

relatively transient features that form during storms on bare soil surfaces. In some areas unchannelled hills are also eroded by tunnels that may, or may not, be apparent from the surface. Often, hillslopes are poorly connected with the channel system and the eroded material is stored at the foot of the slopes in fans, or other colluvial deposits.

A large proportion of the waterways crossed by the different alignments can be categorised as unchannelled hillslopes (Figure 6, Table 8). Generally, these hillslopes are poorly connected with the channel system. Some of these hillslopes appear to have progressed through a past sequence of incision and gulying, but these hillslope hollows are now largely considered stable. The construction of dams in many of these hillslope depressions also reduces the potential for runoff. Landslip was identified as possible risk in the headwaters of Steels Creek and Dixons Creek (Waterway Crossings 136, 138, 148 and 149).

- **Figure 6 – Example of Unchannelled hillslope (Waterway crossing number 4). Refer to Appendix A for location.**





- **Table 8 – Summary of Unchannelled hillslopes (Refer to Appendix A for location of waterway crossings).**

Waterway name	Land system ¹	Crossing number (Designated waterway number)	Risks
Unnamed tributary of Caraman Creek	1.1HsP7-2	78 (1-112-31-2)	-
Unnamed tributary of Dixons Creek	1.1LsP7-3	135, 136, 137, 138, 145, 146, 147, 148	Landslip -136, 138, 148
Unnamed tributary of Goulburn River	1.1HsP7-2	4, 5, 6, 7, 8, 9	-
Unnamed tributary of Rellimeiggam Creek	1.1RsP7-4	75, 76 (1-112-23-1)	-
Unnamed tributary of Steels Creek	1.1LSP7-3	149, 152, 169	Landslip – 149
	1.1Ms8-5	150	-
Unnamed tributary of Sugarloaf Creek	1.1HsP7-4	184	-
Unnamed tributary of Yarra River	1.1MsP7-3	178, 180	-
Unnamed tributary of Yea River	1.1HsP7-2	10, 11, 12, 13 (1-112-7-1-1), 14 (1-112-7-1-1), 52 (1-112-15), 53, 56, 81, 82 (1-112-40), 86 (1-112-44), 87, 97, 98	-
	1.1RsP7-4	16, 17, 18, 19, 26, 29, 41, 44, 45, 63, 68, 70, 105, 106	-

¹See Geomorphology Report for further information on land system characteristics.

Gullied hillslopes

On long hillslopes rills can coalesce into gullies. Gullies convey water only ephemeraly and may or may not be continuous with the channel network. Where gullies are not continuous with the channel network, sediment is typically deposited at the break-in-slope (where the valley side meets the valley floor) in floodout deposits. Where gullies debouch directly into the permanent stream network, sediment is stored locally in benches, bars or sediment slugs or is transported further downstream.

Surprisingly, the pipeline was found to cross only one waterway where gully erosion was identified as being a potential problem. For the Goulburn Catchment it is generally known that there was a period of increased erosion in headwater areas (sheet and gully erosion), and incision along tributaries as a result of increased runoff following historical land use changes after European Settlement. As noted in the earlier section, indications are that many of these historically gullied hillslopes have since been stabilised through a combination of different measures (revegetation, drainage works – redirection of runoff via levee banks on hillslopes and construction of numerous dams at the base of hillslopes and narrow valley floors).

Gullying was identified at waterway crossing number 77, an unnamed tributary of Caraman Creek (Figure 7, Table 9). The gully is covered in part by grasses, however, the bed and banks are generally bare of vegetation. Revegetation can be seen in the distance, where the gully is more incised. Further investigations are recommended to determine if erosional headcuts are present in this vegetated zone, and their potential to migrate further headward and cause further incision in the area between the revegetation zone and the Melba Hwy.

- **Figure 7 - Photograph looking downstream from Melba Hwy at Waterway crossing number 77. Gully partially covered by grasses (Refer to Appendix A for location).**



- **Table 9 – Summary of Gullied hillslope (Refer to Appendix A for location of waterway crossing).**

Waterway name	Land system ¹	Crossing number (Designated waterway number)	Risks
Unnamed tributary. Of Caraman Creek	1.1HsP7-2	77	Possible headcuts in vegetated section downstream

¹See Geomorphology Report for further information on land system characteristics.

Confined headwaters

Many of the streams in this reach type are at least partially controlled by bedrock. They have steep bed slopes, are steep-sided and well connected with adjacent hillslopes and, hence, efficiently route flow further down the channel system during storms.

