4. ANALYSIS OF HISTORICAL EVIDENCE: ESTABLISHING BASELINE CONDITIONS AND POTENTIAL EROSION TRIGGERS

4.1. Introduction

In this chapter the historical data are presented and discussed as a way of discovering the form of the Granite Creeks at the time of European settlement, how they have changed over the last 150 years and what activities might have caused the observed changes.

4.2. Explorers and the Overlanders

The first Europeans to traverse the Granite Creeks were Hume and Hovell in 1824. It appears that they passed through the area not far from the present day location of the Hume Freeway, but unfortunately Hovell made his last journal entry the week before they arrived in the area, on their way back to the settled districts (Andrews 1981). Consequently we have no record of the area from this period.

More than ten years passed before Europeans returned to the area. Major Thomas Mitchell and his exploring party travelled from an encampment near Wormangul Creek to a camp on Castle Creek on the 10th of October 1836 (DCE 1990). Mitchell and his party were on their way back to Sydney after a journey that had already taken them through the present day locations of Swan Hill and Portland. In traversing this section of country, not far from what is now Pranjip Rd (DCE 1990), the party crossed numerous chains of ponds and one running stream before reaching Castle Creek (Mitchell 1839). It seems probable that Creightons Creek was the running stream to which Mitchell referred, and Pranjip, the anabranch of Pranjip, Branjee and Little Branjee Creek were ‘chains of ponds’. The party spent the night camped on Castle Creek, which Mitchell referred to as Violet Ponds because of flowers growing around deep pools in the running creek (Mitchell 1839).

One thing that is not clear is exactly what Mitchell meant by the term ‘chain of ponds’. He may have been referring to ephemeral channels with large pools in which water remained, or he may have been describing the true ‘chain of ponds’ form still evident along sections of Little Branjee Creek today.

Mitchell’s second-in-command, Granville Stapylton, was following Mitchell at this stage of the journey, with a second party. Stayplton, who was about two weeks behind Mitchell, discontinued his diary several days before arriving in the area, and thus does not provide any further information about the Granite Creeks (Andrews 1986).

Following Mitchell’s return to Sydney, his favourable descriptions of ‘Australia Felix’ instigated a wave of overlanding expeditions to the Port Phillip District along the track made by Mitchell’s drays on their return journey to Sydney. This track became known as the Major’s Line.

The Overlanders drove their stock, usually sheep and some cattle, from the settled regions around Goulburn to the Port Phillip District to take up land for pastoral pursuits. One of the first handful of overlanders to make the journey south was Alexander Mollison. Mollison’s diary indicates he first crossed the Granite Creeks in July 1837 and may have camped beside Castle Creek (Randell 1980). Whilst there is no description of the area, Mollison mentions that most of the creeks Mitchell referred to in his journal as ‘“chains of ponds” running’, were not running when his party passed through (Randell 1980). After settling in central Victoria (near Kyneton) Mollison returned to his station near Canberra to collect more stock. Mollison’s second overlanding trip south brought him back to the Granite Creeks in late October–early November of 1837. In his diary Mollison describes the country as follows (Randell 1980, p. 56):

> The country around, sterile and covered with scrubby bushes. On the immediate bank of the creek there is, at present, young grass thinly scattered over the ground. I observe that those creeks and chains of ponds which have large water ponds and a broad, shallow water course, are now full and running, while those which have deep channels, steep banks cut into the earth and ponds small in proportion to their channels, are now quite dry, with the exception of a few ponds in some of them in which there may be found a little muddy water.

The poor grass cover noted here may have been a result of the large numbers of stock which were being driven down the Major's Line at this time. The impact of overlanding parties on land in the vicinity of the Major's Line between Violet Town and the Goulburn River is best illustrated by the following description taken from a traveller's diary in 1838 (Walker 1838, pp. 33–34).

> When we had come to the said thirteen mile creek, we found, however that some time ago the grass all about it had been burnt, and that there was not a single bite for our cattle; this was therefore no place to holt at, so we determined to give the animals a drink, and proceed until we came to grass; to our great mortification, we found not a blade, nor any water nearer than this place (a further 7 miles on). The whole country has been burnt, and no rain having since fallen, not a vestige of grass is to be seen. We have within this last day or two, passed through a great deal of country in a similar state, and most dreary and miserable does it appear; at no time more so than to-day. The country was in itself scrubby and of bad soil, and superadded to that, we under the impression, in passing that we should have to halt in it for the night, without having food or drink for our cattle, ... From the experience I have now had, I should not again think of making an exploring expedition with a bullock-cart to say nothing of the hindrance it is to progression, how dependent it makes us on finding water every few miles, and in this country, how often we are disappointed in doing so.

Besides indicating the poor condition of land in the Granite Creeks area in 1838, this account suggests that burning probably had a significant impact on the landscape. It is not clear either how the fires were initiated (e.g. by the Overlanders, the local Aboriginal people or lightning) or the frequency of such events, but these factors have implications for the magnitude of the impact on the landscape.

4.3. Pastoral runs

With the influx of settlers to the Port Phillip District it was not long before several squatters had taken up runs in the Granite Creeks area. In 1839 William Creighton took up the Five Mile Creek pastoral run, including some 60 000 acres (Billis & Kenyon 1974), covering most of the Creightons Creek catchment, as well as much of the Pranjip–Nine Mile Creek catchment above the Burnt Creek confluence (CPO Run Plans 237 (1852)). The run carried 1200 cattle initially (Billis & Kenyon 1974), but this number appears to have halved by the middle of the 1840s (VPRS 5920). In 1840 William Creighton took up Wanghambeham, a run adjoining Five Mile Creek or Killeen (which may once have formed part of Five Mile Creek). Wanghambeham was situated on the upper reaches of Creightons Creek, comprised 16 000 acres and initially carried 4000 sheep (Billis & Kenyon 1974).

John Livingstone took up the Molka Pastoral Run in 1846. Initially comprising 30 000 acres and carrying 6000 sheep, the station covered the remainder of the lower catchments of Creightons Creek and Pranjip–Nine Mile Creek (Billis & Kenyon 1974, CPO Run Plans 237 (1852)).

The upper reaches of Castle Creek were included in the Seven Creeks run which was first leased in 1838. A.J. Templeton took up 70 000 acres on which he ran 35 head of cattle and 12 000 sheep.

The lower sections of Castle Creek formed the boundaries of a number of pastoral runs, including Arcadia, Noorilim, Croppers, Molka and Euroa. Arcadia was first leased in 1839 by Gregor McGregor, who took up 80 000 acres, running 6000 sheep. By 1858 the run had been subdivided; the southern portion, through which Castle Creek passed, retained the name Arcadia but it was reduced to

48 000 acres. Noorilim, which was taken up in 1840 by Fredrick Manton, comprised 44 320 acres and carried 8000 sheep (Billis & Kenyon 1974). Croppers Station, or Burrabirronga was first leased in 1844 by Charles Cropper. At this time 100 head of cattle and 2500 sheep were run on 19 200 acres (Billis & Kenyon 1974). Euroa, which comprised 80 000 acres and initially carried 500 head of cattle and 6000 sheep, was taken up in 1840–1841 by Roderick McKay.

Although neither the location of run boundaries in relation to catchment boundaries, nor the records of cattle and sheep numbers are accurately known, it is possible to conclude that by midway through the 1840s, all the land within the Granite Creeks catchments had been leased by squatters and may have been carrying up to 40 000 sheep and 1000 head of cattle. If 1 cow is the equivalent of 3 sheep (Powell 1970), then this equates approximately to 1 sheep to 9 acres.

Due to the nature of land tenure, i.e. lease, the pastoralists generally did not make substantial improvements on their runs (Powell 1976). Consequently, fencing, construction of water supplies and clearing were not common. Descriptions of land selected along Creightons Creek in the 1870s and 1880s suggest that improvements introduced into the area by the pastoralists were limited to boundary fencing and some paddock fencing (various Land Selection Files; see list on page 101). Thus by 1850, 26 years after Hume and Hovell first passed through the Granite Creeks catchments, the impact of European settlement had probably been limited to the introduction of hoofed animals and consequent light grazing pressure, as well as the development of a number of tracks across the district.

4.4. The Granite Creeks area in the second half of the nineteenth century

In terms of development, there was relatively little progress in the Granite Creeks catchments before the 1850s, but this changed in the second half of the 1800s with the construction of the North-Eastern Railway and the advent of Land Selection Legislation. A number of sources of information have been used to derive descriptions of the Granite Creeks catchments between 1850 and 1900, including old plans and the corresponding survey notes, Land Selection Files and anecdotal evidence. In particular, attention has been paid to changes in land use, and the impact of land settlement on the Granite Creeks.

General descriptions of the Granite Creeks area can be obtained from the notes of surveyors who conducted surveys in the area in the 1860s to allow the original Parish Plans to be drawn up. Notes by J. Hardy on the Branjee feature survey indicate the area was covered by open forest, chiefly of box, though some areas (predominantly on clay soil) were thickly covered by heath. The soil was generally clayey and quite wet in winter, and considered to be poor (CPO Survey Book 156, Bundle 11). Marchant surveyed an area taking in some parts of the lower catchments of Pranjip–Nine Mile Creek and the anabranch, as well as Creightons Creek. Notes from his fieldbook indicate that the area was lightly timbered with box, gum and wattle, with an understorey of thick scrub. The soil was a light sandy soil. Marchant's notes also indicate that the creeks were between 10 and 40 links wide (2–8 m) (CPO Survey Book 922).

Information can also be gleaned from some of the original parish and town plans. The Pranjip Parish plan, surveyed in 1862, indicates the area was covered by a sandy soil of very inferior quality, which was timbered with box and scrub (CPO Putaway Plans, P123). Plans of the Euroa township indicate that the soil near Castle Creek was a loamy sandy soil (1862) and consequently there were a number of sand and gravel pits on town allotments in 1906. Town plans from 1909 also indicate that the channel of Castle Creek was realigned, probably in relation to the construction of a bridge for the Sydney Road (CPO Putaway Plans E81(2), E82(A), E82(O) (1909, 1862, 1906)). Soils in the Parish of Gooram Gooram Gong, in the vicinity of Castle Creek were shown as being stony, sandy and medium (CPO Putaway Plans G149 (1862)). On the other hand, notes on the original Parish Plan for Longwood indicate that the area was timbered with stringybark, box and gum, and that whilst in some areas the soil was poor and sandy, other areas were considered to be good agricultural land (CPO Putaway Plans L92(A) (1862)). Plans for the Parish of Molka indicate that some parts of the parish could be described as low crabholey ground that was openly timbered with grey box, white gum and bulloak (CPO Putaway Plans M519 (1921)). Other parts of the parish have been described as having indifferent soil and timbered with box and black acacia (CPO Putaway Plans D155(A) (1866)). The Parish Plan for Miepoll indicates the area was covered by open box forest on inferior clayey land (CPO Putaway Plans M418 (1863)).

Clearly both soil types and vegetative cover varied throughout the catchments, prior to widespread clearing. Taking descriptions from the Land Selection Files for allotments along Creightons Creek, it is possible to loosely describe the two broad areas that make up the Granite Creek catchments, i.e. the flats and the hill country, where the flats constitute the land below the Hume Freeway and the hill country is that part of the catchment above the highway.

Land on the flats surrounding Creightons Creek was generally described in the 1880s as being unfit for cultivation, because the land was too crabholey and wet. If cultivation did take place, usually wheat, oats, barley and hay were grown, although yields were never usually very high. Most of the trees in the area had been ring-barked (rung) and some of it cleared by the 1890s, and by the 1920s there was little commercially valuable timber left (PROV VPRS: 5714/344/288; 5714/364/458). The original vegetation was variously described as ‘thick box forest’ or some combination of box, gum, bulloak, she-oak, wattle and cherry. Tea-tree and red gum were said to be found along the stream banks. The soils in the area were often described as either clayey or clay–sand loam.

Although physically the hill country was distinct from the flats it also was considered unfit for cultivation in the 1880s. The reasons given by selectors for not cultivating the required 10% of selected land in the hill country were related to land either being too sandy, too rocky or too wet. (When land was taken up by selectors under the various Land Selection Acts there was a requirement that the land be improved before the selectors could be issued with freehold rights to the land. One of the improvements required by the government was that at least 10% of the land be cultivated.) Where cultivation did take place wheat, oats and hay were grown, but it was not unusual for black wattles to be cultivated for their bark (Land Selection Files; pers. comm. Stan Artridge, landholder, Feb. 1998). With the exception of some of the steeper country, ringing was completed by the 1890s, but timber still remained on a number of allotments in the area through to at least the 1920s (PROV VPRS: 5714/305/101; 5714/351/281). The native vegetation cleared by the selectors was described by the surveyors as some combination of grass, fern, honeysuckle (possibly a banksia), gum, box, peppermint, stringybark, cherry, wattle and oak. The soils in the area were generally described as sandy loams.

