HYDROGEOMORPHOLOGICAL IMPACTS OF LAND USE CHANGES ON THE KIEWA CATCHMENT

Notes for the mid-conference field trip, 11th ANZGG conference, Mt Buffalo
16 February 2004

ANZGG Occasional Paper No 4
ISBN 0-9751909-3-8
Authors: Ruth E Lawrence, Sandra O Brizga & Meredith Orr
Printed by Media Services, La Trobe University, Bendigo

BRIEF ITINERARY

8 a.m. Depart Mt Buffalo Chalet

Brief discussion of land use issues in the Upper Ovens Valley (Site 1: drive past: Ruth Lawrence)
Site 2 stop at Tawonga Gap - discuss relief characteristics of the Bogong High Plains section of the Australian Alps (Meredith Orr)
Travel through the township of Mount Beauty and into the Upper Kiewa Valley
Site 3 stop at Mountain View Lookout - discuss the role of the Kiewa Hydro-Electric Scheme in developing and altering the hydrology of the Upper Kiewa Valley (Ruth Lawrence)
Continue into the Upper Kiewa Valley - discuss environmental gradients, the role of fire on different vegetation types and issues associated with logging (Site 4: drive past: Ruth Lawrence)
Travel on to the Bogong High Plains
Site 5 visit an unburned section of the Bogong High Plains- discuss issues relating to cattle grazing activities, particularly the hydrological and geomorphological impacts of 150 years of summer grazing by stock (Ruth Lawrence)
Return to Falls Creek and drive through the village - discuss issues relating to planningand urban hydrology in the subalpine zone (Site 6: drive past: Ruth Lawrence)

LUNCH on the shores of Lake Guy at Bogong township

Return to Mount Beauty and drive past the Regulating Pondage
Travel north along the valley of the Lower Kiewa River
Site 7 stop examining the geomorphological characteristics of the Lower Kiewa River between Mount Beauty and Gundowring - discuss river management issues (Sandra Brizga)
Site 8 stop downstream of Gundowring examining channel avulsion characteristics and further river management issues (Sandra Brizga)
Discussion of the role of mining in the Yackandandah area on the redistribution of alluvial deposits (Site 9: drive past: Sandra Brizga)

Return to Mt Buffalo Chalet about 6.30 p.m.

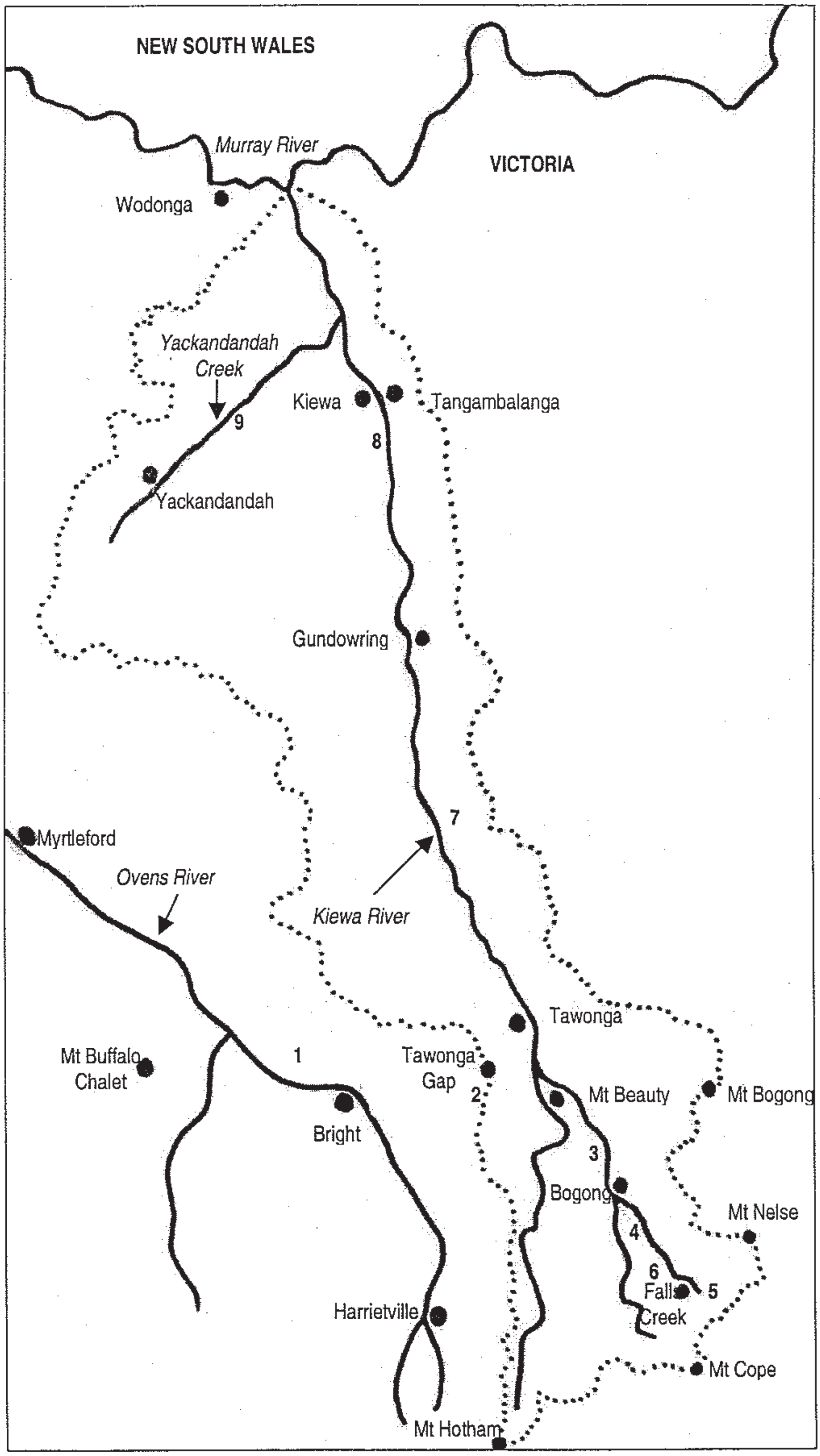


FIGURE 1 Location of sites visited

SITE 1 (drive past) – UPPER OVENS RIVER

The first major river we encounter on this field trip is the Ovens River, which is a major tributary of the Murray River. At the first crossing at Porepunkah, the Ovens River is a braided stream with a course gravel base set in wide floodplain. About 20 km upstream, at the second crossing at Bright, the Ovens River flows through a deep entrenched canyon cut to bedrock. The township of Bright marks the emergence of the Ovens River from the uplands to the extensive floodplain zone downstream.

There is one anthropogenic factor that greatly influences the fluvial geomorphology of the Upper Ovens Valley: mining. Gold has been mined from the Valley since 1852 by a variety of methods including panning, cradling, shallow shaft sinking, ground and hydraulic sluicing, reef mining and bucket dredging. Extensive hydraulic sluicing scars are evident in the Buckland tributary to the Ovens River. Bucket dredging of the auriferous alluvial deposits between Bright and Harrietville was common during the first half of the twentieth century, and remnant dredge ponds and huge mullock piles are common near Harrietville (Figure 1). The impacts of this industry on the fluvial system were extensive:

- Large volumes of sediment were dislocated & redeposited, which ultimately led to the establishment of the Sludge Abatement Board in 1905 in an attempt to alleviate the problem;
- Water quality was poor, necessitating the operation of many pubs and cordial factories;
- Heavy metal pollution was, and remains, a notable problem in the Valley, as the release or use of metals such as arsenic and cyanide have produced some of highest readings in Victoria even today; and
- The existence of The Canyon at Bright is a result of entrenchment of the Ovens River associated with mining upstream and adjacent to the site.

The softwood forestry industry commenced near Bright in the 1890s. Initially, pines were planted on mine-affected (usually dredged) lands and later extended to the foothills. The pine plantations are harvested and utilised by a timber mill at Myrtleford (Figure 1). At some sites, a third successive crop of pines has recently been harvested, and was found to be barely payable. Gullying is found throughout the hillside pine plantations.

Tobacco farming occurs in the Lower Ovens Valley. Tobacco is legally sold to the 'big cigarette' factory in Myrtleford, and illegally sold as part of the 'chop chop trade' on back-country lanes and farms. (There are several outstanding murder investigations associated with the chop chop trade). Tobacco crops serve to break down soil structure and cause floodplain instability.

The Ovens River is one of the last unregulated rivers in the Murray – Darling Basin. Extensive wetlands exist along the course of the lower valley, although most are privately owned and used for grazing at present. At Wangaratta, the King River joins the Ovens River and both rivers have a substantial snowmelt component to their spring flows. When high snowmelt runoff coincides with high rainfall during the spring months, flooding of urban and industrial sites at Wangaratta occurs.

SITE 2 - TAWONGA GAP LOOKOUT

Tawonga Gap is located on the boundary between the Ovens and Kiewa catchments. This stop will introduce you to the Australian Alps (Figure 2), a region unusual in Australia as steep rugged topography has developed during the Cainozoic period. It contains almost all of the alpine and subalpine environments, and the highest land elevations, of the Australian mainland.

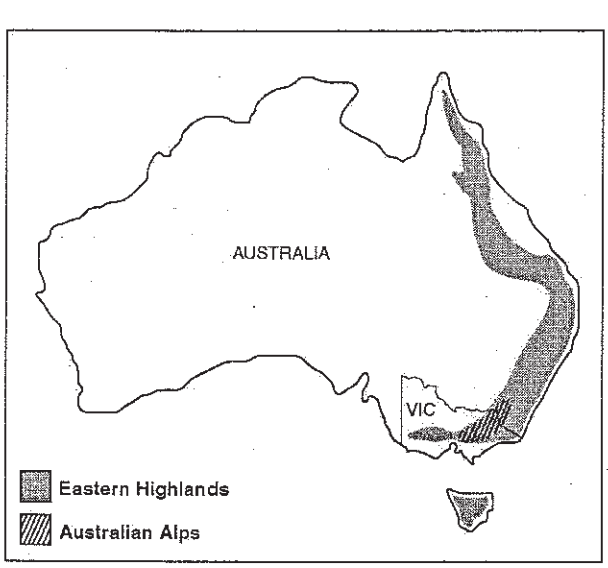


FIGURE 2 Broad distribution of the Australian Alps and Eastern Highlands. Source: Orr (1999).