The pipeline does not cross a significant number of confined headwater reaches. Only two waterway crossings which fall into this class were identified, both of these being unnamed tributaries of Dixons Creek (Figure 8, Table 10). Landslides were identified as a possible risk at one of these sites, waterway crossing 143. Further detailed studies at this site by a geotechnical engineer are recommended.

- **Figure 8 – Photograph taken looking upslope at waterway crossing number 143 (Refer to Appendix A for location of waterway crossing).**



Table 10 – Summary of confined headwaters (Refer to Appendix A for location of waterway crossings).

Waterway name	Land system¹	Crossing number (Designated waterway number)	Risks
Unnamed tributary. Of Dixons Creek	1.1LsP7-3	141, 143	Possible landslides - 143

¹See Geomorphology Report for further information on land system characteristics.

Confined uplands

The channel gradients of confined upland streams are gentler than confined headwater streams. The channel sides are continuous with the valley sides and efficiently move sediments entering from the adjacent hillslopes. Confined upland reaches are often bedrock controlled but are also formed in other material, sometimes even colluvium. Streams classified as confined uplands are shown in Table 11.

A larger proportion of these watercourses, particularly the unnamed tributaries of the Yea River have formed in colluvial material. Increased erosion is likely to have taken place in these reaches in the historical past. This phase of erosion is believed to have long since passed and a general stability now prevails. As highlighted in the Geomorphological Report, where there is a sufficient depth of soils and/or steep slopes in these colluvial areas, a higher risk of gully erosion and tunnel erosion has been identified. Indications of active tunnel erosion were observed on the steep valley side slopes at waterway crossing number 85.

- **Table 11 – Summary of Confined uplands (Refer to Appendix A for location of waterway crossings).**

Waterway name	Land system ¹	Crossing number (Designated waterway number)	Risks
Dixons Creek	1.1LsP7-3	133	-
Unnamed tributary. Of Dixons Creek	1.1LsP7-3	139	-
Wee Creek	1.1RsP7-4	107	-
Yea River	1.1Ms8-5	130	-
Unnamed tributary of Yea River	1.1HsP7-2	25 (1-112-9), 27, 31 (1-112-10), 57 (1-112-16), 71, 83 (1-112-41), 85 (1-112-42), 93 (1-112-52-1), 94 (1-112-52)	Incidence of tunnel erosion noted on steep slopes – 85 (1-112-42)
	1.1Ms8-5	111, 113	-

¹See Geomorphology Report for further information on land system characteristics.

Unchannelled valley fill

Unchannelled valley fill occurs where the river flows inefficiently through poorly drained swampy areas. In these reaches there are multiple flow paths with no discernible banks. Eroded material from further upstream is not transported through this reach. As the gradient steepens downstream, channelled flow occurs again. A significant number of the waterway crossings assessed are classified as unchannelled valley fill reaches (Table 12). In some cases, it was evident that road has acted as a barrier forcing deposition of sediments upstream and the formation of these unchannelled valley fills (for example Waterway crossing 3 as shown in Figure 9).

- **Figure 9 - Sedimentation forming unchannelled valley fill upstream of road at Waterway crossing 3 (Refer to Appendix A for location of waterway crossing).**



There are many instances where the pipeline crosses smaller unnamed tributaries that drain directly on the floodplain of the Yea River and Steels Creek. It is generally recommended that the pipeline alignment stays out of the extent of these floodplains due to the risks associated with these areas



(channel migration impacting on pipeline). Landslides were also identified as a possible risk at waterway crossing 142 and 144. Further detailed studies at this site by a geotechnical engineer are recommended.

■ **Table 12 – Summary of Unchannelled valley fill waterway crossings (Refer to Appendix A for location of waterway crossings).**

Waterway name	Land system ¹	Crossing number (Designated waterway number)	Risks
Unnamed tributary of Dixons Creek	1.1LSP7-3	142, 144, <u>155 (1-49-2-1-3)</u> , <u>158 (1-49-2-1-2)</u>	Possible landslides – 142, 144
Unnamed tributary of Goulburn River	1.1FcQ7-1	1	-
	1.1HsP7-2	3 (1-117)	-
Unnamed tributary of Ross Creek	1.1RsP7-4	33	-
Unnamed tributary of Steels Creek	1.1LSP7-3	156, 167 (1-49-4), <u>173 (1-49-1)</u> , 182 (1-43.5)	Steels Creek floodplain – 156
Triangle Creek	1.1RsP7-4	<u>60 (1-112-17)</u> , <u>61 (1-112-17)</u>	-
Sugarloaf Creek	1.1LsP7-3	177	-
Unnamed tributary of Sugarloaf Creek	1.1HsP7-3	183, 187	-
Unnamed tributary of Yea River	1.1RsP7-4	<u>20 (1-112-7-2)</u> , <u>30 (1-112-8-1)</u> , 32, 39, 42, 43, 46, 47, 51, 55, 62, 64	Yea floodplain – 42, 43, 46, 47, 51, 55, 62, 64
	1.1HsP7-2	28, 49, 80, <u>90 (1-112-51)</u> , 91	-

