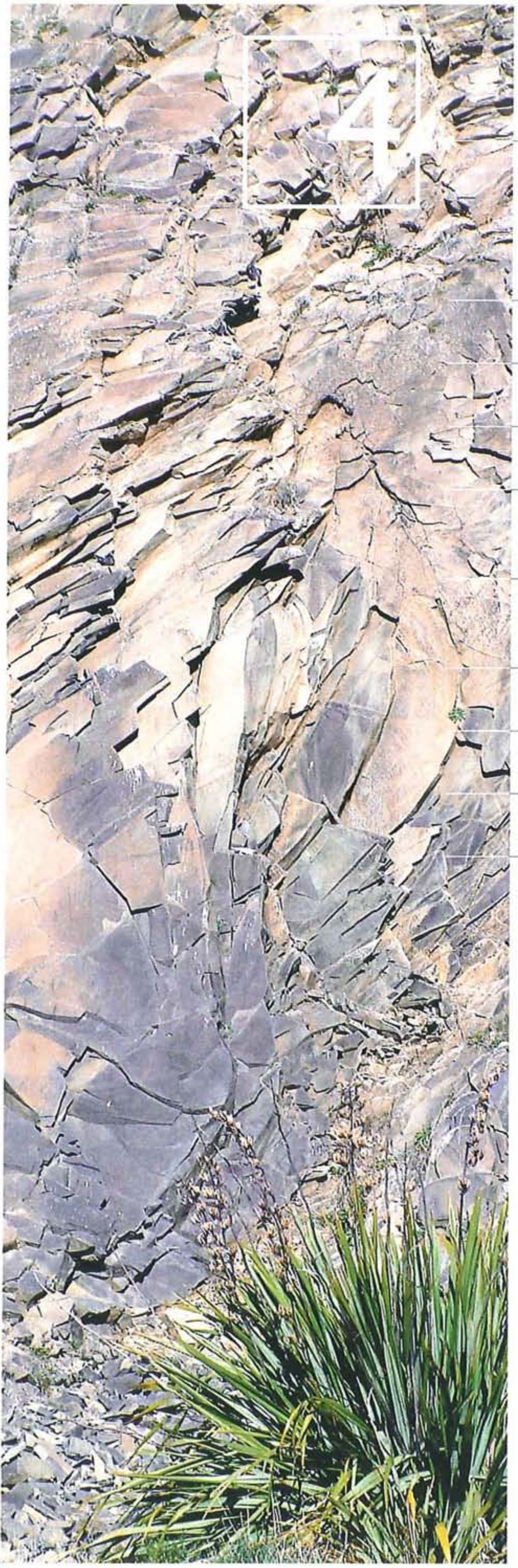
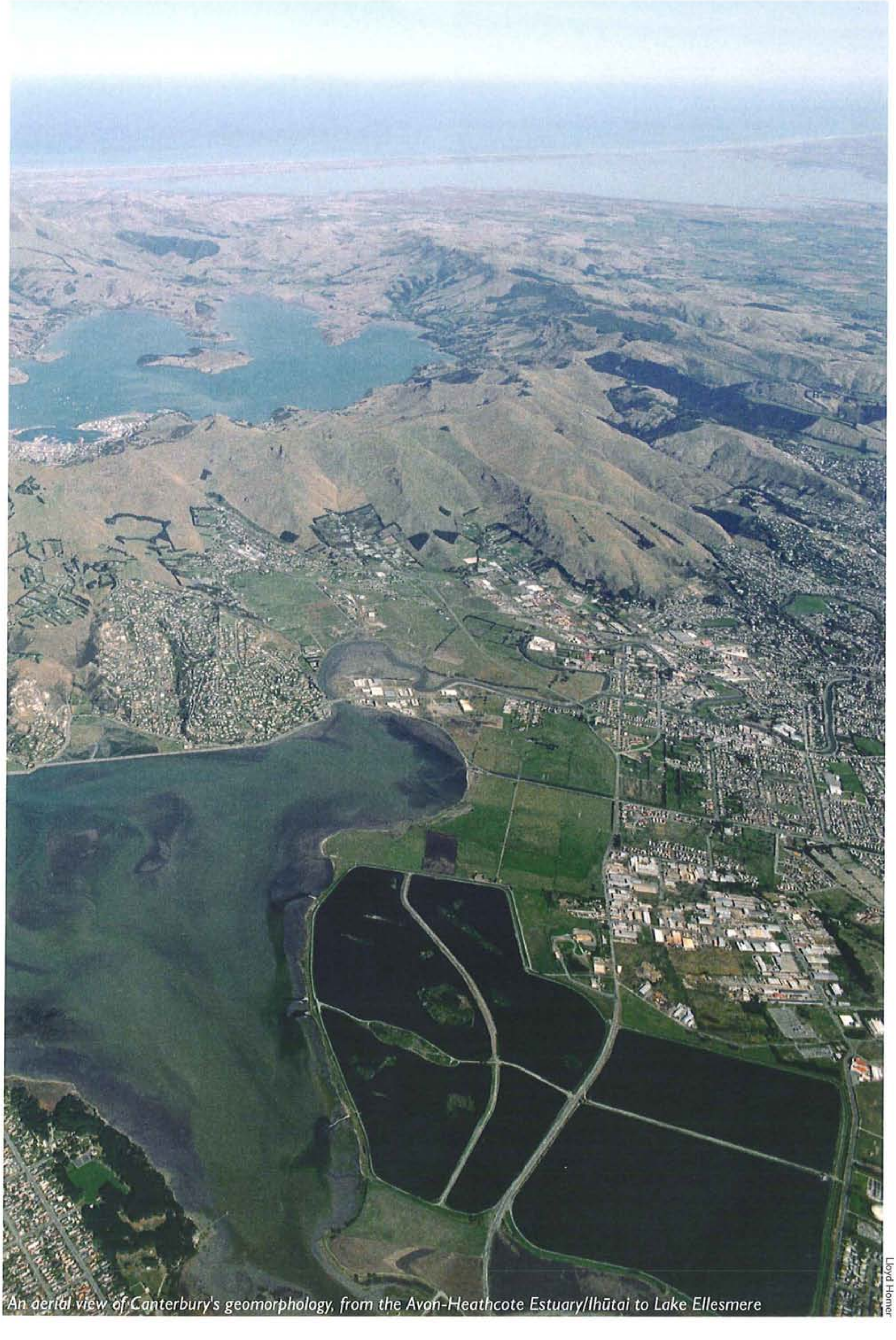