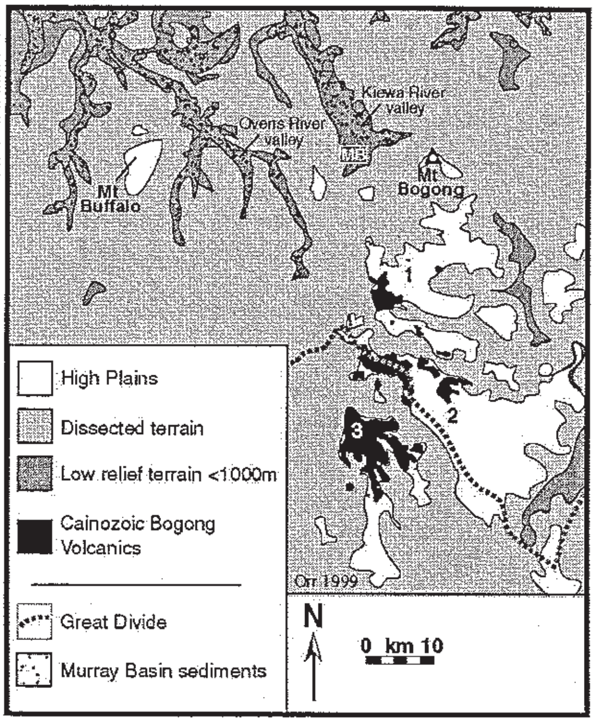


FIGURE 3 Land surface types in the Mt Buffalo and Bogong High Plains region.
1 = Bogong High Plains; 2 = Cobungra High Plains; 3 = Dargo High Plains; MB = Mount Beauty.
Adapted from Orr (1999).

In eastern Victoria, the Alps are higher than the general level of the Eastern Highlands and are more deeply dissected. High relief occurs both at the highland margins and at the continental divide. Some valleys are over one kilometre in depth, including the Kiewa River East Branch valley seen here, which is over 1500 m deep near Mt Bogong.

In addition to the steep dissected terrains, low relief and high elevation "high plains" surfaces exist. The Bogong, Cobungra and Dargo High Plains occur in this area (Figure 3). They occur at elevations between 1300 and 1880 m elevation, and have the appearance of a dissected plateau. Local high plains relief is generally below 200 m. The topography is flat to undulating, with some isolated hill tops.

Remnants of Cainozoic lavas, known as the Bogong Volcanics, overlie the high plains in part. These lavas have been dated by K-Ar methods as around 36 Ma to 30 Ma.

Tawonga Gap overlooks the Kiewa River valley, at the boundary between Quaternary alluvium and the high country of the Australian Alps. The Tawonga Fault is located at this boundary (Figure 4), and it separates the low peaks of the highland foothills from the high peaks of the Australian Alps. The fault is known to have thrust gneissic bedrock over unconsolidated sediments at the boundary (Beavis 1960), and it may also be responsible for an elevated block of land to the south (Figure 5).

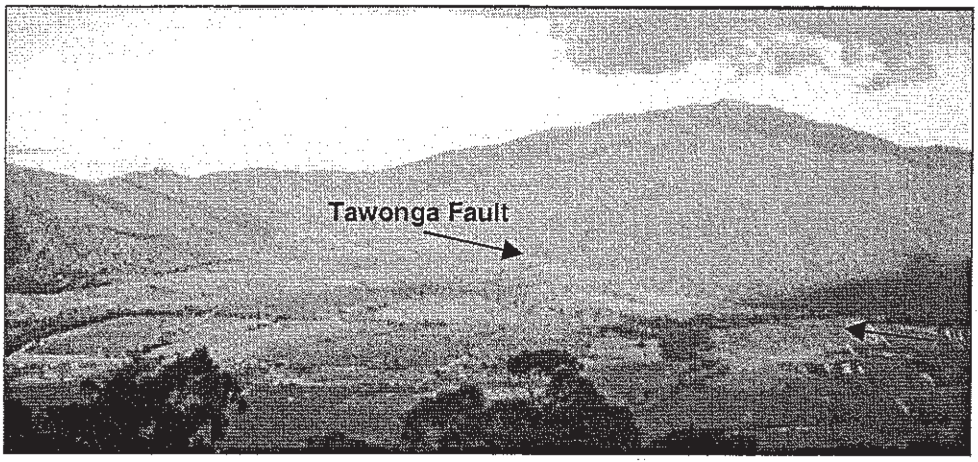
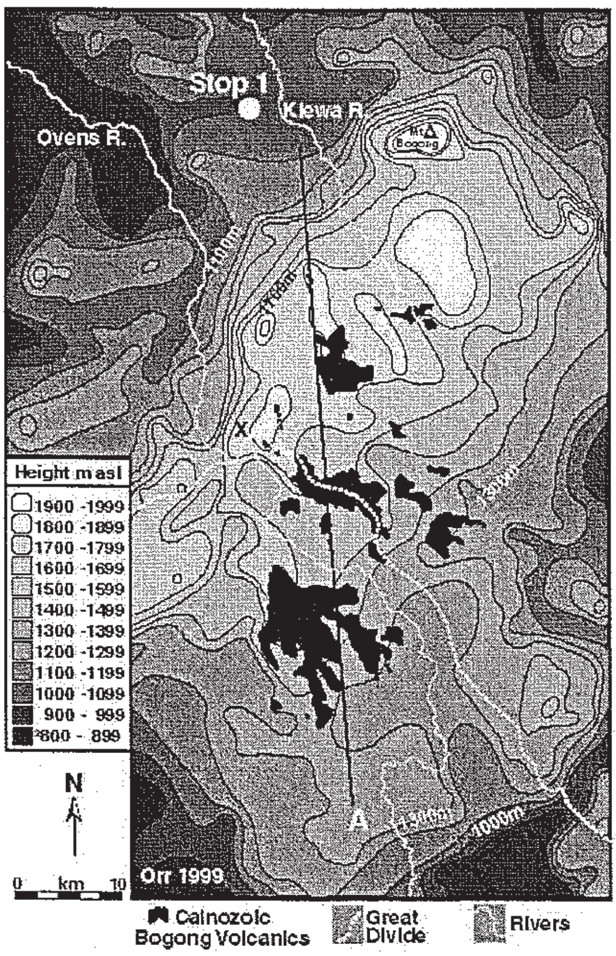


FIGURE 4 View of the upper Kiewa River valley with the position of the Tawonga Fault indicated. Mt Bogong (1986m a.s.l.) is the highest peak visible. Photo by Meredith Orr.



A total of 548 watershed peak heights were plotted for the area shown in Figure 4. These heights were contoured at 100m intervals to produce the peak height contour map. The contours define a large north-easterly oriented zone above 1100 m, bounded by abrupt linear changes in height on the north-western and south-eastern sides. These correspond to the positions of the Tawonga and Livingstone Creek Faults respectively. The map is interpreted as indicating a broad north-easterly oriented fault bound block, with major boundaries along the Tawonga and Livingstone Creek Faults.

These faults have apparently controlled the nature, rate and timing of about two-thirds of the Cainozoic (post-volcanic) stream incision of the areas upstream (Orr 1999). About one-third of the stream incision comes from sources downstream of the faults. The degree of Cainozoic tectonic disruption and erosion in this landscape is unusual compared to the rest of the Australian Eastern Highlands.

FIGURE 5 High plains region peak height contour map. Source: Orr (1999).

SITE 3 - KIEWA HYDRO-ELECTRIC SCHEME

This stop will highlight the role of the Kiewa Hydro-Electric Scheme in the development and use of waters in the Upper Kiewa Valley. Sites associated with the Kiewa Hydro-Electric Scheme visible adjacent to the Upper Kiewa Valley Road include:

- Mount Beauty Regulating Pondage designed to regulate flows from the Hydro Scheme into the Lower Kiewa River;
- Township of Mount Beauty established to house construction workers for the Scheme;
- Pipeline feeding water from the Rocky Valley and Pretty Valley storages to the McKay Creek Power Station (we will be stopping to view this);
- Clover Dam and Clover Power Station: the second and smallest power station in the Kiewa Hydro-Electric Scheme (Figure 6);
- Township of Bogong established to house construction workers for the Scheme (partially burnt by the 2003 fires);
- Pretty Valley Stream crossing: carries its own flow and water diverted from the Rocky Valley Stream via the McKay Creek Power Station;
- Rocky Valley Reservoir: the head storage reservoir for the Scheme; and
- Watchbed Creek gauging station.

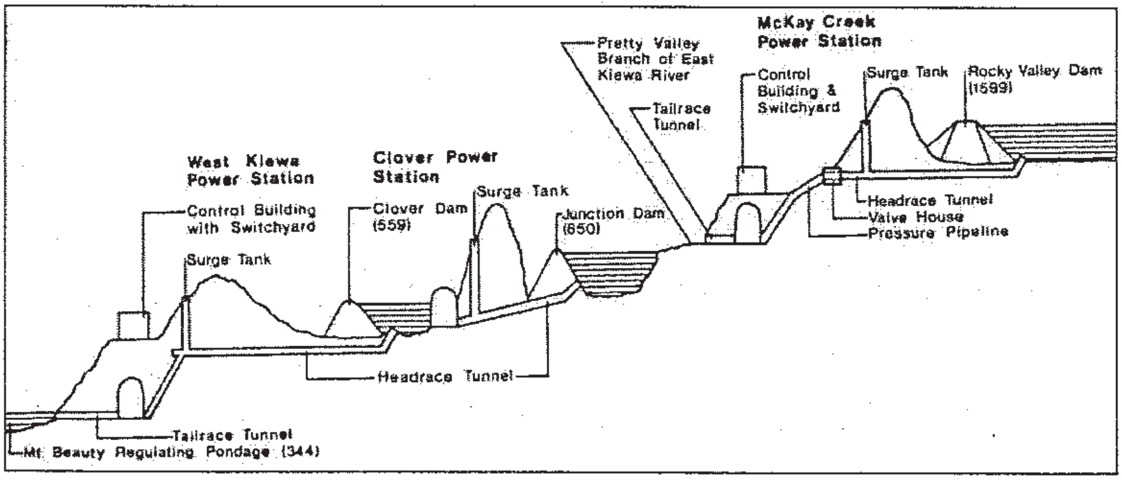


FIGURE 6 *Cross section of the Kiewa Hydro-Electric Scheme.*
Numbers in brackets are elevation in metres. Source: Lawrence (1990)

The Hydro Scheme

The Kiewa Valley is eminently suited to the production of hydro-electric power generation due to the following factors:

- The geomorphology of the area comprises high plains with average slopes of 1 : 120 suitable for water storage adjacent to steeply dissected valleys with a high stream gradients of 1 : 15 suitable for water diversions into pressure tunnels feeding power stations (Figure 6);
- The geology of the area is stable - the majority of the area is underlain by metamorphic rocks of predominantly granodiorite, gneiss and schist; and
- Water volumes generated from the area is high, as the Kiewa River boasts the highest ratio of runoff to catchment area of any of the Murray River tributaries.