4.4.1. Creek morphology

Early plans and maps of the area suggest that the anabranch of Pranjip Creek existed in 1851, but that Branjee Creek was apparently not connected to Creightons Creek by a distinct channel during this period (CPO Historic Plans, Goulburn 22 & 68 (1851 & 1852)). A survey carried out in 1862 for the preparation of the first parish plan for the Parish of Branjee, shows Branjee Creek only extending to within 2 km of the present divergence point (CPO Historic Plans, Features 3, Parish of Branjee (1862)).

Plans based on a survey conducted in 1849 suggest that while only short sections of the upper reaches of Nine Mile Creek and Castle Creek were swampy, much of the area adjoining Creightons Creek, above the present location of Kelly’s Bridge, was swampy (CPO Historic Plans, Goulburn 72 (1849)).

Much more detailed information has been collected about the morphology of Creightons Creek from anecdotal evidence and Land Selection Files (for the reasons discussed in Section 3.2.1). This information is presented below, in two parts for clarity; first the hill country (i.e. above the Hume Freeway) is described, and then the flats (i.e. below the Hume Freeway).

Creightons Creek: the hill country

Survey notes are available for the surveys of six allotments along Creightons Creek in the hill country. The survey notes, which include information on the planform of the creek, cover most of Creightons Creek between Halsalls Lane and Bartons Lane. The descriptions and bank widths given in the notes suggest that the channel was well defined below Bartons Lane, with bank widths of between 8 m and 10 m. The surveyors' notes for two allotments in the area indicate that some sections of the creek below Bartons Lane were quite shallow and sandy, with no pools (PROV VPRS: 626/2095/3774; 625/365/25452), which may well be indicative of aggradation or simply the natural form of the creek.

Information from several Land Selection Files also provides evidence of possible sources of sediment. For example a surveyor noted in 1874 that where the Gobur Road crossed Creightons Creek (at Kellys Bridge) there were two deep ravines cutting through the swamp. This description suggests that two channels had eroded into the swamp at Kellys Bridge (PROV VPRS: 626/2021/610).

Similarly, in 1880, a surveyor who was responsible for surveying CA 15 of H Longwood (the road-front allotment at Baronga) noted that two channels were cutting back across the designated road reserve into the selector's allotment. The low lying area on the allotment was referred to as 'swampy flats' and the channels were said to be cutting farther back into the these flats each year, forcing travellers on the Gobur Road to travel into the selector's allotment to avoid having to cross the channels (PROV VPRS: 626/2058/2287).

A possible third example of erosion in the upper catchment was evident in Creightons Creek near the boundary of the Artridge property and an allotment now owned by the MacDonalds. In 1884 the surveyor responsible for surveying the upstream allotment (MacDonalds) noted that the stream morphology changed near the property boundary. According to him, downstream of the boundary the creek was wide, up to half a chain (10 m) in places, whilst further upstream the creek was so small it could be stepped over in places. Whilst this is not strong evidence it does suggest that a head of erosion may have been moving up Creightons Creek as early as 1884 (PROV VRPS: 626/44/3079).

Anecdotal evidence suggests that a fourth site of erosion may have existed on the lower section of Ramages Creek. Stan Artridge recalls his grandfather telling him that incision on Ramages Creek started when the original selector, Mr Ramage, used a plough line to drain part of the swamp that existed on the lower reaches of the creek (pers. comm. Stan Artridge, Landholder, Feb. 1998). It is highly probable that this occurred towards the end of the 1800s.

Creightons Creek: the flats

On the flats, the Creightons Creek system consists of the main stem of Creightons Creek, Little Branjee Creek and Branjee Creek.

Little Branjee Creek is described by surveyors in several of the Land Selection Files in the early 1880s as non-permanent (PROV VPRS: 626/2055/2134; 626/2093/3713) and a 'mere depression' (PROV VPRS: 626/2119/4673; 626/2121/4740; 626/2096/3801; 626/2129/5116). During selection, two allotments on Little Branjee Creek were surveyed. The surveyors notes from these surveys suggest that the channel of Little Branjee Creek was, at least in parts, a continuous channel with an average width of 4–5 m, but with pools up to 10 m in width (PROV VPRS: 626/2084/3346; 626/2096/3793).

Note that the interpretation of the surveyors' notes presented here assumes that the surveyors were measuring the width of the stream banks and not the width of the water surface, which is a reasonable assumption (pers. comm. Tony Morabito, Central Plan Office, DNRE, March 1998). Distinct 'chains of ponds' have been observed by the author along Little Branjee Creek south of Curries Rd, and these may be relics of the form of Little Branjee Creek prior to European settlement. No Land Selection File survey was available for this area and thus it is not possible to determine how this

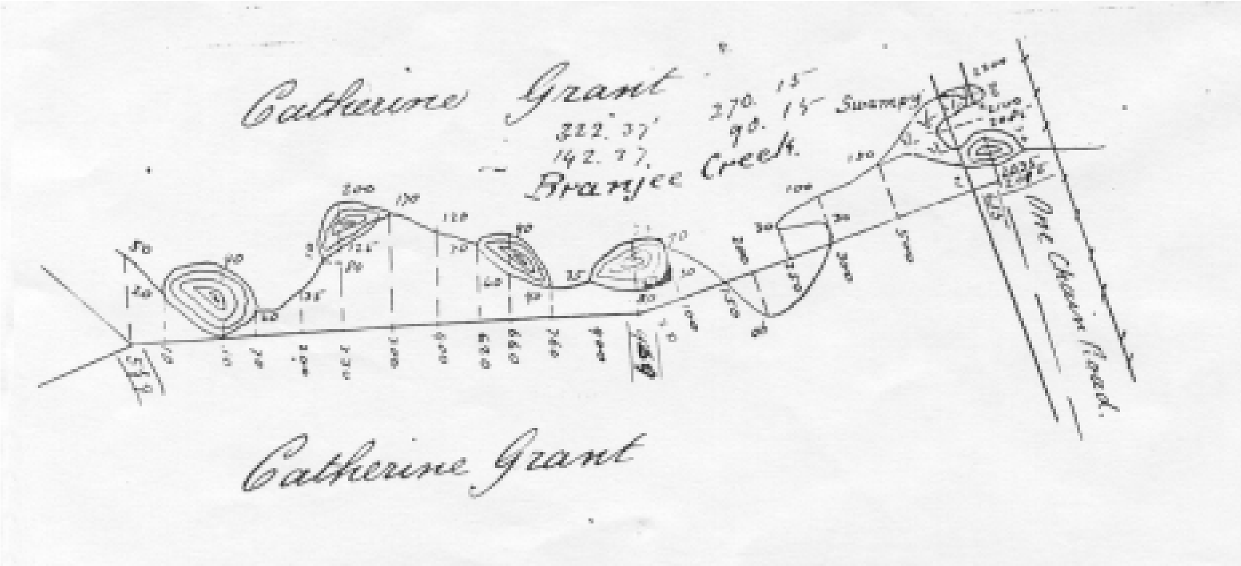
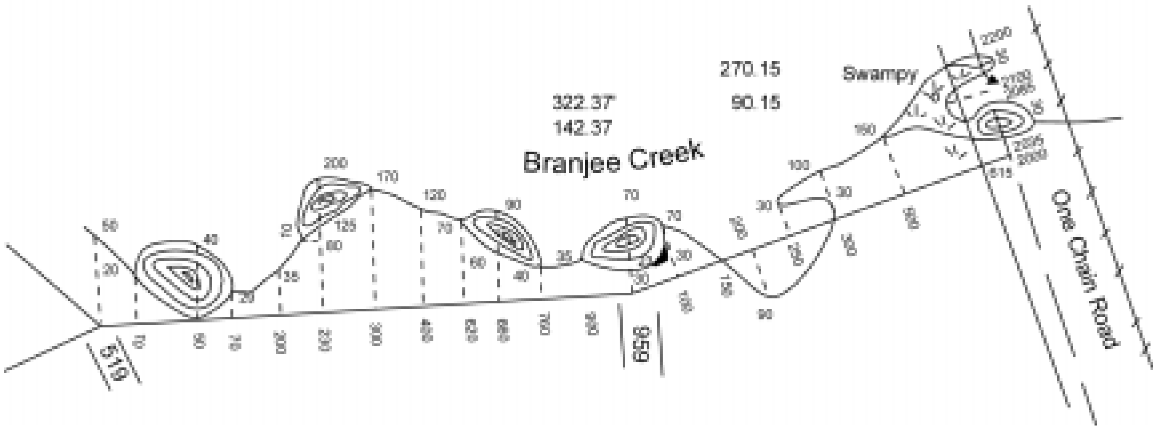


Fig. 4.1. Survey notes showing Branjee Creek in 1882. Note the narrow channel and large pools. Reproduced from PROV VPRS 626, Unit 2119, File 4671/20 (diagram taken from field notes of traverse of Branjee Creek) with the permission of the Keeper of Public Records, Public Records Office Victoria, Australia. A trace of the scan is reproduced below, for clarity.



form of stream was portrayed by the surveyors, i.e. as a distinct channel with regular width, or as a chain of ponds.

Branjee Creek was described in the early 1880s, in several Land Selection Files, as non-permanent (e.g. PROV VPRS: 626/2055/2134; 626/2119/4673). None of the Land Selection Files indicates that there was a swamp at the head of Branjee Creek, just north of Nelsons Rd, or that Branjee Creek received runoff directly from Creightons Creek via a distinct channel (PROV VPRS: 626/614/17419; 626/640/19003; 626/603/16872; 626/603/16871).

Five allotments were surveyed along Branjee Creek during the late 1870s and early 1880s, and as part of these surveys Branjee Creek was also surveyed (PROV VPRS: 626/2096/3793; 626/2054/2081; 626/2119/4671; 626/2137/5435; 626/2129/5120). Although it is necessary to be cautious about interpreting the results of these surveys, the notes suggest that Branjee Creek may have had two distinct morphologies. Downstream (below Hills Rd) it may have been a well defined channel, approximately 6 m wide. Upstream it is possible that Branjee Creek consisted of a narrow channel interspersed with pools, some 8 m wide and 50 m long (Fig. 4.1). The upstream channel area may have also tended to be swampy in winter.

The main stem of Creightons Creek was noted as being permanent during most of the surveys that took place on allotments along the creeks during the late 1870s and early 1880s (e.g. PROV VPRS: 626/2080/3171). Only one swamp was noted on the creek below the Hume Freeway during this period. Belton's Swamp, as it will be referred to, extended along the line of the creek from a point just north of the Pranjip Rd to the confluence of Creightons Creek and Branjee Creek (PROV VPRS: 626/2055/2134).

Survey notes for Creightons Creek were found for a large proportion of the allotments on Creightons Creek between the Pranjip Creek confluence and the Hume Freeway (19 in total). The notes suggest that Creightons Creek ran in a defined channel for most of its length except at Belton's Swamp where a small channel wound its way through the swamp. Upstream and downstream of the swamp the channel tended to be between 4 m and 10 m wide, with pools up to 20 m wide in places. The surveys indicate that the stream was probably at its narrowest (4–5 m) between the Geodetic Rd and the Longwood–Pranjip Rd, before appearing to double in width (~10 m) between the Geodetic Rd and the present Hume Freeway. This evidence indicates that the Creightons Creek channel may have been narrowing in the vicinity of the present-day location of the Branjee Creek off-take, in the early 1880s.

The North-Eastern Railway was constructed in 1873, substantially altering the hydrology of high flows from the hill country onto the flats by restricting flows to one or two specific drainage lines under the railway line. However, there is no evidence to suggest that channel incision resulted as might have been expected (see Section 4.7 for more information).

Anecdotal evidence suggests that there were several deep pools along Creightons Creek up to the beginning of the 1900s. There are stories of pools 12–14 feet (3–4 m) deep on Creightons Creek near the Pranjip Rd and an even deeper pool, 15–20 feet (4.5–6 m) deep, adjacent to the Longwood–Pranjip Rd (pers. comm. Jack Stevens, landholder, Feb. 1998). There is also a story about woodcutters leading their horses under the bridge on the Geodetic Rd near the beginning of the 1900s, which suggests the creek was at least 3 m deep at this point (pers. comm. Jack Stevens, landholder, Feb. 1998), but today there is not even a culvert — the stream simply no longer exists (Fig. 4.2). Thus it is possible that at the beginning of the 1900s Creightons Creek flowed in a well-defined channel with deep pools for much of its length below the present Hume Freeway. Figure 4.3 shows remnant pools in this section of Creightons Creek today.

