Understanding the environmental water requirements of platypus

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Executive summary

The platypus (*Ornithorhynchus anatinus*) is an iconic Australian species. Along with being a unique and popular symbol of Australian fauna, as a top-order predator it is an important indicator of catchment health. In Melbourne Water's Healthy Waterways Strategy (HWS), the importance of appropriate flow regimes for platypus is recognised, however, further understanding of the species' flow and water quality requirements is needed to help MW to manage environmental water for platypus effectively. The overall aim of this project is to improve the ability of Melbourne Water to manage platypus in the Melbourne area.

This study has two main parts. Part A is a review of the key flow requirements for platypus. Part B presents the additional (non-flow related) recommendations for managing platypus in the Melbourne area. Summarised below is the key outcomes of Part A. the review of flow requirements for platypus and a conceptual model, which provides a visual representation of the flow requirements. The full report should be consulted for details of each flow component and justifications for each.

Key flow requirements of platypus

The platypus's biology and ecological requirements (including those related to flow) have manifestly been shaped primarily by environmental conditions that prevailed in the millennia prior to European settlement. Recommended practices to meet the platypus's flow requirements in modern managed systems are as follows:

- The ideal platypus flow regime entails plenty of surface water being available throughout the year in every year. Adult females in particular require access to abundant food resources both in the lead-up to the breeding season and during lactation (effectively from March through the following February) for reproduction to reliably succeed. If it is necessary to sometimes institute a low- or no-flow watering regime in a managed river system (e.g. during extended drought periods), enough surface water should be released in at least 50% of years (at a minimum frequency of one year in three) to support successful breeding by a substantial proportion of females occupying the system.
- To reduce the risk that platypus are killed by predators, riffles should never be allowed to dry out entirely and should ideally allow a platypus to remain submerged (and hence hidden from the view of a nearby predator) while travelling along their length. In practice, this will entail a minimum depth of 0.15-0.30 m being maintained in at least part of a riffle's cross-sectional profile.
- To improve platypus foraging opportunities and reduce the risk that platypus are killed by predators along runs (which normally extend for a much longer distance than riffles), minimum water depth should ideally never drop below approximately 0.3 m (if a channel is <5 m wide) or 0.5 m (if a channel is >5 m wide).
- The occurrence of occasional high to very high flow events helps to maintain the quality of platypus foraging habitats by scouring accumulated fine sediment from pools and otherwise promoting healthy geomorphological processes. However, flows that increase water depth by approximately 1 m or more above the spring base flow level may adversely affect platypus reproduction by causing eggs to be destroyed or juveniles to drown. The risk that this occurs is presumed to be somewhat lower during incubation/early lactation (late August to November) than in late lactation and the period when juveniles are learning to swim (December to February).
- High (though not overbank or near-overbank) flows are presumed to present a relatively low risk to juveniles if peak depths exceeding 1 m above base flow are maintained for less than 24 hours (i.e. in line with the duration of most storms) in the period from August to November.
- It is recommended that managed flows exceeding 1 m above base flow should be avoided whenever possible to protect juveniles in the period from December to February. If it is necessary, for operational or other reasons, to schedule a release of greater magnitude in this period, we recommend that it should be preceded by an equal or larger release in August, thereby encouraging breeding females to locate nesting burrow chambers at a greater height in the bank than might otherwise be the case.
- The occurrence of minor to moderate freshes is predicted to benefit platypus foraging success both directly and indirectly, e.g. by filling marginal aquatic habitats, renewing food resources for macroinvertebrates, flushing fine sediment from benthic surfaces and maintaining productive biofilms. In managed systems, the scheduling of freshes during dry periods (i.e. in the absence of freshes caused by natural runoff) is likely to particularly benefit platypus survival and breeding success in summer and autumn when water temperatures tend to peak and evaporation rates are greatest. It is also possible

(though by no means proven) that freshes may be used as a platypus population management tool, to help promote migration to relatively isolated populations by breeding males (in late winter and spring) and dispersing juveniles (in late autumn) (see Section 8.2).

Key flow requirements of Platypus

The flow requirements of platypus are presented in this section as a conceptual model (Figure 4-1). The conceptual model is based on a stylised flow series over time and uses a risk classification system (high, medium, low) to depict the benefit or risk to platypus of different flow components at various times of year.

The following should be considered when using the conceptual model and will aid in its interpretation:

- The blue line represents a stylised flow series (it is not intended to represent an actual flow series in a particular river). It is provided to alert the reader to the different flow components that are important for platypus.
- The numbers on the flow series corresponds with an explanation following the conceptual model.
- At the bottom of the figure is an approximate timeline of important platypus behaviours across the year, categorised as either feeding, breeding or juvenile behaviour.
- Green shading indicates **low risk**, which means that flow of that type (i.e. baseflow) is expected to be beneficial to platypus.
- Yellow shading, or **medium risk**, represents flows that are either tolerated by platypus without providing a significant benefit, or that provide a benefit at some times but not others, for example, related to the frequency.
- Red shading indicates **high risk** flows, which in general, are flows that impact platypus negatively.
- Dashed lines surrounding a flow component indicate that there is uncertainty around its ecological impact, or that the magnitude of the impact is not well understood.

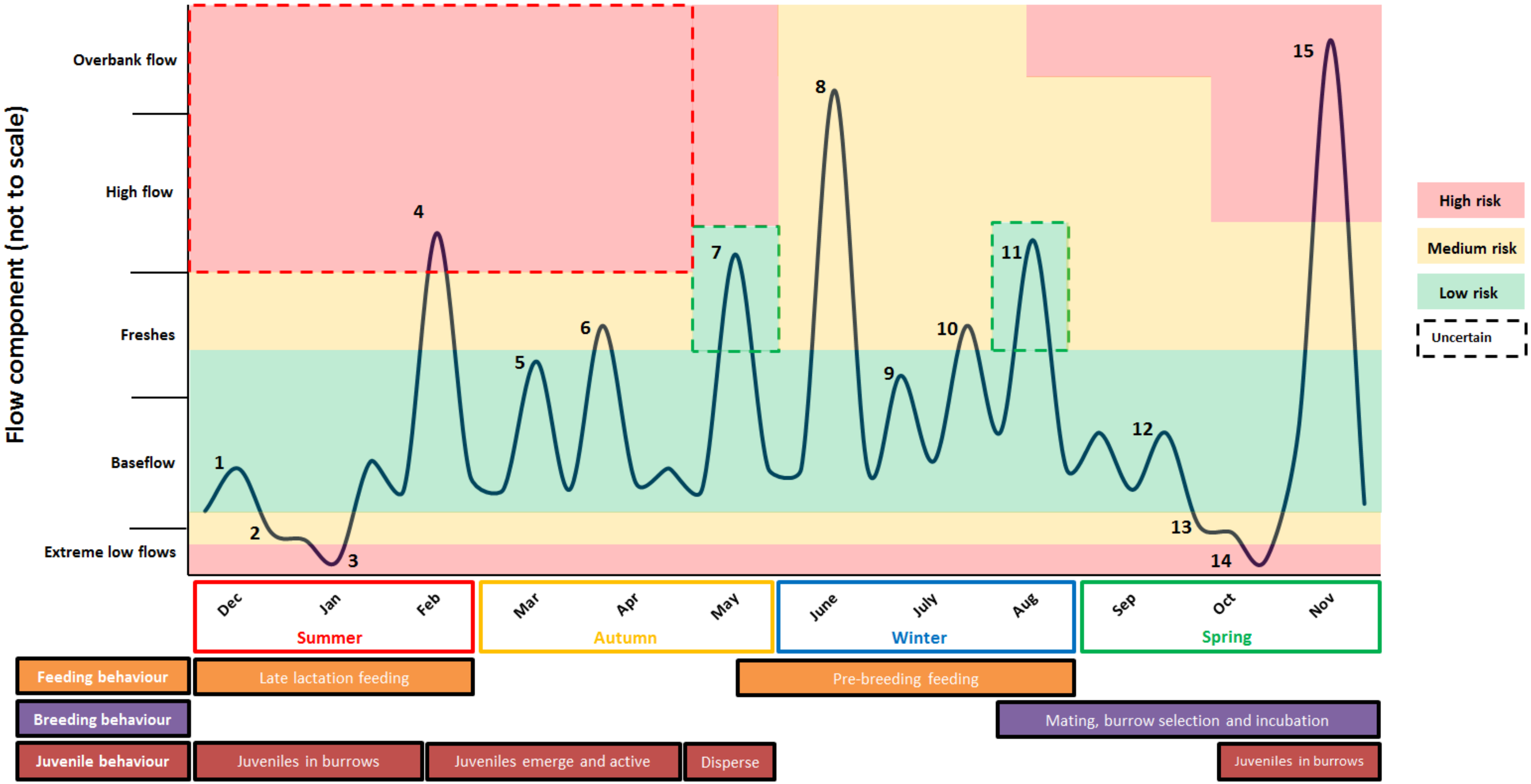

Figure E-1 Stylised flow series indicating the benefit and risk to platypus over the year.

1. Moderate summer/autumn baseflow (low risk): Platypus need to feed on a daily basis all year. Moderate baseflow supports macroinvertebrate production and provides adequate water depth and connectivity along channel for efficient foraging (adults and juveniles). Stable flows from December to February also support platypus reproduction: the energy needs of lactating females peak from December to early February.

2. Low summer/autumn baseflow (medium risk): Macroinvertebrate productivity is reduced at low baseflow, limiting food resources. Can be tolerated for short periods but extended periods can be detrimental.

3. Extreme low flows (high risk): Increased risk from predation due to increased overland movement or movement through a dry channel or shallow water. Insufficient macroinvertebrate productivity to support reproduction or maintain good adult condition. (See Section 3.1 for specific minimum depth guidelines.)

4. Summer/autumn high flow (high risk): Although small to moderate summer freshes are generally beneficial (**see 5**), flows that result in water depth increasing significantly compared to spring baseflow (e.g. rise greater than 1 m) can inundate breeding burrows, causing young animals to drown (highest risk period is December-early February). Juveniles that are just learning to swim may also drown or be swept downstream in flows of this magnitude (highest risk period is late January-early March). High flows should therefore be avoided if possible in these months (but **see 9**).

It should be noted that more research is needed to confirm the maximum amount of flow that is safe with respect to both breeding burrows and juvenile survival: The boundary value provided here (i.e. >1 m of rise in water level as compared to baseflow is inadvisable) is reasonably well supported by current knowledge about platypus burrows near Melbourne, but may conceivably change when more is known. Little is currently known about how juvenile swimming activity varies with flow velocity, though high juvenile mortality has been convincingly linked to February flood events in the Melbourne area.

5. Occasional summer/autumn freshes (low risk): Freshes may benefit platypus by promoting exploratory behaviour, encouraging individuals to discover new resources and habitats. Freshes also maintain habitat quality by scouring fine sediment from pools and riffles and can contribute to macroinvertebrate productivity. Although foraging efficiency may decrease during higher velocity flows, the net effect of summer/autumn freshes should generally be positive to very positive for this species.

6. Frequent summer/autumn freshes (moderate risk): Foraging efficiency is likely to be reduced during freshes and therefore very frequent fresh events should be avoided.

7. Late autumn high flow (possible low risk): It is logically possible that dispersal of first-year juveniles may be promoted by a rise in flow (particularly from a low baseflow) in late autumn (May). However, appropriate studies have not yet been carried out to determine whether this actually occurs in nature.

8. Winter high flow and overbank flows (medium risk): Floods and overbank flows can be important for waterway productivity (e.g. carbon input). However, very high flows also increase metabolic demand in foraging and can scour macroinvertebrate food sources, damage burrows and even result in direct platypus mortality. Adult platypus can use slower flowing habitats to forage during floods insofar as these are available and are generally expected to survive such events, but no positive benefit is expected to accrue to them in the immediate term.

9. Occasional winter/spring freshes (low risk): The benefits to habitat maintenance of winter/spring freshes are similar to those previously described for summer/autumn freshes (**see 5**).

10. Frequent winter/spring freshes (low risk): As with frequent summer/autumn freshes (**see 6**), the reduction in foraging efficiency during freshes means that frequent freshes represent a moderate risk.

11. Late winter /spring freshes (low risk): A high flow event in late winter or very early spring (August-early September; shortly before a breeding female selects her nesting burrow), may result in her choosing or building a burrow that is located higher on the bank than might otherwise be the case. This in turn may reduce the likelihood that the burrow is later inundated if flow increases markedly thereafter (**see 4**). However, appropriate studies have not yet been carried out to determine whether this actually occurs in the wild.

12. Moderate winter/spring baseflow (low risk): Periods of stable baseflow providing good platypus foraging conditions are important as females attempt to gain weight in preparation for breeding.

13. Low winter/spring baseflow (medium risk): As described in **2**, macroinvertebrate productivity is reduced when baseflow is low, limiting food resources. This is particularly problematic for lactating females, given their high energy requirements. Platypus are expected to survive short periods of reduced baseflow but extended periods will be detrimental.

14. Extreme low winter/spring baseflow (high risk): As described in **3**, extreme low flows are a risk both as a result of increased predation and lower food resources.

15. Spring high flow and overbank flows (high risk): Very high or overbank flows present a very high risk to reproduction, due to inundation of burrows containing eggs and/or nestling juveniles.