Construction of the Kiewa Hydro-Electric Scheme occurred between 1938 and 1962, and predates the Snowy Mountains Hydro-Electric Scheme by about fifteen years. It originally serviced the electricity needs for all north-eastern Victoria, but today provides an insignificant amount of power to the national grid, and is utilised only at times of peak demand. The Scheme played a major role in developing other land uses such as silviculture and tourism.

Hydrological analysis

The hydrological record for the Upper Kiewa Valley is impressive. Stream gauges were first installed in 1925 and a total of twelve gauges have been operational at various times to the present. Lawrence (2001) examined the impacts of three aspects of construction activity on the hydrological characteristics of the Upper Kiewa Valley.

- Construction of the Pretty Valley Reservoir (which was later downsized to the Pretty Valley Pondage) to provide water storage for the McKay Creek Power Station resulted in statistically significant increases in stream flow and storm flow runoff.
- Construction of a tunnel feeding water from Rocky Valley Reservoir to the McKay Creek Power Station did not produce discernable hydrological variations.
- Surface construction works at multiple sites in the Pretty Valley and Rocky Valley Stream catchments also resulted in statistically significant increases in both stream and storm runoff, particularly during months of snow accumulation and snow melt.

The elevated stream and storm runoff associated with the general surface construction works were sustained for at least thirteen years. Lawrence (2001) demonstrated that the mean annual increase in runoff due to construction activities was 243 mm and 377 mm for Rocky Valley Stream and Pretty Valley Stream respectively. It is not known for how long the elevated runoff continued as the relevant stream gauges were drowned in 1959.

SITE 4 (drive past) - UPPER KIEWA VALLEY

Environmental gradient

An outstanding example of an environmental gradient is seen on the drive from Mount Beauty township (on the Tawonga Fault) to the Bogong High Plains, as depicted in Figure 7. The following changes are noted in the ascent from Mt Beauty to the Bogong High Plains:

- Elevation rises from 300 m at Mt Beauty to 1800 m beyond Rocky Valley Reservoir;
- Mean annual precipitation rises from 1100 m at Mt Beauty to 2250 m on the Bogong High Plains;
- Mean annual temperature drops from 16°C at Mt Beauty to 5°C on the Bogong High Plains;
- Soils typically grade from sandy loams to highly organic and friable loams (although local variation is pronounced); and
- Vegetation changes from open forest species (Peppermint, Box, Gum, etc.) between 300 and 800 m, to stands of continuous Alpine Ash (*Eucalyptus delegatensis*) between 800 and 1200 m, to stands of continuous Snow Gum (*Eucalyptus pauciflora*) between 1200 and 1500 m, to a mosaic of Snow Gum woodlands, heathlands, grasslands and peat bogs above 1500 m.

The distribution of vegetation on the plateau area of the Bogong High Plains is determined by the complex interaction of moisture storage in waterlogged valley sites, cold air drainage producing an inverted tree line, and past and present disturbance factors such as fire and grazing (Lawrence 1999).

Fires in the Upper Kiewa Valley

Fire has played a role in shaping the present distribution and characteristics of vegetation. Parts of the Upper Kiewa valley were burnt in 1901, 1914, 1923, 1926, 1932, 1939 (Lawrence 1999) and 2003. The ecological and hydrological response of each vegetation community to fire is as follows:

- Open Forest species are generally fire-adapted species that produce epicormic sprouting following fires. Studies elsewhere in south-eastern Australia have shown runoff will increase and display flashiness for one or two years following fire, but fire-effects do not tend to persist for more than a few years.
- Alpine Ash (*E. delegatensis*) forests are fire-dependent: fire kills Alpine Ash trees but then produces an ash bed that is required for seedlings to germinate. However, seed is only produced when trees reach maturity, which is generally around 80 to 100 years. If a fire burns an immature Alpine Ash forest, vegetation succession usually results. Most of the trees in the Upper Kiewa valley date to either the 1926, 1932 or 1939 fires, and had not reached maturity when burned in 2003. It is planned to aerially seed the burnt Alpine Ash forests in the Upper Kiewa Valley to maintain this community. Other studies on Ash species have demonstrated runoff will increase and display flashiness for four or five years following fire, but then decline markedly for several decades until the trees reach maturity.
- Snow Gum (*Eucalyptus pauciflora*) woodlands are fire-adapted: they regenerate from lignotubers following fire. The prolific lignotuber growth stands as a stark contrast to the blanched branches of the fire-affected tree for many years. Some studies have demonstrated Snow Gum woodlands display altered stormflow characteristics following fire, although evidence of this in catchments on the Bogong High Plains were muted.

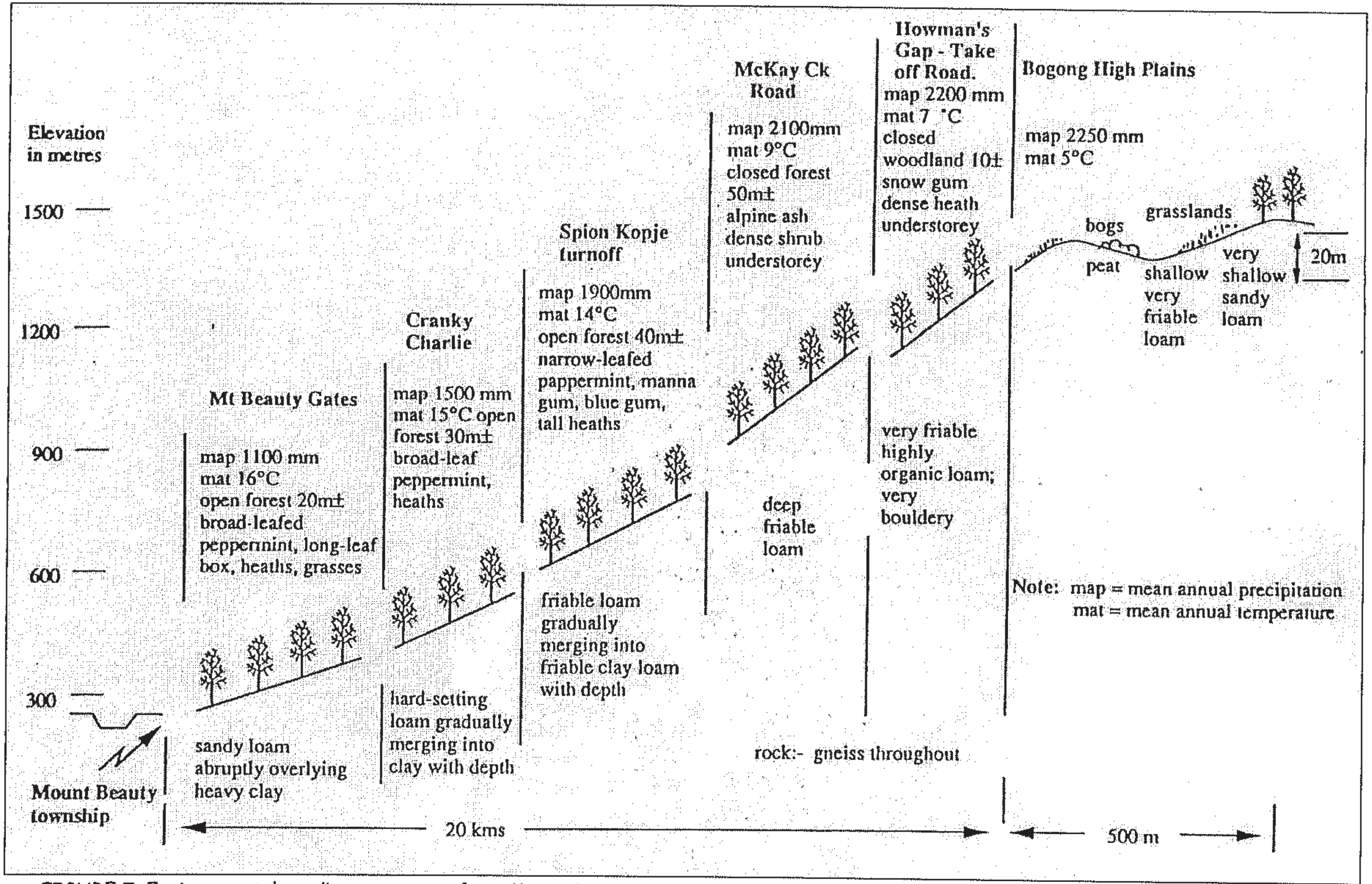


FIGURE 7 Environmental gradient sequence from Mount Beauty township to the Bogong High Plains. Source: Alpine Ecology Course notes

- There is an inverse relationship between the proportionate cover of heathland and grassland communities on the Bogong High Plains depending on time since fire. In the absence of fire or other disturbance factors (such as grazing), grasslands will dominate in the alpine and subalpine zone. However, if a fire (and/or grazing) occurs, heathland communities will be established where grasslands previously existed. Heathland plants on the Bogong High Plains germinate following fire, will persist for several decades, and senesce after 60 to 80 years. Once senescence occurs, grassland communities will again dominate. There have not been any hydrological investigations examining the specific role of heathland - grassland dynamics of runoff.
- Bog communities are usually resistant to fire due to their high moisture content. However, if a bog is degraded (due to grazing, for example) they may become vulnerable to fire and catch alight. Once the bog and underlying peat starts to burn, it is very difficult to extinguish the fire and the peat may smoulder indefinitely. Healthy bogs are an important hydrological regulator of both volumes, timing and quality of runoff. Catchments with much bog cover produce good-quality, high-volume, sustained runoff, whereas degraded bogs generate flashy runoff. Most catchments on the Bogong High Plains display some level of degradation and don't store the volume of water they may have over 150 years ago.

Silviculture & sediment dams

The Alpine Ash forests of the Upper Kiewa Valley have been progressively logged since 1960. When all the Alpine Ash forest in the West Kiewa Valley had been harvested and the Mount Beauty Timber Mill sought to access the Alpine Ash in the East Kiewa Valley in the 1980s, the State Electricity Commission (S.E.C.) objected. The S.E.C. argued that sediment generated from the logging operations in catchments feeding water into the Hydro Scheme power stations would compromise the efficient operation of their turbines. This was a great irony, given the accelerated levels of runoff and erosion the S.E.C. themselves produced when constructing the Kiewa Hydro-Electric Scheme. Nevertheless, a experimental logging operation was undertaken in several catchments upstream of the Clover Power Station, and Leitch (1982) demonstrated natural variation in sediment production was greater than demonstrable changes due to logging operations. The Mount Beauty Timber Mill was then given access to the timber in the East Kiewa Valley, but only after several sediment dams were constructed on the East Kiewa River upstream of the Clover Power Station. In late 2002, the Mount Beauty Timber Mill ceased operations.