Fig. 4.2. Former channel of Creightons Creek upstream of Geodetic Rd. Anecdotal evidence suggests that a deep pool (2–3 m deep) existed at this point towards the end of the 19th century.

Fig. 4.3. Remnant pools on Creightons Creek today. This stream form could be representative of the lower reaches of Creighton's Creek (i.e. below the present Hume Freeway) in the 1800s.

In summary, the channels of Little Branjee, Branjee and Creightons Creek on the flats differ from those apparent today. Little Branjee Creek was intermittent and probably comprised a narrow channel interspersed with pools. Branjee Creek was permanently linked to Creightons Creek only at its downstream end and had two distinct forms. Below Hills Rd, Branjee Creek was a well-defined, moderate size channel, while above Hills Rd the channel was narrow and interspersed with pools, and tended to be swampy. Creightons Creek flowed in a well-defined channel with deep pools, from the present Hume Freeway down to Pranjip Rd where the channel then became narrow and swampy.

4.5. The Creightons Creek area in the 20th century

The following is a chronological description of activities affecting Creightons Creek and its behaviour during the 20th century based on anecdotal evidence, agency files and some fieldwork. Creightons Creek is the only creek for which detailed information was sought, because of time constraints, but it is probable that the history of erosion and sedimentation outlined below for Creightons Creek is representative of the histories of the other Granite Creeks.

4.5.1. Creightons Creek: the hill country

From the description of creek morphology for the hill country between 1850 and 1900 it is possible to derive an approximate description of Creightons Creek at the beginning of the 1900s. Between the present Hume Freeway and Bartons Lane, at least, it is probable that Creightons Creek was relatively wide (~10 m), shallow and sandy. Above Kellys Bridge it seems likely that, while some swamp may have remained adjacent to the creek, the creek itself was contained in a distinct channel. Further upstream, above Stan Artridge's property, in the steeper reaches of the catchment, it is probable that the creek was channelised in some sections, but where floodplains exist the channel adjoined swampy flats. Bert Threlfall recalls much of Creightons Creek above the MacDonald property as flowing in narrow deep channels which were almost completely covered with the sword grass and fish fern that grew on the banks. In some areas the only indication that the stream was running was from the sounds coming from beneath the dense canopy (pers. comm. Bert Threlfall, former landholder, March 1998). Although it is possible that this stream form may have existed prior to European settlement, it seems likely that it co-existed with an unchannelised swampy form.

The state of the tributaries at the start of the 20th century is even more difficult to establish. For Baronga Creek it is probable that the lowest section of the creek (i.e. below the waterfall near Barrie Noye's house) was channelised but not deeply incised, and the flats surrounding the creek may have still tended to be swampy, particularly in winter. Ramages Creek was probably in a similar state with the lower reaches channelised but not deeply incised, and the surrounding flats swampy.

The first major changes in the upper catchment in the 20th century probably coincided with the 1916 flood, one of the largest on record (Sinclair Knight Merz 1997). Anecdotal evidence suggests that the flood resulted in massive channel incision (of the order of 8–10 m in places) on Creightons Creek above the Ramages Creek junction (Fig. 4.4) (pers. comm. Stan Artridge, landholder, Feb. 1998). This incision event can be traced upstream to a waterfall on Stan's property. Similar incision may have also occurred on Ramages Creek near Bill O'Connor's house (pers. comm. Bert Threlfall, former landholder, March 1998), and on sections of Creightons Creek above the Artridge property, e.g. on John Nielsen's property (based on observations made by author). This event must have excavated large volumes of sediment and had a catastrophic impact downstream; however, there is no evidence available of significant siltation above the present Hume Freeway at this time.

A second phase of channel incision appears to have coincided with the 1950s, which was a particularly wet decade. Over 1050 mm of rain fell in 1956 alone and there were three years between 1952 and 1956 in which more than 800 mm fell annually, compared with the annual average of 653 mm (based on rainfall data for Euroa published in the Centenary Edition of the *Euroa Gazette* December 1997). The process by which incision occurred is not clear, but it seems likely that a series of erosion heads moved up Creightons Creek during the 1950s and 1960s (e.g. pers. comm. Barrie Noye, landholder, Feb. 1998), resulting in incision throughout much of the system. Baronga Creek, for example, incised 4–5 m between the Creightons Creek Rd and the waterfall (pers. comm. Barrie Noye, landholder, Feb. 1998; Goulburn-Murray Water File: 2020 WW). Incision elsewhere does not appear to have been as severe (closer to 1–1.5 m), but it is clearly evident along the lower sections of Ramages Creek, as well as on Creightons Creek above the Ramages Creek junction.

The only evidence of stream incision downstream of Kellys Bridge during this period is at the present Hume Freeway where a highway bridge had to be replaced in 1957/8 because of stream enlargement (pers. comm. Paul Tucker, Vic Roads, Benalla, March 1998). A comparison of cross-sections measured on Creightons Creek at the Hume Freeway in 1957 and 1998 indicates that in that 40 year period the streambed at the bridge has dropped approximately 50 c m (Appendix Fig. B3). A bed control structure in the creek immediately below the bridge (Fig. 4.5) is holding another 30–50 cm erosion head from moving upstream. It is not possible to determine the timing of this incision.

Sediment deposition from this second major phase of channel incision was noted at a number of locations in the creek downstream of the Baronga Creek confluence. Sedimentation in the creek in the vicinity of the Creightons Creek Reserve was noted by Brian Kelly. According to Brian there were a number of large pools (approximately 6 m in diameter) along Creightons Creek just downstream of Kellys Bridge in the 1940s and 1950s which started to fill with sediment in the 1950s;

Fig. 4.4. Creightons Creek above the junction with Ramages Creek on Stan Artridge's property. This section of Creightons Creek has incised more than 10 m and anecdotal evidence suggests that most of this incision occurred during the 1916 flood.

Fig. 4.5. Creightons Creek at the Hume Freeway Bridge. The concrete sill visible in the photo is a bed control structure that is protecting the bridge piers from being undermined.

and within a few years they had disappeared altogether. Other changes during this period were also noted by Brian in, and just above, the Creightons Creek Reserve, as well as at Kellys Bridge. Throughout the decades that followed the 1950s, the creek in and just above the Reserve began to silt up, with up to 0.5 m of sediment deposited (pers. comm. Brian Kelly, landholder, Feb. 1998).

Just below the Reserve at Kellys Bridge, sediment deposition of 8–9 feet (2.5–3 m) occurred following the 1950s, engulfing the old road bridge (pers. comm. Brian Kelly, landholder, Feb. 1998). Downstream of Kellys Bridge, below the Longwood–Mansfield Rd, Jim Shovelton also has recollections of pools in Creightons Creek in the 1950s that were 3–4 feet (~1 m) deep, although he believes that the pools higher up the creek were not as deep. These pools filled in not many years after the 1950s (pers. comm. Jim Shovelton, landholder, Feb. 1998). These observations suggest that sediment deposition in this section of the creek commenced in the 1950s, starting further upstream, hence the shallower pools; and by the 1960s all the bed form above the Longwood–Mansfield Rd had been sanded out.

A third phase of incision may have moved through the upper reaches of Creightons Creek over the last 20 years, particularly affecting the lowest section of Baronga Creek, as well as much of Creightons Creek above the Hume Freeway. As mentioned above, according to Brian Kelly the old road bridge (Kellys Bridge) was almost completely buried in the decades that followed the 1950s, but over the last decade or so the sediment engulfing the bridge has receded and the creek, in the vicinity of the old bridge, is apparently at a similar bed elevation today to that prior to the 1950s (pers. comm. Brian Kelly, landholder, Feb. 1998). This anecdotal evidence is supported to some extent by information generated by comparing the original design of the current bridge (Strathbogie Shire Council Bridge Plan: 129 (1966)) with the current bridge cross-section. Such a comparison suggests that over the last thirty years Creightons Creek may have degraded by 1 m, lending some support to Brian Kelly's claim.

Heads of erosion have also continued to move up Baronga Creek to the waterfall over the last two decades. Barrie Noye planted vegetation in the bed of Baronga Creek in the late 1970s, and today the streambed is, in places, 10 feet (3 m) below the vegetation (pers. comm. Barrie Noye, landholder, March 1998). However, comparisons of cross-sections measured at the Creightons Creek Rd bridge over Baronga Creek in 1988 (Strathbogie Shire Council Bridge Plan: 518 (1988)) and 1998, indicate that there has been limited change in bed elevation in this vicinity over the last ten years (1988–1998). This suggests that there has been limited bed movement at the lower end of Baronga Creek during the last decade.

Fig. 4.6. Creightons Creek upstream of Bartons Lane. This section of Creightons Creek would once have had a much smaller channel and would have flowed across a swampy plain. The stream is now incised and is continuing to incise in places (see headcut in channel bed).

Incision has also been noted upstream of Bartons Lane (Fig. 4.6.). Dino Furlanetto has noticed Creightons Creek incising over the last 25 years, with much of the incision occurring during flood events. The 1993 floods were particularly damaging, causing severe incision and widening immediately upstream of Bartons Lane, where the creek is now 3–4 m deep in places. To halt the incision Dino has put in two rock chutes to act as sediment traps. He claims they have caused the bed to rise about 3 feet (1 m), with most of the sediment being trapped within a year of chute construction (pers. comm. Dino Furlanetto, landholder, March 1998). It was interesting to note that the incision at the Furlanettos' has revealed the stumps of two large gum trees in the creek bed, suggesting that the creek has been at its current level in the past. This scenario is consistent with the filling and cutting of the creek bed at Kellys Bridge, 1–2 km further upstream, noted by Brian Kelly.

It is not clear if such incision extended down to the Longwood–Mansfield Rd. Conflicting bridge design records indicate the bed may have degraded up to 1 m in this vicinity over the last 30 years, or it may have degraded less than 0.2 m in total over the last 20 years.

Further downstream still, just above Halsalls Lane, Jim Dunn has also noted the creek deepening in recent years. The bed may have dropped a couple of feet (approximately 0.5 m) in this area, but it is also possible that some of the incision observed may be localised.

The legacy of the third phase of incision in the upper section of Creightons Creek has been another wave of in-stream sedimentation resulting in the infilling of some of the pools remaining in Creightons Creek above the Baronga Creek confluence. Sue Haggard, for example has noted that many of the pools that existed in the creek adjacent to her property (in the MacDonalds property) 25 years ago, have now filled (pers. comm. Sue Haggard, landholder, March 1998). Sedimentation has also continued in Creightons Creek adjacent to the Creightons Creek Recreation Reserve (immediately upstream of Kellys Bridge). The local landholders became so concerned about flooding resulting from this sedimentation that in the late 1980s the channel was dredged to increase the stream capacity locally (pers. comm. Brian Kelly, landholder, Feb. 1998). This action may, however, have caused incision. At the Recreation Reserve the creek has incised 1 foot (0.3 m) since dredging (pers. comm. Brian Kelly, landholder, Feb. 1998) and upstream of the Recreation Reserve it has cut down 5 feet (1.5 m) (pers. comm. Laurie Davidson, landholder, Nov. 1998).

While the three main phases of incision appear to have been responsible for many of the changes noted in the upper section of Creightons Creeks over the years, there have been other isolated cases of erosion in the upper catchment. Examples include channel avulsion, incision and an erosion head forming in the lower reaches of Ramages Creek, triggered apparently by significant local rainfall events in 1988/9 (pers. comm. Bill O'Connor, landholder, March 1998; Goulburn-Murray Water File 2020 WW), and gullying initiated during a wet 1973 (annual rainfall for 1973 was 1078 mm) (DNRE, SCA File: N/ 230). Inappropriate land management in the form of ploughing lands has been blamed for at least one gully on Jim Shovelton's property (pers. comm. Jim Shovelton, landholder, March 1998), and bushfires (1990–91) and drought (1982–83) are considered to be the disturbances responsible for triggering gullies on the properties of Dino Furlanetto (pers. comm. Dino Furlanetto, landholder, March 1998) and John Nielsen (pers. comm. John Nielsen, landholder, March 1998) respectively.

Bert Threlfall and Barrie Noye have both observed a number of small erosion heads moving up the headwater reaches of Creightons Creek and its tributaries in recent years, and they have attributed these heads to uncontrolled stock access to the streams, particularly by cattle (pers. comm. Bert Threlfall and Barrie Noye, landholders, March 1998). These erosion heads are said to be the source of sediment that is starting to fill some of the small pools remaining higher up the creek. The upper section of Creightons Creek has few segments that are today in a form similar to that which would have been seen by the first settlers over 150 years ago. Few swamps remain and the channelised segments are sanded out with little variation in bed form.