1. Introduction

The platypus (*Ornithorhynchus anatinus*) is an iconic Australian species. Along with being a unique and popular symbol of Australian fauna, as a top-order predator it is an important indicator of catchment health. The platypus is also of considerable evolutionary significance, being one of only five monotreme species (egg-laying mammals) extant today. The monotremes branched off from the other mammals in the Jurassic (over 100 million years ago) making it one of the oldest known mammalian lineages.

The Melbourne Water Urban Platypus Program has been monitoring populations at many locations in and around Melbourne since 1995. As described in this report and elsewhere (e.g. Griffiths *et al*. 2015), the distribution and abundance of many platypus populations in the Greater Melbourne Region have declined in recent decades, with several small populations apparently becoming locally extinct. At the same time, research on the platypus's ecological requirements and its behaviour in urban and other habitats has helped to reveal how flow regimes are linked to platypus reproduction and survival.

In Melbourne Water's Healthy Waterways Strategy (HWS), the importance of appropriate flow regimes for platypus is recognised, however, further understanding of the species' flow and water quality requirements is needed to help MW to manage environmental water for platypus effectively.

1.1 Scope of the current study

The overall aim of this project is to improve the ability of Melbourne Water to manage platypus in the Melbourne area. To do this, a technical panel, made up of specialists with considerable experience in platypus biology and ecology and environmental flow management, was formed. The technical panel included:

- Dr Melody Serena (Australian Platypus Conservancy)
- Josh Griffiths (cesar)
- Geoff Williams (Australian Platypus Conservancy)
- Dr Andrew Weeks (cesar)
- Dr Tom Grant (University of New South Wales)
- Cheryl Edwards (Melbourne Water)
- Dr Rhys Coleman (Melbourne Water)
- Sarah Gaskill (Melbourne Water)
- Tiana Preston (Melbourne Water)
- Dr Simon Treadwell (Jacobs)
- Dr Josh Hale (Jacobs)

The technical panel was assembled for a one day workshop in April 2016. At this workshop, a range of factors important to platypus management in Melbourne Water's region were discussed, with particular emphasis on the species' key flow requirements. In addition, the importance of designing regulatory structures (e.g. pipes, culverts, weirs) with consideration for platypus and of identifying and managing drought refuges were both considered. Finally, the significant problem of fragmentation of the platypus populations in Melbourne in relation to genetic and demographic aspects of population viability was discussed.

1.2 Structure of this report

Following the workshop, a number of areas were identified for further research. This report presents the outcomes of the technical panel workshop and has been divided into two parts. Part A is a review of the key flow requirements for platypus. Part B presents the additional (non-flow related) recommendations for managing platypus in the Melbourne area.

1.2.1 Part A – Platypus flow requirements

The aim of Part A of this report is to review the available information relating to the platypus's water requirements, with a view to developing a robust conceptual understanding to allow Melbourne Water to improve its management of water for the species. The information contained in this report will feed into environmental release planning and other programs such as the *Drought Refuge* and *Unregulated Rivers* programs.

Part A is made up of three sections (report Sections 2, 3 and 4):

- Section 2 is a comprehensive literature review of available information relating to platypus flow requirements. It is organised around a number of key biological processes, including diet and foraging, adult movements and burrow use, direct mortality risk, reproductive success and juvenile dispersal.
- Section 3 summarises the major known flow requirements of platypus and outlines a number of additional factors (called modifiers) that can affect how platypus populations respond to flow.
- Section 4 presents a series of conceptual models outlining our current understanding of the major flow requirements of platypus in a format that will allow Melbourne Water to incorporate the findings of this review into management planning for Melbourne Water's waterways.

1.2.2 Part B – Additional (non-flow related) recommendations for managing platypus in the Melbourne area

A number of additional, complementary actions were identified at the technical panel workshop as being important for successful management of the platypus populations in the Melbourne Water area. Part B presents a summary of these complementary actions and consists of four sections:

- Section 7 presents a set of guidelines for platypus-friendly regulating structures (e.g. pipes, culverts, weir walls and drop structures).
- Section 8 outlines guidelines for identifying and managing platypus drought refuges.
- Section 9 is an assessment of barriers in Melbourne Water's management area, which provides a basis from which to consider one of the major threats to Melbourne's platypus populations, namely fragmentation.
- Finally, in Section 10, a number of the key complementary actions to conserve platypus in the Melbourne area are summarised, including identification of knowledge gaps and future research priorities.

2. Part A: Literature review of platypus flow requirements

Reliability and volume of water flow may influence the size, distribution and sustainability of platypus populations by affecting a number of processes and factors:

- Diet and foraging
- Adult movements and burrow use
- Direct mortality risk
- Reproductive success
- Juvenile dispersal

In this section, relevant background information about each of these topics is presented, followed by a discussion of the implications for platypus flow management and a list of other factors (both positive and negative) that can modify how platypus populations respond to flow regimes. Lastly, conceptual models are presented to summarise our current knowledge of the key elements of platypus flow requirements.

2.1 Foraging

2.1.1 Food consumption and diet

The platypus feeds exclusively in the water and requires access to large amounts of food on a regular basis throughout the year. Adults typically (i.e. when not breeding) ingest the equivalent of around 15-30% of their body mass in small aquatic prey each day (Krueger *et al.* 1992; Holland and Jackson 2002). The diet mainly comprises a broad range of benthic macroinvertebrates, ranging in size from chironomid (midge) larvae up to large dragonfly nymphs (Faragher *et al.* 1979; Grant 1982; McLachlan-Troup *et al.* 2010; Marchant and Grant 2015). Although mayfly and caddis fly larvae have often been shown to be important food items in platypus dietary studies, this finding probably reflects the numerical dominance of these invertebrates at many sites supporting reasonably abundant platypus populations (as opposed to being due to selective foraging *per se*) (Marchant and Grant 2015). It's also worth noting that soft-bodied macroinvertebrates, especially oligochaete worms, have almost certainly been underestimated as a food resource in dietary studies (Klamt *et al.* 2015). The composition of male and female diets is not known to differ (McLachlan-Troup *et al.* 2010).

2.1.2 Foraging behaviour and habitat/water quality

Platypus foraging behaviour in the wild is reasonably flexible. For example, along Badger Creek in the upper Yarra River catchment, the animals obtained food by diving in pools, searching methodically among rocks and gravel located along shallow riffles, and investigating the submerged perimeters of undercut or densely vegetated stream banks along runs (sometimes accompanied by brief bouts of digging) (Serena 1994). At the same time, a number of studies have documented that platypus are selective with respect to habitat attributes at preferred feeding sites:

- *Depth*. Most platypus foraging preferentially occurs at a depth of about 1 to 5 metres. For example, in the lower Hastings River in New South Wales (maximum depth = approximately 4 m), Grant (2004b) found that animals avoided depths of less than 1 m and significantly preferred depths greater than 1.5 m. Elsewhere in New South Wales, Grant and Gill (2012) reported that about 80% of platypus foraging dives in the Manning River (maximum depth = approximately 8 m) occurred at depths between 1.6 and 4.9 m, with the deepest dive descending to 6.1 m. At Lake Lea in Tasmania (where holes extend down to a depth of more than 10 m), use of data loggers revealed that 98% of platypus dives did not go deeper than 3 m, though in one instance an animal descended to a depth of nearly 9 m (Bethge *et al.* 2003).
- *Instream substrates*. A significant negative relationship exists between the distribution of platypus foraging activity and the occurrence of silt, consolidated clay or willow roots on the channel bottom (Serena *et al.* 2001). Conversely, platypus foraging activity is positively associated with the instream

occurrence of cobbles (Grant 2004b) or gravel, pebbles, cobbles, large rocks and coarse particulate organic matter (Serena *et al.* 2001).

- *Instream woody habitat.* A significant positive relationship has been identified between the distribution of platypus foraging activity and the occurrence of large woody debris (partly or entirely submerged logs and branches) in stream channels (Serena *et al.* 2001; Coleman 2004).
- *Riparian vegetation*. A significant positive relationship has been identified between the distribution of platypus foraging activity and the amount of bank vegetation overhanging the water (Ellem *et al.* 1998) and the number of medium and large native trees growing on the banks (Serena *et al.* 2001).
- *Stably undercut banks*. A significant positive relationship has been identified between platypus foraging activity and the occurrence of banks that are undercut (or 'notched') at the water surface during base flow (Serena *et al.* 2001).

Platypus population density near Melbourne has also been found to be related to the phosphorus concentration in stream water: higher platypus numbers were associated with lower total phosphorus levels. Sites where a breeding platypus population occurred were also characterised by less suspended solids in stream water and less zinc, lead and cadmium in bottom sediment as compared to sites where the animals did not occur. These relationships were presumed to mainly reflect the detrimental effects of nutrient enrichment, suspended solids and heavy metal contaminants on platypus foraging success (Serena and Pettigrove 2005).

2.2 Adult movements and burrow use

2.2.1 Home range size

Long-term mark-recapture studies conducted near Melbourne indicate that male and female home ranges typically encompass around 6-11 km and 2-4 km of channel, respectively (Serena and Williams 2012b). Based on use of radio-tags or acoustic tags, the longest home ranges described to date have stretched 15.1 km in the case of a male (Gardner and Serena 1995) and 6.0 km in the case of a female (Griffiths *et al.* 2014a). Most adults appear to show strong site fidelity over time, occupying stable home ranges over several years (Serena and Williams 2012b).

2.2.2 Size of daily foraging area

In Lake Lea, a subalpine Tasmanian lake supporting a large platypus population, daily foraging areas encompassed 3-35 hectares in the case of adult males (up to 25% of the lake's surface area) and 2-58 hectares in the case of adult females (up to 41% of the lake's surface area) (Otley *et al.* 2000).

In Badger Creek, a small stream supporting an estimated mean density of 1.3-2.1 resident animals per kilometre of channel, about half of the local platypus population regularly foraged in both the creek channel and small man-made ponds draining into the creek, whereas the remainder fed only along the creek. Daily foraging areas for animals in both groups encompassed 0.4 hectares on average, with individuals using 24-70% of their total home range in a given foraging bout (Serena 1994). The much smaller size of foraging areas along Badger Creek as compared to Lake Lea plausibly reflects the fact that the narrow dimensions of Badger Creek meant that it was easier for animals to reduce food competition in any given spot by partitioning their collective foraging effort (both spatially and temporally).

2.2.3 Camping burrows

Platypus camping burrows provide shelter for all age and sex classes apart from mothers and their eggs or dependent offspring. They are often used sequentially by different individuals and may be occupied by more than one animal at the same time, indicating that they are not a defended resource (Grant 1983; Grant *et al*. 1992; Serena 1994; Gardner and Serena 1995; Serena *et al.* 1998). In the Melbourne area, camping burrows are simple earthen structures that are typically 1-2 (though occasionally up to at least 4) m long; entrances are generally cryptic, often hidden below an undercut bank, overhanging vegetation or substantial structures such as logs fallen across the bank. It is not unusual for a platypus to occupy up to around 12 different camping burrows within a period of several weeks (Serena 1994; Gardner and Serena 1995; Serena *et al.* 1998).

In a radio-tracking study carried out along Mullum Mullum Creek and the Yarra River, Serena *et al.* (1998) ascertained that camping burrows were only found in banks extending $\geq$ 0.5 m vertically above the water surface, presumably so the burrow chamber was (1) located above the water table (and hence reasonably dry), and (2) covered by adequate overlying soil (and hence unlikely to cave in easily). Along both the creek and river, camping burrows were positively associated with stably undercut banks and moderate-to-dense vegetation overhanging the water, and negatively associated with banks having a convex profile where the bank meets the water.

Suitable sites for platypus camping burrows are unlikely to be in limited supply along natural water courses. However, this generalisation may not apply to man-made impoundments where a high proportion of the perimeter consists of relatively flat, low-lying banks (e.g. Otley *et al.* 2000). In the case of water bodies where substantial interseasonal variation in water depth predictably occurs due to changing irrigation requirements, it has been suggested that a different set of camping burrows may be occupied in high- and low-flow conditions (Gust and Handasyde 1995). Supporting this hypothesis, Holwell *et al.* (1998) noted that a subset of burrows used by radio-tagged animals along the Wimmera River was only (and repeatedly) occupied when river height rose substantially after heavy rainfall. As a final flow-related point, animals that are forced to move back and forth across exposed portions of a creek or river bed to access burrow sites (e.g. if reduced flow causes wetted channel width to narrow) will be subject to increased predation risk (Grant and Bishop 1998).

2.2.4 Extent of platypus activity

Given the platypus's known aptitude for behavioural flexibility and mobility, these animals are expected to try to optimise foraging by adjusting daily movement patterns in response to changing water depth and current velocity. It would also not be surprising to find that an increase in flow tends to elicit exploratory or investigative behaviour, as animals seek to determine if changing water levels have created new foraging opportunities within their established home range or in nearby areas. For example, a post-works monitoring study carried out approximately 10-11 months after the Hull Road wetlands were developed found that animals residing along Olinda Creek failed to enter the wetlands *except* on one occasion when a radio-tagged male visited one pond for approximately 30 minutes. Rain had fallen on the previous day in what was otherwise a very dry period, prompting some surface water to start flowing down the rock bank at the pond's outlet into the creek. This sequence of events suggested to researchers that the new trickle of water entering the creek may have stimulated the male's interest in following the water to its source; the short period of time he spent in the pond (which hadn't yet developed much in the way of fringing or submerged vegetation) also suggested that it didn't yet support substantial numbers of edible macroinvertebrates to maintain his interest in feeding there (Serena and Williams 2000).