SITE 5 - HIGH COUNTRY GRAZING

The Bogong High Plains has had a long and tortuous association with the high country grazing industry. Europeans 'discovered' the Plains immediately after the 1851 bushfires when graziers were seeking feed for their stock. High country grazing on the Bogong High Plains has continued since that time, albeit with the following highlights and trends:

- Stock are depastured on the Bogong High Plains each summer between mid-December and April (although in the past, stock sometimes grazed the Plains for up to eight months);
- Stock are allocated to specific 'grazing runs', but runs are not fenced, and graziers attempt to keep stock within their runs through the use of salt licks;
- Today only cattle are permitted to graze the area, whereas sheep, horses and cattle were regular visitors to the Plains until the mid 1940s;
- Cattle grazing the Bogong High Plains today number about 2000, whereas numbers in the past were a lot higher (for example, in the drought year of 1884/85 numbers reached 20000 sheep and an indeterminate number of cattle, and in 1902/03 - another drought year - numbers reached 40000 sheep and several thousand cattle);
- Government management of high country grazing activities was virtually absent until the 1940s, when limits on the type and timing of stock grazing were introduced;
- Based on estimated grazing numbers, grazing densities were probably over 1000 cattle per hectare during selected years between the 1860s and 1930s, whereas grazing densities in the late 1940s were around 200 cattle per hectare and at present are less than 25 cattle per hectare (based on known grazing numbers); and
- Several fences have been erected since the 1950s to protect certain areas from grazing.

Concern for the impacts of grazing on the environment of the Bogong High Plains was first expressed by the S.E.C. in the early 1940s. The 1943 Annual Report for the S.E.C. recorded:

> Because of deterioration of the catchment which resulted from uncontrolled grazing, and the periodical burning of grass by cattlemen to promote fresh growth, the Commission, in 1943, drew the attention of the Soil Conservation Board [later Authority] to the circumstances.

This led to the establishment of some exclusion plots on the Bogong High Plains that were established in 1945, which have been continuously monitored to the present. Results from those ecological studies have consistently demonstrated detrimental effects of grazing on floristic composition and cover. Figure 8 depicts the changes in vegetation that occurred during the unregulated era of high country grazing and Figure 9 illustrates the post-mid-1940s vegetation succession that has been demonstrated in the exclusion plots. Not all areas of the Bogong High Plains have followed the scenario presented in Figure 9. Stock numbers on the Bogong High Plains in the early 1940s were around 10000 cattle and today are at about 2000 head. In areas where grazing has continued since the mid 1940s, changes in the floristic composition has generally reached Stage 2 in Figure 9.

The 2003 fires will serve to recommence the sequence of vegetation succession shown in Figure 9 but the rate of succession will be depend on grazing levels over the next few decades.

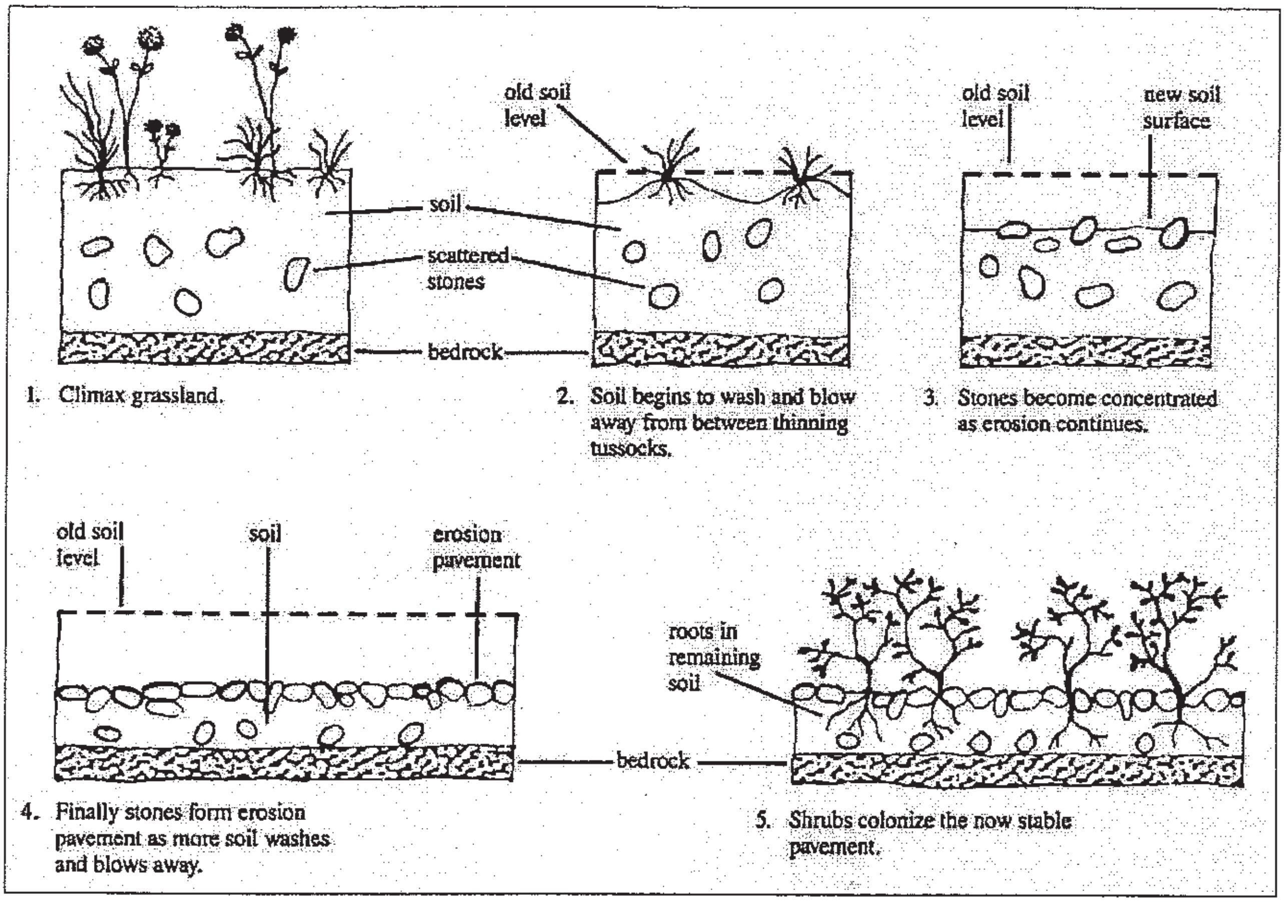


FIGURE 8 Schematic diagram indicating the impacts of excessive grazing from the 1860s to mid-1940s on soil and the composition of plant species. Source: Australian Alps Education Kit

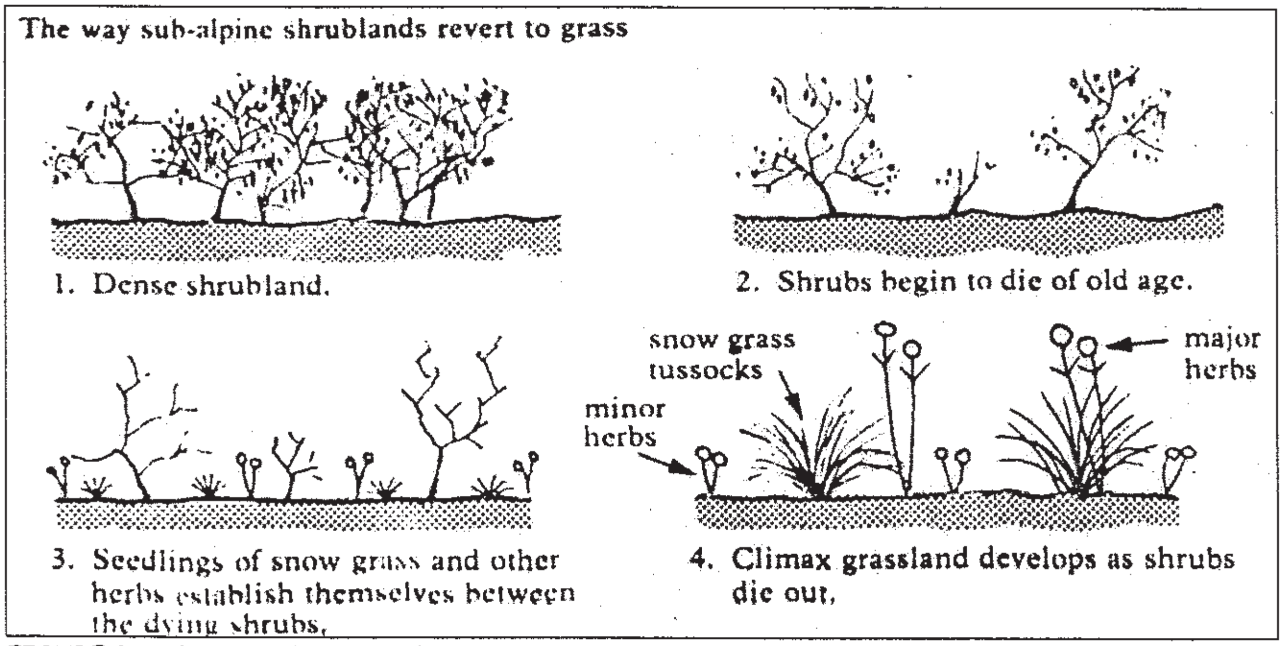


FIGURE 9 Schematic diagram indicating vegetation succession in the absence of grazing and other disturbance factors. Source: Lee, B. 1979. A high-country perspective. *Ecos*, 22: 24-31

The hydrological non-result
In light of the overwhelming evidence of ecological damage associated with grazing, it was expected the hydrological record would demonstrate comparable results. Lawrence (1995) conducted multiple tests on the streamflow record of several subalpine catchment on the Bogong High Plains on the assumption that high grazing densities between the mid 1920s and mid 1940s would produced higher runoff than in subsequent years when grazing densities declined.

Of the four types of hydrological investigations conducted, only one produced a statistically significant result. That one statistically significant result was evident in two of the four catchments examined, but the two catchments demonstrated quite different outcomes. Long term trends in the proportion of precipitation occurring as streamflow for the Watchbed Creek catchment demonstrated a statistically significant decline in flow between 1940/41 and 1981/82, which was consistent with expectations. By contrast, long-term trends in the proportion of precipitation occurring as streamflow for the Pretty Valley Creek catchment demonstrated a statistically significant increase in flow between 1926/27 and 1957/58: the opposite to what was expected. However, it was determined that the increase in flows in the Pretty Valley Creek was actually produced by construction activity for the Kiewa Hydro-Electric Scheme. Thus, only one statistical test in one catchment provided a positive correlation between grazing pressure and runoff characteristics (Lawrence 1995). Furthermore, if more recent data is added to the Watchbed Creek analysis hydrological record, statistical significance is lost. It seems that the interaction between grazing and runoff is more complex than the interaction between grazing and ecology.

