeds birds bring) and invertebrate habitat that differs from that near the ground
12	Check site for safety. Minimal maintenance and Monitoring

5.4 Photographs of Rehabilitation to Native Forest

Figure 10 A variety of root zone material and variation in topography creates a variety of stable sites and drainage types.
This promotes natural vegetation establishment and natural vegetation pattern. The 'island' of undisturbed (not mined) forest (mid-left) will also assist natural regeneration. The mine pond will develop naturally into a wetland, December 2010.

Figure 11 Successful relocation (direct transfer, VDT) of stumps with native trees and shrubs at 2 to about 6 m spacing after about 5 years.
As long as the native plants are tall enough to avoid being smothered by woody weeds, this technique is effective at introducing beech trees, a range of other native tree seedlings and soil invertebrates, December 2010.

Figure 12 Regenerated silver beech saplings (foreground and centre) 17 years after direct transfer of beech stumps with root plates attached and inter-planting of small beech seedlings salvaged from in front of mine stripping.
Undisturbed beech forest is in the background, December 2010.

Figure 13 Direct transfer of relatively tall native trees and shrubs placed densely together can achieve outstanding results almost immediately.
This is the best way to mitigate adverse effects on landscape, plant diversity and invertebrates. This strip of 3 to 6 m tall lowland podocarp/hardwood shrubland has been in place for about 3 years, December 2010.

Figure 14 Placing bands of mixed topsoil and wood (mixed during stripping) is effective at stabilising relatively steep slopes.
The combination of stable, rough surface, adequate infiltration and favourable growing medium favours rapid growth of planted seedlings, December 2010.

Figure 15 Extensive plantings of native nursery-raised seedlings into slopes covered with salvaged mixed soils and wood stabilised with aerial seeding of browntop (a low-fertility grass for providing rapid, but not usually smothering, ground-cover), February 2011.

Figure 16 Rill erosion on an unstable, bare, gravel backfill.
Formation of a stable landform is a key requirement for effective revegetation, December 2010.

Figure 17 In the absence of weed management, the most common outcome in rehabilitated sites is development of gorse, broom, blackberry, and/or Himalayan honeysuckle.
Such covers stabilise soils and minimise erosion, but delay regeneration of native forest, and favour broadleaf–podocarp forest over beech. Beeches in the background were placed using Direct Transfer.

Figure 18 A clump of shrubs or trees with attached soil is an effective method of temporarily preventing vehicle access while retaining the ability to quickly open the road.
If this was permanent rehabilitation, the road surface would be ripped and clump placed in a hollow, December 2010

Figure 19 If topsoil is not replaced, fertiliser has a major influence on plant growth.
Ten-year-old silver and red beech trees on overburden without fertiliser (left side of person) and with 110 g/tree of diammonium phosphate (DAP) fertiliser (right side of person), March 1995.

Figure 20 Ten-year-old native plantings into replaced soil, with topsoil replaced over subsoil (foreground), and with the same plantings into overburden gravels, i.e. no soil replacement (background), March 2002.

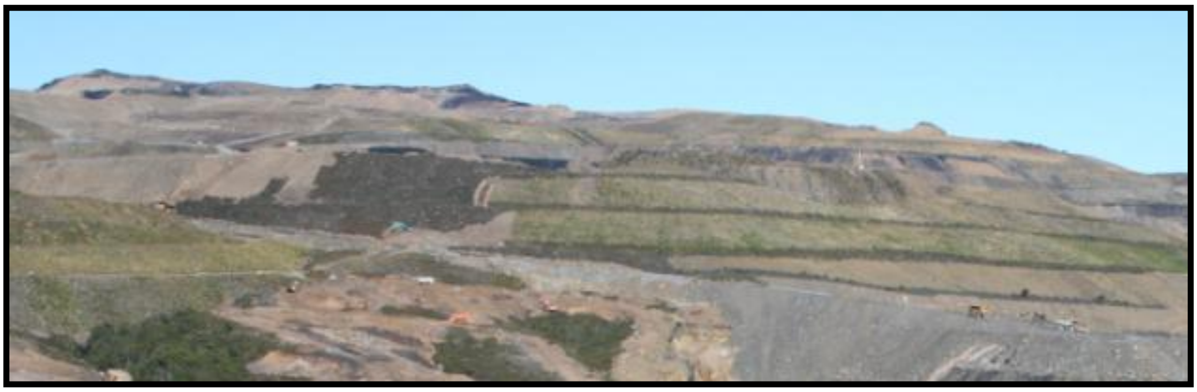

Figure 21 Typical engineered overburden landforms for long-term stability.
Many benches have a line of VDT (dark green vegetation) at the top and bottom of each batter to assist erosion control (2012).

Figure 22 Native plantings in rocky soil substrate with a low rate of browntop ground cover and scattered tree trunks and stumps provide erosion control and protected microsites for plant growth, December 2010.

Figure 23 Pasture cannot establish into unfavourable materials – this favourable topography allows covering of the acid-generating overburden (scattered, yellow, sulphidic rock) with suitable soil or a non-acid rock to enable plant growth.
The long, steep, lower slopes are also poor practice, December 2010.

6 Glossary of Rehabilitation Terms

Division – a method of asexual or vegetative plant propagation in which a new plants are grown from a vegetative part or section of a plant with multiple stems emerging from the ground (a clumping growth habit, e.g. red tussock). A plant is removed from the ground and cut it into several pieces containing shoots and roots which are then grown. Propagation by division is best done when the plant is not actively growing and moisture stress is low (late autumn and through winter to early spring).

Fascining (also called layering) – a labour-intensive process in which branches carrying ripe seeds are spread over bare or cultivated ground to achieve a 30–100% cover depending on site conditions (i.e., coverage is higher on erosion-prone and exposed sites). Branches can be fixed to the surface with pegs and wire or biodegradable netting. The technique is mainly used for mānuka and kānuka but has also been successful in establishing some hebe and coprosma species (*Coprosma robusta* and *Hebe salicifolia*). Timing is critical as seeds must be ripe and on the branches (mānuka and kanuka capsules can open rapidly in hot, dry conditions).

Hydroseeding – a method of establishing plants using a slurry of seed or other propagules (such as moss, lichen and rhizome fragments) and organic mulch (commonly wood fibre or newspaper) in a base of water, usually with fertiliser and a tacifying agent to stick the material to the surface. The slurry is sprayed over prepared ground in a uniform layer from the ground (through hoses or a turret gun from a tanker) or by air (helicopters have been used at Strongman). Hydroseeding is an alternative to broadcasting or sowing dry seed. The mulch inhibits soil erosion and promotes quick germination and establishment by maintaining the moisture level of the seed and seedlings. Heliseeding can also be used with dry seed mixes.

Mixed soils and vegetation – salvage and re-use of mixed vegetation, topsoil, and forest duff in a way that conserves its potential for natural regeneration. The technique involves collecting all surface biotic material with an excavator, and transporting it to a storage area, (or preferably to a final destination for direct application. Direct application should be used whenever possible. Surface rocks and subsoils may be included where access is difficult (slope and unstable ground) and soils are discontinuous, but such material should be salvaged separately from high-value jumble dump where possible.

Propagules – plant material used as the base from which to grow plants, often seedlings, used in rehabilitation. Plant propagules include seed, stem fragments, cuttings, divisions (of large plants such as tussock and potentially flax), and sometimes whole plants.

Soil Sod – intact surface layer of ground containing vegetation attached to underlying roots. This includes 200–400 mm depth of attached topsoil and upper subsoil to ensure the retrieval of the majority of the root mass. Sods are not usually more than 500 mm depth.

Subsoil – weathered soil or rock that lies immediately below the topsoil. Few roots generally penetrate this layer. In forest and shrubland, the subsoil is usually a lighter brown or pale grey colour than topsoil. This is a poor growing medium and degrades topsoil if mixed with it.

Topsoil – dark brown, organic-rich layer at the soil surface, usually 50–300 mm depth. This is sometimes referred to as the A Horizon of a soil profile, and is the most fertile part of the soil matrix. Topsoil usually differs in colour (darker brown) and structure (crumbly) from underlying subsoil (paler with larger, harder lumps).

Vegetation Direct Transfer (VDT) – salvage and re-use vegetation, topsoil and forest duff in a way that conserves its potential for natural regeneration. The technique involves gently lifting the vegetation off in ‘sods’ or ‘slices’ in a way that maintains the integrity of individual sods using a specialised bucket and excavator, and transporting, preferably to a final destination for direct application, or to a storage area if there is no final receiving area available. Trees that are too large to shift are felled to a height of 1.0 – 1.2 m before transfer of remaining vegetation and stumps with attached root plates. Direct application should be used whenever possible. This technique allows the ‘direct transfer’ of surface vegetation, subsoil, duff and intact root structures (including mycorrhizae) and is the highest priority rehabilitation technique currently used at Stockton.

Wilding – naturally established plants salvaged by hand from areas that are to be stripped of vegetation and/or soil, for example soil stockpiles or undisturbed ground. Wildings are usually labour intensive to salvage and plant; however, are an effective way to quickly establish large individuals of species that are tolerant to shifting (e.g. flax, tussock). It is also valuable to establish plants that are not propagated by nurseries, and introduces mycorrhizae (particularly important to establish beech species) and small hitch-hiker plants, such as herbs and wire-rush, that can then spread into adjacent soils. Plants suited to salvage grow in exposed, well-lit sites created by erosion or tree fall. Success is highest when plants are salvaged with large, intact root balls on cool, moist days and immediately transplanted.