John Walter

4

Soils and Geomorphology of Christchurch



An aerial view of Canterbury's geomorphology, from the Avon-Heathcote Estuary/Ihūtai to Lake Ellesmere

Lloyd Homer

4.1 Introduction

Soils and landforms are an integral part of the urban landscape, forming the foundation for the built and living environment. Soils also act to filter and buffer natural waters in their passage from the atmosphere to surface waterways or to groundwater.

Development of land for urban uses has resulted in significant impacts on soils and geomorphology. The landscape of the Christchurch urban area has been considerably altered by drainage, the shifting of waterways, infilling of hollows, and construction of roads and buildings since its establishment in the 1850's. Figure 4-1 shows the Christchurch mosaic of shallow soils, the related waterway pattern, current roading pattern, and urban boundary. See Webb et al. (1991), for more detailed soil maps.

The Christchurch area showing waterways, wetlands, and vegetation cover present in 1856 is shown on the Black Maps compiled by J. Thomas and Thomas Cass Chief Surveyors. Figure 4-2 (overpage) is a schematic representation of the Black Maps, modified from a compilation in Wilson (1989). Information on the original Christchurch landscape has been compiled by Hercus (1948), Scott (1963), and Wilson (1989).

This chapter describes the evolution of the present surface landform and those near-surface soil types relevant to waterway form and water flow, as well as the impacts of urbanisation on landform and soils.