Geomorphological changes
Excessive grazing of alpine and subalpine pastures on the Bogong High Plains between the 1850s and mid-1940s has produced two prominent geomorphological changes.

(1) In grassland communities, which tend to occur on the gently rolling slopes of the subalpine area and summits of the alpine zone, excessive grazing resulted in the reduction of continuous plant cover. Exposure of alpine soils to rain, snow, wind and frost-heave action has produced the removal of considerable quantities of soil material, as seen in Figure 9. Historic photographic evidence from the 1920s, '30s and '40s indicates that Phase 2 in the sequence in Figure 9 was widespread across the Bogong High Plains and adjacent peaks. Where grazing was particularly intense, erosion pavements resulted. These were not continuous across the Bogong High Plains but restricted to isolated patches, particularly on the summit peaks. Today, very little evidence of the erosion pavements remain, even in areas burnt in 2003.. Tighter controls on grazing since the mid-1940s has virtually eliminated evidence of this land form.

(2) The geomorphological story for bog communities is somewhat different. Bog vegetation on the Bogong High Plains develops in permanently moist valley-bottom sites, and is notable for the presence of *Sphagnum* species. Bog vegetation overlies peat material, which is comprised predominantly of decaying surface plant material. Many peat bogs have developed on top of Tawonga Gravels deposits, which are course gravels of fluvial origin up to 65 metres thick (Beavis 1962). A number of changes to the bog communities have occurred and are still evident today.

- A healthy bog community consists of multiple isolated pools that may designate local or perched water tables (Figure 10). Bogs act as a hydrological sponge that hinders water movement and minimises storm runoff. They serve to regulate both the volumes and quality of water that is eventually released into streams.

- Cattle have always sought access to bog communities as their main source of drinking water. Cattle tracks into the bogs have served to focus water flow into channels. Once channels were initiated, creek lines developed and pools were drained. Creeks then incised into the peat formation and cut down to the Tawonga Gravels formation. Today, most valley lines on the Bogong High Plains contain creeks rather than healthy bogs, and most creeks are cut into the Tawonga Gravels (Figure 10).
- Drought and fire have also impacted on the bog communities. A sequence of drought years between 1900 and 1939 served to accelerate the drying out of bogs that was initiated by the cattle. Fires on the Bogong High Plains also accompanied two drought years in 1926 and 1939. The fires caused some areas of bog and peat to catch alight. Graziers reported that a fire which started in peat in the Pretty Valley area in January 1939 was still burning four months later, even after snow had covered it.
- The result of the combination of grazing, drought and fire has been deflation of many bog surfaces. The depth of peat in valley bottom locations has been considerably reduced. For example, in 1888, a visitor to Pretty Valley reported that a horse could sink out of sight in the bog communities. This report relates to the same area that was burnt in 1939 and that is easily traversable on foot today. Evidence of deflation is often seen at the edges of extant bog communities, where cliffs about one metre in height may be found (Figure 10), indicating a lowering of the bog surface by that amount.

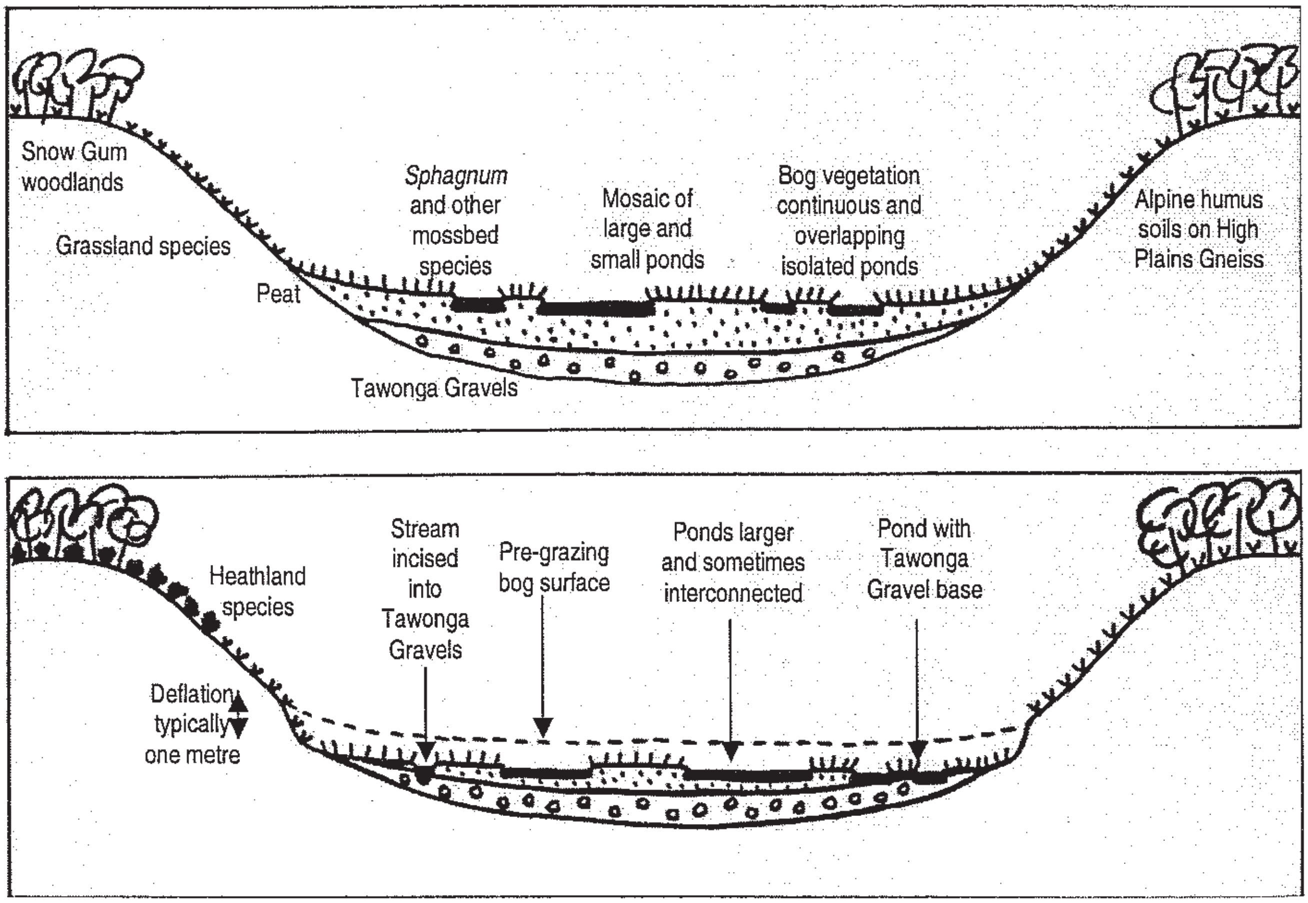


FIGURE 10 Schematic diagram illustrating the geomorphological changes to valley bog communities on the Bogong High Plains as a result of drought, fire and excessive grazing pressures

SITE 6 - FALLS CREEK SKI VILLAGE

Planning issues

The Falls Creek Alpine Village has its origins with keen skiers who were employed in the construction of the Kiewa Hydro-Electric Scheme. Most of the ski club lodges in the Village were built during the 1950s and '60s, whereas commercial and administrative buildings have been progressively been established since the late 1950s. Between 1945 and 1959, the Village was administered by the State Electricity Commission, after which the Falls Creek Tourist Area Management Committee governed it. During those years, the Soil Conservation Authority played a major role in managing all lands over 1200 metres elevation. In 1983, the Alpine Resorts Commission was established to administer all ski resorts in Victoria, including Falls Creek. Despite warnings of limited future viability due to global warming, development of the Village has steadily progressed in the last decade.

In 1996, an application was made to the relevant planning authority to construct a ski lodge on a creek reserve within the Village. The creek reserve existed to preserve a vegetated block stream with a high topographic gradient. The planning permit was challenged by the adjacent lodge lessee but was not upheld and the lodge was built. Several months later, the Thredbo disaster occurred. The similarities between the creek reserve site at Falls Creek and the Thredbo landslide zone are noteworthy.

Urban hydrology above the snow line

The alpine and subalpine areas of Victoria and New South Wales produce the most runoff of any place in southern Australia. The quality of the alpine waters is usually outstanding and Bogong High Plains waters are no exception. However, Alpine Villages have the potential to seriously pollute the otherwise pristine waters. When the Soil Conservation Authority was actively managing the high country, they contributed to the maintenance of water quality standards. For example, at the base of 'The Bowl' in Falls Creek, there used to be a large bog. Ski lift operators repeatedly requested drainage of this bog to facilitate skier comfort whilst queuing at the multiple ski lifts that terminated at The Bowl. Until the mid 1980s, the Soil Conservation Authority insisted the bog be retained to regulate flow volumes and quality. When the Alpine Resorts Commission gained control of the Village, a large metal grate funnelling water directly into the Falls Creek watercourse replaced the bog. Small sediment slugs and litter is now a common sight in the Falls Creek watercourse, particularly after snow melt.

A study of the water quality of runoff from the Falls Creek Alpine Village undertaken by Fluin (1995) identified two major issues:

- Elevated levels of heavy metals were found in waters draining the village area; and
- Elevated levels of nutrients and algae were found in waters downstream of the sewage treatment plant (Figures 11 and 12 (a)).

While these results are not remarkable in themselves, the following observations were noteworthy:

- Several people were seen drinking water immediately downstream of the sewage treatment plant, as no signage had been erected advising them of the dangers;

- The secondary treatment plant was deemed to be satisfactory provided no incident such as an oil spill or bushfire occurred that killed the streamside vegetation, increased sunlight incidence to the stream waters, and produced algal blooms and
- A tertiary treatment plant, such as that operating at Thredbo, would have minimised the pollution problem (Figure 12 (b)).

The 2003 fires have since burned the effluent receiving stream.