7 Acknowledgements

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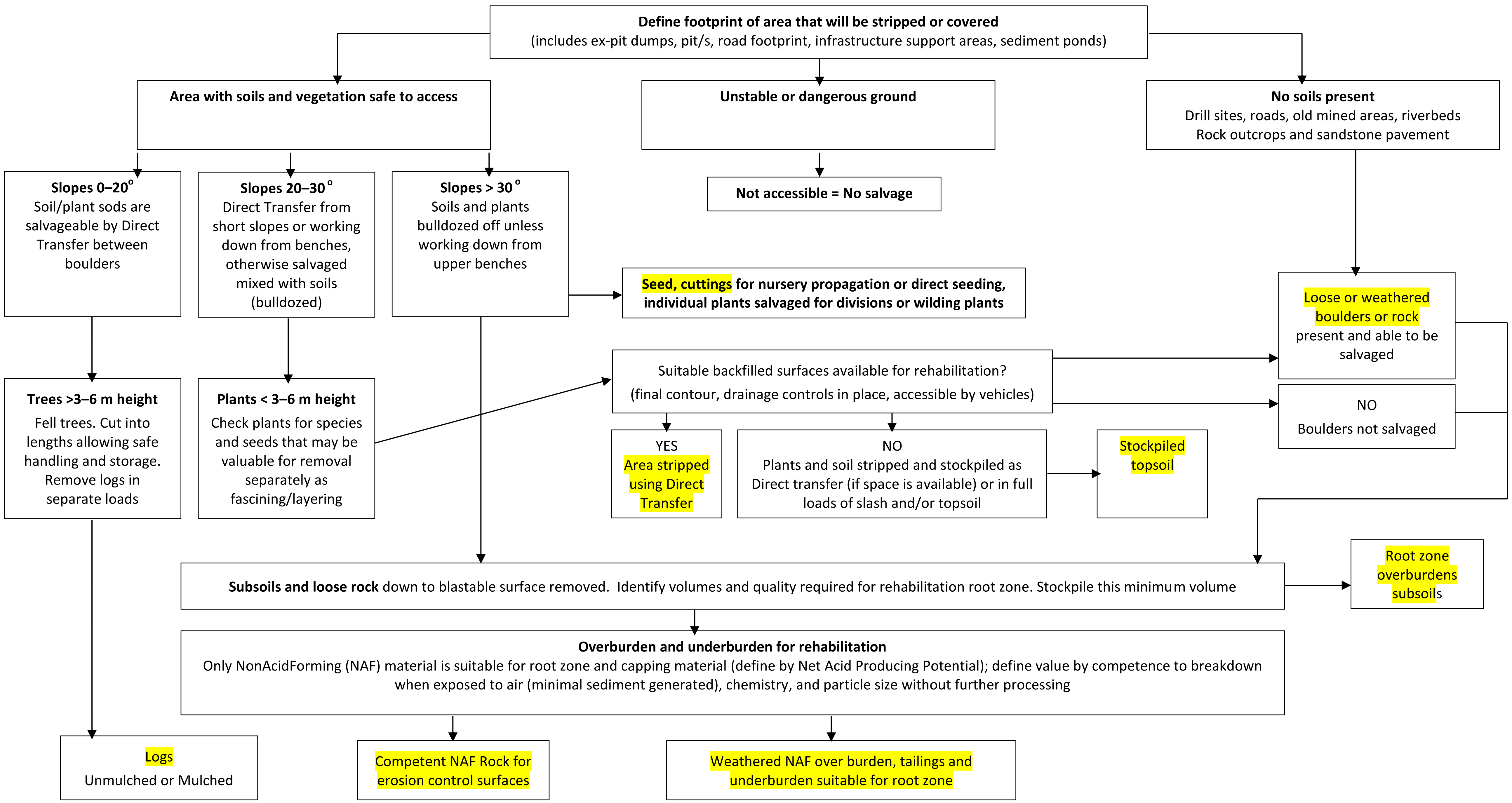
Appendix 1 – Rehabilitation Flowcharts

Identification, Salvage and Use of Rehabilitation Resources

(yellow highlights the resources for rehabilitation, NAF = Not Acid Forming, DT = direct transfer)



Planning and Agreeing Pasture and Farm Rehabilitation

1. Decide what is possible at the site

A. Site assessment

What are current site conditions?

Land-use capability measures versatility (e.g. cropping potential and identifies main limitation to pastoral production)

Current productivity (stock units/ha, pasture production as DM/ha/year)

Trees, shelter belts, ponds, drains, watercourses and their values

Infrastructure: fences, races, sheds, reticulated water

B. Site assessment

What are current site limitations? These may be reduced or removed in rehabilitation

- Poor drainage due to perched water table (iron pan) -> mining will break this pan
- Poor drainage due to flat site with slowly-permeable soils (pakihi) -> mining can reshape the landform to shed water
- Floods frequently -> deeper gravel mining will likely raise the land surface
- Chemical infertility and low-producing pasture species -> rehabilitation can increase fertiliser, add lime and establish higher producing pasture species
- Gorse, rushes or other weeds -> these be managed during stripping and revegetation. Rushes can be outcompeted if free-draining soils and healthy pasture are established, heavily gorse-infested soils may be replaced if adequate alternatives and moderate to high fertiliser rates are used

C. What resources are available?

Machinery and equipment used in mining may influence what resources can be salvaged and separated, e.g. size range of fines, ability to access slopes.

See FLOWPATH ONE

Is any mine infrastructure useful to retain for post-farming use? E.g. access roads (races), power supply, dredge pond (with reshaped batters), culverts and bridges, bonded refuelling depots, sheds

Will the land owner provide resources (dairy shed effluent, old hay bales for erosion control, etc.)?

D. How does the mine plan influence resource availability and use?

When will areas be available to separately stockpile resources for rehabilitation?

What areas are likely to be available for rehabilitation and grazing in each year, and when? (This can help farm operations.)

HINT: Using aerial photos or farm map to mark key features helps clarify discussions

2. Agree general and specific success criteria to guide rehabilitation

General criteria are needed to allow mine flexibility and guide decisions when mine plans need to change. Changes are most likely for very small alluvial gold projects and larger, multi-year mining projects using flexible equipment/mining approaches. Farm/landscape-scale criteria and paddock-scale criteria should be developed.

HINT: Access, bridges and culverts may need to be upgraded to support mining equipment, and can be an important long-term benefit of mining

a. Farm scale criteria

- Location of mine access, mine infrastructure, general location of ex-pit stockpiles or overburden dumps
- Post-mining general location of farm races, gates, stand-off areas/feed-pad (may prioritise)
- General location, width of shelter belts, water courses (with riparian buffers) and crossings, whether planted or not
- Specific location of areas not to be mined (trees, wetlands)

b. Paddock-scale criteria

- General paddock sizes and shapes
- General land contour (minimum and maximum slope, especially if hump and hollowing)
- General water reticulation density and capacity
- Specific fencing standard for temporary, electric, and permanent fences
- Treatment of high-wear areas such as gateways, around troughs (may not replace topsoil in these areas and sheet with small gravels)

HINT: Ensure treatment of permanent watercourses (e.g. streams) is consistent with WCRC 2004 'Clean Streams' Guide and WCRC stock crossing policy

3. Agree administrative and health and safety criteria

- Treatment of high-walls and ponds (sediment ponds, dredge ponds, new amenity ponds) to make them safe for stock, people-vehicles
- Agreement on access times and exclusion times for shared areas (e.g. during tanker pick up or school bus pick up), or places (e.g., lambing paddocks);
- Agreement on access times and exclusion times or places for mining areas (e.g. operational zones, mine site rehabilitated areas except non-operational periods).
- Responsibility for security of fences and gates to prevent stock / people accessing mining areas.
- Agreement on farmer assistance with rehabilitation, pasture management, if farmer is providing stock or machinery for pre-stripping grass removal or post-rehabilitation grazing. Post rehabilitation grazing needs to be done by light stock (young cattle or sheep) for short periods.
- Agreement on input to signoff for first grazing (stock & vehicle safety) and closure signoff, or contracting of an independent farm advisor in case of a dispute.

HINT: It is often better to use contractors to establish grass and carry out weed control and fertilisation. This decreases the risk to the miner of poor pasture establishment or grazing outcomes related to poor timing, may also provide independent feedback

4. Define measures of a standard root zone (or zones)

The standard needs to be flexible enough to allow adapting to site experience and changing resource availability.
The standard may be include minimum, target (optimum) and maximum values.
A standard root zone for pasture allows:

- 300 mm rooting depth (free-drained, uncompacted) of which 100 mm is topsoil
- pH >5.5 and Olsen Phosphorus 20 to 30 ug/g for dairy pasture, >10 ug/g for sheep pasture

When topsoil is thin:

- the underlying root zone needs to be sands rather than gravels to improve water and nutrient supply
- nitrogen fertiliser needs will be higher until organic levels build up

It is helpful to identify specific remedial options for any areas that do not meet the standard.
Monitoring is most effective if it identifies non-compliance early, especially for remediation options that require earthmoving, as these need to be done while suitable machines are still on site

HINT: Trees, whether in shelter belts of plantations, need a greater rooting depth than pasture to be stable and healthy but often grow adequately in lower-fertility soils as long as drainage is adequate. Flax shelter belts are suited to wetter, lower sites and are valuable sources of nectar for tui and bellbirds; poplars can provide additional fodder for stock in dry periods. Both grow rapidly and are complementary.