In summary it would appear that there have been three main phases of channel incision in the upper section of Creightons Creek. The first two phases appear to have been related to flood events or 'wet years', when stream power was sufficient to drive a number of existing erosion heads a great distance, and perhaps initiate some others. The combined result of these was a single incision event of the order of several metres. The third phase of channel incision does not appear to have had an obvious external trigger but it may be a combination of events over the period, e.g. 1982–83 drought, 1990–91 bushfires and 1993–94 floods, that have pushed a number of erosion heads quite quickly through the system. This implies that erosion heads are just as prevalent in the system now as they have been at any time in the past 100 years, but it may also be an artefact of greater stream awareness and the temporal proximity of these events in people's minds. Possible sources of disturbance for initiating erosion heads are explored in Section 4.7.

Bushfires and droughts, as well as land management activities, also appear to have had an impact on stream and drainage line stability at a local level.

4.5.2. Creightons Creek: the flats

Changes during the 20th century along Creightons Creek and its tributaries on the flats have been just as dramatic as those that occurred upstream of the present Hume Freeway, but they seem to be more closely linked to changes induced by sediment delivered from the upper catchment than to local activities.

At the beginning of the 1900s Creightons Creek was probably carrying all the low flows derived from the upper catchment. In terms of the creek form it is likely that for much of its length it was similar to the sections near the Longwood–Shepparton Rd today, i.e. with long deep pools as well as shallower 'run' sections (see Fig. 4.3). The only place in which it may not have had a well defined course was through Beltons Swamp, although there is anecdotal evidence to suggest that drains cut through the swamp around the beginning of the 1900s may have 'captured' the creek and allowed it to develop a more well-defined course (pers. comm. Jack Stevens, landholder, Feb. 1998). This incision, as well as possible incision initiated at the railway line by the channelisation of flow, may have been the most significant disturbances visible along Creightons Creek at the beginning of the 1900s.

Although the lower sections of Branjee Creek may have had a well defined channel, it is possible that the upper section was in the form of a chain of ponds which had no direct connection to Creightons Creek. The same may also have applied to Little Branjee Creek. Despite being 'disconnected' from Creightons Creek, and thus non-permanent, it is probable that both Branjee Creek and Little Branjee Creek carried overflow from Creightons Creek during flood events, thus behaving as anabranches of Creightons Creek.

Fig. 4.7. A section of Creightons Creek upstream of the Longwood–Pranjip Rd. This section of channel was dredged in 1969 and the dredge material placed in mounds on the creek bank. Since the early 1970s the channel has only carried flood flows.

It is clear that sedimentation commenced along the lower section of Creightons Creek in the early 1900s, but it took a number of years for significant impacts to accumulate. Changes apparently were first noted in the 1930s and 1940s, as Creightons Creek began to fill with sand, particularly in the section just north of Nelsons Rd. In 1935 it was recorded at a meeting of the Euroa Shire Council that siltation of Creightons Creek was causing damage to roads in the Pranjip area (Halsall 1980). Anecdotal evidence suggests that flow in Creightons Creek at the Pranjip Rd began to decline in the 1930s (pers. comm. Jack Stevens, landholder, Feb. 1998), suggesting that some proportion of flow in Creightons Creek was already being diverted into Branjee Creek. This is supported by the claim that Nelsons Swamp came into existence around the 1940s (pers. comm. Jack Stevens, landholder, Feb. 1998), which indicates that Creightons Creek began to have difficulty carrying flows at this time. A local landholder also recalls that Branjee Creek began to change following the 1940s. According to Jack Stevens, Branjee Creek consisted of a series of ponds or pools in the 1940s, but since then the ridges between the pools have been scoured out and the creek is now a continuous channel (pers. comm. Jack Stevens, landholder, Feb. 1998). The changes noted along sections of Branjee Creek after the 1940s may be consistent with the conversion of an ephemeral stream to a perennial stream.

By 1969 sedimentation was so severe under road bridges at Nelsons Rd and the Longwood–Pranjip Rd that the Shire of Euroa sought State Rivers and Water Supply Commission (SRWSC) funding to clear snags and vegetation from Creightons Creek in the vicinity of the bridges. This funding was granted (Goulburn-Murray Water File: 2020 WW) and in the months that followed sand was dredged from the creek at both bridges, and reeds and snags were removed from the bed (pers. comm. Maurie Brodie, landholder, Feb. 1998). Anecdotal evidence suggests that a hole 3 m deep and about 30 m long was dredged under the Nelsons Rd bridge, but this hole had filled again within 12 months (pers. comm. Maurie Brodie, landholder, Feb. 1998). In contrast, there has been very little change following the works conducted at the Longwood–Pranjip Rd bridge. The mounds of dredged silt are still visible on the banks and the channel remains clear of vegetation and relatively deep (Fig. 4.7). The contrasting responses can be explained by the fact that the Creightons Creek at the Nelson Rd bridge has continued to carry all the flow delivered from the upper catchment, while below Nelsons Swamp Creightons Creek was carrying only 14% of low flows in 1971, the remaining 86% being diverting into Branjee Creek (Goulburn-Murray Water File: 2020 WW). A short time after this breakdown in flows was measured, the diversion was completed with the construction of a drain by a landholder (pers. comm. Maurie Brodie, landholder, Feb. 1998), which resulted in 100% of low flows entering Branjee Creek. Consequently Creightons Creek at the Longwood–Pranjip Rd has carried little flow derived from the upper Creightons Creek catchment since 1969, and thus there has been little opportunity for this section of the creek to fill with sediment.

Since the diversion drain was constructed in 1971 all low flows have been carried by Branjee Creek, but it is not clear if some of the high flows are still carried by Creightons Creek below Nelsons Swamp. In terms of the creek's morphology, the original course of Creightons Creek has been obliterated by cultivation in the paddock where the creek has been diverted. Immediately below the paddock the channel has completely filled with sediment and is only discernible by vegetation patterns. The creek has a similar appearance at the Geodetic Rd, but by the time the creek reaches the Drysdale Rd a shallow course is visible.

Changes to Creightons Creek and Branjee Creek over the last couple of decades appear to relate to management activities in the creeks. For example the drain that was cut to divert all the flow into Branjee Creek was originally 18 inches (0.45 m) deep and 2–3 feet (~0.75 m) wide, but it is now approximately 1.5 m deep and 10 m wide (Fig. 4.8). Other activities affecting the creek in recent years include the cutting off of meander bends on Branjee Creek several hundred metres below the diversion point (1980s) and where the drain begins (1997), and desnagging and poisoning of cane grass (*sic*) in the bed of the creek (1997). The landholder carried out these activities to prevent sand building up in the bed and claims that the activities carried out in 1997 alone have led to the creek bed dropping 15 inches (~0.4 m) (Fig. 4.9) (pers. comm. Maurie Brodie, landholder, Feb. 1998).

At the bottom end of the Creightons Creek system, below the Branjee Creek confluence, sand deposition has been minimal, to date. This is indicated both by visual inspection and by a comparison of stream cross-sections measured at the Longwood–Shepparton Rd bridge. Observations of Creightons Creek below the Branjee Creek confluence indicate that although there is some evidence of sand deposition in this reach it is minor and comprised mainly of small deposits on point bars and in low velocity zones along the stream. Sand can also be observed in the bed, but, as discussed in Section 5.1.2, the local streambed and banks are the most likely source of this material. A comparison of the original bridge design for the Longwood–Shepparton Rd bridge (Strathbogie Shire Council Bridge Plan: 529 (1989)) with the present cross-section reveals that there has been little change in bed elevation over the last nine years.

To briefly summarise, Creightons Creek below the present Hume Freeway has changed dramatically since the start of the 1900s. Originally the channel contained deep pools and runs, and carried 100% of low flows. During high flows it is probable that overbank flows were captured by Branjee Creek and Little Branjee Creek which functioned as anabranches and had predominantly 'chain-of-ponds' forms. Since European settlement, change appears to have been driven by sediment being transported from the upper catchment to the lower catchment. Sedimentation has obliterated many of the pools in Creightons Creek above the Branjee confluence; it blocked the Creightons

Fig. 4.8. Branjee Creek between Nelsons Rd and Drysdale Rd. This section of Branjee Creek was originally a narrow drain cut to divert all baseflows from Creightons Creek into Branjee Creek. The channel has deepened and widened substantially over the last 30 years.

Fig. 4.9. Branjee–Creightons Creek meander cutoff, initiated in 1997

Creek channel to such a degree that over a period of about 30–40 years low flows began to divert into Branjee Creek. The diversion, which was assisted in 1971 by direct human intervention, has altered the form of Branjee Creek to that of a continuous channel, the pools of which are now filling with sand. While there is little doubt that such channel abandonment is a natural feature of these Riverine Plain streams, as is evidenced by the existence of sand filled channels on the flats (pers. comm. Len Stevens, landholder, Feb. 1998), it seems probable that this process has been accelerated by the effects of European settlement.

4.6. Evidence of erosion and sedimentation along Castle Creek and Pranjip–Nine Mile Creek

Castle Creek and Pranjip–Nine Mile Creek have not been considered in the same detail as Creightons Creek. Some information has been gathered for these two creeks, but it is patchy, and no clear picture of the timing and location of erosion and aggradation can be formed. However, the information provides an approximate means of comparing the history of stream morphology for all three creeks.

4.6.1. Castle Creek

There is evidence that erosion was occurring in the Castle Creek catchment not long after the beginning of the 1900s. A Soil Conservation Authority (SCA) file indicates that trees may have been planted along a gully in the catchment to stabilise it between 1910 and 1920 (DNRE SCA Files: S/1064). Since that time, the SCA has been called in by landholders on a number of occasions to address problems, primarily gullying. Most of the gullying problems were reported in the 1960s and 1970s, but in some instances the gully was old and was quite stable or had been reactivated in recent years. Therefore, it cannot necessarily be assumed that this was an especially erosive period (DNRE SCA Files: B/1282, H/573, H/1099, M/966, R/222, S/1064, W/519). It is also important to note that only a small proportion of landholders would have approached the SCA about erosion problems, and these landholders may not have been aware of the SCA prior to the 1960s.

One notable example of erosion in Castle Creek catchment has been recorded in SCA, NRE and RWC Files, namely the movement of an 8 foot erosion head (2.4 m) up Castle Creek during the 1970s. According to an SCA report between 1973 and 1977 the head advanced 80 m upstream, degrading the bed 2.5 m and widening the stream 5–15 m (S/1064). It is interesting to consider this rate of advance in relation to rainfall in this period. Annual rainfall in 1973 was 1078 mm, the wettest year since records began. This was followed by 897 mm in 1974 and 896 mm in 1975 (based on rainfall data in the Centenary Edition of the *Euroa Gazette*, 1997). The SCA report does not reveal what initiated the erosion head/s, but it indicates that the wet 1970s led to the rapid liberation of approximately 2000 m^3 of sediment from the bed and banks of Castle Creek.

The NRE/RWC Files for Castle Creek indicate that the 8 foot erosion head that moved through the upper reaches of Castle Creek in the 1970s incised a section of creek that had already been incised 10 feet (3 m) in 1961 (NRE/RWC File, 62/19071). Anecdotal evidence from a local landholder suggests that this reach of Castle Creek, i.e. above Killeens Hill Rd, was quite stable and relatively undisturbed until the 1960s when his father decided to move the creek so it was closer to the house for convenience (pers. comm. Geoff McLean, landholder, May 1998). He did this by using his tractor to dig a new channel for the creek, and he succeeded in diverting the creek over a length of 500 m. However, once the creek changed course it began to incise. On the McLean's property there have been two periods of incision, the first coinciding with the diversion of the creek in the 1950s–60s, and the second in response to the 1993 floods. Both periods of incision have reduced the bed elevation by about 2 m. The erosion head initiated by the diversion of the creek in the 1950s–60s migrated upstream until it reached a waterfall (several kilometres above the McLean's property). It appears that as the head migrated upstream it increased in height, incising into the streambed more deeply, and in fact it appears that the head has incised into the original creek bed up to 10 m, just below the waterfall (Fig. 4.10).