¹See Geomorphology Report for further information on land system characteristics.

Meandering

Meandering reach types occur on broad valley floors and are free to migrate laterally on both sides. The stream is a sinuous single thread channel formed in alluvium. On meander bends, the outer bank is typically steep (and often actively eroding) while the inner bank is formed in a gently shelving point bar. Meandering streams develop a pool-riffle morphology where the pools occur on the bends and riffles at inflection points.

A large number of the waterway crossings traverse meandering reaches (Figure 10, Table 13). These meandering watercourses vary greatly in the character, many have been significantly disturbed as a result of changes in land use (vegetation clearing) and drainage works. Lateral movement of meandering channels across their floodplain is a fundamental property of channel types. Clearing of vegetation from the floodplain and channel banks is likely to have accelerated rates of lateral channel migration.

A number of meandering waterways also appear to be actively deepening (Ewing Creek, Caraman Creek, Dixons Creek, Eaglenest Creek and Steels Creek). It is recommended that longitudinal surveys are carried out using differential GPS, surveying in detail changes in bed level to ascertain the location and size of headcuts and their potential for further headward erosion. This is important for determining the minimum depth at which the pipeline can be laid below the channel so that it is not exposed through future headward erosion of the channel bed.

■ **Figure 10 - Rellimeiggam Creek.**



■ **Table 13 – Summary of meandering waterway crossings (Refer to Appendix A for location of waterway crossings).**

Waterway name	Land system	Crossing number (Designated waterway number)	Risks
Caraman Creek	1.1RsP7-4	<u>79 (1-112-31)</u>	Bed and bank erosion, possible headcuts - <u>79 (1-112-31)</u>
Dixons Creek	1.1LsP7-3	<u>163 (1-49-2-1)</u> , <u>165 (1-49-2-1)</u>	Possible headcuts - <u>163 (1-49-2-1)</u> , <u>165 (1-49-2-1)</u>
Unnamed tributary of Dixons Creek	1.1LsP7-3	134 (1-49-2-1-5-1), 163a	Headcut - 134 (1-49-2-1-5-1), 163a
Eagle Nest Creek	1.1RsP7-4	<u>103 (1-112-59)</u> , <u>104 (1-112-59)</u>	Bed and bank erosion, possible headcuts - <u>103 (1-112-59)</u> , <u>104 (1-112-59)</u>
Ewing	1.1RsP7-4	50 (1-112-14)	Unstable, bed and bank erosion - <u>50 (1-112-14)</u>
Kalatha Creek	1.1RsP7-4	99 (1-112-55), 100 (1-112-55)	-
Katy Creek	1.1RsP7-4	101 (1-112-57), 102 (1-112-57)	-
Unnamed tributary of Goulburn River		2 (1-117)	-
Limestone Creek	1.1RsP7-4	59 (1-112-18)	-
Rellimeiggam Creek	1.1RsP7-4	74 (1-112-23)	-
Ross Creek	1.1RsP7-4	<u>34 (1-112-13-1)</u>	Unstable banks - <u>34 (1-112-13-1)</u>
Unnamed tributary of Ross Creek	1.1RsP7-4	<u>38 (1-112-13-1-1)</u>	Bank erosion, some deepening - <u>38 (1-112-13-1-1)</u>
Steels Creek	1.1LsP7-3	151a, <u>153a (1-49)</u> , <u>168 (1-49)</u>	Possible headcuts - 151a, <u>153a (1-49)</u>
Unnamed tributary of Steels Creek	1.1LsP7-3	<u>175 (1-49-1)</u>	-
Tea Tree Creek	1.1RsP7-4	<u>73 (1-112-22)</u>	-
Yea River	1.1RsP7-4	<u>65 (1-112)</u> , 66, 67, <u>88 (1-112)</u> , <u>89 (1-112)</u>	Yea River and floodplain - <u>65 (1-112)</u> , 66, 67
Unnamed tributary of Yea River	1.1RsP7-4	<u>15 (1-112-7-1)</u> , <u>21 (1-112-7-2)</u> , <u>22 (1-112-7-2)</u> , <u>58 (1-112-16)</u> , <u>69 (1-112-19)</u> , <u>92 (1-112-52)</u> , 95, 96	Yea River floodplain - <u>69 (1-112-19)</u> , <u>92 (1-112-52)</u> , 95, 96
	1.1HsP7-2	48	-

See Geomorphology Report for further information on land system characteristics.