HINT: If topsoil or root zone materials are in short supply, discuss creating areas that do not need soil (ponds) or can be successfully rehabilitated with less input (shelter belts, plantation forestry, native plantings, wetlands)

5. Define acceptable pasture quality

The standard may include specifying:

- pasture species,
- acceptable weed level and
- acceptable pasture dry matter production

Production should be relevant to local farms. If soil physical conditions and pasture establishment are acceptable, pasture production and composition can be manipulated with grazing or mowing frequency and fertilisation.
When drainage is improved the monthly pasture production may be higher in spring and lower in summer (the land more susceptible to drought)

HINT: Photographs of agreed outcomes (acceptable standard of pasture, races, etc.) may be useful, as will be photos of the land before mining starts

HINT: Criteria may be supported by specific conditions that reinforce outcomes wanted, e.g. large native trees may be identified as a landscape feature. Because they are impossible to replace in the lifetime of the land owner, they may be given a $ value that encourages mining to avoid them.

6. Agree specific rehabilitation criteria for bond release

This may include specific criteria for rehabilitated farm infrastructure, e.g. races (width, fencing, water-table, surfacing - ideally refer to an example from the farm, or cross-section), fencing standards and gate standards.
It may be useful to agree to post-closure
Check site safety for steep drops, vehicle trafficablility and dangerous areas (sediment ponds with soft sludges) Eliminate hazards, e.g., fill in sediment ponds, recontour steep drops, especially drops into water, or mitigate hazards, e.g., excluding vehicle access using boulders, fenced ditches or other contouring

HINT: Progressive bond release can be beneficial for both farmers and miners and incentivises faster rehabilitation, especially for larger, multi-year sites

7. Agree success criteria (closure criteria)

These are measurement or descriptions that when met, mean the area is handed back to the land-owner or manager. At this stage the owner is responsible for maintaining the rehabilitated areas

8. Agree bond or compensation

Compensation may be 'in kind', i.e. upgraded access, races, culverts, water supply, and/or riparian protection
Linking compensation to the length of time land is removed from production incentivises rehabilitation

EXAMPLE: 'Typical' overall criteria may be a dense cover of ryegrass/clover pasture with no visible gorse after 12 months, a reticulated water supply to each paddock; post and batten fencing 5 m from streams and along the boundary; 2 wire internal electric fences. No stock injury during grazing.

Pasture Method (stripping, stockpiling, establishment & maintenance)

1. Identify rehabilitation resources and constraints

- Calculate approximate volumes of suitable materials available and volumes needed
- Allow 10% wastage if stockpiling topsoil; overburden is likely to swell
- Identify any resources that can be produced Run of Mine, e.g. boulders for riprap, fines for root zone, gravels for surfacing races, gateways & around troughs

HINT: ROM (Run of Mine) materials may be more cost-effective sources for rehabilitation than separately stockpiling during stripping, especially where stockpile area is limited, haul distances or handling can be reduced

2. Strip

- Identify, mark, and protect riparian zones and agreed no go zones (remnant forests, sheds)
- Survey weeds and areas with high weed seed bank; decide on management of these areas (e.g. spraying, separate stripping and stockpiling, disposal)
- Fell/remove large wood and plants that will be shifted intact as direct transfer; remove fences/troughs, etc.
- Identify stockpiling areas, check their capacity, and prepare these areas with firm bases, cut-off drains, sediment control and (at larger sites), signs and fencing to protect from trafficking
- Reduce pasture mass by intensive, close-grazing immediately prior to stripping, or spraying with herbicide 2–3 weeks earlier
- Preferably use low ground-pressure machinery to retain soil quality
- Strip topsoil separately from subsoil
- Strip and stockpile free-draining materials that will be used in rootzone separate from general backfill
- Remove poorly-drained or hostile subsoil and overburden. Dispose in suitable backfill areas below root zone

HINT: Placing stockpiles adjacent to areas that will be rehabilitated may reduce haulage distances or eliminate haulage

HINT: The cost of double handling is avoided by managing the mining schedule to allow direct placement of soil and rock from stripped area to rehabilitated area

3. Stockpile and conserve root zone

- Separately stockpile topsoil, subsoil, and other materials to be used for rehabilitation in accessible areas that are flat to gently sloping
- No surface water should enter stockpiles
- Reduce 'dirty water' needing treatment by diverting clean water away from stockpiles
- Create soil stockpiles by back-dumping, not compacting the soil (i.e., not driving over stockpiles)
- If stockpiles will be unused for > 3 months, sow with grasses or legumes to stop erosion and conserve quality

HINT: Keep track of topsoils and root zone volumes needed and volumes used/stored; many mines run out of suitable root zone material. Lack of soil /root zone increases costs and risk of inadequate plant growth.

4. Reinstate landform or create modified landform

- Place overburden to minimise the amount of reshaping (bulldozing) and re-handling required
- Identify and mark watercourses (streams, drains) and water detention areas; confirm flood capacity is adequate and overflows/outflows will not block access to important areas;
- Reinforce the surfaces of water-courses with rock armouring if necessary; install culverts and crossings, ensuring runoff from these areas drains to land, not directly to the watercourse
- Check site safety for steep drops, vehicle trafficability and dangerous areas (sediment ponds with soft sediment)
- Eliminate hazards, e.g., fill in sediment ponds, recontour steep drops, especially drops into water, or mitigate hazards, e.g., excluding vehicle access using boulders, fenced ditches or other contouring

HINT: Check to ensure compliance:
- with land-owner access agreement,
- with WCRC requirements and relevant bond release conditions

HINT: Ensure treatment of permanent watercourses (e.g. streams) is consistent with WCRC 2004 'Clean Streams' Guide and WCRC stock crossing policy

5. Create root zone

- For pasture: Create a free-draining root zone minimum 300 mm depth over compacted gravels or overburden. This should include at least 100 mm topsoil, unless fine sands and silts are substituted (silts increase risk of surface sealing)
- Trees (shelter belts & native plantings) need a root zone of 300 mm minimum and preferably 1 m root zone depth to ensure stability and reduce stress
- Minimise compaction of topsoil by avoiding movement in wet periods, use light or low ground-pressure tractors
- Soils may be tested to confirm initial (capital) fertiliser and lime recommendation for good pasture growth.

HINT: Wet and pond margins also need soil, this can be protected from wave erosion by a sheeting of gravel, placing logs in the water parallel to the edge, and/or using diggers to remove and place buckets of rushes/raupo into pre-dug holes

6. Establish pasture, revegetate

- Stone pick or rake as necessary
- Remove pieces of metal or concrete and other stock and vehicle hazards
- Decide if a pre-sowing spray of weeds is needed (most likely when sowing is delayed)
- Apply fertiliser as indicated by soil tests or farmer agreement (lime/gypsum, phosphate, nitrogen, etc.)
- Minimise compaction of topsoil by combining fertilising, harrowing, sowing operations during drier periods
- Minimise erosion by travelling across the contour
- Best results (germination and growth) are in spring and autumn
- See native vegetation establishment flowchart for TREE and SHRUB establishment

HINT: Keep records of what root zone, pasture sowing rates and fertiliser were used and when. Mark the areas on a map.

This helps identify best methods for your site

7. Monitor pasture outcomes

(after first storm and/or 3–6 weeks after planting)

This should be done for each rehabilitation area.

HINT: This is a good time to establish permanent photopoints that will show rehabilitation progress.

Check and Control Weeds

- Identify source of weeds (soil, adjacent areas, late control) and why weeds are dominant
- Will grazing control weeds or are other methods needed?

Check Pasture Vigour

- Will pasture resist grazing?
- If grass is yellow check soil drainage / compaction, then nitrogen deficiency by spot fertilising or testing
- Is remedial oversowing required?

Check Pasture Cover

- Successful if >90% cover and minimal bare or thin areas after 3 months
- Find causes for low grass cover is low (weather, soil, erosion, pests)
- Resow remediated areas

Check Erosion *

- Check land surface & watercourses & cut-off drains
- Identify cause of erosion, then do remedial work, e.g. oversowing, hay mulching, recontouring, armouring
- Amend rehabilitation method (slope, surface roughness, timing) unless erosion is caused by an unusual rainfall

Area ready for grazing or trafficking with mower/topper

8. Prepare for first grazing or topping/mowing

- Is the area stock-proof (permanent or temporary fences in place) and watercourses excluded from grazing?
- Can stock get to and from the area to be grazed without impacting mining?
- Is the ground surface safe for stock or mowing (no wire, concrete, etc.)? Is an adequate water supply present (not stream or drain)?
- Are wet areas present that are likely to be pugged (damaged)?
- Walkover with grazing manager/ farmer and confirm objectives: short duration with light stock under dry conditions leaving adequate pasture height.

Grazing/topping

Record the duration, and weather (e.g. rain)

9. Monitoring after grazing

- Pasture health and density (was pasture pulled out by roots, is residual pasture height tall enough to help rapid pasture regrowth or has it been over-grazed with bare soil evident?)
- Grass/legume balance (a very high clover cover often indicates lack of nitrogen for grass growth)
- Weed species and cover (was grazing effective in controlling weeds?)
- Are areas of erosion or pugging present (identify cause, stock may need excluding from area)?
- Check fences remain stockproof
- Check no damage or runoff from grazed areas to watercourses or trees

Feedback with farmer / manager

- Did grazing go to plan (duration: was it during dry conditions to protect soils and pasture?)
- Review access, effectiveness of fencing effectiveness, etc..
- Review stock health, pasture health
- Does grazing intensity, timing or duration need to be altered?