The material excavated from the upper reaches of Castle Creek by stream incision has been deposited over the floodplain between Geoff McLean's house and the lower boundary of his property, at a depth of 4–5 feet (~1.4 m) (pers. comm. Geoff McLean, landholder, May 1998). This information suggests that more than 500 000 m^3 of sediment may be held in this store. There is some evidence to support Geoff McLean's claims. For example the original creek is still visible on the floodplain, and it is relatively small (~0.5 m deep and 1.5–2 m wide) suggesting that it was stable prior to diversion. There are also several pieces of evidence suggesting that 1.4 m (4–5 feet) of sediment has been deposited on the floodplain. First, the authors observed a piece of milled timber sticking out of the stream bank about 4 feet below the top of the stream bank, which is consistent with it having been buried under the sediment deposited on the floodplain. Second, a number of red gums that were located along the creek have died, apparently because their trunks have been indundated by sediment. Further evidence supporting Geoff McLean's story is that soil layering exposed in the stream banks shows 1.4 m of lighter material overlying a darker layer that may correspond to the original A Horizon. The final piece of evidence relates to the stripping of the lighter sediment layer at several points along the creek by the 1993 floods. At a number of sites along the creek the floods stripped soil to create benches,

Fig. 4.10. Castle Creek upstream of the McLeans' property. Severe stream incision and widening has led to the formation of this chasm since the 1960s.

but in each case the soil was stripped to exactly the same level, which corresponded to the top of the darker soil layer just described, and following the floods a large number of native plants germinated on the exposed benches. All these observations are consistent with the original soil surface being covered by 1.4 m of sediment, which was predominantly sandy and lacked cohesion and thus strength, making it susceptible to further erosion.

Erosion has also been a problem at several other locations along Castle Creek, according to NRE and NRE/RWC Files. Erosion was recorded on Castle Creek at the Newtons' in 1963, when a short section of creek was abandoned and a new channel formed that was much deeper and wider (the original channel was 3 ft (0.9 m) deep and 6 ft (1.8 m) wide, and the new channel was 12 ft (3.7 m) deep and 20 ft (6.1 m) wide) (NRE/RWC File, 62/19071). Erosion was still a problem on this reach of Castle Creek 17 years later when deepening and widening was noted over a length of 0.5–0.75 miles (800–1200 m) (NRE/RWC File, 62/19071). In 1982, funding was granted for the construction of an erosion control structure in this reach to control the erosion head that was responsible for destabilising the creek. In the 12 months preceding 1982 the head had moved 300 m (NRE/RWC File, 62/19071). More recently, in 1993, funding was allocated for the construction of a floodway to prevent the creek abandoning a section of channel (NRE File, 85/22219).

In 1998 a drop structure was constructed on Castle Creek on John King's property to prevent several erosion heads by-passing the willows that were stopping the heads from moving further upstream (pers. comm. Wayne Tennant, GBCMA, May 1998). Another head of similar size (3–4 m) is located a short distance downstream and is presently caught on a bedrock bar. However, there is concern that the bar will soon be out-flanked and it is proposed that works be carried out to control this erosion in the future.

Stream erosion has also occurred downstream of Euroa. During a wet winter in the early 1980s, part of Castle Creek and some of the surrounding paddocks eroded (NRE/RWC File, 62/19071).

At three locations along Castle Creek the creek has been straightened to facilitate the realignment of roads. An historic map (CPO Putaway Plans E81(2) (1909)) indicates that a meander bend was cut off in about 1910, from Castle Creek near Sydney Road (the old Hume Highway) to allow the road to be realigned. Later, plans for road bridges over Castle Creek prepared by the Euroa Shire Council in 1959 (Cullens Rd) and 1970 (Geodetic Rd) (Strathbogie Shire Council Bridge Plan: 182 & 022 (1959 & 1970)), indicate that the creek was to be realigned to allow the roads to be realigned. In all three cases the creek realignment involved cutting off a substantial meander and in the process steepening the creek gradient locally, which may have had the potential to initiate erosion heads (Galay 1983).

Some of the earliest information readily available regarding the morphology of Castle Creek suggests that although deep holes were noted in the streambed near Sydney Road at about the start of the 1900s (Halsall 1980), the bed in this reach of creek was probably flat and sandy by the 1930s. Two pieces of evidence support this suggestion. One piece of evidence comes from a story about a railway ganger having to jump from the railway line in 1933 to avoid being struck by a train; it was said that he landed safely in the sandy bed of Castle Creek (Halsall 1980). The second piece of evidence comes from a photo of Castle Creek taken adjacent to the Euroa Golf Course sometime before 1947/8, which shows the bed to be shallow and sandy (Halsall 1980).

Aggradation in Castle Creek has been recorded in the RWC and NRE files as occurring primarily between the old Hume Highway bridge and the Drysdale Rd, although it has also been noted upstream between Euroa and the Euroa–Mansfield Rd bridge (i.e. Telfords Bridge). The deposition of sand in this area is said to have exacerbated flooding problems in parts of Euroa, and as a result desnagging and sand extraction have been authorised on a number of occasions. However, on at least one occasion (in 1982) sand extraction and the removal of all vegetation and snags from the creek resulted in the formation of a small erosion head just upstream of the old Hume Highway bridge (DNRE RWC File 62/19071).

Fig. 4.11. Sand deposition in Castle Creek downstream of the old Hume Highway Bridge

Comparisons of stream cross-sections measured at the railway line and the old Hume Highway suggest that the bed of Castle Creek in this vicinity accreted during the 1900s. A re-survey of the old Hume Highway bridge suggests that between 1938 and 1998 (60 years) the bed may have risen slightly (Fig. 4.11 and Appendix Fig. B4). A re-survey of the railway bridge at Castle Creek indicates that between 1926 and 1995 the bed may have accreted more than 50 cm, whilst between 1995 and 1998 it may have degraded slightly (Appendix Fig. B8). The degradation between 1995 and 1998 may, however, be related to the removal of sediment from beneath the bridge (PTC Bridge Files, Somerton to Wodonga Line, Index: 186). From these data it is possible to say that this section of Castle Creek has aggraded since 1926, but given the data for the old Hume Highway and the story about the railway ganger described above, it is possible to speculate that much of the aggradation may have occurred in the late 1920s and early 1930s. The evidence presented above regarding sand extraction from Castle Creek in the vicinity of the old Hume Highway bridge and the railway line, suggests that the rates of sedimentation estimated from the bridge cross-sections are probably substantial underestimates of the actual rate of sedimentation.

A comparison of bridge design cross-sections with present cross-sections at a number of other sites along Castle Creek indicates that bed elevations have risen, dropped, and remained stable at different points along the creek over the last 30 or so years. Cross-sections at the Euroa–Mansfield Rd (Telfords Bridge) for example, indicate that the creek was silting up prior to 1939 (Strathbogie Shire Council Bridge Plan: 002 (1939)), and between 1939 and 1991 it may have aggraded by more than 1 m (Strathbogie Shire Council Bridge Plans: 002 & 554 (1939 & 1991)). Since the bridge was replaced in 1991 the channel has adjusted its shape and may have experienced some aggradation (Strathbogie Shire Council Bridge Plans: 554 & 554-3 (1991 & 1991). Downstream at the Pranjip Rd bridge, Castle Creek appears to have scoured. Between the early 1960s and 1998 the creek bed may have degraded 1–1.5 m. Further downstream at the Cullens Rd bridge a comparison between the design cross-section, which was constructed sometime after 1959, and the present day cross-section indicates that the bed may have aggraded slightly (~20–30 cm).

The lowest cross-section available on Castle Creek is at the Murchison–Violet Town Rd bridge (Strathbogie Shire Council Bridge Plan: 076 (1961)). When the bridge was built in the early 1960s up to 10 feet (3 m) of material was removed from the streambed to form the present day channel.

Fig. 4.12. Pranjip Creek at the Hume Freeway. More than 0.5 m of sediment may have been deposited in this section of channel between 1958 and 1998.

Such a disturbance might be expected to propagate upstream via knickpoint migration, but an inspection of the reach upstream revealed no such degradation, with the narrow run–pool sequence intact. Even at the bridge site change has been minimal, with the bed elevation appearing to have dropped 10–20 cm at the most over 30 years.

4.6.2. Pranjip–Nine Mile Creek

The earliest evidence of erosion in the Pranjip–Nine Mile Creek catchment comes from Killeen on the Nine Mile Creek, in 1949, where a gully had formed in a cropped paddock (DNRE SCA File: C/18). Just as for Castle Creek, there were a number of instances of gully erosion reported in the Pranjip–Nine Mile Creek catchment in the 1960s and 1970s (DNRE SCA Files: B/1143, C/18, D/547, L/1168, O/102, P/682, T/418), but because not all landholders reported erosion to the SCA, and local landholders may not have been aware of the SCA before the 1960s, it cannot be assumed that this period was necessarily an erosive period.

In terms of possible disturbances capable of initiating erosion heads along Pranjip–Nine Mile Creek there is evidence of only one such event. According to road plans produced by the Euroa Shire Council in 1973 (Strathbogie Shire Council Bridge Plan: 099 (1964)), the Longwood–Avenel Rd was realigned in the vicinity of Threlfalls Lane. To facilitate the realignment of the road a section of Nine Mile Creek was straightened. Straightening of the creek increased the grade locally and may have initiated an erosion head.

Anecdotal evidence suggests that incision which has produced streams more than 8 m deep in some sections of the upper reaches of Pranjip Creek, has been caused primarily by cattle access to the creek and its tributaries (pers. comm. Ian Elder, landholder, May 1998). This conclusion is, however, based only on observations made in the area over the last 32 years, so it is not clear what may have initiated erosion before this period.

Whilst Nine Mile Creek has incised above the present Hume Freeway, it does not appear that incision is as extensive (in terms of volume of sediment eroded) as is seen on the upper reaches of Pranjip, Creightons and Castle Creeks.

Comparisons of stream cross-sections measured at the railway line and the Hume Freeway for Pranjip Creek (or Camerons Well Creek) and Nine Mile Creek indicate that aggradation and incision have occurred at different times. Cross-sections measured on Pranjip Creek at the Hume Freeway (Fig. 4.12) indicate that there may have been 50–70 cm of sediment deposited in the bed in this vicinity between 1958 and 1998 (40 years) (Appendix Fig. B1). The railway bridge (Fig. 4.13) cross-sections, in contrast, indicate that up to 1.5 m of sediment may have been deposited in the bed of Pranjip Creek between 1871 and 1922, but that since then the bed may have degraded back to its original level. The bed appears to have degraded approximately 50 cm between 1922 and 1947, a further 30 cm between 1947 and 1995 and perhaps another 40 cm between 1995 and 1998 (Appendix Fig. B5). Degradation over the last 15–20 years may, however, be related to at least two attempts to clear out sediment and vegetation from under the bridge (PTC Bridge Files, Somerton to Wodonga Line, Index: 143). These operations appear to have been quite extensive, judging from the size of the mound of sand adjacent to the bridge. These data may therefore be indicating that Pranjip Creek, in the vicinity of the present Hume Freeway and the railway, has filled (1871–1922), incised (1922–1947) and is in the process of filling again (1958–1998).

The data from Nine Mile Creek in the vicinity of the Hume Freeway and the railway line indicate that the bed elevation has been relatively stable. Cross-sections of Nine Mile Creek measured at the Hume Freeway indicate that a substantial pool (2–3 m deep), that was under the current bridge when it was built in 1927, was completely filled-in by 1958 (Appendix Figs B2a,b,c). Anecdotal evidence suggests that in fact the filling was complete by the 1930s (pers. comm. Bert Threlfall, former landholder, Feb. 1998). Comparisons of cross-sections for 1958, 1997 and 1998 suggest that there has been minimal change in the bed elevation since. This is reflected in a comparison of cross-sections measured at the railway bridge on Nine Mile Creek. Comparison of cross-sections from 1871, 1926, 1995 and 1998 indicates that there has been minimal change in the bed elevation of the creek in this vicinity over 127 years (Appendix Fig. B6). These data together suggest that with the exception of the filling-in of pools, possibly in the 1920s or 1930s, there has been no real change in the bed level of Nine Mile Creek in the vicinity of the present Hume Freeway and the railway line since at least the 1870s. This hypothesis is not supported by a comparison of bridge cross-sections measured at the Avenel–Longwood Rd bridge, where it would appear that Nine Mile Creek may have aggraded up to 1.5 m in the vicinity of the road bridge between 1973 and 1998 (Strathbogie Shire Council Bridge Plan: 038 (1973)). This evidence suggests that either aggradation is occurring in the vicinity of the Hume Freeway and the railway line in highly localised places, or that waves of sediment are moving through the area and the timing of cross-section checks at the Hume Freeway and railway line have failed to capture the oscillating behaviour of the streambed.