The section of Steels Creek between Yarra River and Gulf Road is an area of major concern requiring further detailed investigation if a pipeline is to cross this channel or traverse its floodplain. There has been a long history of management intervention dating back to the 19th century including channelisation, realignment and bed and bank protection works. Major changes in channel morphology have occurred, involving erosion and aggradation. These changes are still continuing, with bed and bank erosion evident in the some parts of the creek, and significant aggradation in others. Craigie and Brizga (1998) completed a geomorphological study of Steels Creek and their findings are reported in brief in Table 14.

■ **Table 14 - Steels Creek geomorphological processes (from Craigie and Brizga 1998).**

Reach	Geomorphological processes
1	500m north of Pinnacles Lane to Hunts Lane No evidence to suggest significant changes have occurred in this reach. Creek is bordered by Eucalyptus forest. It is important that this section of creek is protected from any threat of headward erosion progressing upstream from Reach 2.
2	50m north of Willow Bend Drive to 500 m north of Pinnacle Lane. The creek is deeply incised downstream of a drop structure, below Pinnacle Lane. Upstream of the structure the bed is less deeply incised and the creek has a meandering channel. Some vertical banks and erosion heads are located in this part of the reach. Erosion in this reach appears to have been caused by realignment of Steels Creek in Reach 3.
3	Wills Road to 50m North of Willow Bend Drive. At the time of European settlement, this reach of Steels creek had a sinuous channel bordered by a reddy swamp. By 1956, the natural meandering channel had been bypassed by a straight drain, thought to have been cut in 1925. This drain has enlarged by severe bed and bank erosion processes. It now measures some 20m in width and 10m deep. The channel now has a large hydraulic capacity, generally around 1:100 year ARI.
4	Forest (to Wills Road). No major changes are thought to have occurred in this reach and there is no record of management works having been carried out here. Field evidence that there may have been aggradation in this reach, as may be expected given the extensive erosion in Reaches 2 and 3 upstream.
5	Maroondah Aqueduct to the southern edge of the Forest. Channel here is perched and has limited flood capacity (less than 1 year ARI). No records are available of management works in this reach. The Maroondah Aqueduct may be protecting the reach from erosion heads which have affected areas further downstream.
6	Melba Hwy to Maroondah Aqueduct. The channel bed is aggrading in the lower parts. In the middle and upper parts of this reach, the channel has incised down to bedrock, now serving to protect the channel form further headward incision. These changes have occurred in response to the construction of a drain connecting Steels Creek to Dixons Creek.

Similar to Steels Creek, there are also concerns over the stability of Dixons Creek, where it crosses the Melba Highway beneath two road bridges located upstream and downstream of Bottings Lane. At the upstream bridge, there is significant bank erosion along the creek downstream of the bridge. This is attributed in part to the effect the bridge has in directing flow downstream towards the left hand bank. The bed of the creek immediately downstream from this bridge has incised down to bedrock, restricting further bed erosion, but continued bank erosion may be expected to occur. Between the two bridges there is also a lateral gully which has eroded into the floodplain by the advancement of a headcut from Steels Creek.

An earlier fluvial geomorphological study has also been carried out on Dixons Creek (ID&A 2000). A similar history of channel adjustment to management works is also noted for Dixons Creek as Steels Creek. Severe incision occurred after the relocation of Steels Creek confluence and



channelisation of Dixons Creek. Active erosion heads are moving headwards towards the southern bridge. A smaller erosion head was also noted between the two bridges, but this has reached a bedrock bar forming a natural bed control structure. ID&A (2000) also raised concerns about the bank erosion downstream from the northern bridge and its potential to continue headward and outflank the bridge.

Anastomosing

As with single thread meandering channels, anastomosing reaches are formed in broad valleys of low slope. However, owing to deposition in the main stream, the channels bifurcate, branch and rejoin irregularly to create a net-like planform. Meandering can occur in any of the anabranches with most erosion occurring on the outer bank of bends.