In very broad terms, flow volume is predicted to affect platypus movement patterns in the following ways:

'Normal' summer and winter baseflow (i.e. moderately low to moderately high base flow). This is generally expected to create relatively benign conditions for platypus foraging: the distribution of macroinvertebrates should be relatively easy for a platypus to predict within its home range; macroinvertebrate densities are unlikely to be greatly depleted by drift downstream; prey will find it more difficult to evade capture in relatively slow-moving water; the amount of energy needed for a platypus to maintain its position in the stream or travel upstream should not be particularly high. High foraging efficiency in turn should mean that the amount of movement required to find food is relatively low, resulting in comparatively small daily foraging areas.

***Natural freshes or modest increases in managed flow*.** The extent of platypus movements is likely to increase for two reasons: (1) higher flow may promote exploratory behaviour (see above), and (2) prey may be somewhat more difficult to obtain because detected items are less easily captured in faster moving currents. Supporting this prediction, Griffiths and Weeks (2015) found that the frequency of travel by acoustic-tagged platypus between neighbouring locations in the Tarago River was slightly higher during the three peak days of an environmental water release (12% of all detections) as compared to several days occurring just before and after the peak flow period (3% of all detections).

High flow events (i.e. more extreme increases in flow). Increased turbulence and current velocity during periods of high to very high flow will undoubtedly both increase a platypus's energy expenditure and reduce its foraging efficiency (Grant and Bishop 1998). Animals are predicted to respond by increasing their usage of slower moving water, e.g. deep pools, backwaters or relatively protected areas under banks or behind logs. Depending on the availability and distribution of such habitats (and the magnitude and persistence of high flows), platypus foraging areas might potentially either contract or expand. It has also been suggested that animals may sometimes respond to rapid and severe increases in flow by postponing activity and simply remaining inside a burrow, though this needs to be confirmed by direct observations (Griffiths *et al.* 2014a).

Observations of platypus behaviour during high flow events include the following:

- Animals occupying the Goulburn River downstream of Lake Eildon increased their use of a large (up to 1.5-kilometre-long) billabong or backwater when irrigation water was being released during the peak flow season in summer (Gust and Handasyde 1995).
- Along the Barron River in flood, platypus were most often seen foraging near the bank in relatively slow-moving water, though they also sometimes entered faster currents (Grant 2007).
- Radio-tagged platypus that spent time feeding both in Mullum Mullum Creek and the Yarra River were particularly likely to occupy burrows along the much deeper Yarra on days following substantial rainfall events (Australian Platypus Conservancy, unpub. data). Similarly, Griffiths *et al.* (2014a) documented two cases in which an acoustic-tagged animal left Mullum Mullum Creek as flow increased after a storm and made use of the Yarra River as long as creek height remained high.

Extreme low flow. As streams and rivers dry out, their wetted surface area contracts and instream woody debris become increasingly exposed to air, reducing the extent of platypus foraging habitat. Macroinvertebrates that are sensitive to reduced flow and poor water quality decline in numbers, typically including mayfly and caddis fly larvae (Chessman 2003), i.e. groups that often comprise a large part of the platypus diet. Macroinvertebrate productivity per m^2 of channel has also been found to be much greater when flow is moderate as opposed to low flow associated with drought (Marchant and Grant 2015). As the wetted channel becomes shallower and narrower, the risk that a platypus may be killed by predators also increases (see Section 2.3). In response to these changes, animals are expected to shift their activity to optimise use of the best remaining foraging areas (which are also likely to constitute the safest remaining areas). Supporting this hypothesis, the results of platypus mark-recapture studies conducted from 1997 to 2005 along the Mackenzie River show that animals were widely dispersed along the river in spring but became concentrated as the summer progressed at sites where adequate water remained in the channel (Williams *et al.* 2005). Similarly, results of mark-recapture studies conducted near Melbourne suggest that relatively deep river and lake habitats may attract more platypus usage during very dry (as well as wet) periods (Serena *et al.* 2014).

2.3 Adult mortality

A platypus's life span can extend up to at least 21 years (Grant 2004a). Although adults and subadults mostly survive floods, flood-related mortalities do occur at times (Connolly *et al.* 1998; Grant 2007; Serena and Williams 2010). At the other extreme, a platypus will starve if its foraging habitats dry up entirely (Serena and Williams 2010). A platypus also becomes much more vulnerable to predators (notably foxes, dogs and birds of prey) if it is forced to travel regularly across dry or nearly dry land to access feeding sites or burrows (Grant and Bishop 1998). Supporting this generalisation, a recent analysis of platypus mortality factors in Victoria found that deaths due to predation were reported in all months *except* July to October, when unregulated streams and rivers generally flow quite reliably (Serena and Williams 2010).

Other important factors known to contribute directly to platypus mortalities in Victoria include animals drowning in illegal fishing nets and enclosed yabby traps, becoming entangled in items of litter, being hooked by anglers (and then released with a fishing hook still embedded in the animal's bill or body) and entering irrigation pumps that have not been fitted with adequate guards (Serena and Williams 1998, 2010).

2.4 Reproduction

2.4.1 Platypus reproductive biology

A female platypus is believed to require at least two years to reach sexual maturity (Temple-Smith 1973; Grant *et al.* 2004a) with most litters comprising 1-2 (though sometimes 3) offspring (Burrell 1974). Reproduction is energetically expensive: lactating females (which are solely responsible for raising their offspring) must capture the equivalent of up to 80% of their own body mass in prey each day to meet their energetic needs (Holland and Jackson 2002). In a study spanning 27 years, less than half of breeding age females were found to be lactating (on average) in any given year along the upper Shoalhaven River in New South Wales (range = 18-80% of eligible females in any given year); some young females bred for the first time at the age of three or four years and some females failed to breed successfully in consecutive years (Grant *et al.* 2004a). The body condition of lactating females in the upper Shoalhaven was also found to be poorer at the end of summer as compared to females that did not lactate (Bino *et al.* 2015).

Serena *et al.* (2014) concluded that the key demographic process distinguishing a Melbourne platypus population that declined dramatically from 1997 to 2007 (Monbulk Creek) from one that varied little in the same period (Olinda Creek) was reproductive success rather than adult mortality: adults were lost at similar rates in the two systems, but this loss was redressed by the number of new recruits along Olinda Creek but not Monbulk Creek (where on average less than 0.1 juvenile was recorded annually per breeding age female over the 10-year study period). The resilience of the Olinda Creek population in coping with drought was ascribed to (1) the mainly forested nature of its catchment (and consequent lack of impervious surfaces to affect rates of storm water runoff and infiltration), and (2) a relatively small but highly reliable environmental flow (approximately 2 ML/day) entering Olinda Creek from Silvan Reservoir throughout the dry period.

2.4.2 The platypus reproductive calendar

Platypus mating behaviour in the wild has been noted from early August to late October in southern Victoria (De-La-Warr and Serena 1999; Easton *et al.* 2008), with animals at Healesville Sanctuary breeding as late as 8 November (Holland and Jackson 2002). Based on data obtained in captivity, gestation and incubation respectively last an estimated 15-21 days and 10-11 days (Holland and Jackson 2002; Hawkins and Battaglia 2009). Assuming that platypus breeding dates are normally distributed (in the statistical sense of the term), mating activity in the wild near Melbourne is predicted to peak in approximately the third week of September, with peak hatching frequency occurring 25-32 days later. Supporting this hypothesis, the frequency of adult females captured in Victorian survey nets has been found to reach its minimum in October, presumably because more females are engaged in either incubating eggs or caring for recently hatched young in this month than at any other time (Serena and Williams 2012a). Lactating females are believed to produce substantial amounts of milk for less than 4 months (Grant *et al.* 2004); the earliest occasion on which a juvenile has been captured in a survey net in southern Victoria occurred in the second half of January (Williams *et al.* 2013).

2.4.3 Nesting burrows and maternal behaviour

In captivity, gravid females prepare a new or renovated nesting burrow and furnish it with nesting material around 1-2 weeks before eggs are laid (Holland and Jackson 2002; Hawkins and Battaglia 2009). Three presumed nesting burrows (either occupied by a radio-tagged lactating female or an adult female and juveniles) have been described to date near Melbourne along Badger Creek. These burrows had two or more apparent entrances that were generally located higher up the bank (to a maximum height of 0.8 m above base flow) as compared to camping burrows found in the same area. Nesting burrow length was also somewhat greater (at least 3-5 m) as compared to camping burrows (Serena 1994).

The greater length and more elevated entrances of nesting burrows presumably help to reduce the risk that eggs are lost or juveniles drown during high flow events. To further limit this risk, a female platypus blocks the tunnels leading to her nesting burrow with a series of consolidated soil ‘pugs’ when it houses young juveniles (Burrell 1974). However, this practice is not guaranteed to safeguard juvenile welfare under all circumstances: pugs may not function effectively when saturated and, in any event, mothers have to breach pugs to attend their young and feed them. For example, an otherwise puzzling absence of juveniles recorded along the Shoalhaven River after half of adult females had previously been shown to be lactating was explained by the occurrence of over-bank flooding in early to mid-summer (Grant *et al.* 2004). Furthermore, mothers stop pugging burrows around the time that juveniles are old enough to start becoming active outside the burrow (as inferred from Hawkins and Battaglia 2009). Because they are relatively weak and inexperienced swimmers, juveniles are likely to be vulnerable to drowning or being swept downstream in high flows for some weeks or months thereafter.

2.4.4 Rainfall/ flow and reproduction

Serena *et al.* (2014) investigated the relationship between rainfall and platypus reproductive success near Melbourne in the mainly dry to very dry years from 1997-2007. The study showed that a large proportion (71%) of annual variation in reproductive success was explained by a positive relationship with the amount of rain falling in the five months prior to breeding (March-July), along with a negative relationship with the amount of rain falling from late lactation to early juvenile independence (January-May). Reproductive success was not significantly related to the amount of rain recorded from the onset of breeding to mid-to-late lactation (August-

December), though possibly only because Melbourne is normally wettest in spring and very early summer (www.bom.gov.au).

The authors concluded that the likelihood that a female platypus enters oestrus and raises offspring in a given year depends on the amount of energy reserves she can accumulate by the start of the breeding season, thereby explaining the positive relationship between March-July rainfall and reproductive success. They also concluded that the negative impact of January-May rainfall on reproductive success is most readily explained by juvenile survival being reduced by high flows. Supporting this hypothesis, significantly fewer juveniles were recorded in years when large storm systems delivered >50 mm of precipitation in January or February rainfall events, around the time that young platypus are emerging from nesting burrows and perfecting their swimming skills. More recently, low numbers of juveniles were recorded near Melbourne in live-trapping sessions conducted in the autumn of 2011 (though numbers remained within the historical range) following widespread flooding in February 2011 (Griffiths *et al.* 2011).

Based on Bayesian modelling of platypus distributional patterns near Melbourne, Martin *et al.* (2014) concluded that the species is adversely affected by urban stormwater runoff conveyed through impervious drainage systems. Adult females appear to be more sensitive to this issue than adult males, presumably due to their very substantial food requirements while raising young.

2.5 Juvenile dispersal

Along with possible long-range movements by adult males during the breeding season, juvenile dispersal is presumed to be a key mechanism to avoid inbreeding and promote genetically diverse platypus populations. It is also believed to be an important mechanism by which vacant platypus home ranges are filled and newly created (or recently rehabilitated) habitats are colonised. Unfortunately, many aspects of platypus dispersal remain relatively unknown, due largely to practical difficulties in carrying out appropriate studies. It is quite well established that young males move farther on average than young females do (Serena and Williams 2012b), whereas young females are more likely than young males to settle and potentially breed in their birth population (Grant 2004a; Furlan *et al.* 2013; Serena *et al.* 2014). Given that the number of juveniles captured in fyke nets in Victoria dips quite sharply in May, it has also been inferred that many first-year animals initiate dispersal in late autumn (Serena and Williams 2012a). A radio-tagged juvenile female that apparently dispersed from her natal home range along Badger Creek (starting early on the evening of 17 May) swam more or less steadily downstream for a distance of 2.3 km to reach the Yarra River in about 1 hour, and was not detected in the study area thereafter (Serena 1994). In New South Wales, Grant (1989) reported that juvenile dispersal also occurred in the Shoalhaven River system around this time of year.

Young platypus are frequently taken by predators, presumably due to their small body size and general lack of experience (Serena and Williams 2010). Successful dispersal is consequently predicted to depend on their ability to avoid predators as well as find enough food in unfamiliar terrain. Both requirements are most likely to be met if water bodies carry a reasonable volume of surface flow. It would therefore not be surprising to find that dispersal of first-year animals may be promoted by a sudden rise in flow, particularly if this starts from a low base level and is timed to occur in late autumn.

3. Part A: Summary of platypus flow requirements

In this section, information presented in the comprehensive literature review (Section 2) is summarised with respect to its implications for managing flows to maintain productive platypus populations.