Below the railway line a combination of visual inspection and comparison of cross-sections at the Longwood–Pranjip Rd bridge over the Pranjip Anabranch, suggests that there has been only minor sand deposition in the vicinity. Observations of the Pranjip Anabranch in this area indicate that while some sand has been deposited through this reach, the narrow run–pool sequence remains

Fig. 4.13. Pranjip Creek at the railway line (Pranjip West Bridge). The stream bed in this vicinity has aggraded and degraded during the period since European settlement.

intact. Comparison of cross-sections measured at the bridge in the early 1960s (Strathbogie Shire Council Bridge Plan: 019 (1959)) and 1998 reveals that over the intervening 35–40 year period change at the cross-section has been limited to the channel adjusting to a form similar to that existing before the bridge was built, i.e. bed elevation has not changed.

4.7. Potential sources of disturbance

Quite clearly Creightons Creek has been severely affected by sedimentation derived apparently from drainage lines in the upper catchment. To have any chance of rehabilitating such a system we must consider the disturbances that might have initiated erosion in the upper catchment, i.e. factors that have caused the erosion heads. As was suggested earlier, floods and wet years have played an important part in driving incision, but it seems probable that these events have simply accelerated the movement of heads that were already in the system. From the information presented above and past experience, a number of potential sources of disturbance, and thus erosion heads, are now discussed with regard to their relevance to the Granite Creeks.

Goldmining

Historically, goldmining has been noted as highly detrimental to drainage line stability because of some of the practices employed. Gullies were dug up and puddling machines were used to wash sediment dug out of streams and hill sides, before flushing it downstream (Powell 1976). Later came the introduction of hydraulic sluicing in which miners used jets of water to displace alluvial deposits (Shakespear *et al*. 1887). These alluvial mining practices resulted in severe environmental degradation, usually in the form of downstream siltation (Powell 1976).

While the area from Mangalore to Wangaratta was not considered a ‘goldfield’ there were a number of isolated discoveries in the area. According to Flett (1970) gold was found near Benalla, as well as at Violet Town, Euroa and Avenel, though the exact location of these discoveries is not discussed. No mention is made of gold discoveries in the catchments of the Granite Creeks in any of the historic documentation relating to the area, and notes in many of the Land Selection Files indicate that land selection was only authorised after it was confirmed that the land was not auriferous. Shafts into quartz reefs were found on land at the head of Creightons Creek (PROV VPRS: 626/2025/782) and Castle Creek (Halsall 1980), but there is no evidence that any gold was found.

Consequently whilst gold mining can have a significant impact on drainage lines in particular, it appears that goldmining has not been a major activity in the Granite Creeks catchments.

Channelisation

The concentration of flow from a broad stream or several streams into one channel (‘channelisation’) has the potential to cause channel incision by increasing the shear stress acting on the streambed. A number of activities can result in the channelisation of flow, including construction of bridges, both road and rail, development of tracks and roads, and construction of drains. The impact of channelisation in relation to the initiation of erosion has been observed at a number of sites in Australia and overseas. For example, Bird (1980) reports that flow concentration via drain construction and river entrainment on the Lang Lang River in Victoria resulted in significant incision and stream erosion. Bird (1987) reports that channel incision in Bruthen Creek, also in Victoria, was initiated by the construction of drains and flow channelisation. At Wangrah Creek in NSW Prosser (1991) concludes that channel incision had commenced as a result of the construction of a road crossing the valley floor. Cooke & Reeves (1976) also recognise the important role flow concentration has played in channel incision in the south-west of the United States.

The potential of a range of ‘channelising’ activities that have taken place adjacent to the Granite Creeks are discussed below.

The railway line

The construction of the North-Eastern Railway through the area in 1873 had the potential to significantly affect the Granite Creeks. During the construction of the railway, bridges were built over many of the drainage lines crossing the Riverine Plain. However, because of the costs associated with the construction of these bridges they were only used where necessary and only made as wide as absolutely necessary. Thus the end result was a barrier to flow, which had a minimum number of openings and ran perpendicular to flow right across the Riverine Plain. The original survey carried out along the railway before its construction indicates the location and size of drainage lines on the Riverine Plain before the railway was built. Assessment of the survey in comparison to the position and size of drainage lines allowed by the bridge openings indicates that although bridges were built to span the main creeks, more often than not the small, high-flow channels and/or floodways running parallel and adjacent to the main creeks were filled in when the railway went through. Consequently, the hydrology of flood water movement on the Riverine Plain was significantly altered. During high flows that followed construction of the railway, Pranjip, Nine Mile, Creightons and Castle Creeks would all have been forced to take larger discharges than they had previously, increasing the shear stress on streambeds and thus increasing the potential for channel incision. Intuitively one would expect that stream incision would occur where flow was channelised, i.e. under the bridge and downstream of the bridge. Upstream of the bridge where flow was not channelised one would still expect incision to take place, but via progressive upstream migration of the erosion head/s that were formed at the initial point of incision.

In contrast to expectation, there is no direct evidence to suggest that incision occurred at the bridge sites. Comparisons between the original surveys (1871), bridge cross-section designs (1871–1872), pier depth checks (1922–26, 1947, 1995) (PTC Bridge Files, Somerton to Wodonga Line, Index: 143, 150, 160 & 186) and a re-survey carried out by the authors in 1998, suggest that there has been little change to the channels at the bridges over the last 125 years, and where change has occurred it has been in the form of aggradation rather than erosion (see Appendix Figs B5–B8). The Pranjip West bridge (over Pranjip or Camerons Well Creek) is the exception, but incision has only been apparent since 1922 (recent incision may also be related to the removal of sediment and vegetation from under the bridge during the last decade to maintain channel capacity), and prior to that the channel may have filled 1.75 m. Resurveys of the channel under the East Pranjip bridge (over Nine Mile Creek) suggest little change, in terms of average bed elevation, over the last 125 years. Similarly the resurveys carried out at the Creightons Creek bridge suggest minimal change in bed elevation over the last 125 years. At Castle Creek there would appear to have been minimal change between 1871 and 1926, followed by more than a metre of aggradation since, which has necessitated the clearing of vegetation and sediment from the bridge openings at least once in the last 10 years.

It is possible that the resurveys will not have necessarily picked up all episodes of cutting and filling; for example on Creightons Creek between 1871 and 1922 there may have been a major episode of incision, followed by a major phase of infilling, which effectively cancelled one another out. Consequently incision following the construction of the railway cannot be ruled out, but because such events would have been of great interest to the PTC, with respect to ensuring the integrity of the railway line, it is expected that such an incident would have been mentioned in the bridge file, and no mention is made. Thus it is unlikely that there was undetected incision at the railway line.

Road bridges

Road bridges were built in the area as early as the 1870s and even earlier (e.g. PROV VPRS 626/2043/1697, CPO Historic Plans, Features 3, Parish of Branjee (1862)). The impact of road bridges may, however, not have been as severe as that of the railway because high flow channels and the floodplain were not restricted by a continuous embankment as was constructed for the railway, and thus the creek could still follow its original high flow course to a certain extent. Nevertheless, flow channelisation in sensitive areas such as over a swamp may have caused incision, a possible example being incision in Creightons Creek where the Gobur Road originally crossed the creek or swamp (near the present site of Kellys Bridge). However, it is not clear whether there was a bridge at that site as early as the 1870s.

While old road bridge plans, particularly those for Sydney Road (the present Hume Freeway) can be, and have been, used to determine the extent of bed elevation change over time, the bridge plans that are available only relate to the most recent bridge; thus the impact of the original bridges and initial channelisation cannot be determined.

Tracks

Tracks or paths worn by constant use can be a source of disturbance because vegetation is worn away and a depression is formed which can capture and concentrate flow along the path, resulting in incision. There are two examples where this may have occurred along Creightons Creek. The first is where Gobur Road originally crossed the creek or swamp (near the present day site of Kellys Bridge) and incision was noted as early as 1874 (PROV VPRS: 626/2021/610). As mentioned above there may or may not have been a bridge at this site, but even if there was only a track traversing the swamp it may have provided an area with minimal vegetation where incision could commence. A similar situation may have arisen on what is now Baronga Creek in the 1870s, where the Gobur Track may have been the source of disturbance that initiated an erosion head (PROV VPRS: 626/2058/2287). It is possible that tracks may have initiated erosion heads at a number of other points along Creightons Creek, as well as along the other Granite Creeks.

Drains

Drains are probably the most obvious mechanism for flow channelisation and thus the introduction of erosion heads into the Granite Creeks, and there have been a number of examples of drains cut into or adjoining Creightons Creek and its tributaries. Drains were constructed by several selectors in the Creightons Creek catchment, primarily in wet areas, to drain the land and so make it more productive. Land Selection Files indicate that drains had been constructed by Clinnick in Beltons Swamp by 1909 (PROV VPRS: 5357/5502/2477), possibly by Worland or Earl on the flats just below the railway line by 1889 (PROV VPRS: 626/2068/2725), by Ramage through the swampy flats which formed part of Ramages Creek by 1901 (PROV VPRS: 5357/5428/2786) and by Cameron on land to the east of Kellys Bridge by 1880 (PROV VPRS: 626/2017/315). In most cases the drains built were 500–1000 m long. In more recent times a drain was cut to complete the diversion of flows into Branjee Creek at Nelsons Swamp (pers. comm. M. Brodie, landholder, Feb. 1998).

Anecdotal evidence suggests that drains constructed by Clinnick and Ramage had an impact on Creightons Creek. Clinnick’s drain, for example, was reported to have at least partially channelised flows through Beltons Swamp (pers. comm. Jack Stevens, landholder, March 1998). Some of the drains constructed by Ramage are said to have channelised flows through the swampy flats of Ramages Creek, and subsequently led to substantial incision (pers. comm. Stan Artridge, landholder, Feb. 1998). Comparison between the dimensions of the drain cut by M. Brodie in 1971 and the dimensions of the drain today indicate that it may have initiated 1 m of incision in Creightons Creek.

A drain or creek diversion was also put in place on Castle Creek in the 1950s, initiating erosion heads that have resulted in the creek incising between 2 m and 10 m, upstream of the diversion (pers. comm. Geoff McLean, landholder, May 1998).

Clearly the construction of drains in the Creightons Creek and Castle Creek catchments has been an important source of disturbance and thus erosion heads.

Channel dredging, clearing and straightening

The dredging of sediment and removal of vegetation from channels can have two effects. First, the removal of vegetation allows flow velocities in the bed to increase, and reduces the resistance of bed sediments to erosion. Prosser & Slade (1994) report that vegetative cover can play a crucial role in determining the susceptibility of valleys to channel incision. Dredging of material from the bed can lead to both upstream and downstream progressive bed degradation (Galay 1983), i.e. the development of erosion heads that move both upstream and downstream. Consequently in a situation where sediment supply to a stream section is limited, channel clearing and degradation can initiate upstream and downstream degradation.

There have been several examples of vegetation clearing and dredging in Creightons Creek. Two attempts have had minimal impact on the creek. The local shire council carried out clearing and dredging at the Longwood–Pranjip Rd and Nelsons Rd. As discussed earlier, Creightons Creek at the Longwood–Pranjip Rd had virtually been abandoned by 1969, so dredging at this location had no impact on the creek as a whole. At Nelsons Rd, the impact on the creek overall was minimal because the sediment supply was sufficient to fill the hole within the year.

In contrast, the removal of snags and vegetation from Creightons Creek, just downstream of Nelsons Rd in 1997 has, in combination with a meander cutoff (see below), caused the bed elevation to drop 15 inches (~ 40 cm) (pers. comm. Maurie Brodie, landholder, Feb. 1998). Similarly, channel dredging in Creightons Creek in the late 1980s, adjacent to the Creightons Creek Recreation Reserve, has initiated 1–5 feet (0.3–1.5 m) of bed incision upstream of the Reserve (pers. comm. Brian Kelly, landholder, Feb. 1998; pers. comm. Laurie Davidson, landholder, Oct. 1998).

Similarly, in Castle Creek in the vicinity of Euroa, sand and vegetation removal from the bed of the creek initiated a small erosion head (DNRE RWC File 62/19071).

The construction of road bridges may have also initiated erosion heads because of associated clearing and possible dredging of the bed. In a Soil Conservation Authority report into the incision of Baronga Creek in the 1950s it is suggested that a secondary head in Baronga Creek in 1953 may have been initiated by bridge construction (DNRE SCA File: N/50). However, it is not clear which activity may have initiated the head — whether channelisation or machinery clearing/dredging the bed, for example, though the latter seems more probable.