10. Maintain and complete rehabilitation

- Post-grazing fertilisation as needed to ensure rapid grass regrowth and build-up of soil organic matter
- Weed and pest control, erosion control as needed
- Annual maintenance fertiliser as needed (phosphate, potassium, nitrogen, trace elements as needed)
- Complete permanent fencing, races, water troughs, shelter, etc. as agreed
- If soil fertility levels are part of agreement, soil test and fertilise as indicated by results

HINT: This is a good time to re-photograph the permanent photopoints and record the best rehabilitation method for this site.

11. Closure assessment for hand-over to land owner and Bond Release
(part/whole)

- Confirm agreed outcomes with land manager/owner and administrator

Native Vegetation

1. Identify rehabilitation resources, constraints, and sites

- Calculate approx. volumes available and volumes needed for rehabilitation
- Allow 10% wastage if stockpiling topsoil; overburden is likely to swell by 10% to 20%
- Identify any resources that can be produced Run Of Mine, e.g. areas of low native vegetation, trees, and shrubs up to about 5 m high, tree stumps with root plates attached from tree cutting, endangered or locally important plants that can be transplanted, shrub and forest slash, and logs for re-spreading onto rehabilitation sites or used as mulches
- Identify suitable receiving sites for direct transfer, transplanting, nursery planting, or hydroseeding and erosive sites requiring mulches and/or logs. Conduct wildlife surveys and salvage fauna (e.g., kiwi, *Powelliphanta* snails, lizards, skinks, geckos etc.) for relocation and later re-introduction into rehabilitation areas
- Plan areas for wetlands or reinstating pavement

2. Stripping

- Identify, mark, and protect, if the mine plan allows, riparian zones and agreed no go (ecological protection) zones
- Survey weeds and areas with high weed seed bank; decide on pre-stripping management (spraying, separate stripping and stockpiling, disposal)
- Identify stockpiling areas, check their capacity, and prepare these areas with firm bases, cut-off drains, sediment control and (at larger sites), signage or fencing to exclude vehicle traffic
- Fell/remove large trees and slash for direct re-use, mulching, or stockpiling
- Strip vegetation and tree stumps with root plates attached for direct transfer or indirect transfer via temporary stockpiling
- Strip topsoil separately from subsoil if using subsoil for rehabilitation
- Strip and stockpile potential NAF plant growth materials, that will be used in rootzone, separately from general backfill
- Place NAF backfill immediately under the plant growth media
- Identify and dispose of PAF rock in isolated cells below NAF in the ELF so it won't contaminate the plant growth media or develop AMD

3. Stockpiling

- Separately stockpile topsoil, subsoil, slash, mulches, logs and vegetated sods in accessible areas that are flat to gently sloping.
- No surface water should enter stockpiles; reduce 'dirty water' needing treatment by diverting clean water away from stockpiles
- Create soil stockpiles by back-dumping, not compacting the soil (i.e. not driving over stockpiles)
- If stockpiles will be unused for >12 months, cover with mulch or sow with grasses, cereals or legumes to stop erosion and conserve soil quality

4. Reinstate landform or create modified landform

- Place overburden to minimise the amount of reshaping (bulldozing) and re-handling required
  Design landforms (ELF) that create micro-environments that replicate, as much as is practicable, pre-mining condition
- Tie the ELF into the adjacent landscape
- Identify and design watercourses (streams, drains) and water detention areas; confirm flood capacity is adequate and overflows/outflows will not block areas required to be accessed
- Reinforce the surfaces of water-courses with rock armouring if necessary; install culverts and crossings where access is required
- Check site safety for steep drops, vehicle trafficablility and dangerous areas (create wetlands from sediment ponds with soft sludges)

HINT: ROM (Run of Mine) materials may be more cost-effective sources for rehabilitation by direct transfer or as surface mulches for erosion control. Where possible avoid stockpiling. Avoiding stockpiling conserves stockpile area, reduces handling costs and reduces haul distances

HINT: Placing stockpiles adjacent to areas that will be rehabilitated may reduce haulage distances or eliminate haulage

HINT: Maximize the salvage of plants with root plates attached as Direct Transfer to establish diverse native vegetation and enrich habitat

HINTS: The cost of double handling is avoided by managing the mining schedule to allow direct placement of soil and rock from stripped area to rehabilitated area

Pre-order nursery-raised seedlings 1 to 3 years ahead to allow time for nurseries to collect seeds or cuttings, then grow and harden-off plants

HINT: Keep track of topsoils and root zone volumes needed and volumes used/stored; many mines run out of suitable root zone material. Lack of soil or inadequate root zone increases costs and risk of inadequate plant growth.

HINT: Check to ensure compliance:

- with DOC or land-owner access agreement,
- with WCRC requirements and relevant bond release conditions

HINT: Ensure treatment of permanent watercourses (e.g. streams) is consistent with WCRC 2004 'Clean Streams' Guide

HINT: Wetland and pond margins also need soil or VDT. They can be protected from wave erosion by a sheeting of gravel, placing logs or boulders on the water's edge parallel to the edge, and/or using diggers to remove and place VDT of wetland species

HINT: **Boulder fields:** Weathered and unweathered boulders 0.5- to 3-m diameter cover 30–66% of surface in single layer.
Rock-fields: Flat slabs of rock placed amongst pakihi VDT.

5. Create planting media

- Spread topsoil over subsoil or use other suitable plant growth overburden media over underlying NAF
- Apply greater thicknesses of plant growth media (preferably ≥ 0.5m) where the long-term aim is forest;thinner (≤ 0.3m) growing media required for pakihi, tussock grassland, flax, sedges and rushes
- Leave a surface with varied micro-topography, not a smooth surface.

HINT: Plant growth media can include woody roots or stems. Create mounds and hollows. Scatter logs, slash and/or rocks (slabs) over the surface prior to planting for erosion control and microhabitats.

6. Revegetation Methods

- Link rehabilitated native vegetation associations to adjacent similar associations where-ever practicable
- Prioritise locations for VDT as large blocks or connect VDT as corridors or as islands within plantings or around the edges of ponds and small waterways
- Select similar microsites to the collection locations for transplants
- Pack VDT slices as close as practicable, adding topsoil or rocks (including slabs) to fill in significant gaps and edges
- Strategically place stumps with root plates attached and fascining scrub (e.g., mānuka with ripe seed pods) for erosion control and where natural regeneration is best placed
- Plant salvaged low growth plants (seedlings etc.) and hardened-off nursery-raised plants in microsites approximating their natural habitats. Avoid planting in straight lines at regular spacings or as large areas of monospecies, unless this replicates the natural premining condition. Adjust the spacings to suit the species
- Place slow release (with small amounts of more soluble fertilizers is required to boost initial growth) in the planting hole or in a slit just upslope
- Hydroseed or hydromoss with native seeds and low rates of low fertility exotic grasses (e.g., browntop) areas inaccessible for plantiing (e.g., pit walls, road banks, rocky faces)
- Minimal, least cost rehabilitation is only an option for small operations where there is high probability for natural recovery e.g., a narrow coridor within native forest or scrub.

HINT: This is a good time to establish permanent photo-points that will show rehabilitation progress.

Vegetation direct transfer

Used wherever scheduling allows for:

- Pakihi wetlands e.g,. *Chionochloa juncea, Dracophyllum densum,* mānuka/wire-rush, and tangle fern heathland <50 cm height
- Shrubs e.g., mānuka, *Coprosma spp,* wineberry, pepper tree, low statute beeches
- Forest saplings e.g., beech trees, podocarps, kamihi, *Quintinia,* rata less than about 5 m depending on quality of salvage, size of sods, and exposure of receiving site.

7. Re-introduce fauna

- Wait until the rehabilitated habitats are suitable for re-introducing fauna e.g., kiwi, *Powelliphanta* snails, native earthworms, lizards – geckos – skinks, etc. Habitats will require food sources and shelter(hiding places)
- Control predators, e.g.,rats, possums, stoats, ferrets, rats, wild cats, as identified by wildlife management plan

HINT: Pay particular attention to recreating suitable microsite and soil conditions for re-establishing at risk, rare, or endangered plants.

8. Initial monitoring

- Monitor after first storm & at 6 months post-planting
- Monitor annually years 1 to 5
- Each rehabilitation area should be monitored
- Monitoring may include the need to measure habitiat conditions e.g., provision of shelter, bird food supplies, soil water for wetlands
- Monitor preditors.

Check erosion

- Check land surface & watercourses & cut-off drains
- Identify cause of erosion, then do remedial work, e.g. oversowing or re-planting, mulching, recontouring, armouring
- Amend rehabilitation method (slope, surface roughness, timing) unless erosion is caused by an unusual rainfall.

HINT: Re-photograph the permanent photopoints annually and record the best rehabilitation method for each rehabilitation site and/or objective.

HINT: Sediment control using straw mulch, bark mulch, stone mulch and potentially hydromossing, native seeding (minimal non-native seeding in many cases).

Check weeds

Identify source of weeds (soil, adjacent areas, late control) and why weeds are dominant.