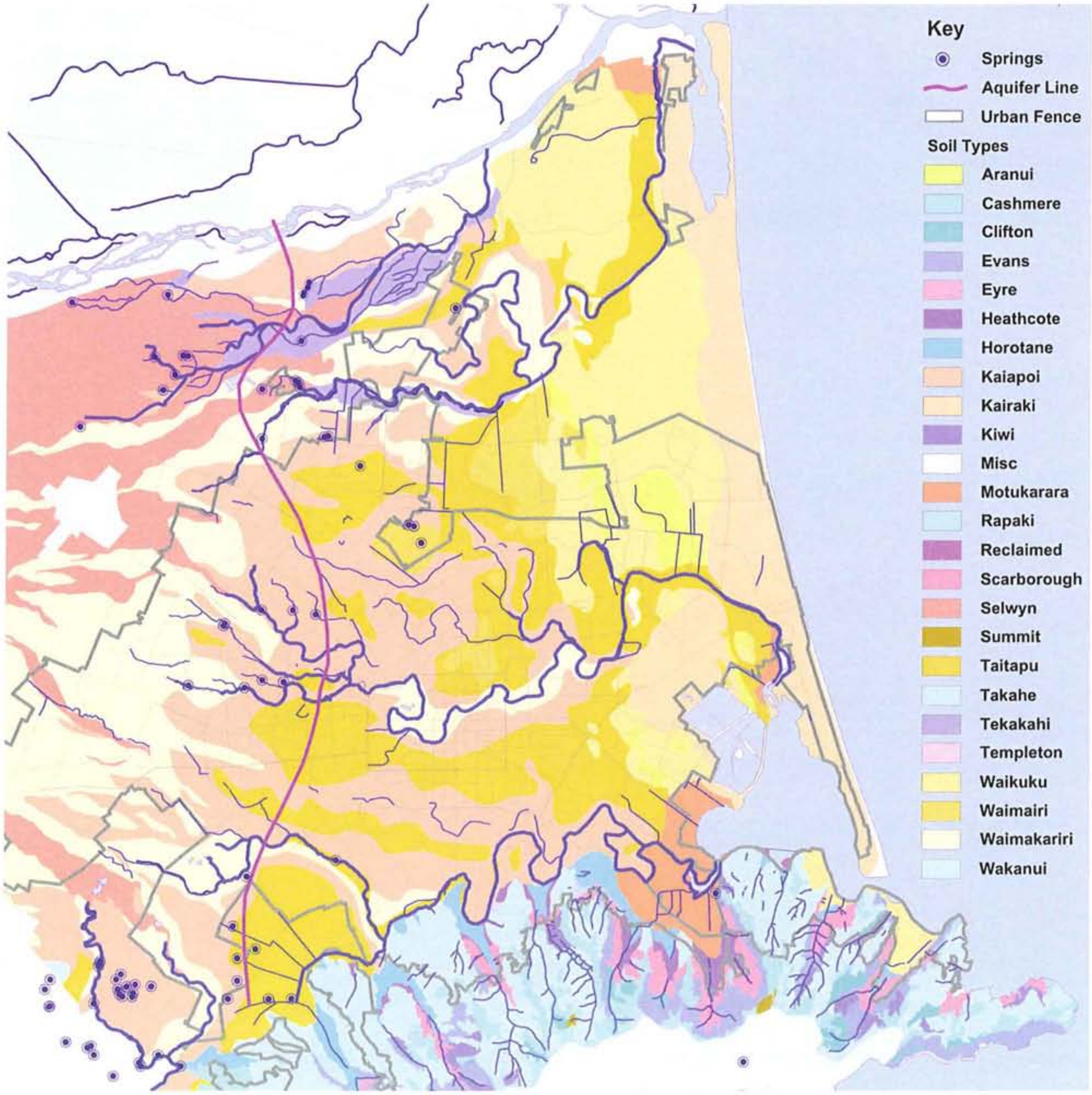


Figure 4-1: Shallow soils found in the Christchurch area. Soils to the west are fluvial in origin, to the east are marine, and in between are a mixture of the two. To the south the Port Hills soils are volcanic in origin, or wind blown loess.