It is appropriate to mention here the practice of channel straightening. Channel straightening can be carried out to increase the channel gradient and in-stream velocities, or it can be used to facilitate the siting of infrastructure such as roads. There is evidence to suggest that two attempts have been made to cutoff meander bends to increase in-stream velocities: one on Creightons Creek (just above the Branjee diversion) and one on Branjee Creek (halfway between the diversion and Drysdale Rd). In both cases the intention of the cutoffs was to reduce sediment deposition (pers. comm. M. Brodie, landholder, Feb. 1998). The increase in channel grade and thus the velocity locally can result in local erosion, as well as upstream progressive degradation (Galay 1983). Anecdotal evidence suggests that the Creightons Creek cutoff, together with desnagging and vegetation removal, led to the streambed dropping about 15 inches (~ 40 cm) (pers. comm. Maurie Brodie, landholder, Feb. 1998), but no direct evidence is available regarding the impact of meander cutoffs on Branjee Creek, although several erosion heads are visible in the creek above the lower cutoff.

There has also been channel straightening at several locations on Nine Mile Creek and Castle Creek to allow local roads to be realigned (Strathbogie Shire Council Bridge Plans: 182, 022 & 099 (1959, 1970 & 1964)). As noted above, this action increases stream gradients locally and has the potential to initiate the formation of an erosion head. There is no evidence available to indicate whether or not erosion heads developed here.

Agriculture

One of the most significant sources of disturbance for the Granite Creeks catchments was clearing. If the experience along Creightons Creek is anything to go by then it would appear that much of the Granite Creeks catchments would have been rung (ringbarked) by 1900, and most areas completely cleared. When land is cleared in this manner, and native vegetation is replaced by crops or grasses for grazing, there are substantial impacts on soil stability and hydrology (Burch *et al*. 1987; Chartres *et al*. 1992), which in turn affect the stability of drainage lines. Flashier flood events greatly increase stream power in drainage lines with reduced erosion resistance, potentially resulting in gullying and channel incision. Coupled with this are the effects associated with stocking and cultivation.

Stocking can have two impacts (e.g. Fig. 4.14). Away from drainage lines, hoofed animals have the capacity to compact soils and reduce vegetative cover, which can increase runoff rates and erosion potential. Along drainage lines, stock can potentially do far more damage, particularly when stocking rates are not managed appropriately. Stock can damage vegetation that has an important stabilising role along a drainage line, and also initiate erosion. Stock paths through drainage lines can form points of flow concentration and thus erosion heads. Stock, particularly heavier animals such as cattle, can also break down stream banks. A study in the USA found that uncontrolled grazing along streams by cattle caused six times as much bank erosion as was measured at ungrazed sites, due mainly to the trampling of banks by stock (Trimble 1994). The study concluded that uncontrolled grazing of streambanks in the eastern United States has played an important role in stream widening during historical time.

Anecdotal evidence suggests that stock, cattle in particular, have initiated and are continuing to initiate erosion heads and bank erosion on Creightons Creek (pers. comm. Bert Threlfall, former landholder, Feb. 1998; Barrie Noye, landholder, Feb. 1998). Cattle and general stock access to the upper reaches of Castle Creek and Pranjip Creek have also been identified as major contributors to stream instability in these areas (pers. comm. Geoff McLean, landholder, May 1998; Ian Elder, landholder, May 1998). It is not clear whether or not stock were a major destabilising influence historically, but it appears that in more recent times stock access to drainage lines has been a source of erosion heads and bank erosion.

Cultivation also has the potential to affect drainage line stability where used inappropriately. Two examples of the impact of cultivation in the Creightons Creek catchment have been brought to the authors' attention. The first example relates to lands that were ploughed in the 1800s adjacent to Creightons Creek between the Longwood–Mansfield Rd and the present Hume Freeway. The ridges and furrows channelised surface runoff which enabled a gully to form (pers. comm. Jim Shovelton, landholder, Feb. 1998). While it is probable that cultivation may have resulted in the formation of several gullies in the Creightons Creek catchment, and possibly in other Granite Creeks catchments, it would not appear to be a major source of sediment or erosion heads. The second example is from a property near the top of the Creightons Creek catchment where cropping prior to the 1960s was not carried out on the contour, resulting in rilling of the cropped area (DNRE SCA File: L330). However, an isolated incident such as this, where the area is not in close proximity to Creightons Creek and its main tributaries, is unlikely to have had a major effect on the creek as a whole.

Fig. 4.14. Creightons Creek upstream of the Creightons Creek Rd. This photo shows examples of both on-stream (stream bank) and off-stream (natural spring discharge site) damage caused by stock.

The impact of agriculture, with regard to the modification of vegetative cover, and particularly the impact of grazing, has been exacerbated by the prevalence of rabbits in the area. Rabbits were in plague proportions in the area in and after the 1880s. The Longwood Railway Station received 986 dozen rabbit scalps in one month in 1889 (Halsall 1980). Rabbits greatly increase pressure on pastures and riparian vegetation, and this, together with their burrowing, can play an important role in erosion initiation. The advent of myxomatosis in the 1950s brought the local rabbit population under control (Halsall 1980), but rabbits are still a problem for local farmers today (Martin 1994).

Floods

The role of flooding in channel incision has already been briefly discussed. It is possible that flood events may initiate erosion heads by developing stream power greater than that which a saturated drainage line can withstand; this mechanism was suggested by the Soil Conservation Authority in connection with the initiation of several heads in a gully about 1 km west of Kellys Bridge (SCA File: N/230). However, it is more likely that the major contribution of floods and 'wet years' to channel incision is that they drive existing heads up drainage lines at a much greater rate than during drier periods. By so doing, high flow events allow several smaller heads to link up, thus causing substantial incision in a short time. Several examples of this have already been discussed, including the 1916 floods which resulted in the incision of Creightons Creek at Stan Artridge's property and the 'wet' 1950s which led to incision along Baronga Creek at Barrie Noye's property.

Bushfires

Bushfires can initiate erosion by removing all vegetation and organic matter from the ground, leaving the soil bare and exposed to raindrop impact. Removal of vegetation also removes barriers to overland flow, increasing the potential for erosion to occur (Leitch *et al*. 1983; Ronan 1986; Prosser 1990). In some circumstances soils may become hydrophobic following a bushfire, reducing infiltration and increasing surface runoff, again increasing the potential for erosion (Leitch *et al.* 1983; Prosser 1990). Thus intense bushfires, followed by high rainfall totals, can cause severe sheet erosion as well as gullying and possibly stream incision.

There have been at least two severe bushfires in the Granite Creeks area since settlement. The 1901 bushfires were extensive, starting near Locksley and running north-east through the upper catchments of Pranjip–Nine Mile Creek, Creightons Creek and Castle Creek (Halsall 1980). The Strathbogie fires in 1990–91 also affected a large area, moving through parts of the Creightons Creek and Castle Creek catchments (pers. comm. Sue Haggard, landholder, March 1998; Dino Furlanetto, landholder, March 1998).

In the autumn and winter that followed the 1901 fires there were four months in which 50–100 mm of rain fell. Similarly in January 1991 nearly 120 mm of rain fell (based on rainfall data published in the Centenary issue of the *Euroa Gazette*, 1997). Consequently conditions conducive to severe erosion were present in the upper catchments of several of the Granite Creeks in both 1901 and 1990/1. As mentioned in Section 4.5.1, there is only one example of erosion being initiated by bushfires, from the old Wanghambeham Pre-emptive Right, south of Bartons Lane in the Creightons Creek catchment, where the local landholder claims gully erosion was initiated by rainfall events following the 1990 bushfire (pers. comm. Dino Furlanetto, landholder, March 1998). However, this does not, preclude serious erosion having occurred elsewhere, particularly in relation to the fires of 1901.

Droughts

For reasons similar to those described in relation to the impact of bushfires, droughts can also provide conditions conducive to erosion. Like bushfires, drought conditions can lead to reduced vegetative cover and increased soil hydrophobicity (Leitch *et al*. 1983; Ronan 1986); consequently erosion resistance is minimised and, if the drought is broken by rainfall events with moderate to high intensity rainfall, surface runoff will be maximised and erosion potential will be high or

Fig. 4.15. A sand pit on Castle Creek downstream of the old Hume Highway Bridge. Sand has been extracted from this site in the past.

extreme. The most severe droughts in the area since settlement have been 1884–89, 1897–98, 1914–15, 1944, 1968 and 1982–83 (Centenary Edition of the *Euroa Gazette*, 1997; pers. comm. Stan Artridge, landholder, Feb. 1998). There are, however, no rainfall intensity data available for drought breaking rains and hence it is not possible to evaluate the potential for erosion following each of these drought events.

As noted in Section 4.5.1 only one example of erosion following a drought has been reported, on John Nielsen's property near the top of Creightons Creek, where several gullies on the property were either initiated or reactivated following the 1982–83 drought (pers. comm. John Nielsen, landholder, March 1998). However, this lack of reporting does not prove that droughts, especially those in the late 1800s and early 1900s, did not instigate severe erosion in the Granite Creeks catchments.

Sand and gravel extraction

The extraction of bed materials from a stream can be detrimental, for the same reasons that dredging of the streambed can be detrimental, i.e. it can initiate upstream and downstream progressive degradation (Galay 1983). Sand extraction from streams in the Granite Creeks area has only officially been carried out at four locations on Castle Creek: one site adjacent to the golf course, and three sites between the Old Hume Highway bridge (Fig. 4.15) and a point 1 km downstream. Extraction has been authorised only for stream management purposes and approximately 2500 m^3 of sand has been removed (pers. comm. Michael Kaponica, NRE, Seymour, Feb. 1998).

However, this is certainly not the only sand extraction that has been carried out. The authors of this report have observed probable sand extraction sites on Castle and Creightons Creeks. These sites are generally located immediately adjacent to roads and are probably illegal extraction sites, but the volumes involved are small. There is also evidence that both VicRoads and the PTC have extracted sand from areas adjacent to their bridges in the past. For example, at some time in the last couple of years VicRoads obtained permission to remove sand from Creightons Creek between the two Hume Freeway bridges, for use in road maintenance (pers. comm. Paul Tucker, VicRoads, Benalla, March 1998). Similarly PTC bridge files for bridges along the North-Eastern Railway indicate that vegetation and sediment have been removed from the vicinity of the Pranjip West (Pranjip Creek or Camerons Well Creek) rail bridge and the Castle Creek rail bridge (PTC Bridge Files, Somerton to Wodonga Line, Index: 143, 150, 160 & 186).

There is little to suggest that sand extraction from the Granite Creeks has been detrimental: only one erosion head appears to have been initiated by sand extraction activities (DNRE RWC File 62/19071). Nevertheless it cannot be entirely discounted as a potential source of erosion heads in the creeks.

Internal triggers

All the sources of disturbance discussed up to this point are external triggers, imposed on the system from the outside. However, erosion heads can be initiated by internal triggers, or natural adjustments to the stream system. For example, incision can result where a section of the creek has been over-steepened by sedimentation. Another potential cause of bed degradation is the passing of a sand slug. At a given site the response of a stream to the passing of a sand slug is to aggrade and then degrade (Nicholas *et al*. 1995). Rutherfurd & Budahazy (1996) describe bed degradation following the passage of sand slugs in the Glenelg River system. As is discussed in the next section, it is not clear if this model of sand slug behaviour fits the Granite Creeks, or if bed degradation observed at Kellys Bridge, Bartons Lane and the Hume Freeway represents the sand slug leaving these segments of stream. However, bed degradation at these sites could be due to the passing of the sand slug, and consequently bed degradation could occur elsewhere in the system as the sand slug passes.

4.8. Patterns of aggradation

In the previous sections, patterns of erosion and aggradation have been discussed in chronological order, but to understand the overall response of these systems to disturbance it is more useful to look at spatial patterns. In particular, the location and dynamics of sand slugs are important. Hence this section discusses spatial patterns of aggradation, and explores their relevance to the system's overall response.

When considering spatial patterns of aggradation, time-scales are of utmost importance. Sediment is rarely transported from an upstream erosion source out of a catchment within the timeframe of a single event. For example, the channel incision observed during the 1916 flood on Creightons Creek would have liberated a large quantity of sediment, only a small proportion of which would have been removed from the Creightons Creek catchment during the flood event. While the floodwaters may have been capable of entraining some of the finer material (i.e. clays and silts) and transporting them significant distances downstream, the coarser material (i.e. sands and gravels) would have travelled only a short distance from the point of erosion. This is because large amounts of energy are required to mobilise the larger particles, and as the floodwaters move downstream the physical characteristics that provide energy to the flow (e.g. steep stream bed slope, confined channel) change. The coarser particles are deposited where there is a reduction in energy. Even during the flood of 1916, ponding and storage of floodwaters on the Riverine Plain would have created conditions under which some of the finer material would also have been deposited, though much farther downstream. So it could be assumed that, following the 1916 flood, sediment would have been deposited in the middle and upper reaches of the catchments (sands and gravel) as well as in the lower reaches of the catchments (fine sands, silts and clays), while some of the finer sediments would also have flowed into the Goulburn River. These stores would have been temporary, with sediment being remobilised when flows adjacent to the store once again gained sufficient energy.