Control weeds by selective spraying or hand weeding.

Check Plant Survival and Growth

- Identify reasons for plant deaths or poor growth
- Re-plant (blanking) with species adapted to microsite conditions
- Fertilize adjacent to poor growth plants and below the surface.

Check Fauna Recovery

- Monitor populations of re-introduced or re-colonising faunal species at optimum times of the year
- Identify causes of population failure or decline
- Adaptive management to adjust rehabilitation methods to re-create suitable habitat
- Control predators.

8. Maintenance and completion of rehabilitation (part or mine closure)

- Adaptive management is implemented to control weeds, pests, disease, and predators, and to establish sustainable native plant and faunal communities
- Prematurely 'walking away and leaving it to nature' is a risky option
- Plant density, growth (height and spread), and species mix (biodiversity) is managed to achieve targets that ensure eventual canopy closure and natural succession of native plants
- Ground cover is acceptable and erosion controlled or within acceptable limits
- Key fauna have re-colonised rehabilitated areas to achieve sustainable populations

HINT: This is a good time to re-photograph the permanent photopoints and record the best rehabilitation method for different parts of the site and different ecosystems.

Closure assessment for hand-over to DOC or land owner and Bond Release (part/whole)

Confirm agreed outcomes with DOC/owner.

West Coast Regional Council Bond release

Appendix 2 – Useful, web-available tools and templates to help maximise Biodiversity and profitability on your farm

Extract from Fukoda Y (2012). Benefits of biodiversity for farmers. Report for New Zealand Landcare Trust. P. 33. Complete report available free at: http://www.landcare.org.nz/files/file/746/Biodiversity%20for%20Farmers.pdf

Landcare: A Practical Guide

Biodiversity and sustainable land management case studies and guidance on how to form a landcare group.

www.landcare.org.nz/Landcare-Guide

Biodiversity Information Online

Provides information about Aotearoa New Zealand's native biodiversity, what is being done to help conserve and manage it, and who is involved.

www.biodiversity.govt.nz

The Green Toolbox Species Selector

Free software to help users choose and evaluate plants for a variety of land management applications, throughout New Zealand.

www.landcareresearch.co.nz/services/greentoolbox

Weedbusters

Free regional booklets 'Plant Me Instead'.

http://weedbusters.co.nz/get_involved/plant_me_instead.asp

Bird Identification Tool (online)

Photos, descriptions and bird calls of native and introduced birds in New Zealand.

www.whatbird.co.nz/index.php

What is this Bug?

Free online guide to common bugs, worms and spiders of New Zealand.

www.landcareresearch.co.nz/research/biosystematics/invertebrates/invertid/index.asp

Managing Natural Features on Farms (2003)
– from Farm Environment Award Trust.

Farmer stories about how they improve farm management while managing their natural features, such as wetlands, bush remnants and gullies.

http://maxa.maf.govt.nz/sff/about-projects/search/04-037/natural-features-insert.pdf

Farming with Native Trees (2007)
– New Zealand Indigenous Tree Bulletin No. 5.

Farmers' stories about the useful functions of native trees within farm systems. It covers sustainable use and management of native plants.

www.tanestrees.org.nz/docs/Farming_with_native_trees_promo.pdf

Appendix 3 – Review of Rehabilitation Research and Practice

Mine rehabilitation on the West Coast started in the late 1970s and early 1980s, initiated after the Mining Act 1971 and Mining Amendment Act 1981. Before these acts, a levy was paid to central government in lieu of rehabilitation. Most rehabilitation research has been associated with Environmental Impact Assessments required for large mining operations since 1971, notably gold dredging of alluvial river terraces in the Taramakau (Kaniere Dredge) and Grey River Valleys, and coal mining at Island Block and Giles Creek Mines. Early trials were carried out by Ronald Keating, a private agricultural consultant from Christchurch (Keating 1986), Forest Research Institute (Russell Fitzgerald and Dudley Franklin), the DSIR Soil Bureau (Craig Ross and Geoff Mew; Ross & Mew 1990), Ministry of Agriculture and Fisheries (Jeff Morton) and Grey River Gold Ltd (Rob Harrison; Morton & Harrison 1990). Methods of establishing *radiata* pine and pasture on alluvial dredge tailings were compared. At that time dredges produced a characteristic 'herring-bone' pattern of undulating mounds of boulders, interspersed with occasional small ponds. Early dredges did not salvage topsoil or subsoil; both were buried. Tree and pasture growth was limited by very low fertility, particularly low nitrogen levels, and drought during establishment due to the absence of water-holding fines. In some cases 10-year-old pine trees were less than 3 m tall.

Early rehabilitation trials planted *radiata* pine seedlings into unmodified tailings with 12 legume species aiming to boost nitrogen supply to the demanding pines. Red and white clover (*Trifolium pratense* and *T. repens*) were more successful at providing nitrogen for tree growth than subterranean clover (*Trifolium subterraneum*) or lotus (*Lotus pedunculatus*), lupins (*Lupinus* species) or lucerne (*Medicago sativa*). Tree Lucerne (tagasaste, *Cytisus proliferus*), Russel lupin (*Lupinus polyphyllus*), and yellow tree lupin (*L. arboreus*) grew well without fertiliser applications. Clover dry matter production was increased when fertilised with superphosphate containing molybdenum, potassium and magnesium (Fitzgerald, 1981). Vigorous legumes improved pine nutrition, measured by N-content in needles. This improved tree form and tree height, with the exception of tree lucerne, which severely suppressed tree growth due to light competition. These trials lasted 3 years. Later trials showed deliberate reshaping of tailings to create more gentle slopes, and heavy compaction of coarse tailings aided establishment by increasing water supply to tree seedlings. The latter method can be seen in the second rotation pine plantations on Kaniere dredge tailings near Hokitika where the tops of the mounds have been flattened.

Figure 24 Second rotation of *radiata* pine planted into herring-bone mounds of old, bouldery dredge tailings with tops flattened, near Hokitika, December 2010.

Modern gold dredging

From the 1980s, new dredges avoided leaving herringbone stacks by contouring tailings, creating a gently rolling topography. Many of these were small-scale operations comprising hydraulic excavators and small floating or land-based sieving plants. Modern dredge technology also enabled 'fines' to be separated and salvaged – these were mainly gravels and stones <10–15 cm diameter. The fines were placed as a layer over contoured boulders. Kanieri Gold and Grey River Gold Mining Ltd developed pasture rehabilitation techniques on the Taramakau and Grey Rivers. Fertiliser trials were followed by comparisons of topsoil, dredge fines and coarse tailings as growth media. Trials at the Taramakau River showed satisfactory pasture production could be achieved by using heavily-rolled fines as a growth medium. Fines were fertilised with 600 kg ha^{-1} molybdic super phosphate and sown with 37 kg/ha ryegrass (*Lolium perenne*), white and alsike clovers pasture.

Where dredges travelled through alluvial soils, topsoil (a 5–20-cm deep layer of darker, organic-enriched material) began to be salvaged. On the Taramakau River, topsoil salvage meant early and on-going management of gorse, using grazing and herbicides, was required to maintain pasture. In one trial, spreading 15–20 cm of soil was unsuccessful due to surface sealing, consequent rill erosion, silt transfer to depressions, and impeded drainage in these areas. Grey River Gold began stripping and stockpiling soil in advance of mining in the Grey Valley at Ngahere in about 1989. Soil cover was approximately 50 cm average depth, with minimal topsoil that was not separately recovered (Morton & Harrison 1990).

Two extensive reviews of West Coast mine rehabilitation in the early 1990s reported the most successful pasture and pine plantation establishment occurred where fines and topsoil were spread over levelled (re-contoured) dredge tailings (Metcalfe & Godfrey 1990; Mew & Ross 1991). The benefits of respreading 10 cm of topsoil were an increase in nutrient and water storage capacity, and nutrient supply (particularly nitrogen). This reduced the risk of pasture deterioration in the absence of adequate maintenance fertiliser and was considered to outweigh the increased risk of short-term soil sealing. Even highly humic Maimai topsoil was useful as thin surfacing material when dried out by improved drainage resulting from breaking of the humus-iron pans. The importance of separately stripping topsoil and subsoil, and identifying subsoils with different textures so free draining subsoils could be replaced and poorly draining subsoils buried was highlighted. Mew and Ross (1991) also advocated using traditional silvicultural practices such as contouring to create planting mounds where drainage was inadequate or water tables too high. However, this may increase the risk of tree wind throw, especially where mounds are small or narrow, and trees are fast-growing. They also promoted non-traditional treatments such as replacing logs and stumps to provide favourable micro-sites for seedling survival and growth, and enhance tree nutrition in the medium term.

Effective weed management is even more important now than in the 1980s, as expected weeds now include pampas (*Cortaderia* species), butterfly bush (*Buddleja davidii*), and Himalayan honeysuckle (*Leycesteria formosa)*. In isolated instances, aggressive weeds of native and plantation forests such as Asiatic knotweed (*Fallopia japonica*), Himalayan balsam (*Impatiens glandulifera*), and Spanish heath (*Erica lusitanica*) may be present in soils. Areas with these weeds should be identified, stripped and placed in discrete areas away from watercourses to avoid dispersing the seeds and propagules over large areas of rehabilitation when soils are spread.