3.1 Implications for platypus flow management

The platypus's biology and ecological requirements (including those related to flow) have manifestly been shaped primarily by environmental conditions that prevailed in the millennia prior to European settlement. Recommended practices to meet the platypus's flow requirements in modern managed systems are as follows:

The ideal platypus flow regime entails plenty of surface water being available throughout the year in every year. Adult females in particular require access to abundant food resources both in the lead-up to the breeding season and during lactation (effectively from March through the following February) for reproduction to reliably succeed. If it is necessary to sometimes institute a low- or no-flow watering regime in a managed river system (e.g. during extended drought periods), enough surface water should be released in at least 50% of years (at a minimum frequency of one year in three) to support successful breeding by a substantial proportion of females occupying the system.

To reduce the risk that platypus are killed by predators, riffles should never be allowed to dry out entirely and should ideally allow a platypus to remain submerged (and hence hidden from the view of a nearby predator) while travelling along their length. In practice, this will entail a minimum depth of 0.15-0.30 m being maintained in at least part of a riffle's cross-sectional profile. To improve platypus foraging opportunities and reduce the risk that platypus are killed by predators along runs (which normally extend for a much longer distance than riffles), minimum water depth should ideally never drop below approximately 0.3 m (if a channel is <5 m wide) or 0.5 m (if a channel is ≥5 m wide). An abrupt and ongoing reduction in flow that separates the banks from water in the channel will be particularly problematic for platypus survival if this occurs when females are raising dependent young, as a mother and her young are tied to a specific nesting burrow site from early spring to late summer.

The occurrence of occasional high to very high flow events helps to maintain the quality of platypus foraging habitats by scouring accumulated fine sediment from pools and otherwise promoting healthy geomorphological processes. However, flows that increase water depth by approximately 1 m or more above the spring base flow level may adversely affect platypus reproduction by causing eggs to be destroyed or juveniles to drown. As detailed previously, the risk that this occurs is presumed to be somewhat lower during incubation/early lactation (late August to November) than in late lactation and the period when juveniles are learning to swim (December to February). More specifically, high (though not overbank or near-overbank) flows are presumed to present a relatively low risk to juveniles if peak depths exceeding 1 m above base flow are maintained for less than 24 hours (i.e. in line with the duration of most storms) in the period from August to November. In contrast, it is recommended that managed flows exceeding 1 m above base flow should be avoided whenever possible to protect juveniles in the period from December to February. If it is necessary, for operational or other reasons, to schedule a release of greater magnitude in this period, we recommend that it should be preceded by an equal or larger release in August, thereby encouraging breeding females to locate nesting burrow chambers at a greater height in the bank than might otherwise be the case.

The occurrence of minor to moderate freshes is predicted to benefit platypus foraging success both directly and indirectly, e.g. by filling marginal aquatic habitats, renewing food resources for macroinvertebrates, flushing fine sediment from benthic surfaces and maintaining productive biofilms. In managed systems, the scheduling of freshes during dry periods (i.e. in the absence of freshes caused by natural runoff) is likely to particularly benefit platypus survival and breeding success in summer and autumn when water temperatures tend to peak and evaporation rates are greatest. It is also possible (though by no means proven) that freshes may be used as a platypus population management tool, to help promote migration to relatively isolated populations by breeding males (in late winter and spring) and dispersing juveniles (in late autumn) (see Section 8.2).

Both the distribution and number of substantial platypus drought refuges in the Melbourne region would undoubtedly have been much higher before European settlement than it is today. To boost the number of platypus that survive dry years (and thereby reduce platypus population recovery times after protracted droughts), it is recommended that strong consideration be given both to improving the quality of existing drought refuges throughout the Melbourne area and identifying sites where additional refuges can be developed or rehabilitated (see Section 6).

3.1.1 Factors that can modify the effect of flow on platypus populations

A number of factors other than flow can potentially influence whether a platypus population expands or contracts over time. These factors (hereafter called modifiers) can be either negative or positive. The relevance of these modifiers to flow management is that they can (in the case of positive modifiers) complement and enhance the beneficial effects of improved platypus flow management. Conversely, negative modifiers will tend to cancel out such beneficial effects, and can also exacerbate the impacts of suboptimal flow regimes. To contribute to a broad conceptual understanding of the processes affecting platypus population trends, we provide a consolidated list of known modifiers below, along with some remarks about how they are believed to interact with flow regimes.

Negative modifiers

- *Urban stormwater runoff from impervious surfaces*. This is probably the single most important negative modifier for platypus occupying heavily urbanised catchments or rapidly developing catchments where new infrastructure is connected to conventional drainage systems (Martin *et al.* 2014). Firstly, it exacerbates the adverse effects of both floods (by speeding up the rate at which runoff enters natural water courses) and droughts (by reducing infiltration of rain through soil, and hence base flow). Secondly, it magnifies the impact of several other negative modifiers, particularly by promoting transport of litter and chemical pollutants from terrestrial to aquatic environments and increasing rates of channel scouring as well as bank erosion (and hence sedimentation).
- *Nutrient enrichment (total phosphorus concentration) in surface water*. This is commonly caused by uncontrolled livestock access in and along water courses, runoff of agricultural fertilisers, or infiltration of sullage from septic systems into streams. It may adversely affect platypus foraging success by reducing the abundance of preferred macroinvertebrate food sources and contributing to rampant algal growth that impedes the detection and capture of invertebrates (Serena and Pettigrove 2005). Depending on the source, nutrient enrichment may be particularly problematic when flow (and hence the rate of nutrient dilution) is low, and also after flooding that fosters movement of nutrients and other pollutants to waterways, e.g. due to sewerage overflows.
- *High concentrations of toxic contaminants (e.g. lead, zinc and cadmium) in bottom sediment*. These common pollutants in highly urbanised streams may adversely affect platypus populations by reducing the abundance and diversity of edible macroinvertebrates or (possibly) as an outcome of direct toxic effects (Serena and Pettigrove 2005). Effects of flow volume are likely to parallel those described above for nutrient enrichment.
- Any other factors that reduce productivity or abundance of aquatic macroinvertebrates (Marchant and Grant 2015), notably including:
  High rates of erosion and sedimentation (see Section 2.1.2)
  Reduced availability of instream woody habitat (see Sections 2.1.2 and 2.2.4)
- *Illegal use of fishing nets or enclosed yabby traps in inland waterways*. This contributes to platypus mortality when animals drown (Serena and Williams 2010, Section 2.3) and is not expected to vary much with flow regime.
- *Occurrence of litter in streams and rivers*. This contributes to platypus morbidity and mortality, primarily after animals become entangled in constricting rings or loops of plastic, rubber or metal (Serena and Williams 1998, 2010, Section 2.3). The frequency of litter-related injuries is likely to increase during protracted periods of low flow, if insufficient scouring causes litter to accumulate in urban water bodies.
- *Use of irrigation pumps that have not been fitted with devices to exclude platypus entry*. This contributes to platypus mortality when animals drown or otherwise die after being sucked into pumps while these

are being operated (Serena and Williams 2010, Section 2.3). The frequency of pump-related deaths is expected to parallel the amount of pump usage, and so is likely to increase in dry years.
- *High densities of urban foxes*. Canids (dogs and especially foxes) were responsible for 11% of all platypus deaths reported to the APC from the 1980s to 2009 where the cause could be assigned (Serena and Williams 2010). The frequency of mortalities is expected to increase when flow is low (see Section 2.3).

Positive modifiers

- *Any factors that promote productivity of aquatic macroinvertebrate communities* - particularly insects belonging to the orders Trichoptera (caddis flies), Ephemeroptera (mayflies), Odonata (dragonflies and damselflies), Diptera (midges and blackflies) and Coleoptera (water beetles). These groups have consistently been found to be important platypus dietary items, so their presence will contribute both to the quantity and quality of platypus food resources (see Section 2.1.1).
- *Occurrence of large permanent pools, backwaters and billabongs, either natural or man-made*. These features provide platypus refuges in dry years, premium sites for platypus reproduction in normal-to-wet years, and preferred locations for platypus to feed during high flow events (see Sections 2.1.2, 2.2.4 and 6.1-6.3).
- *Occurrence of dense terrestrial vegetation on-stream and river banks and overhanging the water*. These features provide cover and consolidated banks for burrows (see Section 2.2.3), improve the quality of platypus foraging habitat (see Section 2.1.2) and can help to protect animals from predators, especially in places where platypus are forced to travel across dry or nearly dry land (see Sections 2.3 and 6.7). Benefit is predicted to accrue to platypus populations in high, low and moderate flow regimes.
- *Occurrence of instream woody habitat.* The presence of large numbers of fallen logs and branches in the water is expected to improve the quality of platypus foraging habitat in high, low and moderate flow regimes (see Sections 2.1.2 and 2.2.4).
- *Predator (fox) control programs.* Reducing fox density will reduce the likelihood that platypus are injured or killed due to predation. This is likely to be particularly beneficial in dry years as water depth declines, making it easier for foxes to detect and capture aquatic prey (see Section 2.3).

4. Part A: Conceptual model of platypus flow requirements

The flow requirements of platypus, as identified in Section 2 and summarised in Section 3, are presented in this section as a conceptual model (Figure 4-1). The conceptual model is based on a stylised flow series over time and uses a risk classification system (high, medium, low) to depict the benefit or risk to platypus of different flow components at various times of year.

The following should be considered when using the conceptual model and will aid in its interpretation:

- The blue line represents a stylised flow series (it is not intended to represent an actual flow series in a particular river). It is provided to alert the reader to the different flow components that are important for platypus.
- The numbers on the flow series corresponds with an explanation following the conceptual model.
- At the bottom of the figure is an approximate timeline of important platypus behaviours across the year, categorised as either feeding, breeding or juvenile behaviour.
- Green shading indicates **low risk**, which means that flow of that type (i.e. baseflow) is expected to be beneficial to platypus.
- Yellow shading, or **medium risk**, represents flows that are either tolerated by platypus without providing a significant benefit, or that provide a benefit at some times but not others, for example, related to the frequency.
- Red shading indicates **high risk** flows, which in general, are flows that impact platypus negatively.
- Dashed lines surrounding a flow component indicate that there is uncertainty around its ecological impact, or that the magnitude of the impact is not well understood.

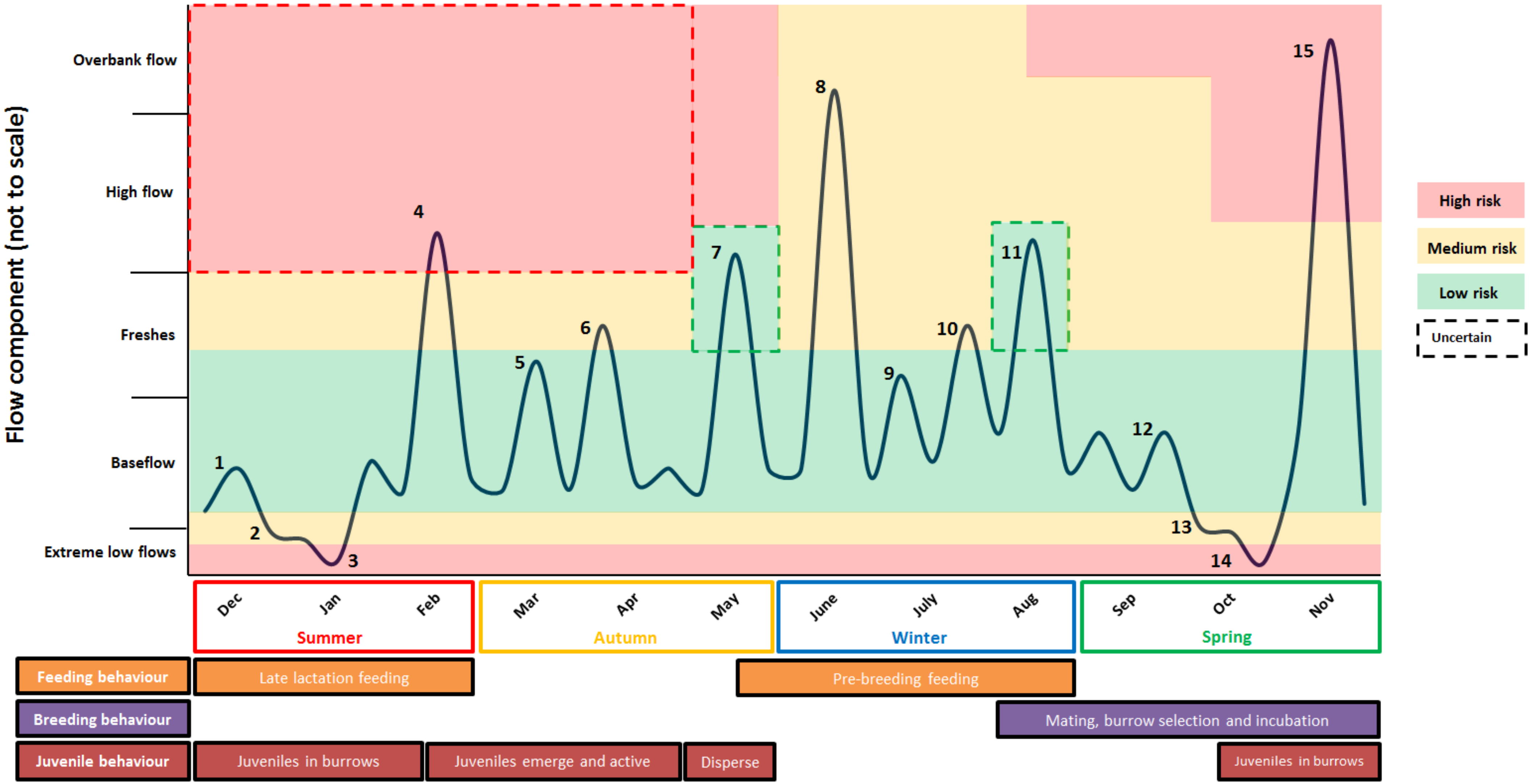

Figure 4-1 Stylised flow series indicating the benefit and risk to platypus over the year.