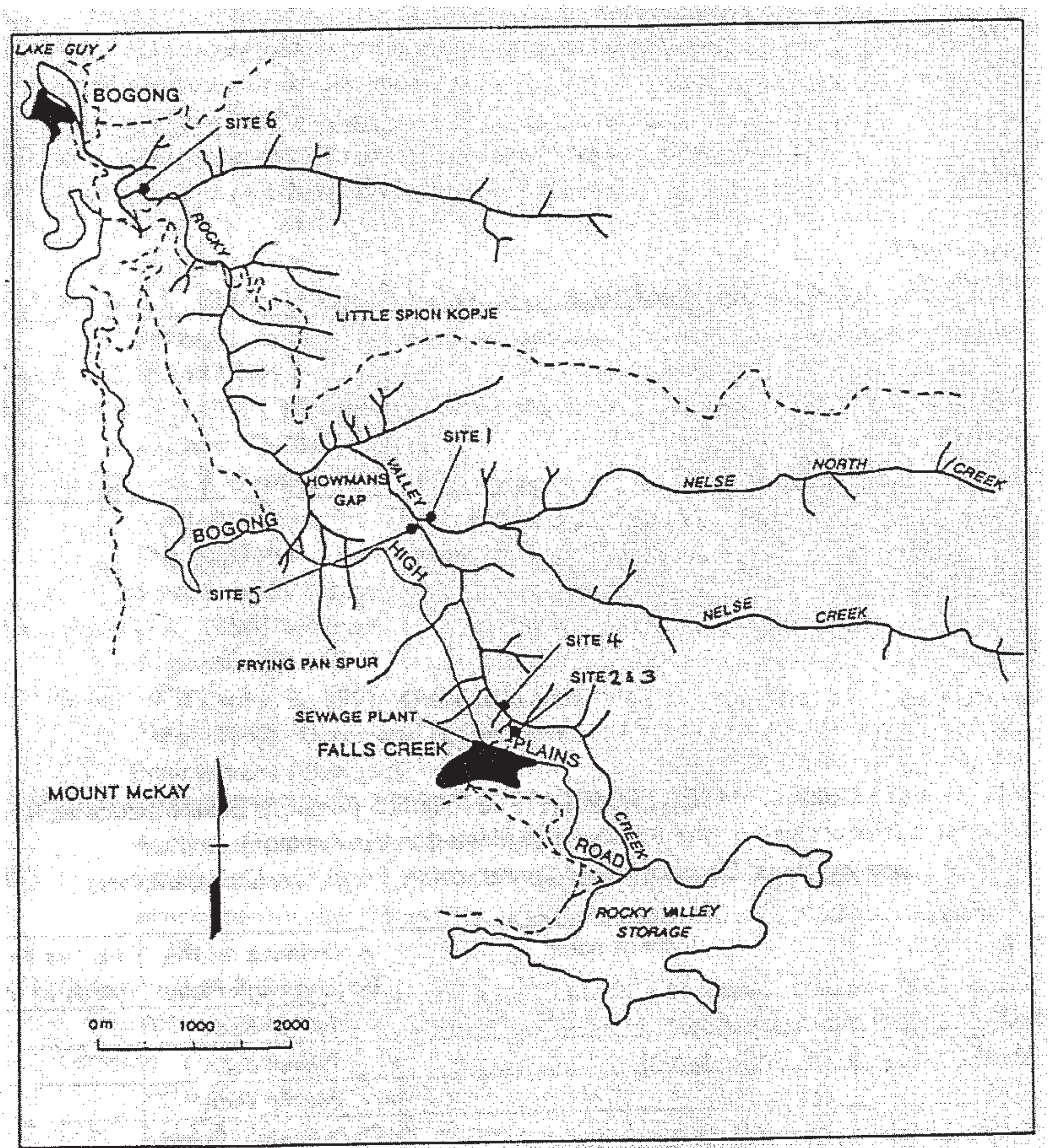


FIGURE 11 Location of sample sites in the study of urban runoff from Falls Creek Alpine Village. Source: Fluin (1995)

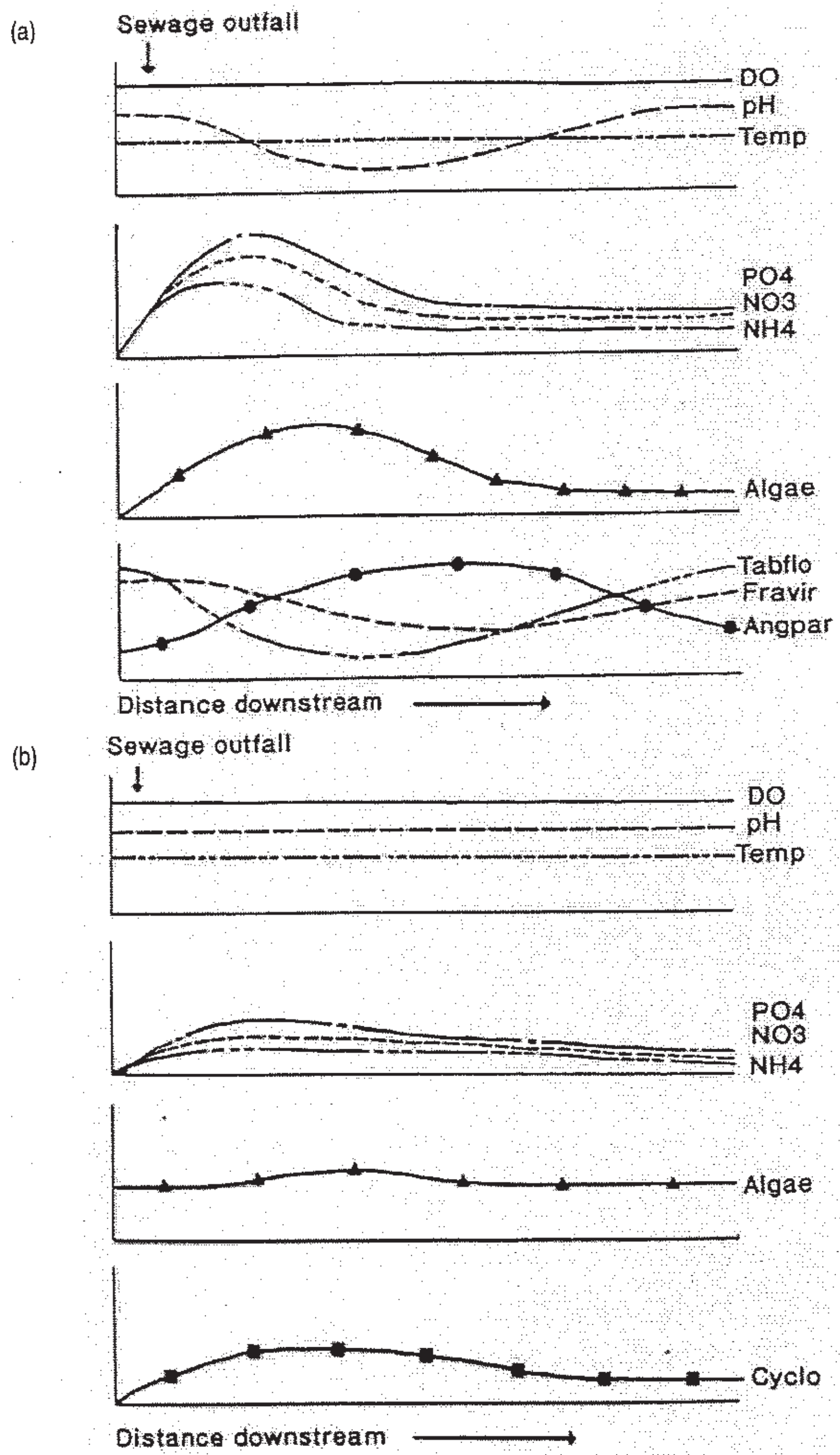


FIGURE 12 (a) Schematic representation of water quality parameters downstream of the secondary treated effluent discharge from Falls Creek Alpine Village.
(b) Schematic representation of water quality parameters downstream of the tertiary treated effluent discharge from Thredbo Alpine Village.
DO = dissolved oxygen, PO4 = phosphate, NO3 = nitrate, NH4 = ammonia, Tabflo = diatom *Tabellaria flocculosa*, Fravir = diatom *Fragilaria virescens*, Angpar = diatom *Angustum parvulum*, Cyclo = *Cyclotella*. Source: Fluin (1995)

SITE 7
KIEWA RIVER BETWEEN TAWONGA AND GUNDOWRING

The key themes of the several sites examined in the Lower Kiewa Valley are the anabranching river and river management. The notes for Sites 7, 8 and 9 are based on a report prepared by Brizga (1996) as part of the Lower Kiewa River Action Plan being developed by the Upper North East River Management Authority (now part of the North East Catchment Management Authority [N.E.C.M.A.]).

Background

The East and West Branches of the Kiewa River descend from headwaters in the Great Dividing Range to Tawonga South, where they join to become the Kiewa River. The river is bordered by a floodplain that extends from Mount Beauty (upstream of the confluence of the East and West Branches) to the Murray River. From Mount Beauty to Gundowring, valley width is highly variable and there are some major constrictions that affect hydraulic conditions and geomorphological processes. Downstream of Gundowring, the floodplain is generally at least 1 km wide and in some places more than 2 km wide. The sediments of the Kiewa floodplain belong to the Coonambidgal Formation. Downstream of Bandiana the floodplain of the Kiewa River merges with the Murray River floodplain.

Mean annual flow in the Kiewa River increases downstream, but mean annual runoff decreases (Table 1). This is in accordance with the spatial distribution of rainfall. Mean annual rainfalls are greater than 1500 mm upstream of Mt Beauty and exceed 2250 mm in the high country, while downstream of Tangambalanga, mean annual rainfall is less than 750 mm. Mean annual runoff is high compared with Australian average values, whereas annual streamflow variability is low, comparable to world averages.

River Management

N.E.C.M.A. is currently the lead agency for river and floodplain management on the Lower Kiewa Valley. Formal arrangements for river management in Victoria commenced in 1930 with the establishment of the Rivers and Streams Fund, which supported works on rivers and streams throughout Victoria on a needs basis. The Kiewa River Improvement Trust (K.R.I.T.) was formed in 1952, with the initial objectives being:

- to arrest erosion in the Gundowring, Upper Gundowring and Tawonga areas;
- to prevent avulsions that would result in Bight Creek and/or Finns Creek becoming the main channel of the river; and
- to remove snags and willows from the river in order to increase channel capacity and prevent prolonged inundation.

The objectives of the K.R.I.T. changed as some of the initial problems were brought under control, and in response to the general attitudinal shift in the river management industry and wider community that has seen a greater emphasis placed on environmental concerns. For example, the objective of the 1984 Master Plan for the K.R.I.T. was to achieve a compromise between the following two aims:

- to alleviate or prevent stream related damage to public and private land and assets; and
- to retain and enhance the amenity of the river system for the benefit of the general community.

TABLE 1 Summary statistics for annual stream flows in the Kiewa River compared with Australian and world averages. Source: Brizga (1996)

	Mongans Bridge	Kiewa[1]	Bandiana	Australian Average[2]		World Average[2]	
Catchment Area (km^2)	552	1145	1655	0 - 1000	1000 - 10000	0 - 1000	1000 - 10000
Years of Record[3]	40	59	28	35	42	28	35
Mean Annual Flow (GL)	496	595	728	n.a.	n.a.	n.a.	n.a.
Mean Annual Runoff (mm)	899	520	440	547	208	818	542
C_{vr}	0.37	0.46	0.39	0.59	0.88	0.45	0.48

1 combined flows in river and anabranch

2 average values are from Finlayson, B.L. and McMahon, T.A. 1988. Australia v. the world: a comparative analysis of streamflow characteristics. In Warner, R.F. (Ed.) *Fluvial Geomorphology of Australia*, Academic Press, Sydney, 17-40.