Techniques for establishing pasture after dredging were summarised by Ross and Chamberlain (1987), Ross (1988a and b), Mew and Ross (1989, 1991) and Parker (1991). These reports identify the following requirements:

- Reduce above-ground vegetation by close-grazing, mulching or desiccating before stripping topsoil
- Separately strip topsoil and subsoil. Preferably strip and replace in one operation during the progressive stages of mining. Conserve all soil materials in separate stockpiles for topsoil, free-draining subsoils, and poorly draining subsoils, when necessary. Ensure these piles are out of flooding risk and will not be diluted with dredged materials
- Contour dredge tailings to create rolling (5–15 degrees) topography. Slopes that are flat can impede drainage; slopes over about 20 degrees are difficult to traffic with machines and have greatly increased erosion potential
- Replace 20–100 cm of free-draining subsoils and/or fines (gravels and sands) and cover with topsoil; work in lime and fertiliser to achieve pH >6 and Olsen P of 15 to 25 based on soil agronomic tests. A typical rate suggested was 500–700 kg/ha molybdic superphosphate or DAP or potassic superphosphate if dairying and sulphur-superphosphate for inland locations
- Sow pasture species mix that meet farmer and site requirements. These are typically red and white clovers, and ryegrass at a total of 35–45 kg/ha
- Maintain a dense sward to resist weeds and quickly build up soil organic matter and structure, aiming for high post-grazing biomass, e.g. short-duration, mob-grazing by

light stock in the first 12–24 months with light side-dressings of nitrogen post-grazing when grass is growing

- Control woody weeds (gorse abd broom) and noxious weeds (such as ragwort, nightshade and pennyroyal). Control insect pests when significant, e.g. grass grub, porina and mānuka beetle larvae; clover root and Argentine stem weevils.

Since about 2000, the larger and more extensive West Coast dredges have tended to refine techniques to their individual circumstances. Many have succeeded in converting flood-prone, low-productivity pasture to consistently high-productivity pasture above flood-level. For example, L&M mining on the Arahura River developed specialist low-bearing load machinery with extra-wide blades for efficient spreading of topsoil. They also developed pre-stripping grazing protocols with local farmers that reduced above-ground biomass immediately before stripping. At such sites, dredging has also enabled improvements to farm efficiency by altering paddock size and shape, the placement and quality of races and water reticulation (water-troughs). Companies developed site-specific fertiliser and liming application rates, seed mixes and grazing methods with or without irrigation to reduce dust and speed-up establishment. Trees and ponds rarely featured, except where avoided by dredges.

Reviews of natural forest regeneration on old gold mining tailings by Franklin (1987) and Fitzgerald (1987) concluded that old gold "workings can regenerate back to forest with a composition approaching that of natural forest within a hundred years or so, but it would take several hundred years for the full species complement and natural structure of the forest to be achieved". The principal barriers to satisfactory regeneration had been fire, grazing, removal of duff and topsoil, removal of fines, and deposition of fines in settling ponds. General principles for establishing indigenous ecosystems after dredge mining were advanced initially by Norton (1991). Practical techniques for restoring native vegetation were developed by Murray Davis, Craig Ross, and Lisa Langer (Davis et al. 1997). These were largely based on published and unpublished trials at Giles Creek open cast coal mine with the mine manager at the time, Robin Birchfield, and his staff. Results are applicable to dredge tailings, as the coarse gravel alluvium on outwash terraces formed the rehabilitation overburden surface for most trials. Salvaging forest topsoil and subsoils separately, and replacing them as separate topsoil and subsoil layers over levelled gravels, produced significantly higher growth rates of all species than either replacing mixed soils or not replacing any soils (Ross et al. 1995; Mew et al. 1997; Langer et al. 1999).

Naturally established woody seedlings were denser on the replaced topsoil. Naturally established rush-cover was densest on the imperfectly drained mixed soils. Lisa Langer also reported higher native seed germination and establishment on separately salvaged and replaced topsoil over subsoils compared with gravel or mixed soils. Craig Ross, Lisa Langer, and Murray Davis repeated a modified version of Fitzgerald's trials on Kaniere. Wild-grown and relocated beech seedlings and stumps (later followed by saplings) into topsoil sown with clover and (in a later trial) rolled compacted gravels. In the former case beech trees grew successfully over 15 years but the dense cover of exotic plants between trees supressed natural establishment of native vegetation. In the latter case beech growth was very slow. In a trial at Greenstone, native shrubs were planted into gorse-infested mixed tailings and topsoil where the gorse was either herbicided and left, or replaced with fertilized pasture. Survival and growth of shrubs planted into pasture was initially lower than where no pasture was established. Slower growth and survival was attributed to competition from pasture, infestation of grass grubs, and more difficult planting conditions. However, when maintenance was stopped, gorse eventually regenerated and dominated the site.

Similar results were reported by Mackenzie and Cave (1991) for Yank's Road. Alders grown on contoured tailings were taller than those on topsoiled tailings. This was considered due to competition from gorse on the topsoiled treatment. The first field and glasshouse trials at Giles Creek also reported growth of native species was limited by competition from exotic weeds (Ministry of Forestry 1992). Field effects were probably compounded by compaction and poor drainage where topsoil and subsoils were mixed. Applying fertiliser to individual trees was reported to be more effective than broadcast fertilising because the former reduced weed competition (Metcalfe & Godfrey 1990). This is consistent with pine plantation establishment, where fertiliser, if needed, is placed into a slit near the root ball.

Rehabilitation of coal mines and hard-rock mines

West Coast Coal mines generally have fine silty subsoils and rocky overburden materials and operate in much steeper topography than alluvial dredges. Most coal mines are in native vegetation (forests and shrubland) and not pasture. Rehabilitation research has typically focused on simple growth trials comparing survival and growth of planted or sown native species with / without fertiliser, with/without soil and with/without woody mulches. The typical rehabilitation method is to sow grass species tolerant of low fertility (brown-top) and the most acid- and aluminium-tolerant legumes (Lotus species) to stabilise slopes. At the same time, or later, nursery-grown or wilding native seedlings are planted. As with gold dredging, many early mine sites did not salvage topsoil, and this limited results.

The value of fertiliser in promoting growth is fairly unequivocal where topsoil is absent. Repeated applications of DAP (nitrogen and phosphorus) stimulated growth of red beech at Island Block Mine (Iain Buckman and David Norton, unpublished reports; Norton et al. 2002). There was no measurable response from silver beech due to the trial design. Theinhardt (2003) also reported strong growth responses to a 55 g/plant application of DAP to toetoe and mountain flax planted into windrows of mixed soils and inter-row sandstone at Stockton Mine. The response of silver beech and koromiko depended on the level of exposure and substrate. In the highly exposed conditions of Stockton Mine the shelter created by windrows was a strong determinant of growth rate. More recently biosolids have been shown to dramatically enhance growth of grasses at Stockton. The impact of sawdust, biosolids or lupin green manure additions to three substrates planted with red beech and wine berry (*Aristotelia serrata*) is being quantified at the Globe-Progress Mine (Krisnayanti et al. 2006).

Fertiliser has also been shown to enhance growth of mosses (Buxton et al. 2002; Ross et al. 2003; Stanley et al. 2003). Legumes have been shown to improve growth of *radiata* pine on dredge tailings. However, there are negative impacts to increased fertility in native ecosystems, with or without legumes, but especially in the presence of legumes and pasture grasses. A dense sward of lotus or pasture grasses slows natural regeneration and germination of native seedlings, herbs, and orchids. In highly exposed environments, grass-legume swards can destabilise planted seedlings by creating a 'lollipop'-shaped plant that is susceptible to collar-rock (destabilised) if swards die back in winter. This effect appears to occur at altitudes above 500–600 m and exposed sites. At some sites, fertilised pasture or native shrubs attract browsers such as deer, which then tend to remove the most palatable planted native species (for example broadleaf and large-leafed coprosmas).

Given the risk of smothering inhibiting growth, reduction in native plant diversity, and reduced wind resilience associated with a fertilised grass/legume cover on some sites, alternative approaches are being used to establish native plants and at the same time minimise erosion of precious topsoil resource. The approaches include:

- spreading or blowing of mulch or unmulched vegetation (slash), wood chip or straw (hay only if pasture species, including common pasture weeds, are acceptable)
- hydroseeding or seeding a grass-only mixture at low rates, e.g. browntop at 3 kg/ha
- spreading a thin rock or gravel mulch over topsoil
- laying live vegetated sods across slopes as barriers to water flow (Direct Transfer, DT)
- ensuring spread topsoil has minimal handling to retain roughness and live vegetation

All approaches are combined with minimising erosion risk by managing continuous slope length, slope steepness and water flows into, across, and from rehabilitated areas. Such approaches are used at Stockton Mines north of Westport, Strongman Mine near Greymouth, and Oceana Gold Mine near Reefton. Over the last 10 years, vegetation direct transfer has been successfully used for a wide range of ecosystems and this is probably the most effective rehabilitation technique available, although very little research has been published on the technique's efficacy. Direct transfer was pioneered in New Zealand in the early 1990s at Giles Creek coal mine, where stumps and root plates of beech trees (*Nothofagus menziesii*,*N. solandri* var. *cliffortioides* and *N. fusca*) with attached seedlings and underlying soils were placed close together on contoured backfill. In 1993, direct transfer was evaluated for rehabilitating pakihi wetland dominated by tangle fern (*Gleichenia dicarpa*), wire rush (*Empodisma minus*), and sedges associated with the Giles Creek Coal Mine. After 4 years, 90% vegetative cover was achieved. The proportion of adventive species increased from about 3% to between 30 and 40%, depending on whether direct transfer had achieved a complete or partial vegetation cover (Ross et al. 1998).