1. Moderate summer/autumn baseflow (low risk): Platypus need to feed on a daily basis all year. Moderate baseflow supports macroinvertebrate production and provides adequate water depth and connectivity along channel for efficient foraging (adults and juveniles). Stable flows from December to February also support platypus reproduction: the energy needs of lactating females peak from December to early February.

2. Low summer/autumn baseflow (medium risk): Macroinvertebrate productivity is reduced at low baseflow, limiting food resources. Can be tolerated for short periods but extended periods can be detrimental.

3. Extreme low flows (high risk): Increased risk from predation due to increased overland movement or movement through a dry channel or shallow water. Insufficient macroinvertebrate productivity to support reproduction or maintain good adult condition. (See Section 3.1 for specific minimum depth guidelines.)

4. Summer/autumn high flow (high risk): Although small to moderate summer freshes are generally beneficial (**see 5**), flows that result in water depth increasing significantly compared to spring baseflow (e.g. rise greater than 1 m) can inundate breeding burrows, causing young animals to drown (highest risk period is December-early February). Juveniles that are just learning to swim may also drown or be swept downstream in flows of this magnitude (highest risk period is late January-early March). High flows should therefore be avoided if possible in these months (but **see 9**).

It should be noted that more research is needed to confirm the maximum amount of flow that is safe with respect to both breeding burrows and juvenile survival: The boundary value provided here (i.e. >1 m of rise in water level as compared to baseflow is inadvisable) is reasonably well supported by current knowledge about platypus burrows near Melbourne, but may conceivably change when more is known. Little is currently known about how juvenile swimming activity varies with flow velocity, though high juvenile mortality has been convincingly linked to February flood events in the Melbourne area.

5. Occasional summer/autumn freshes (low risk): Freshes may benefit platypus by promoting exploratory behaviour, encouraging individuals to discover new resources and habitats. Freshes also maintain habitat quality by scouring fine sediment from pools and riffles and can contribute to macroinvertebrate productivity. Although foraging efficiency may decrease during higher velocity flows, the net effect of summer/autumn freshes should generally be positive to very positive for this species.

6. Frequent summer/autumn freshes (moderate risk): Foraging efficiency is likely to be reduced during freshes and therefore very frequent fresh events should be avoided.

7. Late autumn high flow (possible low risk): It is logically possible that dispersal of first-year juveniles may be promoted by a rise in flow (particularly from a low baseflow) in late autumn (May). However, appropriate studies have not yet been carried out to determine whether this actually occurs in nature.

8. Winter high flow and overbank flows (medium risk): Floods and overbank flows can be important for waterway productivity (e.g. carbon input). However, very high flows also increase metabolic demand in foraging and can scour macroinvertebrate food sources, damage burrows and even result in direct platypus mortality. Adult platypus can use slower flowing habitats to forage during floods insofar as these are available and are generally expected to survive such events, but no positive benefit is expected to accrue to them in the immediate term.

9. Occasional winter/spring freshes (low risk): The benefits to habitat maintenance of winter/spring freshes are similar to those previously described for summer/autumn freshes (**see 5**).

10. Frequent winter/spring freshes (low risk): As with frequent summer/autumn freshes (**see 6**), the reduction in foraging efficiency during freshes means that frequent freshes represent a moderate risk.

11. Late winter /spring freshes (low risk): A high flow event in late winter or very early spring (August-early September; shortly before a breeding female selects her nesting burrow), may result in her choosing or building a burrow that is located higher on the bank than might otherwise be the case. This in turn may reduce the likelihood that the burrow is later inundated if flow increases markedly thereafter (**see 4**). However, appropriate studies have not yet been carried out to determine whether this actually occurs in the wild.

12. Moderate winter/spring baseflow (low risk): Periods of stable baseflow providing good platypus foraging conditions are important as females attempt to gain weight in preparation for breeding.

13. Low winter/spring baseflow (medium risk): As described in **2**, macroinvertebrate productivity is reduced when baseflow is low, limiting food resources. This is particularly problematic for lactating females, given their high energy requirements. Platypus are expected to survive short periods of reduced baseflow but extended periods will be detrimental.

14. Extreme low winter/spring baseflow (high risk): As described in **3**, extreme low flows are a risk both as a result of increased predation and lower food resources.

15. Spring high flow and overbank flows (high risk): Very high or overbank flows present a very high risk to reproduction, due to inundation of burrows containing eggs and/or nestling juveniles.

5. Part B: Guidelines for platypus-friendly pipes, culverts, weir walls and drop structures

5.1 Background information

Given that platypus spend much of their lives in underground burrows, it is not surprising that they will travel through pipes and culverts. For example, radio-tagged animals were found to move routinely through a 45-metre-long concrete culvert (1.3 m in diameter) conveying creek water through an embankment downstream of a retarding basin (Serena *et al.* 1999) (see photo of tunnel entrance, Figure 5-1 left). Platypus will also enter PVC pipes that are as little as 10 cm in diameter, though animals are apparently unable to back up or turn around in such a confined space and hence may die if the far end is blocked (Taylor *et al.* 1991). Water passing rapidly through a constricted pipe may also discourage longitudinal movement through the pipe, especially in the upstream direction. Animals may then be killed by predators or motor vehicles as they travel across dry land to avoid the barrier (Tyson 1980).

A platypus will generally find it extremely difficult or impossible to climb down (or especially up) vertical or nearly vertical concrete or metal walls (see Figure 5-1 right) particularly if large volumes of water are cascading down (Otley and le Mar 1998). Accordingly, weir walls and drop structures often obstruct platypus movements. As in the case of culverts, platypus can exit the channel and walk around impassable vertical surfaces, but this necessarily exposes them to increased mortality risk.

Figure 5-1 Left: Tunnel downstream of a retarding basin that is routinely traversed by platypus. Right: Platypus find it extremely difficult to traverse vertical drop structures such as the one pictured.

5.2 Recommendations

- Pipes and culverts located along a natural waterway or manmade channel that is known to be frequented by platypus (or that carry water from such a waterway to an off-stream storage) should have a minimum internal diameter of 0.3 m to ensure they can be negotiated safely.
- If a pipe or culvert is very long (>30 m) and often likely to be filled to capacity with water, consideration should be given to incorporating one or more vertical breathing bays along its length. (An example of such a breathing bay has been incorporated into the in-flow pipe at the Hull Road flood retention wetlands along Olinda Creek (see Figure 5-2, showing the breathing bay as viewed from above.)

Figure 5-2 Breathing bay on in-flow pipe at Hull Road flood retention wetlands.

- To enable a platypus to safely negotiate grilles or mesh barriers, these structures should be designed with grid spacings or apertures of >0.12 m, as shown in Figure 5-3. Conversely, barriers meant to exclude a platypus (e.g. exclusion caps or covers for pipes or pump diversion structures) should be constructed of solid materials or have grid spacings or apertures <0.03 m in diameter, based on the finding that a platypus weighing up to 1 kg (i.e. a large proportion of adults and subadults) can pass with relative ease through a rigid grid measuring 0.055 x 0.055 m, with small juveniles presumably capable of passing through even narrower gaps (Grant *et al.* 2004b).

Figure 5-3 Grilles or mesh barriers that are meant to be accessible to a platypus should be designed with grid spacings or apertures greater than 0.12 m. However, the vertical design of this drop structure (with a face measuring about 60 cm in height) means that it is at best only marginally navigable by a platypus, and then only in the downstream direction.

- To avoid forcing a platypus to leave the channel, culvert designs that frequently constrict stream flow and may therefore trigger platypus avoidance behaviour (due to increased water velocity) should not be adopted. The lip of pipes and culverts conveying water along a water course should also not substantially protrude from or overhang their surrounding substrate. Outfall height (but not culvert length, diameter or slope) has been reported to be a strong determinant of platypus usage of culverts in Tasmania (Mooney and Spencer 2000).
- Concrete drop structures associated with culverts should incorporate stepped or slanted (<40^{o}) faces to allow platypus to scramble up and down safely.
- Concrete channels should have sloping sides, or incorporate stepped or slanted sections at minimum intervals of 0.1 km, to enable a platypus (or other wildlife) to climb out after inadvertently becoming confined within (see Figure 5-4 showing a steep-sided channel that provides no opportunity for a platypus to climb out). The greatest risk to a platypus is likely to occur if an open channel gives rise to a long piped section; several animals are known to have drowned in the Upper Canal of the Nepean section of Sydney's water supply when they were unable to exit the channel before a long piped section commenced (T. Grant, unpub. data).

Figure 5-4 Steep sided channels provide limited opportunity for a platypus to escape the channel.

- Where litter racks occur in channels they must be regularly cleared to prevent a platypus from becoming entangled in accumulated rubbish and potentially drowning. At least one instance of this has occurred in the Upper Canal of Sydney's water supply (T. Grant, unpub. data).
- Fish ladders that also accommodate the needs of platypus should be constructed whenever possible to provide a relatively safe route for both groups to negotiate substantial dam and weir walls (for example, Figure 5-5 shows a fish ladder in the foreground that would facilitate platypus passage around a steep weir structure). In contrast, vertical-slot-type fish ladders are generally not suitable for platypus use.

Figure 5-5 Weir structure with a fish ladder that could readily be used by a platypus (foreground).

- If a weir cannot realistically be fitted with a fish ladder, consider whether it might instead be possible to create a ramp of large rocks or the equivalent to make it easier for wildlife (including the platypus) to negotiate the wall without having to leave the water (see Figure 5-6). If this is not feasible, at the very least protective cover (in the form of dense and ideally prickly shrubs) should be encouraged to grow at the points where a platypus is most likely to travel across land to move around the barrier.

Figure 5-6 Large rocks leading up to the weir structure can allow a platypus to pass over the structure without leaving the water.

6. Part B: Guidelines for identifying and managing platypus drought refuges

6.1 General considerations

A platypus needs to consume large amounts of food (in the form of benthic macroinvertebrates) on a daily basis throughout the year and will starve if surface water disappears. Mortality due to predation will also increase as water levels drop, particularly if animals have to travel across dry land to access foraging areas. To enable platypus populations to survive extended dry periods in places where flow is intermittent, it is imperative that large permanent pools are available to provide refuge habitats when surface water is otherwise in short supply.

Apart from their role in supporting platypus populations during drought, large pools and backwaters constitute valuable platypus foraging areas in average-to-wet years: up to six animals were recorded feeding concurrently at Toorourrong Reservoir in 2000 (Easton *et al.* 2008), with up to seven individuals seen to be active on Lake Elizabeth in a given two-hour period in the late 1990s (De-La-Warr and Serena 1999). Similarly, sizable pools and backwaters are expected to serve as important areas for successful reproduction by adult females, particularly (though by no means exclusively) in relatively dry years.

In broad terms, the minimum essential attributes of an on-stream platypus drought refuge are as follows:

- It must hold adequate surface water reliably throughout dry periods.
- It must support a productive population of benthic macroinvertebrates.
- It must provide appropriate bank habitat for burrows.

In the case of an off-stream drought refuge, there is an additional requirement that it needs to be linked by surface water for at least part of the year to a nearby natural water body supporting platypus, so that animals can detect the refuge's existence in the first place.

6.2 Identifying high priority locations for drought refuges

Although it is beyond the scope of this document to recommend specific sites where platypus drought refuges could or should be developed in the Melbourne Water region, Figure 6-1 illustrates some examples of on-stream and off-stream dams that reliably attract high levels of usage by platypus (with two or more animals sometimes concurrently active) throughout the year. In addition, the following conceptual guidelines should help to inform future decision-making and planning.

Key pieces of information that are needed to assist identification of high priority platypus drought refuge sites are as follows:

- The current distribution and status of platypus populations in the greater Melbourne region
- A list of creeks and rivers in the greater Melbourne region in which surface flow is expected to be reduced severely in unusually dry years (as projected for the next 50 years), along with a case-by-case assessment (for those creeks and rivers currently supporting platypus populations) of the predicted frequency and severity of drought impacts on flow
- An analysis of the relative cost-effectiveness of different general approaches to developing a network of platypus drought refuges (and the projected scope for their implementation in the greater Melbourne region)
- The core attributes of a platypus drought refuge (see below)

In general terms, the most cost-effective options for developing a network of platypus drought refuges are likely to be as follows:

- Improve connectivity of existing permanent billabongs or backwaters to adjoining natural water courses in cases where this is likely to assist platypus access.

- Retain existing small on-stream weir structures, particularly in cases where these do not pose a significant barrier to fish movements (or can be modified at relatively low cost so that a reasonable degree of connectivity for fish is restored).
- Identify natural depressions or basins located on public land near creeks or rivers (i.e. sites that are likely to have functioned as natural billabongs or backwaters in the past) that could be rehabilitated at relatively low cost to function as drought refuges.
- Ensure that new man-made water bodies developed near creeks and rivers to retain stormwater or as primarily ornamental features in golf courses, etc. are designed with a view to being accessible to and providing additional permanent habitat for platypus and other wildlife.