3 average number of years of record for gauging stations in Finlayson and McMahon's (1988) data set

SITE 8 - KIEWA RIVER DOWNSTREAM OF GUNDOWRING

Anabranches

Major anabranches exist on the floodplain of the lower Kiewa River downstream of Gundowring (Figure 13). Significant losses of flood flows from the Kiewa River occur for two main reasons.

- small channel capacity - for example, the capacity of the Kiewa River at Kiewa is approximately 8000 ML/day: floods of this magnitude have an average annual recurrence interval of less than 2 years; and
- elevated position on the floodplain - for example, the floodplain cross sections presented in Figure 14 indicate that the Kiewa River is situated in higher part of the floodplain than Finns Creek, although it is at a similar level as the Kiewa Anabranch.

Substantial works were undertaken in the early 1960s to prevent avulsion of the Kiewa River. They included the blockage of breakaways and flood outlets that had previously carried overflows to major anabranches such as Finns Creek as well as straightening and stream clearing works to increase the capacity of the Kiewa River. For example, Figure 15 shows the increase in the volume of flow carried by the Kiewa River at Kiewa and a corresponding decrease in the volume of flow carried by the Kiewa Anabranch. Land that had previously been swampy was reclaimed for agricultural purposes. However, breakaways have continued to occur from time to time and works to block them have been carried out in response.

Kiewa River

The positions of the Kiewa River downstream of Tangambalanga in 1939 and 1995 were compared on the basis of the Kiewa River survey (1939) and aerial photographs (1995) (Figure 16). Numerous cutoffs took place over this period, resulting in a minor increase in stream gradient. Some of the cutoffs may have occurred due to natural processes, although many bends were deliberately bypassed by artificial floodways. The changes in channel planform and capacity were accompanied by a fall in gauging station control level at Kiewa (Figure 17).

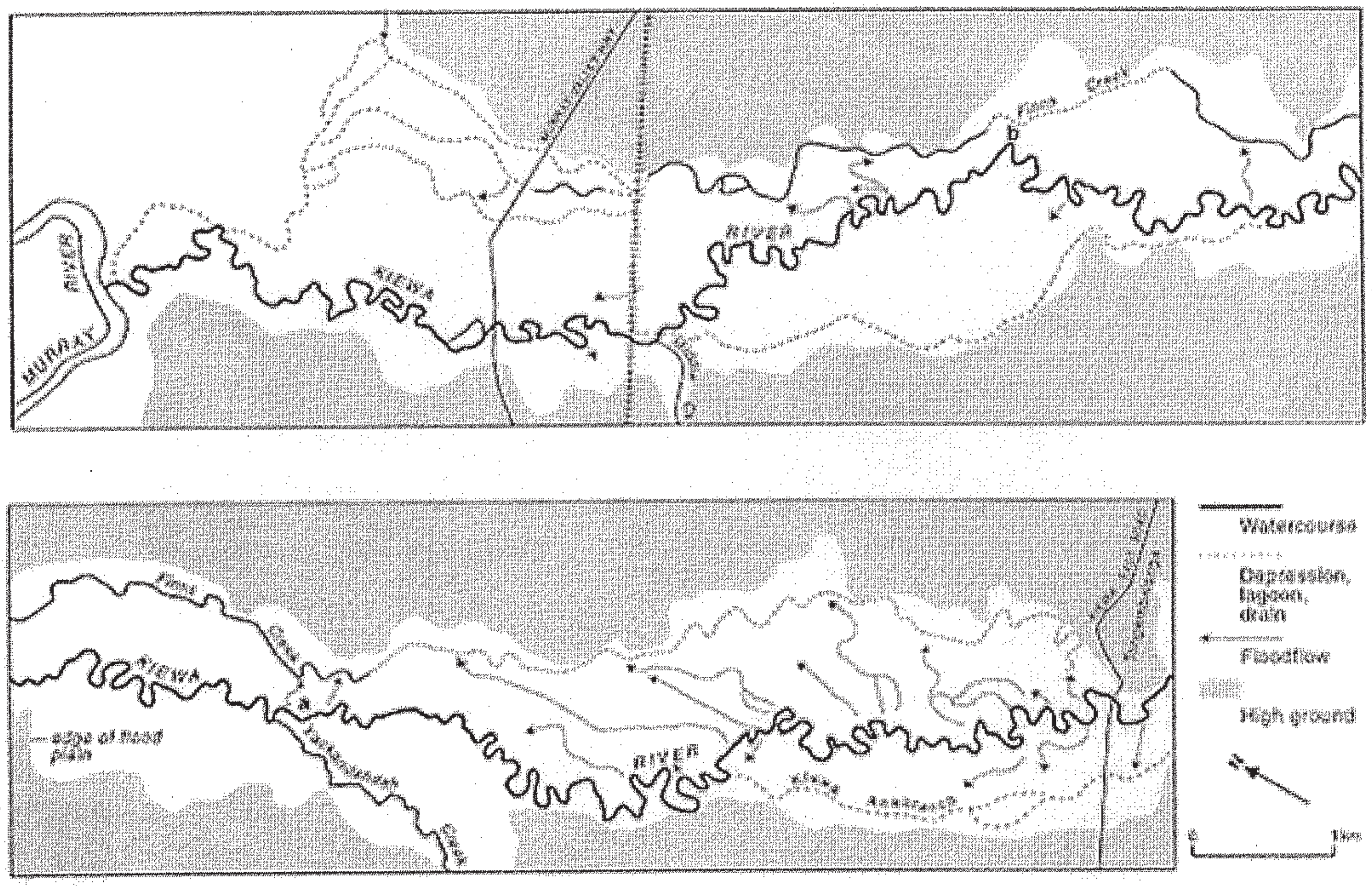


FIGURE 13 Kiewa River and floodplain downstream of Tangambalanga. Source: Brizga (1996)

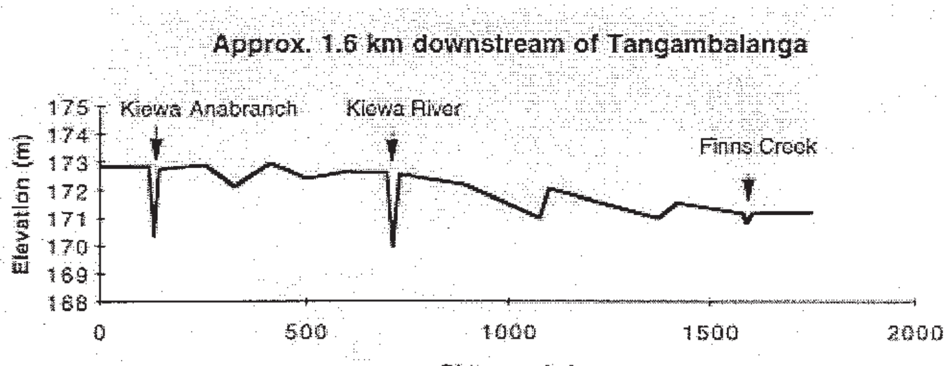


FIGURE 14 Floodplain cross-section showing the relative elevations of the Kiewa River and Finns Creek. Source: Brizga (1996)

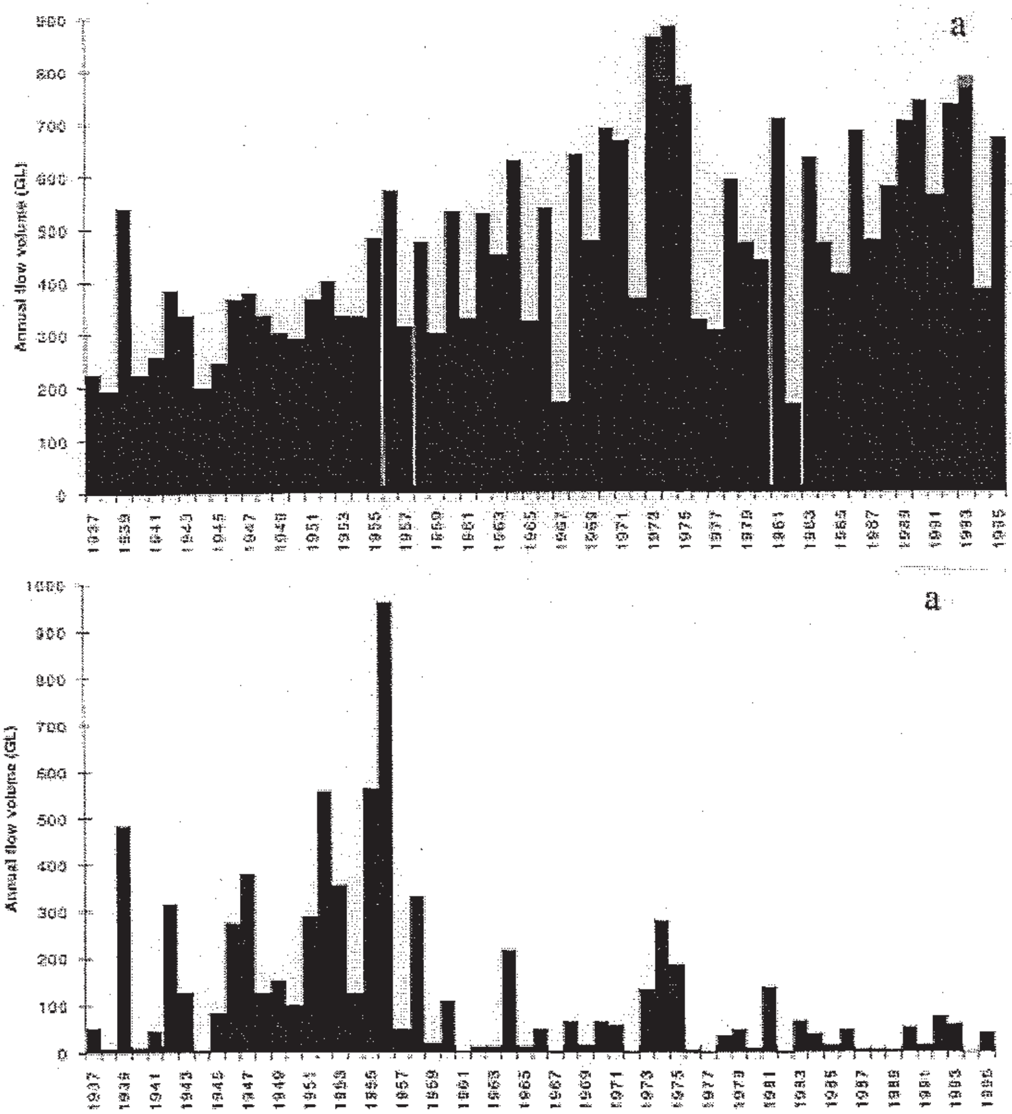


FIGURE 15 Mean annual flow in the Kiewa River main channel (upper plot) and Kiewa Anabranch (lower plot) at Kiewa. Source: Brizga (1996)