Direct transfer was trialled at Stockton mine in 1997 for rehabilitation of mānuka shrub land and tussock wetlands. Early invertebrate, plant and soil results reported survival of up to 4 m tall, 60-year-old mānuka and rātā. Although plant diversity in direct transfer and undisturbed (control) plots was similar, direct transfer plots had 10% of the control canopy and sub-canopy cover. Invertebrate communities in direct transfer shrubland communities were more similar to the vegetated controls, while the conventionally rehabilitated communities were similar to the bare overburden after 6 months. Poorly dispersing invertebrates and plant species survived transfer, including flightless invertebrates (carabid beetles, weta) and beech species (Simcock et al. 1999). Rodgers et al. (2011) also described the cost effective benefits of VDT at Stockton mine for conserving both vegetation and biota (*Powelliphanta augusta* and earthworms). Vegetation direct transfer is now attempted at many sites, with best outcomes occurring with plants with shallow root systems, so the whole root mass can be removed with minimal disturbance, and climates or sites with low moisture stress.

There has been very little research on revegetation of high walls and steep rock faces at West Coast mines. Hydroseeding and hydromossing research at Strongman and Stockton Mines in the early 2000s identified native woody, herb and moss species that were generally successful at those sites and 'recipes' for application. The key limitation was sourcing the volume and species of seed and moss required for large scale application (Ross et al. 2003; Stanley et al. 2003). Results confirm the factors favouring successful plant establishment are: adequate moisture (largely controlled by exposure and aspect on steep slopes), a rough, stable substrate that creates microsites, a favourable pH, and viable propagules. No plants will grow directly on highly acidic (pH about < 3.5 – 3.7) substrates.

Management of acid-generating materials

Research generally confirms that, when faced by acid generating material, by far the best practice is to isolate it from the root zone. This is best achieved by identifying acid-generating materials during mine planning and excavation, then ensuring such materials are not placed at the surface in an overburden area. Liming is rarely a long-term option if such materials are exposed within a root zone, as Acid Rock Drainage (ARD) inhibits plant establishment and growth. When acid rocks are at or near the surface, they keep being exposed to water and oxygen. Potentially acid materials, therefore, need to be isolated from oxygenated water. One method is to cover the acid rocks with a compacted low-permeability layer, which is in turn covered with a protective soil or non-acid forming (NAF) media into which plant roots can establish.

This above rehabilitation review excludes information of rehabilitation techniques for specific/at risk or threatened native plant or animal species associated with sandstone coal measures ecosystems of the Stockton and Denniston Plateaux. This information was presented in 2012 and 2013 Council Resource Consent and Environment Court hearings for the Mount William and Escarpment open-cast coal mines. General techniques only have been reported.

Application of rehabilitation research from other South Island mines

Rehabilitation experience from alluvial gold mines and coal mines in Central and South Otago, and Southland is largely applicable to West Coast Mines, for example, see Earnscleugh, Waikaka Valley, and Glenore alluvial gold mines, New Vale, Goodwin, and Mataura Southland lignite mines, Ohai coal mine, and Wangaloa coal mine remediation. The key difference between these and most West Coast sites is the benefit and tolerance of finer texture and higher water tables in the much drier Central Otago climate. In these drier climates there is a greater focus on topsoil and a lower focus on topography as a key way of ensuring drainage (less surface runoff of water)

Appendix 4 – Administrative Suggestions to Enhance Mine Rehabilitation

The main indicators of acceptable post-mining outcomes for administrators such as the Council include:

- limited erosion and sediment captured within land
- sediment not adversely affecting streams (and aquatic life)
- no increased flooding risk, particularly that may impact infrastructure
- safe sites that do not compromise public safety
- maintenance of public infrastructure adjacent to and within mined sites, such as roads and stop banks (no decrease in service level or increase in risk)
- high compliance of mining companies/contractors with consent conditions
- low number and severity of complaints from land owners adversely impacted by mining either on their property or on adjacent properties
- timely bond release.[16]

Stable backfills can generally be achieved by ensuring stable slopes. Stable slope angles depend on the properties of the overburden but typically range from 18 to about 35 degrees. However, steeper slopes (over about 25 degrees) are difficult to cover with favourable, soil-like material without erosion, particularly if the slopes are long or the surfaces are smooth. Soil-like surfaces are important to allow a dense vegetation cover to develop.

Vegetation covers are typically pasture species or self-established woody weeds such as gorse in the short term. The Council does not currently specifically manage biodiversity or terrestrial ecological values through conditions on mining consents/bonds.[17] However, practices that maximise ecological values also often achieve high resistance (and resilience) to erosion. Terrestrial ecological values are enhanced by:

- using direct transfer of intact sods of vegetation with attached soils
- stripping, storing, and replacing topsoil separately from subsoils, and freely draining subsoils separately from poorly draining subsoils and other overburden
- creating variation in topography and drainage
- spreading 'slash' (crushed branches of larger trees), logs and stumps over topsoiled areas
- establishing native vegetation and controlling weeds.

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[16] This a source of tension for some miners and consent holders

[17] Remnant forests on river-flats are some of the most threatened ecosystems in Westland. When alluvial mines include such areas, there may be an opportunity to encourage land owners to conserve these trees or remnants. Rehabilitated dredge ponds can also contribute to biodiversity if created with wetland vegetation on fringes with gradual-slopes edges. Establishing wetlands need not be expensive as rushes, and some sedges, will self-introduce if stock are excluded.

The first four of these actions are being carried out effectively at alluvial gold mines within Department of Conservation estate visited in December 2010. Five mines visited had deliberately established native vegetation.[18] Three alluvial gold mines had successfully relocated native trees, shrubs, and stumps, as had one coal mine. In the absence of weed management, the relocation of 0.5 – 4 m tall native trees and shrubs (often on root plates or stumps) was effective at accelerating native regeneration. It is the only method of establishing native shrubland and forest that is relatively resistant to subsequent growth of weeds such as gorse, blackberry, and Himalayan honeysuckle, with minimum follow-up maintenance. Even widely spaced root plates were effective at introducing patches of native seedlings within extensive areas of non-native shrubs. When trees and shrubs were placed densely together results were outstanding, leading to conservation of much native biodiversity (plant and insect), rapidly accelerating natural succession and eliminating erosion. The only mines establishing a native vegetation cover using relatively dense plantings of small nursery-grown seedlings are relatively large operations. Long-lived mines in areas with low initial weed content means miners can realistically commit to weed control that prevents smothering of planted seedlings until they reach a height and cover (canopy closure) that is resistant to invasion.

Salvage and separate storage of topsoil is a key rehabilitation performance indicator. Natural succession requires a favourable root zone. The most favourable substrate is nearly always topsoil mixed with vegetation under about 1–2 m height that is stripped at the beginning of mining, and placed on areas to be rehabilitated with a minimum amount of handling (so a rough surface is created into which seeds can lodge and sediment movement is restricted). The volume of topsoil available for rehabilitation is nearly always limited by sufficient storage space. When topsoil volumes are insufficient, erosion control and vegetation establishment can still be achieved by decreasing topsoil depth over the whole site (to as little as 100 mm), or applying bands of topsoil around the contours. Priority should be given to areas where rapid vegetation cover and growth is important, e.g. steeper, more erosion-prone slopes (not benches), the upper parts of slopes and riparian areas. Mixing topsoil with subsoil or overburden is rarely beneficial and does not create more topsoil but rather dilutes the fertility!

Early backfill and formation of final landforms is another key indicator of likely rehabilitation success and risk of inadequate rehabilitation outcomes. Early backfill provides miners with local rehabilitation experience from which they can develop site-specific methods, based on understanding local vegetation and overburdens. Early rehabilitation also provides hard costing data, spreads rehabilitation costs and establishes erosion control requirements. Potential weed issues, adverse overburden properties, logistics of plant supply, and fertilisation needs are identified earlier.

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[18] Some small mines in areas of native shrubland or plantation forest appeared to have no deliberate revegetation strategy. Sometimes pasture grasses and clover were sown, but without fertiliser to assist establishment. The most common outcome of such mining was a dense growth of gorse, broom, blackberry, and/or Himalayan honeysuckle. At these short-lived sites there is little value gained from planting native species in the absence of weed control as weeds smother the small seedlings However, *if suitable drainage, topsoils and rooting depths are replaced*, these typical narrow, relatively small mined areas develop a native shrub cover over 20+ years, provided they are not burnt. Plant diversity in such areas probably differs from areas that regenerate through mānuka and kānuka. Without topsoil, the speed of succession is generally slowed, and regeneration can be prevented altogether if acid-generating materials influence the root zone.

Use of bonds

Bonds can encourage desirable post-mining outcomes. Bonds are most useful if they match the scale of the operation, if bond release is timely, and conditions to be achieved for bond release are clear. Our observation was that even the size of typical bonds ($7k/ha) on small alluvial mining operations was considered a significant incentive. Key issues with bonds include:

a) council not being notified of mine closure until mining equipment is off site, and in some cases when access to the mine was removed, so any remedial works are expensive and sometime impossible

b) lack of clarity of the requirements for bond release, and (appearance of) inconsistency in the application and release of bonds to different agencies

c) bonds that do not reflect the risk of adverse environmental impacts and/or cost of rehabilitation to address these impacts.