Figure 6-1 Examples of platypus drought refuges. Top Left: On-stream storage, Belgrave Lake. Top Right: On-stream storage, Emerald Golf Club Lake. Middle Left: On-stream dam, Bakers Gully (near Bright). Middle Right: Private off-stream dam, Hoddles Creek. Bottom Left: Off-stream pond, Tidbinbilla Reserve. Bottom Right: Off-stream storage, Tidbinbilla Reserve, Black Flats Dam.

6.3 Surface area and optimum depth profile

All things being equal, large platypus drought refuges will function better than small refuges to provide adequate food resources for (potentially) up to several individuals at a time. To reliably maintain a few animals in fairly good condition for several months in the absence of any other surface moisture, the best available estimate for the minimum amount of required area is probably the size of a daily individual foraging area as used by animals occupying overlapping home ranges in reasonably high quality habitats near Melbourne, i.e. in the order of 0.4 hectare (see Section 2.2.2). Having said that, much smaller drought refuges may serve very well to support several animals for shorter periods of time and, even in the case of protracted drought events, may make it possible for some animals to survive (albeit in poor condition) when they otherwise would have had no prospects for survival. This is particularly likely to be the case if two or more relatively small drought refuges are located near to one another, effectively creating a larger refuge area in aggregate. It should also be kept in mind that small drought refuges are expected to contribute to post-drought platypus population recovery by promoting successful reproduction and thereby generating new recruits to reoccupy vacant habitats.

A platypus prefers to forage at a depth of around 1-4 m, and will rarely be found feeding in water that is >6 m deep. Accordingly, most of the area contained within a platypus drought refuge should ideally retain water at a depth of approximately 1-5 m. A relatively deep depth profile will also be advantageous in restricting the degree of encroachment by vigorous emergent littoral plants (e.g. rushes and sedges, including *Typha* and *Phragmites*); although a platypus can forage to a limited extent in habitats dominated by such species, it is primarily adapted to find food by diving in open water.

6.4 Foraging habitat quality

As previously described in Section 2.1.2, a platypus prefers to forage in habitats characterised by coarse inorganic substrates (e.g. gravel, cobbles, rocks) and substantial amounts of coarse particulate organic matter (e.g. leaf packs) and large woody habitat (logs and large branches) in the water. The occurrence of native trees and dense overhanging vegetation on the banks are also known to be positive habitat features. Conversely, the animals tend to avoid feeding in habitats where silt or willow roots dominate the channel bed, and platypus population density near Melbourne declines as nutrient enrichment of stream water increases. Accordingly, we recommend that platypus drought refuges should be selected (and, if necessary, modified and improved) in line with the following criteria:

- All livestock living in the vicinity must be permanently excluded from a vegetated buffer zone around the entire refuge perimeter by means of secure fencing. Alternate stock watering points may need to be established.
- The buffer zone should ideally be wide enough to support a self-sustaining plant community that includes understorey plants (ground covers and shrubs) as well as mature trees to shade the water and provide inputs of leaves and other organic matter as feeding substrates for macroinvertebrates. Appropriate indigenous species should be planted if not already present.
- If willows are present, particularly at the immediate edge of the water, they should be removed and replaced with fast-growing native trees and shrubs. These activities should be carried out with care (and, if necessary, scheduled in a progressive manner over time) to ensure that adequate vegetation cover is restored as quickly as possible and banks are not subject to erosion.
- Consideration should be given to adding fallen logs and sizable branches to the aquatic habitat, if a substantial amount of large woody debris is not already present.
- Although submerged aquatic plants are generally predicted to make a positive contribution to platypus habitat quality (insofar as they help to support a diverse and productive macro-invertebrate community), the platypus's ability to swim and dive freely may be compromised by densely growing emergent aquatic species such as water ribbons (*Triglochin procerum*) (APC, pers. obs.). Accordingly, control measures may be required to reduce or (particularly in the case of non-indigenous species such as water lilies, *Nymphaea* spp.) eliminate thickly distributed emergent plants from designated platypus drought refuges. By the same token, although the presence of some fringing littoral vegetation (e.g. rushes and sedges) is expected to benefit platypus by providing cover from predators and supporting macroinvertebrates, excessive growth of large reeds in the water will interfere with a platypus's ability to swim and dive and thereby reduce foraging success.

6.5 Burrow requirements

To provide habitat for platypus burrows, a proportion of the perimeter of an on-stream or off-stream drought refuge should rise more or less steeply from the water and attain a minimum bank height of at least 1-2 m. The bank profile where the bank meets the water surface should be vertical or concave (not slumping or convex), and the adjoining water should be deep enough that the bed is unlikely to become exposed even if drought conditions persist for some time. Although a platypus camping burrow requires just a few horizontal metres of suitably steep and high banks, a larger area of bank habitat will be advantageous in allowing enough space for multiple burrows that could potentially accommodate up to several animals. To provide cover around burrow entrances, dense vegetation overhanging the water should be encouraged to grow. Given that plant cover often becomes sparse during drought, consideration should also be given to placing one or more logs against the bank edge if natural stumps, trees or large rocks aren't already present. Figure 6-2 illustrates how a relatively low bank in a previously cleared area can provide suitable habitat for platypus burrows: note presence of rocks and young trees along the creek margin, along with dense, low-growing vegetation.

Figure 6-2 An example of a relatively low bank that provides suitable habitat for platypus burrows.

6.6 Connectivity to off-stream refuges

Platypus are most likely to use an off-stream pond or lake that is located fairly close to a natural stream or river (generally within about 100 m, and ideally within about 20 m). To encourage animals to discover an off-stream water body and subsequently make use of it, it must be directly linked to the neighbouring natural channel for at least several months of the year (ideally throughout the year) by water contained in an earthen channel or pipe measuring $\geq$0.3 m in diameter (see Section 5.2). Where two or more off-stream ponds are located reasonably near to one another, these could also be interconnected in this fashion. If the linking structure consists of an earthen channel, water in the channel should ideally be $\geq$0.2 m deep to facilitate swimming and reduce predation risk. Once they are in the habit of feeding in an off-stream storage, animals will certainly travel along a linking channel that contains less water (and even one that has dried out entirely) but this increases their vulnerability to predators (see below).

6.7 Limiting predation risk

To reduce predation risk, it is recommended that a dense, continuous band of low-growing shrubby cover should be actively encouraged to grow in the following places:

- Along the length (on both banks) of channels linking off-stream drought refuges to natural water bodies or each other
- At any other places near a on-stream or off-stream drought refuge where a platypus is likely to move frequently across land to access other foraging areas
- Around at least half (and ideally more) of the perimeter of both on-stream and off-stream drought refuges, particularly in places where the bank is relatively low and flat and little or no littoral vegetation is present

Because foxes often utilise man-made paths, pedestrian tracks and boardwalks should ideally be placed at least 8-10 m (and ideally more) from the edge of both on-stream and off-stream drought refuges, particularly if intervening shrubby plant cover is patchy or sparse. By the same token, viewing platforms or seating areas placed to capture an unobstructed view over a drought refuge should be located only at sites where the adjoining banks are relatively steep and the water is reliably >1 metre deep, and ideally should be shielded from direct view as seen from the water body (i.e. essentially a 'hide').

6.8 Limiting threats from human activities

In areas where human visitation is likely to be high, consideration should be given to erecting signage near designated platypus drought refuges to highlight the species' vulnerability to being injured or killed by uncontrolled dogs, litter and inappropriate fishing activities.

Appropriate steps should also be taken to ensure that pumps operated in platypus drought refuges (including in average-to-wet years) are routinely fitted with appropriate screens around intake points to exclude platypus and other wildlife. More broadly, given that pumps drawing from creeks and rivers are typically placed in the deepest and most permanent holes available to landowners, it is recommended that a general policy of strongly encouraging pump users to install devices to exclude wildlife reliably from pump entry points should be implemented throughout the greater Melbourne region.

7. Part B: Assessment of movement barriers

7.1 Background information

Habitat fragmentation is recognised as a key threatening process to the viability of wildlife populations globally. The main impacts of habitat fragmentation are a reduction in overall habitat availability and disruption of migration/dispersal patterns, resulting in disjunct populations. Small, isolated populations have an increased risk of extinction due to loss of genetic diversity through drift and inbreeding (Frankham 2005). Small populations are also more likely to disappear following random catastrophic events (e.g. floods, bushfires) or due to random variation in local survival and reproduction that might (for example) result in an unbalanced sex ratio consisting exclusively of males or females. Understanding the level of fragmentation and connectivity between populations is critical for effective management and conservation of wildlife populations.

Platypus are dependent on aquatic ecosystems with movements and dispersal primarily occurring along waterways. Although platypus are known to undertake terrestrial dispersal (Burrell 1974; Kolomyjec *et al.* 2009), this avenue is likely to be less successful in recent times due to introduced predators and modified environments around waterways. Waterway connectivity is therefore fundamentally linked to population connectivity, habitat availability, and population size. Platypus populations around Melbourne in particular appear to be constrained by catchment boundaries, as indicated by recent genetic analyses indicating that six distinct population units are broadly organised on a catchment basis (Weeks 2014).

The earliest discussion of adverse impacts of habitat fragmentation on platypus population persistence near Melbourne dates from the late 1990s, following the capture of an apparently very old male platypus on two occasions in upper Ferny Creek (Williams *et al*. 1997). No other individuals were captured in these (or later) surveys, prompting speculation that a small number of platypus had been isolated as a small remnant population in upper Ferny Creek following the completion of intervening flood control works in the 1970s that diverted Ferny Creek through a concrete-lined underground tunnel, roughly 2 km in length. Given the very limited amount of suitable habitat found upstream of the tunnel, the number of animals stranded there would undoubtedly have been very low. The population presumably dwindled over time as animals died and were not regularly replaced, until the old male recorded in late 1996 and early 1997 was the sole survivor. Subsequent surveys in this area failed to capture the male, suggesting that he had probably died (Serena and Williams 2008).

Although innumerable scientific papers have addressed the genetic implications of habitat fragmentation for population persistence, relatively little factual information is available for platypus. A genetic analysis of the small platypus population found on King Island in Bass Strait (which has been isolated from populations on the Australian mainland and Tasmania for at least 10,000 years) found that levels of genetic diversity were among the lowest ever recorded in a natural vertebrate population, suggesting that the population would struggle to adapt if confronted with a new disease or major environmental change. However, no signs of physical abnormalities or poor physical condition were recorded (Furlan *et al*. 2012), and platypus are believed to be widespread and abundant in all reliably flowing streams and rivers on the island (Ondrea Richards, pers. comm.). Similarly, Furlan *et al*. (2012) reported that an introduced platypus population on Kangaroo Island, descended from 16 founders released in the 1940s, seemed to be saturating its available habitat despite the fact that effective population size (N_e, a measure of the number of individuals making an effective genetic contribution to the next generation) was estimated to comprise just 10-11 animals. The physical features and condition of Kangaroo Island platypus are again entirely normal, and local population densities appear to be similar to (or slightly higher than) those reported for streams of the same size on the Victorian mainland (Serena and Williams 1997).

With respect to the demographic issues facing isolated small platypus populations, Serena and Williams (1999) carried out minimum viable population modelling (using Vortex software) to address the following question: how large must a spatially isolated platypus population be to survive for a reasonably long period of time (deemed to be 100 years for the purpose of the exercise). The authors concluded that in the order of 30-40 resident animals were required to ensure a better than even chance of surviving for 100 years when faced with moderate levels of environmental variability. Interestingly, of six isolated platypus populations near Melbourne that Serena and Williams (2008) subsequently identified as probably including too few members to be self-sustaining over the long term, at least one population (occupying upper Dandenong and Dobsons Creeks) is now believed to be extinct (Kelly *et al*. 2013).

Platypus are particularly vulnerable to becoming fragmented in urban areas due to the high level of modification of waterways and the surrounding catchments. Connectivity (dispersal, and therefore gene flow) between populations within catchments may be partially or completely inhibited by lack of reliable surface water or poor habitat quality that decreases longitudinal connectivity along waterways, or physical barriers such as dams and weirs. The viability of isolated populations is related to population size, which in turn is limited by the available area of suitable habitat and its quality.

Here, we discuss potential barriers to dispersal that contribute to fragmentation of platypus populations in Melbourne Water's management area (Figure 7-1). These barriers have been identified by the presence of physical structures (i.e. dams, weirs, culverts) or discontinuity in the species' distribution indicating unsuitable habitat, as well as expert knowledge of the species' ecology and behaviour. Little is known about the platypus's capacity to navigate such barriers successfully. Although platypus will leave the water to navigate substantial barriers, they are vulnerable to predation while out of the water and the success rate of terrestrial movement is assumed to be lower than aquatic movement. Nevertheless, the barriers described herein are predicted to at least partially inhibit dispersal and isolate populations, therefore increasing their extinction risk.

Threats to platypus are expected to increase in future due to increasing human population growth and climate change. Therefore, it is critical that we encourage resilience in populations to better withstand environmental disturbances.