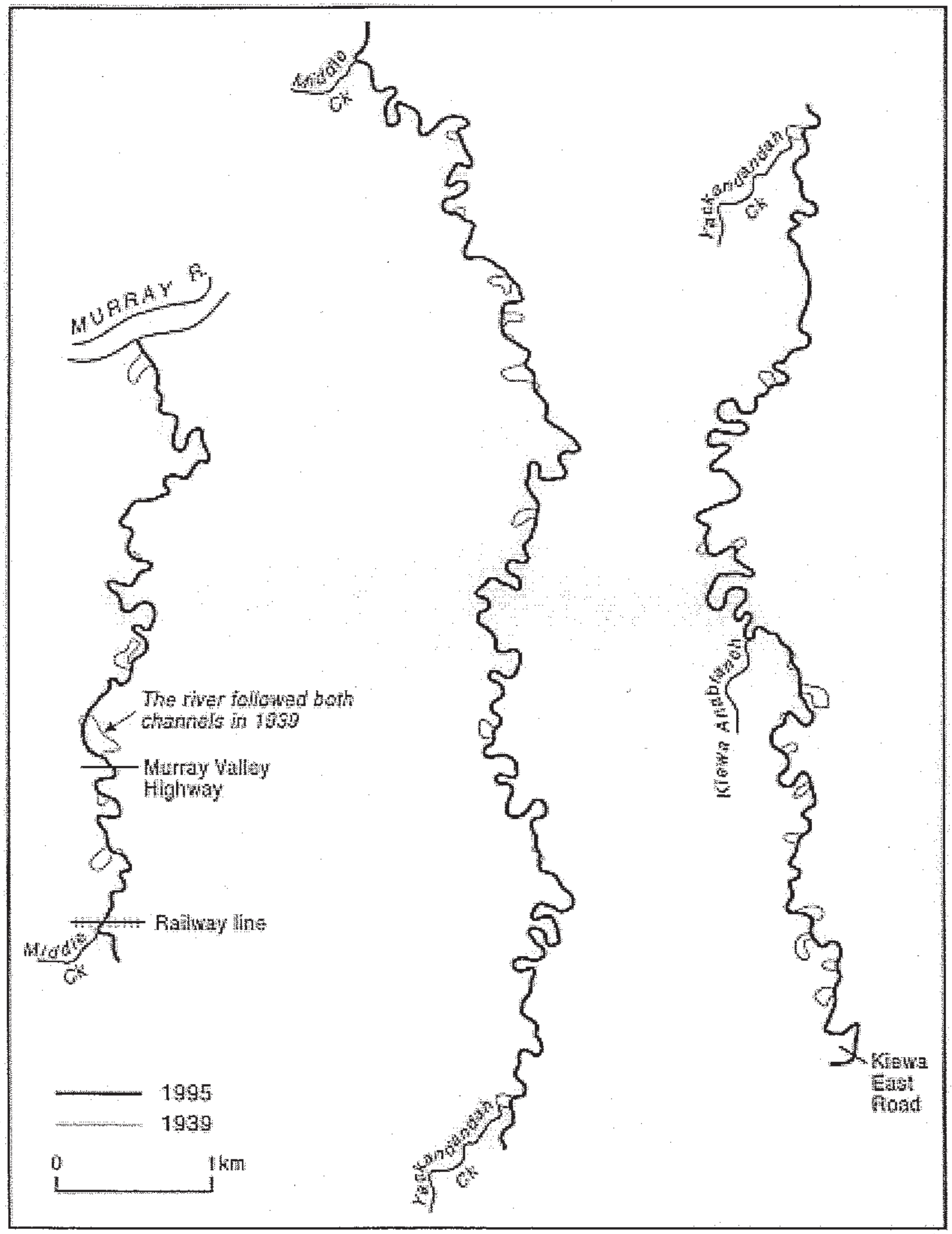


FIGURE 16 Kiewa River downstream of Tangambalanga in 1939 and 1995. Source: Brizga (1996)

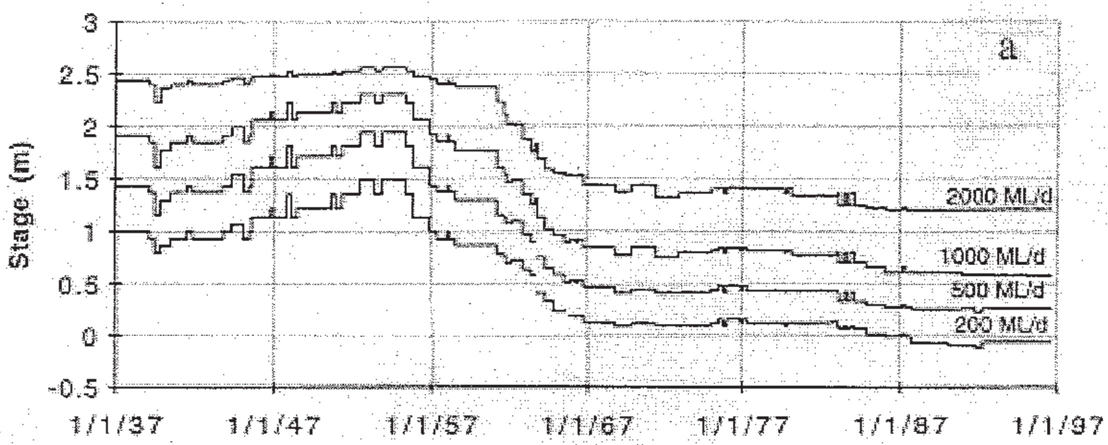


FIGURE 17 Specific gauge plots for the Kiewa River at Kiewa. Source: Brizga (1996)

SITE 9 (drive past) - YACKANDANDAH CREEK

Yackandandah Creek is a major tributary of the Kiewa River. Large-scale gold mining operations were carried out in this catchment from the mid nineteenth century to early twentieth century, leading to substantial interference with the creek and its tributaries, including:

- diversion of creek flows into water races;
- relocation of the creek channel; and
- mobilisation of large quantities of sediment as a result of hydraulic sluicing and dredging.

Sherrard (1990) investigated the fluvial geomorphology of Yackandandah Creek and reported that geomorphological responses have included sequences of aggradation and degradation as well as channel widening and straightening. A dredge pit at Staghorn Flat (linked to the main channel by a low-level floodway) now acts as a sediment trap, as indicated by the presence of an actively prograding delta. Varying responses have been observed in different parts of creek - factors contributing to this variation include proximity to mining activities and natural characteristics of the channel-floodplain system

Rowe (1972) reported that sediment generated by gold mining operations in the Yackandandah Creek catchment has been deposited on the Kiewa floodplain to depths of almost one metre. A nineteenth century avulsion at the downstream end of Yackandandah Creek has been attributed to aggradation with mining sediments (Sherrard 1990). A small delta protrudes from the mouth of Yackandandah Creek into the Kiewa River (Brizga 1996). Rates of sediment supply from Yackandandah Creek to the Kiewa River and downstream transport of this sediment in the Kiewa River are not known. However, much of the sediment liberated by mining operations in Yackandandah Creek catchment is clearly still stored within this tributary system, as argued by Terrazzolo and Erskine (1995).

REFERENCES

* copy included in this volume

Beavis, F.C. 1960. The Tawonga fault, north-east Victoria. *Proceedings of the Royal Society of Victoria* 72, 95-100

Beavis, F.C. 1962. The geology of the Kiewa area. *Proceedings of the Royal Society of Victoria* 75: 349-410

Brizga, S.O. 1996. *Geomorphic overview of the Lower Kiewa River.* Report for the Upper North East River Management Authority

Fluin, J. 1995. *Degradation of alpine streams: the ecological effects of sewage discharge on the alpine aquatic environment.* B.A.(Hons) thesis, Geography Department, University of Adelaide

Lawrence, R.E. 1990. *The interaction between the environment, land use and hydrology of the Bogong High Plains Area from 1850 to 1985.* Ph.D. thesis, The University of Melbourne

*Lawrence, R.E. 1995. The effects of grazing activity on the hydrology of the Bogong High Plains, Australia. *The Rangeland Journal*, 17: 138-153

*Lawrence, R.E. 1999. Vegetation changes on the Bogong High Plains from the 1850s to 1950s. *Proceedings & Transactions of the Royal Society of Victoria*, 111: xxix-lii

*Lawrence, R.E. 2001. The impacts of hydro-electric construction works on the hydrology of a subalpine area of Australia. *Environmental Geology*, 40: 612-621

Leitch, C.J. 1982. Sediment levels in tributaries of the East Kiewa River prior to logging alpine ash. In: *The first national symposium on forest hydrology 1982.* Institute of Engineers, Australia, National Conference Publication No. 82/6, pp. 72-78

Orr, M.L. 1999. *Tectonic geomorphology of the Bogong and Dargo High Plains region, east Victorian highlands, Australia.* Ph.D. thesis, The University of Melbourne

Rowe, R.K. 1972. *A study of the land in the catchment of the Kiewa River.* Soil Conservation Authority of Victoria

Sherrard, J. 1990. *Fluvial geomorphology of Yackandandah Creek: Implications for stream management.* Unpublished report for Ian Drummond and Associates Pty Ltd.

Terrazzolo, N. and Erskine, W.D. 1995. A geomorphic assessment of stream conditions in the Upper North East Region of Victoria. Appendix A in: Ian Drummond and Associates Pty Ltd. *Upper North East River Management Authority: Stream zone restoration plan - Background and assessment.* Unpublished report for the Upper North East River Management Authority.

Note: The following papers, included in the original field guide, have been omitted from this on line file for copyright reasons:

Lawrence, R.E. 1995. The effects of grazing activity on the hydrology of the Bogong High Plains, Australia. *The Rangeland Journal* 17, 138-153.

Lawrence, R.E. 1999. Vegetation changes on the Bogong High Plains from the 1850s to 1950s. Proceedings and Transactions of the Royal Society of Victoria 111, xxix-lii.

Lawrence, R.E. 2001. The impacts of hydro-electric construction works on the hydrology of a subalpine area of Australia. Environmental Geology 40, 612-621.