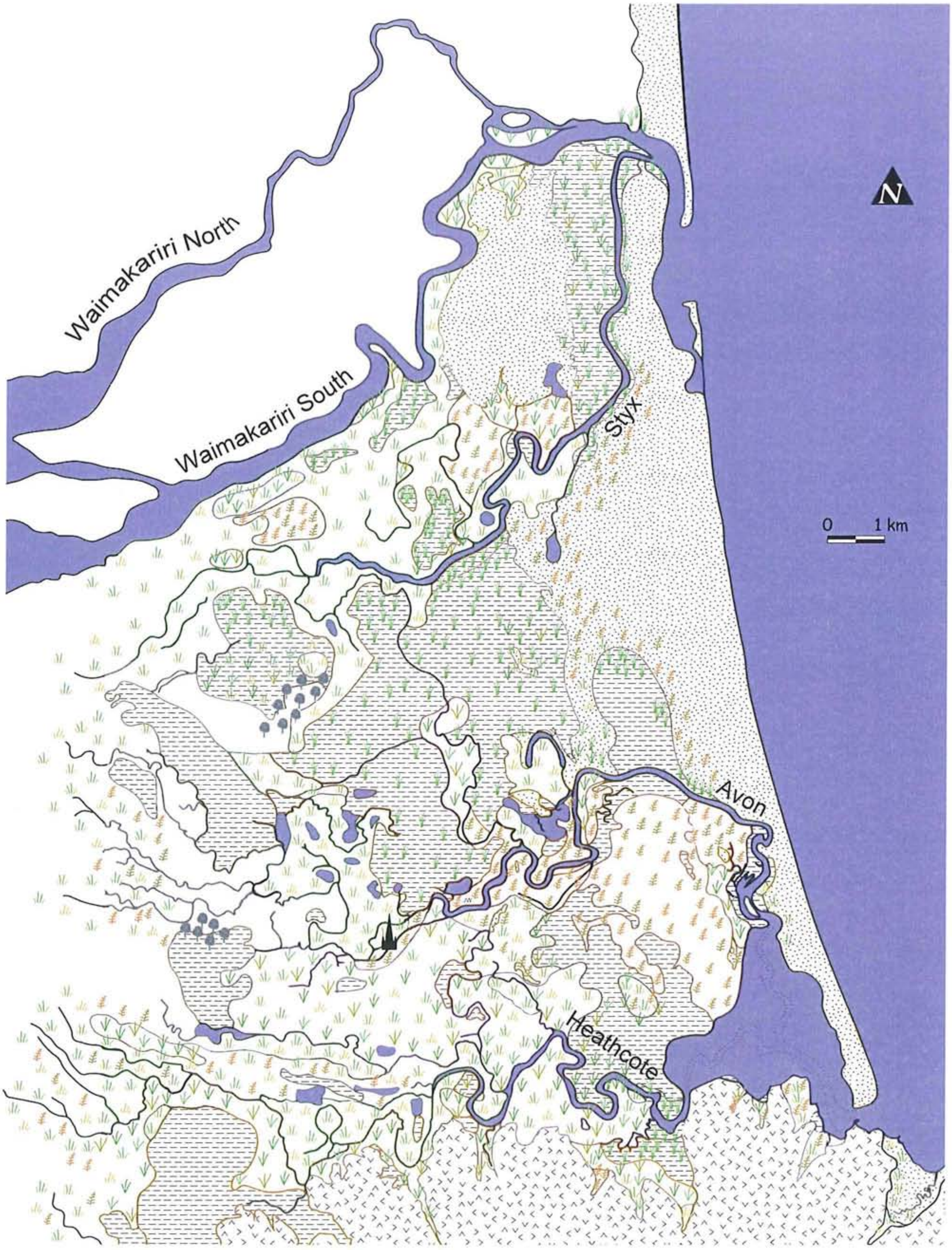


Figure 4-2: Waterways, wetlands, and vegetation cover of the Christchurch region, as at 1856. Modified by J. Walter based on a compilation in Wilson (1989), which was based on the Black Map Rural Section cadastral maps of 1856.

4.2 Geomorphology

Christchurch is located at the southern end of Pegasus Bay on the eastern edge of extensive gravel outwash plains derived from the Southern Alps. The city is built on a very recent low lying coastal margin flanked by the ancient volcanic rocks of Banks Peninsula/Horomaka, with the wide braided riverbed of the Waimakariri River to the north of the city.

Christchurch City lies within an area that was once predominantly swamp, situated behind sand dunes, estuaries, and lagoons. The gravel, sand, and silts of river channels and overbank flood deposits of the Waimakariri River floodplain form the dominant soils, interspersed with areas of peat. Extensive areas of sand dunes and old dune ridges occur throughout the eastern city towards the coast.

The following sections provide a more detailed account of the geomorphology of Christchurch, as modified from Brown & Weeber (1992).

4.2.1 The Port Hills

Between Christchurch city and Banks Peninsula/Horomaka, are the Port Hills (known to tā<u>k</u>ata whenua as <u>K</u>a Kōhatu Whakara<u>k</u>ara<u>k</u>a o Tamatea Pokai Whenua). They are the remnant northern shoulder of an ancient Lyttelton volcano, comprising highly eroded basalt, scoria, and ash layers ranging in age from 9.8 to 12 million years. In the last burst of volcanism on the Peninsula, the Halswell Quarry basalts formed as a side vent of the Charteris Bay volcanics 5.8 million years ago.

The soils of the Port Hills are generally comprised of thin layers of volcanic colluvium, with a coating of the wind-deposited yellow-brown silt, known as loess. Loess occurs predominantly on the lower slopes, but also occurs as outwash materials layered with organic inclusions in the gullies and outwash fans. Loess is typically two metres thick, but can be up to 20 metres thick on more sheltered hillsides and on the detritus toe slopes of the higher ridges. These soils are vulnerable to erosion (Figure 4-3), and consequently soil conservation has become an important issue for managing the Port Hills. Refer to *Chapter 7: Hill Waterways*, for additional information of the characteristics of loess.

4.2.2 Christchurch Lowlands

The lowlands of Christchurch comprise over 90% of the area within the City boundary. Its present surface evolved from the dynamics of the Waimakariri River flood channels, combined with coastal movement due to deposition and sea level rise.

Coast Line Movement and Sea Level Rise

Towards the end of the last glaciation period, sea level rose several metres until about 6000 years ago, when it reached a level very close to the present day level. In the time since, sea level has been relatively static, but the coastline has moved eastwards several kilometres as a result of fluvial and marine deposition. This has led to a succession of beach deposits, sand dunes, estuaries, lagoons, and interdunal swamps. From time to time there have been incursions by the Waimakariri River into the area of marine deposits, resulting in the laying down of alluvial gravel, sand, and silt. Coastal outbuilding or progradation has averaged around two metres per year. The present rate of outbuilding is uncertain because of the difficulty in obtaining measurements on a dynamic shore, but figures from 0.0 to 0.6 m/year have been suggested.