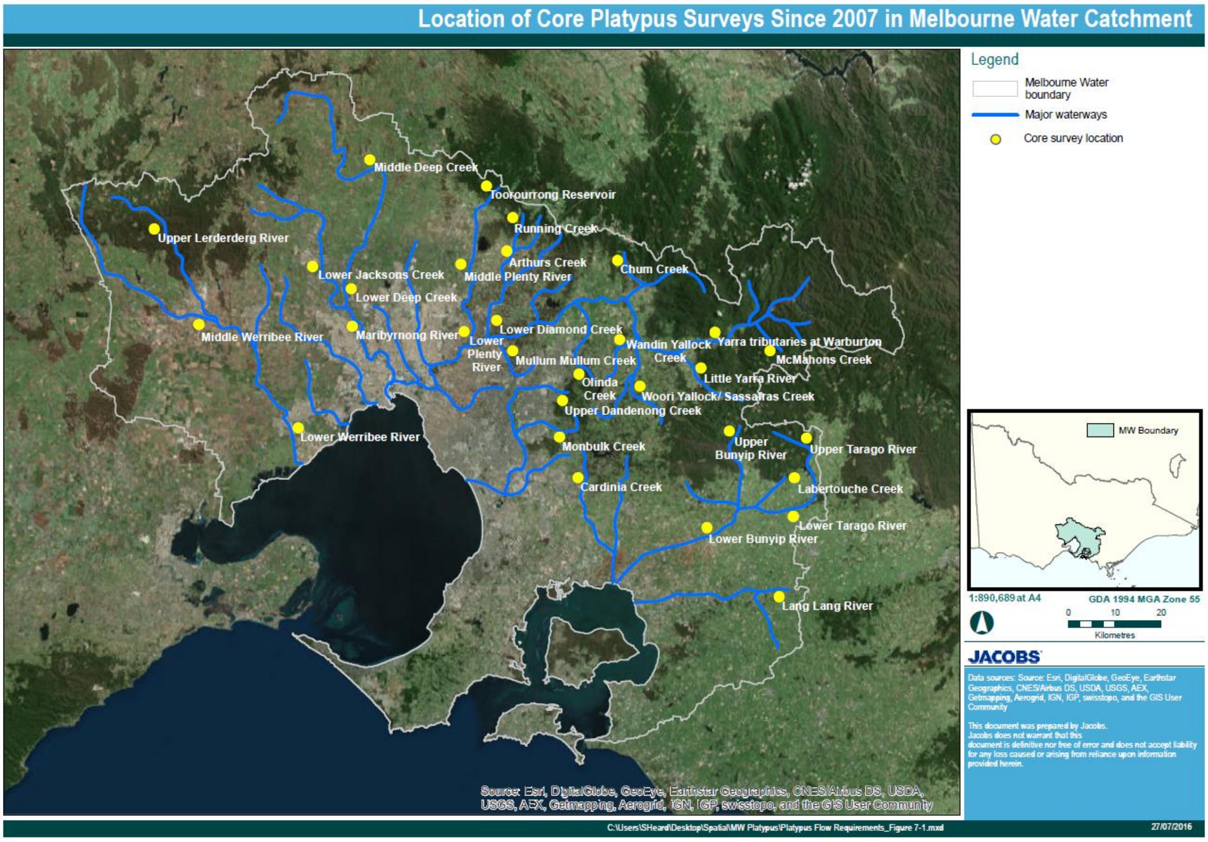

Figure 7-1 Overview of the major waterways in Melbourne's catchments.

7.2 Identification of barriers

7.2.1 Werribee Catchment

Platypus in the Werribee Catchment are considered to be vulnerable to extinction due to low abundance and high fragmentation. A number of weirs along the Werribee River (Figure 7-2) present physical barriers to platypus dispersal and gene flow. The surrounding catchment is highly modified for agriculture and urbanisation and has resulted in poor habitat quality due to clearing of riparian vegetation and altered flow regimes. Mortality due to entanglement in litter is also likely to be exceptionally high, e.g. items of litter had to be removed from 38% of animals captured in surveys carried out from 1997-2000 (Serena and Williams 2008).

A small population is known to reside in the lower Werribee River from the diversion weir to just downstream of Princes Highway. The results of live-trapping session conducted since 1997 indicate a significant decline in abundance during the Millennium Drought with no evidence of recovery in recent years (Griffiths *et al.* 2015). Genetic analyses indicate this population has a very small effective population size and shows signs of inbreeding (Weeks 2014). Community sightings and preliminary eDNA results indicate that platypus also occur upstream of the diversion weir to Melton Reservoir and in the middle reaches of the Werribee River through Werribee Gorge to Ballan (Figure 7-2). There are currently no estimates of abundance for these two populations but they are thought to be low. It is unknown whether population exchange occurs across the diversion weir, though this seems likely given its relatively modest dimensions. Adequate connectivity between populations in the lower and middle reaches is predicted to be much more problematic, due to poor intervening habitat and the large size of the Melton Reservoir weir and its wall. Nets set at Bacchus Marsh from 2008-2013 only captured two platypus (Kelly *et al.* 2013), although several local residents have reported seeing platypus on a fairly regular basis in or near Bacchus Marsh up until the mid-2000s (APC, unpub. data).

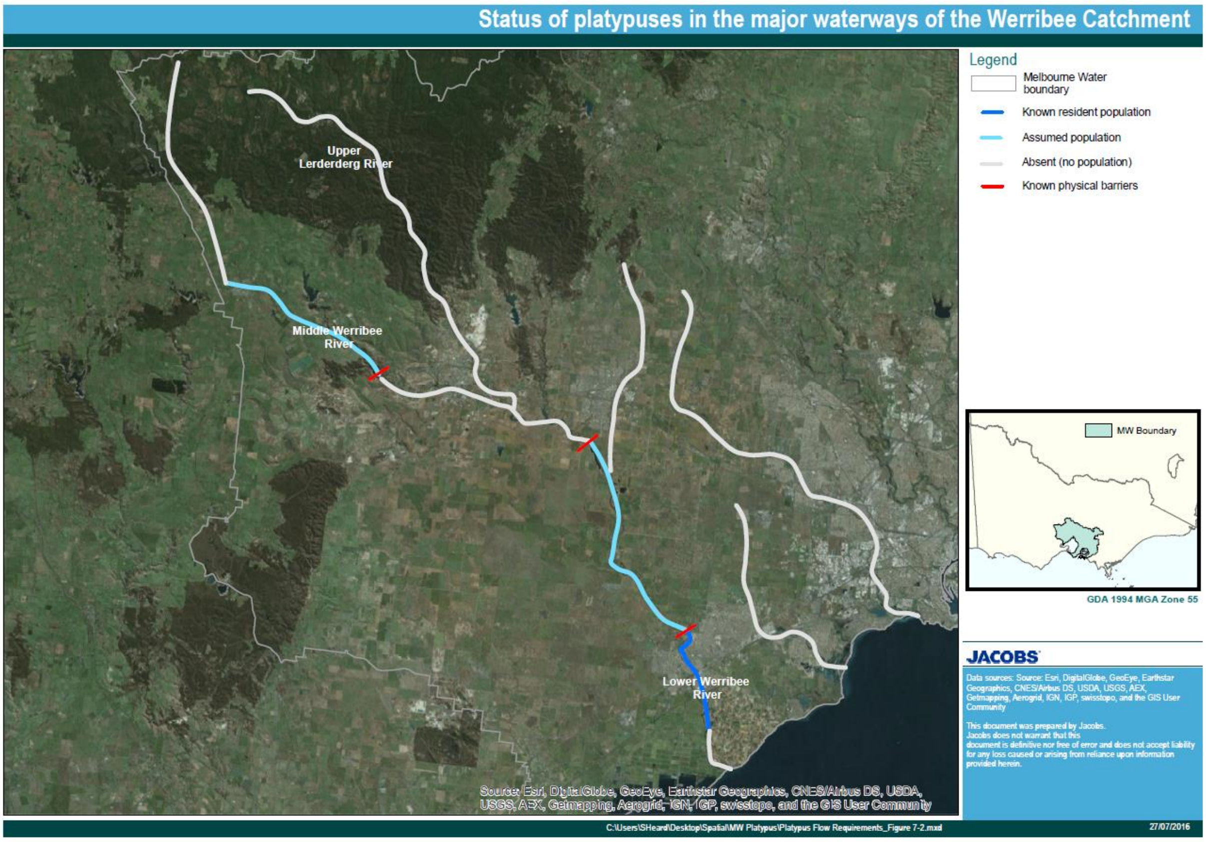

Figure 7-2 Status of platypus in the major waterways of the Werribee Catchment: known resident population (blue), assumed presence (light blue), absence (grey). Known physical barriers indicated in red.

7.2.2 Maribyrnong Catchment

There are no apparent barriers to platypus migration present within the Maribyrnong Catchment. Historically, platypus would presumably have dispersed between the lower Maribyrnong and lower Yarra Rivers, connecting populations in these two catchments. Although these rivers are still physically connected, poor habitat quality from urbanisation has undoubtedly greatly reduced the potential for successful dispersal to occur.

Platypus are currently known to inhabit Jacksons Creek, lower Deep Creek, and the upper Maribyrnong River (Figure 7-3). However, platypus distribution has contracted over the last 15 years and the species is now believed to be largely absent from the middle and upper reaches of Deep Creek (Griffiths *et al.* 2014b), although small numbers of animals may still persist in the vicinity of drought refuges. The main factors behind this decline seem to be a lack of longitudinal connectivity due to poor flow, including extended cease-to-flow events throughout summer and autumn, and poor habitat quality from extensive clearing of riparian vegetation.

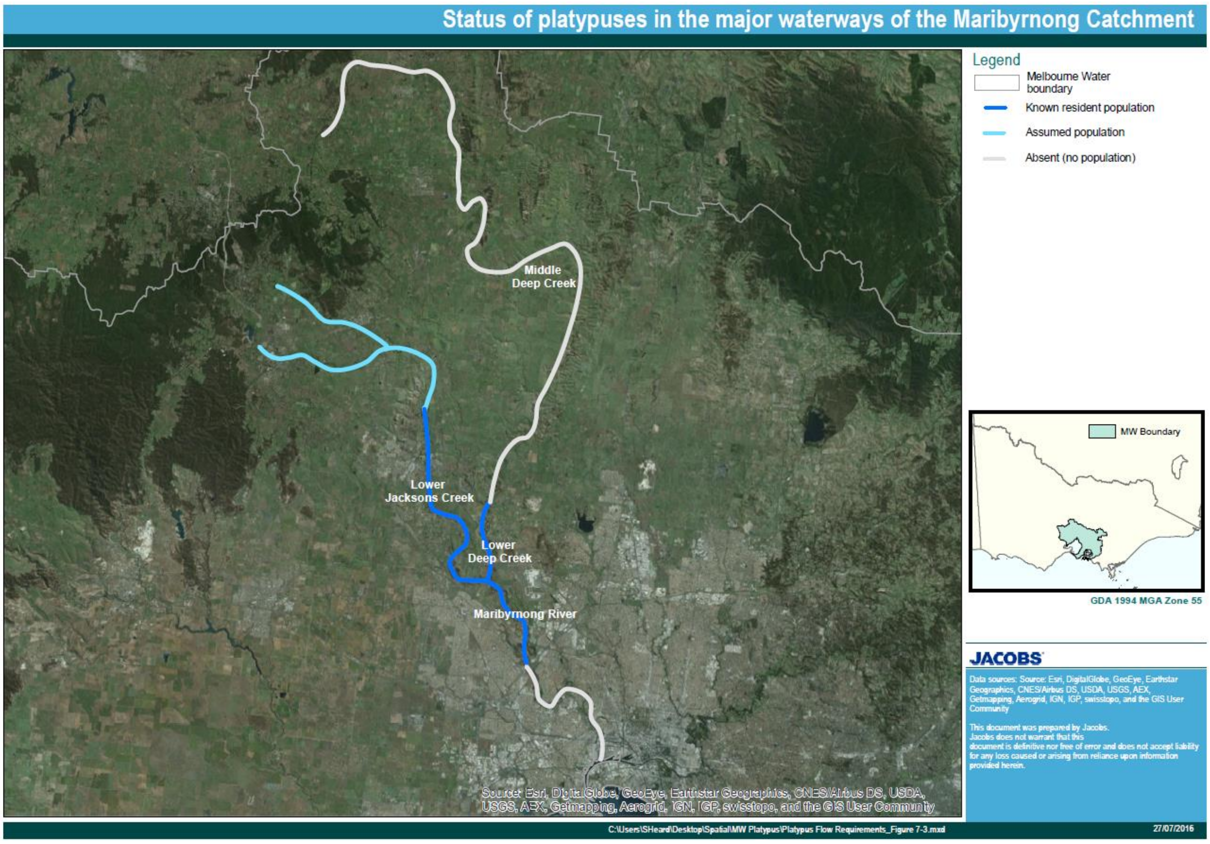

Figure 7-3 Status of platypus in the major waterways of the Maribyrnong Catchment: known resident population (blue), assumed presence (light blue), absence (grey). Known physical barriers indicated in red.

7.2.3 Dandenong Catchment

The only known population of platypus in the Dandenong Catchment occupies upper Monbulk Creek and (probably) neighbouring parts of its main tributary, Clematis Creek. The population extends from Dandenong Ranges National Park to just downstream of Birdsland Reserve (Figure 7-4). Platypus have not been recorded in the lower reaches of Monbulk Creek or in Corhanwarrabul Creek for a number of years, suggesting that habitat quality is poor. Within Monbulk Creek, platypus are known to navigate potential obstacles posed by the Monbulk Retarding Basin outflow tunnel (Serena *et al*. 1999) and (based on mark-recapture records) the Belgrave Lake weir wall. A small population was present in upper Dandenong and Dobsons Creeks upstream of the Liverpool Retarding Basin until relatively recently but is now presumed extinct (Kelly *et al.* 2013). No platypus have been recorded in the remainder of the Dandenong Creek system, apart from one adult male captured in the upper reaches of Ferny Creek in 1996 and 1997 (Williams *et al*. 1997).