Essentially, the transport of sediment through a catchment is episodic and depends on factors such as particle size, local conditions (e.g. bed slope) and discharge. As a result, a single sediment particle will be transported, stored and remobilised many times before it leaves a stream system and clearly this means that patterns of aggradation will also change over time. This is particularly true of in-stream aggradation because these stores are subject to flow on most days and so changes in aggradation patterns can occur frequently. To study aggradation patterns in the Granite Creeks a number of 'snap shots' must be taken over time. While over-bank deposition of sediment forms an integral part of such patterns it is not directly relevant to this study and with few data available it is not directly discussed here. Instead this discussion focuses on in-stream transport of sand and gravel; in other words, the downstream movement of sand slugs.

A brief description of sand slugs was presented in Chapter 1, but to reiterate, Nicholas *et al*. (1995) define a slug as a body of 'clastic material associated with disequilibrium in fluvial systems over time periods above the event scale' (Nicholas *et al*. 1995, p. 502). In other words, a slug is a discrete volume of sand and/or gravel material that is released into a stream channel and only very slowly transported out of the stream network by the stream flow. The slug can fill the width of the channel to depths of the order of metres, and extend over distances of hundreds to thousands of metres. The front of the slug is referred to as its 'snout', and this can be a well-defined face or front downstream of which negligible deposition is apparent. An attempt is made here describe the location of the sand slug in Creightons Creek over time; there are insufficient data available to attempt this exercise for Castle and Pranjip–Nine Mile Creek.

Ideally it would be most useful to describe the location of the Creightons Creek sand slug at several points in time, but the erosion and aggradation data collated are insufficient to generate such a picture. From the data presented previously in this chapter it is possible to say that the snout of the sand slug was located between the Longwood–Pranjip Rd and Pranjip Rd on the old Creightons Creek channel in the late 1960s. After Creightons Creek was diverted directly into Branjee Creek below Nelsons Rd in the early 1970s the sand front advanced quickly down Branjee Creek. By the late 1980s the snout was located between Longwood–Pranjip Rd and Pranjip Rd in the Branjee Creek channel (O'Connor 1991). One of the difficulties associated with finding the location of the snout, both now and in the past, is that, unlike snouts described elsewhere (Rutherfurd 1996), the snout of the Creightons Creek slug is indistinct (this is also true of the sand slugs in Castle and Pranjip-Nine Mile Creek). The channel morphology slowly changes over several hundred metres, from completely sanded at the Longwood–Pranjip Rd to partially sanded above the Pranjip Rd and finally negligibly sanded at the Longwood–Shepparton Rd (see Section 5.1.2). A comparison of conditions in 1998 with those observed by O'Connor in the late 1980s (pers. comm. Nick O'Connor, AWT, May 1998) suggests that there has been little if any downstream movement of the sand slug snout between the late 1980s and late 1990s.

Identifying the tail of a slug is difficult and it is usually only possible to say when a slug has left a segment of stream. At a given site a sand slug is evident as bed aggradation followed by bed degradation (Nicholas *et al*. 1995). However, because of the prevalence of erosion heads in the channels of the Granite Creeks, it cannot be assumed that bed degradation in the sanded segments of stream is indicative of the removal of the sand slug. While bed degradation in Creightons Creek at Kellys Bridge (1990s), above Bartons Lane (1980s–1990s) and at the Hume Freeway (1950s–1990s) could be associated with the evacuation of the sand slug from these reaches, the presence of erosion heads, associated with activities such as channel dredging, makes it difficult to draw any conclusions.

It is useful to consider how the behaviour of sand slugs in the Granite Creeks compares with that observed elsewhere in the world. Gilbert (1917) was the first to describe a sediment slug, the movement of which he compared to a floodwave. In other words, the stream bed will rise and fall as the sediment wave passes, and the wave's amplitude is attenuated as it passes downstream. Many researchers have since found the wave analogy appropriate for slugs studied in various parts of the world (e.g. Pickup *et al*. 1983; Nicholas *et al*. 1995; Madej & Ozaki 1996).

The limited amount of data available makes it difficult to determine the timing and location of bed level changes in the Granite Creeks. The middle reaches of Creightons Creek may have experienced the passing of a sediment wave, with the channel aggrading and degrading between Kellys Bridge and Bartons Lane, for example. Further downstream, on the Flats, the creek bed has aggraded, but degradation has not been observed to date. The lack of bed-level data also makes it difficult to determine if bed-level changes decline in the downstream direction. Hence it cannot be readily determined whether or not the wave model is appropriate for describing sand slug movements in the Granite Creeks.

There are several reasons why the wave model may not be appropriate for describing slug behaviour in the Granite Creeks. First, there are several sources of sediment for the sand slugs, both spatially (e.g. Creightons Creek — adjacent to Stan Artridge's property and Baronga Creek) and temporally (e.g. Creightons Creek — 1916 flood event and wet period during the 1950s). Knighton (1989) concluded that the wave model was inappropriate for the Ringarooma River in Tasmania because there were multiple input points, and this could also be true for the Granite Creeks. Secondly the stream form characteristic of the lower reaches of the Granite Creeks, i.e. anabranches, is decidedly different to those referred to in the literature. The streams for which the wave model has been found appropriate are all single strand streams (e.g. Gilbert 1917; Pickup *et al*. 1983; Madej & Ozaki 1996). It can be hypothesised that the impact of multiple lowland channels would be to distribute material out onto the floodplain during flood events. Water distributed on the floodplain will evaporate, or find its way back into the main channel further downstream, or enter groundwater stores, but sand enters long-term storage on the floodplain. Not only does the channel lose sand to the floodplain but the rate of migration of the sand that remains in the main channel is slowed, because of reduced discharge. Such behaviour could certainly mean that the wave model is not appropriate for the lower reaches of Creightons Creek or the Granite Creeks in general.

Other than this, no real conclusions can be drawn regarding the behaviour of the sand slug in Creightons Creek, except to say that the snout appears to have moved little in recent years.

4.9. Pre-settlement erosion and aggradation

To place the preceding information in context it is important that occurrences of erosion and aggradation prior to European settlement are also examined. There is no direct evidence of pre-settlement erosion or aggradation rates, but there is some indirect evidence available that provides invaluable information.

There is evidence to suggest that gullying and stream incision occurred in the Creightons Creek catchment before European settlement. According to anecdotal evidence, the incision in both Creightons Creek (at Stan Artridge's property) and Baronga Creek has revealed old red gum logs, buried 10–20 feet (3–6 m) below the surface (pers. comm. Stan Artridge, landholder, Feb. 1998; Barrie Noye, landholder, Feb. 1998). This suggests that both Creightons Creek and Baronga Creek have incised to similar depths in the past, prior to European settlement.

Higher up in the catchment on John Nielsen's property there is a gully in the lower end of a drainage line which clearly shows sequences of alluvial material that had been laid down at the bottom end of this steep valley. The layers are each approximately 10 cm thick and alternate between a dark, swampy loam and coarser yellow sediment. At least six layers are clearly visible in the gully wall and they appear to correspond to different types of geomorphic activity. The dark layers appear to correspond to the deposition of fine sediment in a low energy swampy environment, whereas the lighter layers may be from rapid deposition of material eroded from upstream under high energy conditions (the higher energy indicated by the drainage line's capacity to transport coarser materials). Assuming these suppositions are correct then it could be concluded that although the drainage line is probably stable for periods of time, stability is interspersed with periods of instability in which sediment is flushed down the drainage line. This would be consistent with a system in which erosion was episodic and perhaps linked to high flows (i.e. high energy events). It cannot, however, be stated categorically, without dating the layers, that any of these layers predates European settlement. Similar patterns of aggradation have been observed in a small creek system on the Southern Tablelands in NSW (Prosser 1991). The dark, swampy material described by Prosser (1991) was referred to as a swampy meadow unit and was related to a period when the system was not channelised and deposition dominated. The other units found comprised either gravels associated with a channel bed or coarse material derived from floodouts.

A third piece of evidence indicating that incision in the Creightons Creek catchment is not peculiar to the post-European settlement period is the existence of terraces at the lower end of Ramages Creek, which were found by a survey carried out in 1882 (PROV VPRS: 626/2092/3665). Hence it could be concluded that stream incision took place at the lower end of the Ramages Creek valley before European settlement.

The evidence presented above indicates that the Creightons Creek, Baronga Creek and Ramages Creek have all incised in the past, before European settlement. It is also possible that one of Creightons Creek's first order drainage lines may have experienced episodic erosion prior to European settlement. The fact that there are sand-filled abandoned channels on the Riverine Plain (pers. comm. Len Stevens, landholder, Feb. 1998) indicates that the sediment released from such events may have been deposited on the flats. This evidence suggests that the Granite Creeks catchments may be sensitive to disturbance and it seems probable that the gullying and incision that occurred in the Creightons Creek catchment prior to European settlement was in response to specific events such as bushfires, or an intense rainfall event, and that therefore such erosion events were probably isolated and localised. However, the same cannot be said for the erosion and aggradation that has occurred since European settlement. In fact erosion in the Granite Creeks catchments since European settlement appears to have been synchronised across a wide area, and such synchronisation is undoubtedly due to European settlement. Observations of synchronised erosion in Australia, coinciding with European settlement have been noted previously by Prosser & Winchester (1996).

4.10. Conclusions

The first disturbances associated with European settlement imposed on the Granite Creeks catchments coincided with the overlanding expeditions that travelled south from the settled districts in the 1830s. The large herds of sheep and cattle, combined with fires in the area, reduced the vegetative cover; and other impacts such as damage to creek banks by hoofed feet can only be surmised. Between the arrival of the Overlanders and the 1870s the main activity in the catchments was light grazing, which was carried out by the local squatters who leased large areas of the catchments. However, the 1870s heralded the arrival of 'progress' in the Granite Creeks area, and the following decades saw major changes. Land selection commenced in the Granite Creeks catchments in the 1870s, dramatically affecting the area via the introduction of clearing and an increase in grazing pressure. The North-Eastern Railway arrived in the early 1870s, imposing a barrier to flow across the Riverine Plain but also providing a means of transporting produce, including firewood, to Melbourne, thus making the region attractive for farming and woodcutting. Consequently, by the beginning of the 1900s two of the most significant changes to be imposed on the Granite Creeks, i.e. clearing and the construction of the North-Eastern Railway, were already in place. Although some erosion had been noted by this early stage, no other signs of degradation were yet clearly evident.

In contrast to the 1800s, degradation was clearly evident throughout the 1900s. The following description of the response of a creek to European settlement comes from a detailed look at the history of Creightons Creek. However, the evidence presented earlier in this chapter suggests that Castle Creek and Pranjip–Nine Mile Creek may have behaved in a similar manner. Anecdotal evidence for other creeks draining the Strathbogie Ranges (see Appendix A), suggests that what has occurred in the Creightons Creek catchment may also be an analogue for the other Granite Creeks.

In the period since settlement the upper section of Creightons Creek (i.e. above the present Hume Freeway) has incised extensively, and gullying has also occurred. The incision and gullying have been the result of a number of erosion heads moving along the creek; they appear to be related to activities that have taken place in the Creightons Creek catchment, including clearing, agriculture, channelisation, channel dredging and clearing, bushfires and droughts. As a result of the extensive erosion of drainage lines in the upper catchment large quantities of sediment have been released into the creek and this has had a serious impact on the lower section of Creightons Creek (i.e. below the present Hume Freeway).

Below the present Hume Freeway, aggradation of the channel has eventually led to the diversion of low flows from Creightons Creek to Branjee Creek at Nelsons Swamp. While the abandonment of a section of channel in such a manner is probably not unusual for a stream on the Riverine Plain, it is likely that the process was greatly accelerated by the excessive release of sediment induced by activities associated with European settlement. In recent years, erosion heads have continued to move through Creightons Creek, and based on the available evidence it seems most probable that these heads are related primarily to stock access to the drainage lines, and channel clearing and dredging and the initiation of meander cutoffs. Although some episodes of incision and channel filling occurred before European settlement, it would seem that such events were isolated and localised, whereas the erosion and aggradation that has occurred since European settlement appears to have been synchronised over a wide area, and this would have been as a result of European settlement.