Remnant Waimakariri River Flood Channels

The old flood channels of the Waimakariri River connect with the present day Halswell/Huritini, Heathcote/Ōpāwaho, Avon/Ōtākaroro, and Styx/Pūrākaunui Rivers (Figure 4-1). The flood channels are in most cases entrenched into the surface of the plains, and are mainly infilled with gravel and sand. Higher adjacent areas are covered in silt from overbank flooding. Gravel flood deposits are relatively common in the west of the city, and thin eastwards into sinuous, discrete channel deposits.

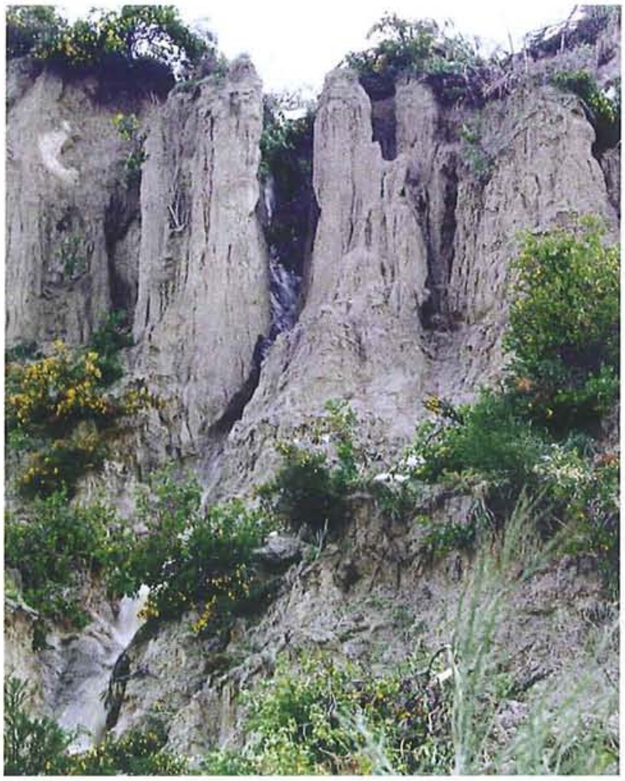


Figure 4-3: Erosion prone loess soils on the Port Hills, Alderson Avenue, 1992.

Lowland Soils

Swamps developed in low-lying areas behind series of coastal foredunes or levees formed by streams. Most of these survived long enough for peat to accumulate. In parts of Papanui/St Albans peat is up to four metres in depth, with shallower areas occurring over much of eastern Christchurch, including pockets within the hillside waterway outwash fans.

Over most of the Christchurch lowland urban area there are generally weak soils with a water table typically one to two metres below the ground surface, which increases to four metres in areas on the western outskirts. Artesian upwelling is a factor to consider when restoring waterways in any location with a shallow water table.

Stratigraphy

The subsurface of lowland Christchurch is formed of alluvial and marine deposits, and includes eight named formations in the upper 150 m. Some of these are permeable gravel formations lying between silty sand aquicludes. It is from these permeable aquifers that the City obtains its water supply and from where spring flows originate. The western limit of the surface confining layer and the general direction of groundwater flow is shown in Figure 4-4.

The upper confined gravel formation (the Riccarton Gravels), was laid down during the last ice age around 70,000 to 14,000 years ago. This gravel aquifer is the primary source of spring water feeding Christchurch's waterways. Christchurch and Springston formations are found above the Riccarton Gravels.

The Christchurch formation consists of dune, beach, estuarine, lagoonal, and coastal swamp deposits made up of gravel, sand, silt, clay, shell, and peat. It extends as far inland as Belfast, Papanui, Riccarton, and Beckenham, and varies in thickness from several metres inland to 40 m at New Brighton. This inland boundary represents the limit of coastal intrusion following several metres of postglacial sea level rise.

The Springston formation consists of postglacial fluvial channel and overbank deposits, accumulated at the inland margin of the Christchurch formation. Deposits are gravel, sand, and silt; the gravel is finer and more permeable than glacial outwash gravels.