Each of these factors is discussed in the following sections.

Notification of closure

The requirement for an inspection prior to bond release is one way Council is able to track small, short term mining operations. Unfortunately, an inspection at the end of mining is almost guaranteed to be ineffective if large-scale earthworks are needed to create stable slopes, no topsoils have been salvaged during mining, or acid-generating overburden or large stones are left at the surface. Therefore, bond calculations would best be based on a transparent risk assessment and bond release linked to critical stages in mining and rehabilitation (i.e. phased bond release).

Phased bonds are most suited to mining operations that last several years and have critical phases that can be clearly identified. Such bonding could use data (larger) companies collect to assess their liabilities. The following measures could be used:

- Bulk or Bank Cubic Metres (BCM) requiring contouring. Sites with highwalls, with deep cuts, and sites excavated into higher terraces usually need the most contouring. Once contouring has created engineered landforms that are stable, the majority of a bond can be released for sites with favourable overburdens, as contouring is the major rehabilitation cost
- Area or volume requiring capping and topsoiling. This measure is critical for mines that expose acid-generating overburdens or overburdens unfavourable for plant growth (e.g., boulders or poorly-structured silts)
- Area requiring revegetation (to calculate $/ha for seed, fertiliser, planting)
- Area requiring maintenance (not yet reached closure criteria or signed off by Council). This measure would be most important for areas needing intensive maintenance, for example, highly erosion-prone areas, pasture prior to return to the farmer, and areas of native ecosystems vulnerable to pest plants or animals.

Bonding could also be linked to the following:

- Volume of topsoil recovered, specifically the volume salvaged and stockpiled separate from subsoils. Once enough topsoil has been stored to cover 50–70% of the site (depending on potential for erosion and post-mining land use), a bond reduction may be appropriate. In very constrained sites, topsoil recovery may not be practicable until a mine has reached a minimum operating area. Alluvial gold mines rehabilitating pasture may deliberately bury heavily gorse-infested topsoil and instead use sands and silts. In such cases, the volume of substitute material available will be important
- Confirmation that no acid-generating overburden is at the surface or will influence the root zone or surface waters. The cost of testing is negligible compared to the potential environmental cost of not managing acidic materials
- Stream riparian management and/or reinstatement. Streams are often the most sensitive sites at most risk of degradation within a mine site. This risk is removed once mining has moved away from surface waters and established an adequate vegetated buffer (specified on a plan). Linking substantial bond release to stream riparian management could encourage operations to quickly rehabilitate these sensitive areas.

Multiple bonds

Currently it is not unusual for a mining operation to be subject to 2 or 3 bonds. These are typically from the Regional Council (regarding watercourse protection & erosion control) and from the land owner. The land owner may be a farmer, the Department of Conservation, or Timberlands/Ngai Tahu. Tension can occur when one bond holder allows bond release but another requests additional contouring or revegetation to stabilise a site before bond release. Tension can also occur when a land owner (not the miner) takes responsibility for revegetation. This situation typically happens on small sites where the farmer is paid to cultivate and seed rehabilitated land. Tension arises if re-grassing is inadequate to protect the catchment from erosion or sedimentation because the reason for inadequate vegetation cover may largely lie with either party. For example, a farmer may underestimate the fertiliser and lime application rates required (especially when topsoil is mixed with subsoils or overburden materials). A farmer may over-graze the area before soil structure is recovered, leading to soil damage. Pasture may have been established outside the optimum growing season due to a delay in overburden or soil placement by the miner. Sometimes the contour (topography), drainage system and/or soil replaced is inadequate, or more weedy than predicted.

Bond sizing

The size of bonds should be based on the cost of rehabilitating or closing a mine site to acceptable standards. Ideally, bonds also take into account the risk of non-compliance. Inadequate bonding is most likely for a small subset of mines that have one or more of the following characteristics:

- Mining involves excavation into steep landforms (hills, tall terraces), especially in highly constrained sites, so that substantial earthmoving is required to create stable slopes
- Additional soils or covering materials are needed for revegetation to occur, e.g. when acidic materials are exposed

- Highly sensitive areas may be affected by mining, e.g. stream or lake beds and banks, roads (expensive to reinstate and disruptive if closed), and flood stop banks
- Rehabilitation standards are likely to be difficult to achieve, or have not been met before (no precedence)
- Operators have a very small machinery fleet. This is most risky when large volumes of material are moved and re-contouring is done in large 'chunks', allowing delays to build up. The risk is exacerbated when combined with poor resource definition (mining may halt unexpectedly if ore value or excavation costs change quickly).

Performance incentives

Two types of performance incentive used by the Department of Conservation appear to be effective. The first assigns a $ value to individual trees or areas based on an inventory of ecological values. A miner can then choose to mine areas based on a cost-benefit assessment. This approach has led to patches of large rimu trees being retained within an alluvial mine, minimising the stripped footprint and enhancing rehabilitation. Large trees may die due to changed hydrological regime but trees are provided buffers and the long term seed source potential of such clusters is valuable. A similar approach could be applied by the Council to encourage avoiding disturbing features that have a highest risk of sedimentation/erosion, such as riparian margins and stream beds disturbed.

The second performance incentive is approval of mine expansion, based on an acceptable previous rehabilitation performance in early stages of the operation.

Key hints to assist miners when considering mine access

Miners can achieve timely bond releases and minimise the potential for disagreements by ensuring rehabilitation and bond requirements are as clear as possible. Visiting a similar, rehabilitated site with the landowner or manager can be extremely useful to clarify rehabilitation outcomes and issues. Experienced Council (and/or DOC) staff may identify these sites. Miners are often best placed to identify key mine stages and measures that influence rehabilitation outcomes, and from this negotiate staged bond releases

Miners need to consider that each site will be somewhat different, so cannot assume requirements will be the same at different sites. Key features that will change an approach will be streams or public infrastructure within or adjacent to the site, land ownership changes, overburden chemistry changes, and if rehabilitation aims change, e.g. from pasture to forest, or subdivision.

Key strategies for land owners when considering mine access

The following paragraphs identify strategies land owners of lifestyle blocks (subdivision), farmland, and forestry can use when contemplating mine access arrangements. These points are expanded as part of a flow chart for pasture or farm rehabilitation (also appended to this report).

It is important to confirm the condition land will be in when handed back and communicate this to the Regional Council (or DOC) in writing, illustrated with plans and photos if possible. Agree post-mining land use(s) and expectations before consenting and mining operations commence. For example, where rehabilitation will create a subdivision for lifestyle blocks, discussion will probably cover location of building platforms, roads, drainage, fencing and power supply. Discussions about farmland are likely to include contouring, drainage, fencing, rehabilitation fertilizer and lime applications, pasture composition and condition, water supplies, access tracks or races, types of drains, soil replacement (just topsoil, topsoil/subsoil or mixed soils materials), and relocation or replacement of buildings. Mining may involve creating new assets at little additional cost if they can be integrated into mining. Such assets include access roads and races, watercourse crossings, power supply, drainage, or lakes. Discussions about forests are likely to include topography, soil cover, erosion control, drainage, weed and pest control, access tracks, firefighting water supplies, and tree specifications. Landowner and miner management of areas before mining can influence the efficiency of rehabilitation and management of adjacent operations. Discussions may include weed control and pest control on the site, adjacent areas and access roads.

Agreeing liability or penalties triggered by damage to specific assets may help reinforce protection of features important to land owners. Features might include buildings or tracks/access lanes, individual trees or shelter belts or trees, or pasture or land outside the defined mine area. It may be useful to identify acceptable/unacceptable disruptions to on-going farm and forestry operations by mining operations, and vice versa. Staged access may suit both land-owner and miner, especially if bonds are reduced. Staging might be linked to successful rehabilitation of earlier stages (or evidence of satisfactory land recontouring, topsoil stockpiling, etc.).

An example of conflict caused by inadequate discussions or written agreements is a small alluvial operation in native shrubland. The landowner wanted to use the mined (i.e. newly cleared) areas to create house sites and considered the rehabilitated area unsuitable. Access was constrained by the location of diverted water courses and the area was not suitable for grazing. However, the stream diversion is stable and the gentle backfill slopes with rough, bouldery surfaces generate low fines, despite relatively poor vegetation cover. The potential to deliver sediment into the diverted stream is low, and the adjacent public road remains in good condition. The rehabilitation therefore fulfils Regional Council consent requirements. The landowner needed to agree at the outset to the general location, the specific condition and size of building platforms, the standard of access required to these sites, and that a grassed surface was required.

One way to achieve better outcomes may be for Council to facilitate joint discussions between bonding agencies, individuals and miner before bonds and resource consents are finalised. The aim of discussions would be to discuss issues subject to bonding, responsibilities, and post-mining outcomes sought. Such meetings could increase the knowledge of mining rehabilitation and requirements across agencies and would be particularly useful for individuals who may only be faced with a mine access request once in their lives. Where bonds covering similar issues are addressed by different agencies, the bond quantum could be reduced. It is unlikely, however, that this would lead to reduced monitoring /compliance costs by WCRC unless agencies such as Timberlands devolve responsibility (and costs) to the Council. The main limitation to DOC and WCRC combining monitoring resources is different expertise and relationships with the mining community. Hopefully this report provides a useful information base upon which all parties (miners, WCRC and DOC) can talk the same language, resulting in improved expertise, relationships and rehabilitation outcomes.