The Alliance was unable to complete a site inspection of waterway crossing points 23 and 24 (Refer to Appendix A for location). These points are positioned just south of Yea, each point crossing an anabranch of the Yea River. As discussed in the geomorphology report, the section of Yea downstream from Murrindindi to Yea has experienced a major avulsion in the recent historical past shortening the main channel some 1.25 km. This avulsion shifted the active channel from the eastern side of the floodplain to the western side where it currently remains.

Avulsions are caused by the development over time of hydraulically inefficient channels. Sinuosity is an index of this developing inefficiency. The present main channel on the west side of the floodplain will continue to laterally migrate and progressively evolve into a meandering channel. The timescales over which this can happen are unknown. However, this does have implications for crossing the Yea channel and its floodplain and overall alignment. Wherever possible the pipeline alignment should be located outside the extent of the Yea floodplain. This will then minimise the risk of the pipeline being exposed, due to avulsion/migration of the Yea River and erosion of the floodplain at a point where the pipeline is located.

4.4 Assessment of Potential Impacts

4.4.1 Available crossing techniques and potential impacts

Methods of construction for the pipeline to cross waterways may include:

- Directional boring; and
- Open cut excavated conduits

Potential impacts that can occur and must be minimised or avoided include:

- Disturbances to bed and banks which can lead to erosion and sedimentation; and
- Disturbances or loss of native vegetation

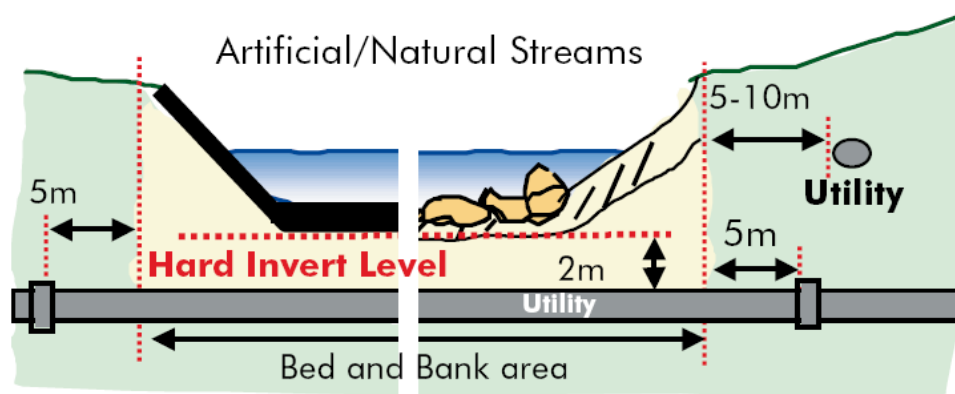
Potential impacts are discussed in further detail with reference to crossing technique.

Directional Boring

This technique involves drilling a tunnel beneath the bed and banks of the waterway into which the pipeline can be laid (Figure 11). The main advantages of this technique is that there is no

disruption to the stream bed and banks and therefore no chance of contributing to rates of erosion; no effect on the hydraulic capacity of the stream, and no adverse visual impacts. Where practical, boreholes should terminate as far as possible from the stream banks so as to avoid disturbances to existing riparian vegetation.

This option provides added flexibility with the timing of works as boring under the crossing can occur when flows remain in waterways and it avoids the need to divert or dam flows. The minimum required distance between the lowest point of the bed and banks or hard invert level of the waterway and the top of the pipeline will be between 1 and 2 m. This will need to be negotiated with Goulburn Broken CMA and Melbourne Water.



■ **Figure 11 - Schematic of a typical directionally bored crossing.** Source: *Utility installation near Melbourne Water Assets.*

Open Cut Excavation

This technique involves excavating soil material to form a trench, enabling the pipe to be laid and then backfilled (Figure 12, Figure 13 and Figure 14). This crossing method may potentially have a greater environmental impact than directional boring.

Where water is flowing in the waterway, the backfill material shall be granular and finished level with the bed of the waterway. Where no water is flowing, the backfill material shall consist of clay or sandy loam and must be thoroughly compacted over the full width of the trench. Surface run-off should be diverted so as to avoid erosion of backfilled areas until such time that the surface has consolidated and been appropriately revegetated. Melbourne Water are likely to require a rock chute to be constructed along the bed and banks of the creek to prevent erosion.

The crossing final crossing method used for waterway crossings is being determined with Goulburn Broken Catchment Management Authority and Melbourne Water.