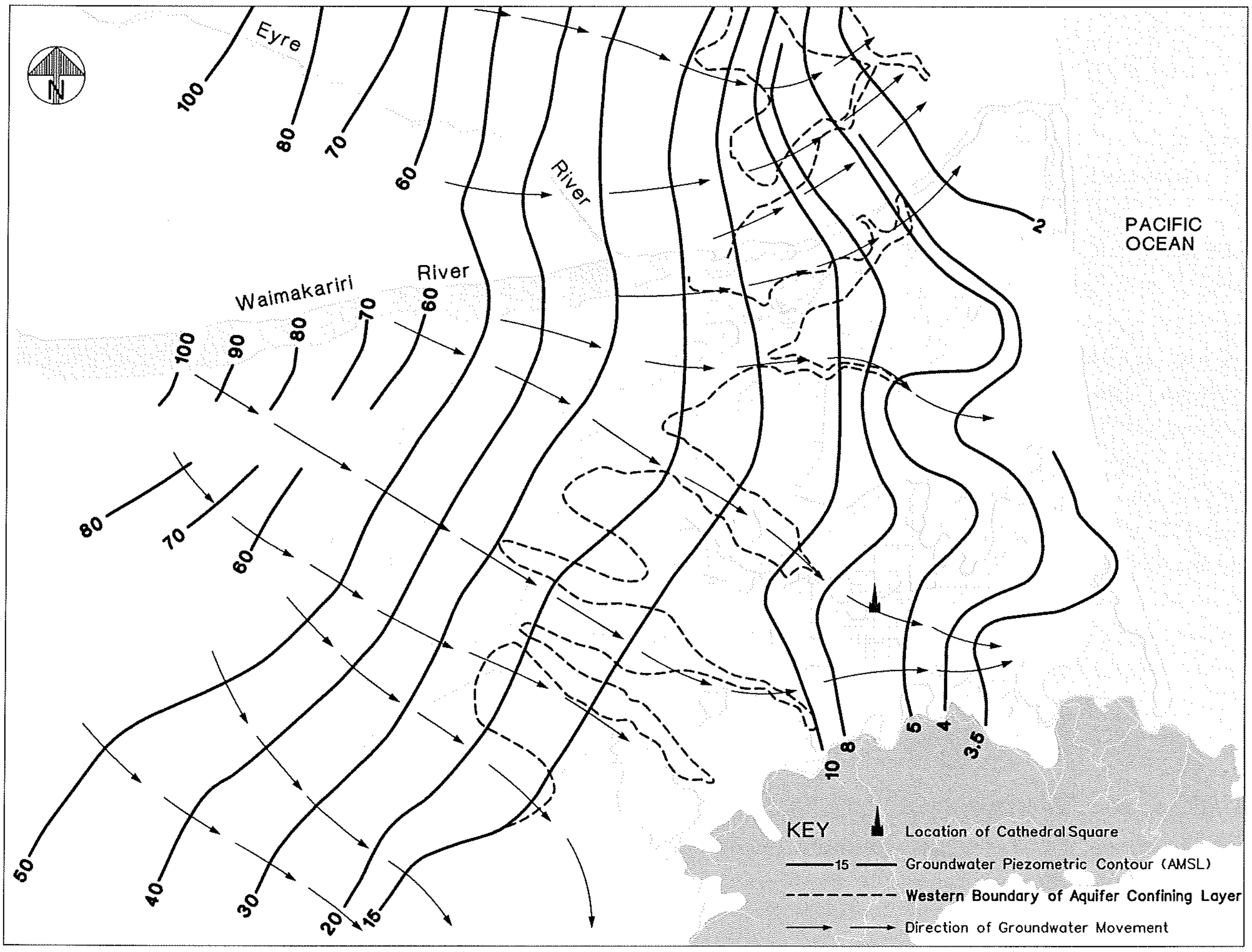


Figure 4-4: Contours of groundwater piezometric surface (in metres above mean sea level) and direction of flow (as at May 1985). Modified from Talbot et al. (1986).

4.3 The Importance of Soils

The nation that destroys its soil destroys itself (Roosevelt 1937).

Soils are substrates at the crossroads between the atmosphere, biosphere and hydrosphere. In this context, the main functions of soil (such as production of biomass; filtering, buffering and transformation between the atmosphere, hydrosphere and biosphere) are of paramount importance central to the design of sustainable systems (Blum 2001).

Healthy soils in urban environments provide similar important functions to those in natural environments:

- provision of mechanical support for plants and structures
- storage of water and nutrients, and regulation of their supply
- neutralisation of pollutants added to the soil to avoid their delivery into aquatic ecosystems
- resistance to erosion
- providing habitat for organisms that play a crucial role in nutrient cycling, soil stability and structural development, water holding capacity, organic matter decomposition, and turnover.

For soils to provide these functions they need to have the attributes of healthy soils, that are un-impacted by urban development. Some of the characteristics of healthy soils include (Basher 2000):

- stable and well developed structure and porosity
- good oxygen and nutrient supply
- acid and base buffering capacity
- organic matter decomposition
- biological processes which provide pathogen destruction, toxic metal and organic compound inactivation and degradation.

Our urban centres are situated where they are for historic reasons: ease of access, availability of natural food and water supplies, and suitability for growing crops. Most are built on relatively flat land and/or close to water (coasts, rivers, and harbours). Hence only the soils and landforms characteristic of these areas are found in our urban centres.

In New Zealand many urban areas are situated on alluvial plains, which coincidentally are some of the most productive soils. As urban populations have grown, cities have spread onto these high-value soils. The resulting permanent loss of these soils to agricultural production continues to be a significant issue for planners, soil scientists, and the community.

Further information on the importance of soils can be found in Basher (2000).

4.4 Impacts of Development on Soils and Geomorphology

4.4.1 Altered Soil Characteristics and Erosion

Soil Characteristics

During urban development considerable modification of soil properties occurs (Bullock & Gregory 1991, Craul 1992, de Kimpe & Morel 2000):

- cutting and filling of slopes
- compaction from the passage of heavy machinery
- an increase in erosion by surface, mass movement, and fluvial processes
- alteration of the soil drainage characteristics, which may increase (by installation of surface or sub-surface drains) or impair (by compaction) surface drainage
- physical or chemical (e.g. heavy metals, and toxic organic substances) pollution
- removal of vegetation cover and covering the surface with impervious materials, resulting in impacts on soil temperature and moisture regimes, organic matter cycling, and reduction in organic matter content and biological activity.

As a consequence of these modifications, typical characteristics of urban soils include (Basher 2000):

- high vertical and spatial variability
- modified soil structure, high bulk density and low structural stability
- the presence of a soil crust on bare soil that is often water repellent
- restricted aeration and water drainage
- modified soil reaction (pH) is usually elevated
- low organic matter and plant nutrients
- interrupted nutrient cycling and modified soil organism activity
- the presence of anthropogenic (caused by humans) materials and other pollutants
- modified soil temperature and soil water regimes.

Sedimentation and Erosion

Average sediment yields of the Avon and Heathcote catchments have been around 35 to 43 t/km^2/yr respectively (as at 1993), values which are typical for mature catchments (Hicks & Duncan 1993). Ignoring entrapment in river channels, these figures suggest input to the estuary of 2,600 t/yr from the Avon River/Ōtākaroro and 4,500 t/yr from the Heathcote River/Ōpāwaho. In both rivers around 99% of the sediment load is carried in suspension, and consists of clay and silt-grade particles. The small bedload component is a mixture of twigs and leaves and medium coarse sand. In the Avon River/Ōtākaroro, the suspended sediment load during storm runoff averages approximately 22% organic material (Hicks & Duncan 1993). This is almost twice the organic load content of the Heathcote's suspended load.

During small magnitude storms, sediment yields from the Avon River/Ōtākaroro are similar to those from the Heathcote River/Ōpāwaho, but during larger events the Heathcote yields quickly outstrip those of the Avon. This pattern reflects increasing sediment production from the Port Hills tributaries, with heavier rain and limited sediment supplies in most of the flat tributaries of the Avon River/Ōtākaroro.

Bank erosion appears to be an important sediment source in the largely urbanised Avon catchment, a situation relic from the early 1900's when much of the drain network in Christchurch had unprotected banks and sediment yields were higher.

The main erosion processes contributing sediment to hill tributaries include slips and tunnel gully erosion. Slips, triggered by heavy rain, tend to occur on steeper slopes. Slips making the largest sediment contributions to waterways tend to occur in road cuts, embankments, driveways, and slopes undercut by streams. Tunnel gullying is a common feature with urban subdivisions, due to concentration of runoff. New subdivisions that have bare ground are susceptible to sheet erosion, rilling and gullying, and are prone to extremely high sediment yields (Figure 4-5). Similar processes occur in areas of market gardens on the lower valley slopes.

Overland flow, silt deposition on roads and footpaths, and blocked drains are some of the effects of these high sediment yields from the Port Hills. However, the main impacts develop when the sediment enters the stream network and affects water quality, in-stream biota, channel sedimentation, and aesthetics. Sedimentation in turn impacts on navigability, flood carrying capacity, and ecology. The bulk of this deposition occurs in the tidal reaches, where the river slopes flatten appreciably and sediment flocculation occurs as fresh water runoff encounters saline water.

The range of soil erosion processes that occur in New Zealand are described in Ministry for the Environment (2001), along with suggested control methods, many of which are directly applicable to Christchurch. Guidelines on erosion and sediment control for land disturbing activities are contained in Auckland Regional Council (1999).

Figure 4-5: The urban development of Westmoreland caused severe ongoing problems with deep erosion of loess soils from the 1970's (above left) to the 1990's (above right).

4.4.2 Altered Geomorphology and Hydrology

Construction activities during urban development result in major changes to the natural geomorphology and hydrology of the surrounding landscape, some of which become permanent features. Topography is reshaped by the cutting and filling to lower slope gradients in order to form smooth, even slopes. The hydrological regime can be altered by the following factors (Basher 2000):

- increasing land surface imperviousness causing a decrease in infiltration and increase in runoff
- modifying drainage patterns and density, and the timing and volume of runoff
- draining wetlands that act as ponding areas
- removing vegetation, which alters interception and evapotranspiration rates of water.

Consequently slope, channel form, timing and runoff volume, and erosion processes and rates are altered.

An increase in imperviousness (roads, footpaths, car parks, and roofs) with urban development is one of the key influencing factors in determining runoff characteristics. In addition, many areas with pervious cover are so compacted, with poor soil structure and low infiltration rates and permeability, that their runoff response is similar to impervious surfaces.

McConchie (1992) reviews the impacts of urban development on hydrology, which are also outlined in *Chapter 2: Impacts of Development*.

4.5 Minimising Impacts on Soils and Geomorphology

To minimise impacts of urbanisation on soils and geomorphology consider the following points (based on Basher 2000):

- preserve natural runoff systems and maximise use of natural channels and detention areas
- minimise imperviousness
- minimise cutting and filling
- avoid or remedy trafficking by heavy machinery
- retain or improve existing vegetation (especially near watercourses)
- utilise riparian buffer strips
- maintain the natural soil organic matter and biological activity
- avoid development on steep slopes, erodible soils, and directly adjacent to watercourses.

4.6 Soils as a Basis for Urban Planning

Soils and geomorphology make up the foundation for the built and living environment. Therefore soil assessment is fundamental to urban planning and restoration.

Analysis of the soil properties and distribution should be a key element in assessment of land suitability for urban development. Such analysis should also be incorporated as part of the appropriate management techniques used during development.

Knowledge of soil properties and soil distribution can be used to direct development to those soils most suitable for urban use and least suitable for food production, to plan ecologically sensitive urban development, and as a basis for ecological restoration at both the site and landscape scales.

At the more detailed scale, site assessment and the interpretation of soils can be used to plan ecologically sensitive urban developments (the "designing with the land" concept), by using natural or modified soil characteristics to provide functions such as stormwater ponding and drainage, and pollutant removal. Interpretation is dependent on intended use and may require the following:

- identifying soils with appropriate characteristics
- amending the existing soil materials
- designing a topsoil or entire soil
- importing topsoil.

Site assessment requires evaluation of appropriate parameters including:

- Soil morphology: natural or disturbed materials, depth to bedrock, water table depth, mottling, depth to restrictive layer, soil structure, texture, and soil crusting.
- Physical characteristics: particle size, bulk density, penetration resistance, infiltration rate, hydraulic conductivity, and dispersion.
- Chemical characteristics: pH, macronutrient and micronutrient levels, cation exchange capacity, electrical conductivity, heavy metals, and organic contaminants.
- Biological characteristics: the type, decomposition, and amount of organic matter, faunal biodiversity, and biological activity.

4.7 Soils as a Basis for Ecological Restoration

The urban landscape can be broken into distinctive assemblages of landforms and soils, which reflect age and origin, have a direct relationship with naturally dominant vegetation and wildlife habitat, and can be used as a basis for ecological restoration.

Site assessment should be used to ensure the planting technique and species selection are appropriate at the individual site scale. These principles are being used as a basis for planning ecological restoration in Christchurch (Lucas et al. 1995, 1996a, b, 1997).

Christchurch City can be divided into three main landform types: volcanic hills, alluvial floodplains and terraces, and coastal plains: and each of these can be further subdivided according to age, parent material texture, drainage, and soil type (Table 4-1). These subdivisions provide the basis for interpreting plant habitats from soil characteristics, as well as providing guidance or revegetation. Refer to Lucas et al. (1995, 1996a b, 1997).

Table 4-1: Ecosystems of Christchurch (after Lucas et al. 1995, 1996a, b, 1997).

Landform Type	Landform Component	Soil Description	Soil Mapping Unit	Ecosystem
Volcanic Hills	dry rocky ridges	shallow soils from volcanic rock	Cashmere	Korokio
	crests and shoulder slopes	well drained moist soils from loess	Summit	Kotukutuku
	mid-elevation, gentle slopes	deep soils from loess colluvium	Takahe	Silver tussock
	steep rocky bluffs	deep, well drained soils from volcanic rock and colluvium	Evans	Porcupine shrub
	steep lower slopes	moist, deep soils from loess colluvium	Kiwi	Mikokoi
	well drained slopes	moist, deep soils from loess from volcanic colluvium	Clifton	Horoeka
	toeslopes and gullies	very moist, deep soils from loess colluvium	Heathcote	Matai
	valley floors and seeps	deep, poorly drained soils	Horotane	Kaikomako
Alluvial Floodplains and Terraces	floodplains	shallow, droughty soils	Selwyn	Tussock
	young terraces	deep, moist soils	Selwyn	Kowhai
		shallow, droughty soils	Waimakariri	Ti Kouka
		deep, moist soils	Waimakariri	Houhere
	older terraces	deep, moist soils	Kaiapoi	Totara
		deep, poorly drained soils	Taitapu, Te Kakahi	Kahikatea
Coastal Plains	young dunes	droughty, raw soils	Kairaki	Pingao
	old dunes	droughty, weakly developed soils	Waikuku	Akeake
	coastal peat plains	organic soils	Waimairi, Aranui	Puko
	estuarine plain	poorly drained, salty soils	Motukarara	Oioi

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