The population occupying Monbulk Creek was estimated to comprise just 12 core residents (8 males, 4 females) in 2006/2007 (Serena *et al*. 2014), and is appropriately viewed as being highly vulnerable to extinction. Genetic analyses have revealed a very small effective population size and evidence of inbreeding (Weeks 2014). As the only population remaining in the Dandenong Catchment, special consideration should be given to protect this population and to improve adjoining habitats to facilitate population growth and expansion. In the longer term, translocations may be required to improve the genetic diversity and viability of the population (Weeks *et al.* 2011), although its long-term prospects for survival need to be weighed up carefully, given that no more than 8 km of stream channel are currently available to provide habitat for breeding females along Monbulk Creek, with perhaps an additional 2 km of channel available along Clematis Creek.

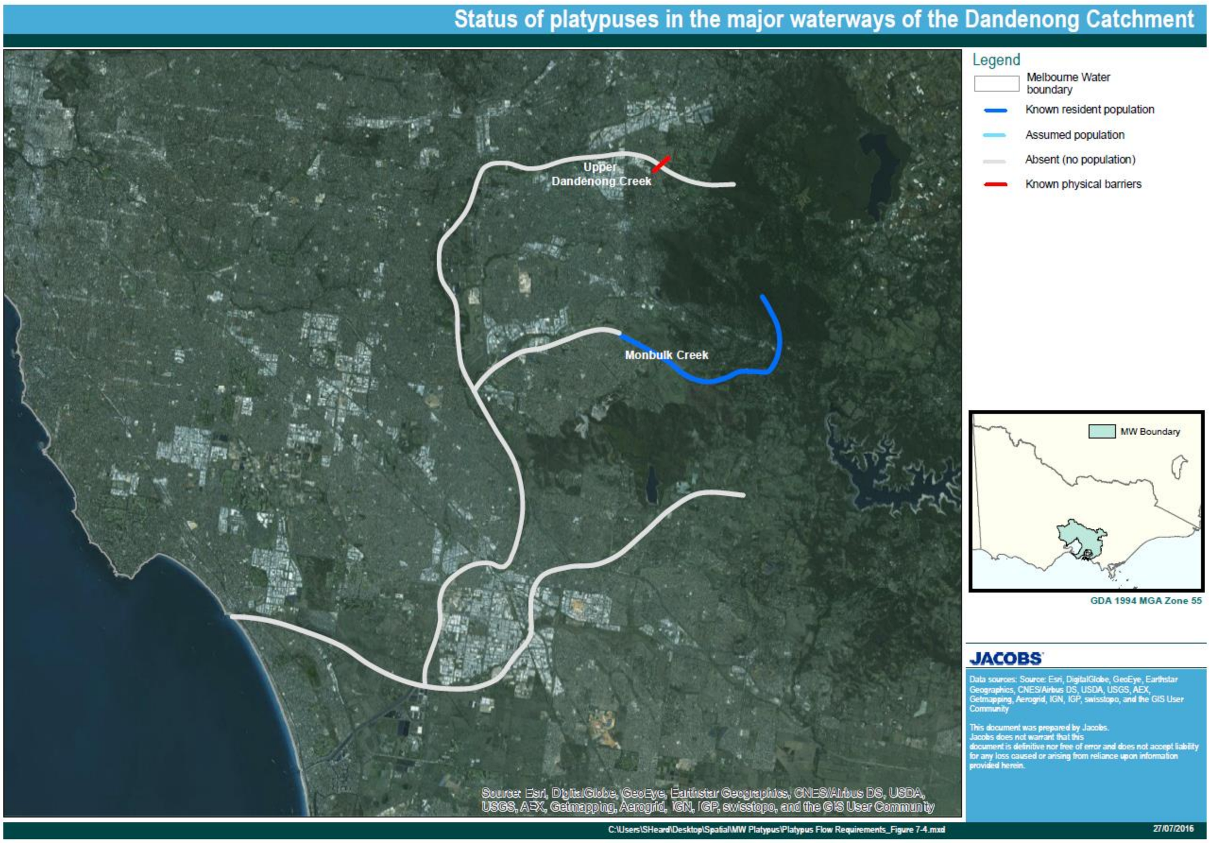

Figure 7-4 Status of platypus in the major waterways of the Dandenong Catchment: known resident population (blue), assumed presence (light blue), absence (grey). Known physical barriers indicated in red.

7.2.4 Yarra Catchment

The Yarra Catchment contains the most extensive interconnected network of waterways in the Melbourne region, including some areas of good habitat. Not surprisingly, it also has the largest and healthiest population (Weeks 2014) with platypus known to occur along the middle and upper Yarra River and associated tributaries as far downstream as Heidelberg (Figure 7-5). Despite this, substantial reductions in netting success were recorded in many parts of the catchment during the Millennium Drought (Griffiths and Weeks 2011). Platypus no longer reside in the lower Yarra River and its tributaries (Moonee Ponds Creek, Merri Creek, Darebin Creek, Gardiners Creek) due to poor habitat quality from extensive urbanisation. This has disrupted any historical connection with populations in the Maribyrnong Catchment. Platypus have also disappeared from Running and Arthurs Creeks in the upper reaches of the Diamond Creek sub-catchment due to poor habitat quality and unreliable flows (Kelly *et al.* 2013). It is expected that platypus will naturally recolonise these waterways from adjacent areas if these problems can be addressed.

Viable populations may also no longer exist in the Plenty River. Low numbers of platypus are still recorded in the lower reaches but trapping data suggest that these are transient individuals originating in the Yarra River. A small population in Plenty Gorge seems to have declined significantly and is probably no longer viable. Poor habitat quality downstream (due to urbanisation) and upstream (associated with agricultural and, more recently, urban development) has effectively isolated this population and degraded the Gorge habitat itself through altered flow regimes and poor water quality. Platypus have declined dramatically in Toorourrong Reservoir and its associated streams in the upper Plenty River catchment, initially due to cumulative impacts of a major flood in 2005 and the very dry summers of 2002/03 and 2006/07; subsequent potential for population recovery was severely constrained by the low number of breeding age females (possibly as few as two) that survived these events (Serena and Williams 2008). However, platypus have been seen by Melbourne Water staff within the last year in and near Wallaby Weir (N. Pratt, pers.comm.), which is linked via a rock-lined channel (known to be navigable to platypus) to a natural stream flowing into Toorourrong Reservoir. The area still contains good habitat but is isolated from the rest of the catchment by the Toorourrong weir wall and, more importantly, many kilometres of unsuitable intervening habitat. A reintroduction program may be an effective way to re-establish platypus in this area, although long-term prospects for survival need to be weighed up carefully, with due consideration given to the impact of future major droughts and any need for future management activities that will entail draining the reservoir.

A number of large weirs exist in the upper Yarra region (e.g. Upper Yarra Reservoir, O'Shannassy Reservoir, McMahons Reservoir, Maroondah Reservoir, Lillydale Lake) where platypus are known to occur. Platypus populations upstream of the weirs are likely to be at least partially isolated from the rest of the catchment although little information on the state of these populations is available. The exception is upper Olinda Creek where extensive studies indicate the population is vulnerable due its isolation (largely caused by the Lillydale Lake weir wall) and small population size (Furlan *et al.* 2013; Griffiths *et al.* 2015; Weeks 2014), although this vulnerability is mitigated to some extent by the population's demonstrated resilience during drought (Serena *et al*. 2014). Therefore removal or modification of the weir wall (i.e. by installing a fish ladder or rocky cascade) will improve the long term viability of the upstream population.

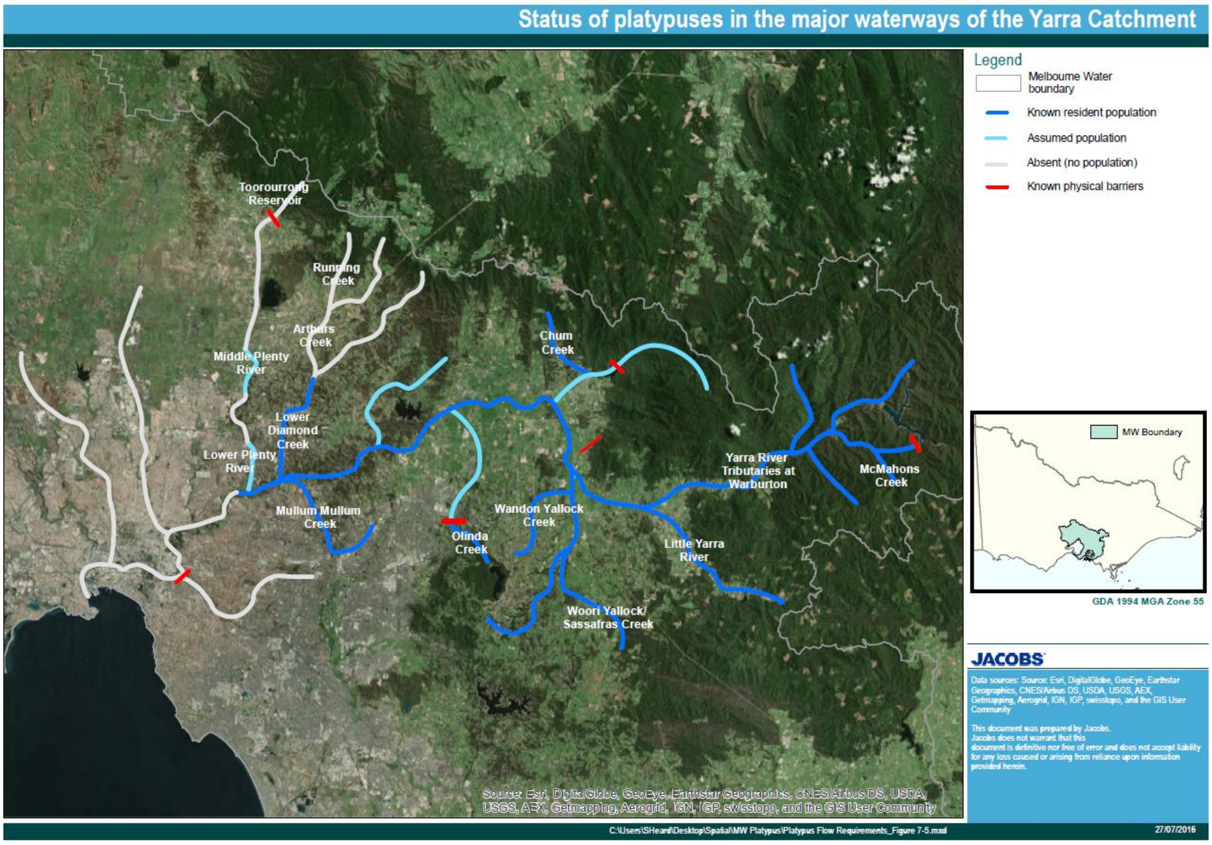

Figure 7-5 Status of platypus in the major waterways of the Yarra Catchment: known resident population (blue), assumed presence (light blue), absence (grey). Known physical barriers indicated in red.

7.2.5 Westernport Catchment

The Westernport Catchment is naturally divided into several unconnected sub-catchments (Cardinia, Bunyip, Lang Lang, Bass). Draining and channelisation of the lower catchment has exacerbated the isolation of these sub-catchments. There is little scope for connecting these systems but improving connectivity and habitat quality within each system will aid long term viability of platypus populations.

Although platypus have been recorded along the length of the Lang Lang River, the population is likely to be relatively small due to poor habitat quality and seasonally dry conditions in the upper reaches. Based on landowner interviews, platypus were quite widely distributed in the Bass River system in the 1980s but declined thereafter, with the most recent reliable sightings occurring in 2003; it is likely that this population is now extinct (Serena and Williams 2008).

Cardinia Creek is a small, self-contained system where platypus were reintroduced in 2004 after apparently being extirpated following the 1983 'Ash Wednesday' bushfires (Serena and Williams 2004). Poor habitat quality in the lower reaches currently restricts platypus to the upper reaches (Figure 7-6) and limits population size. Due to its limited founder size, small population size and isolation, the Cardinia Creek population is susceptible to loss of genetic diversity and should be considered vulnerable. Work is required to improve habitat quality in the lower reaches to facilitate population growth, though the effectiveness of such activities may be constrained by impacts of urban runoff. In the longer term, translocations may be required to improve genetic diversity as natural migration from the nearest sizable population (in the Bunyip system) is likely to occur infrequently at best via approximately 2-3 km of coastal waters in Westernport.

The most extensive platypus population occupies the Bunyip system. Despite the surrounding catchment being highly modified for agricultural use, platypus still occur throughout the Bunyip and Tarago Rivers and associated tributaries holding reliable water. The Tarago Reservoir presumably poses a barrier between platypus of the upper Tarago River and the rest of the system. There is insufficient data to determine the current status of platypus in the upper Tarago but its long term viability may be compromised by its relative isolation.

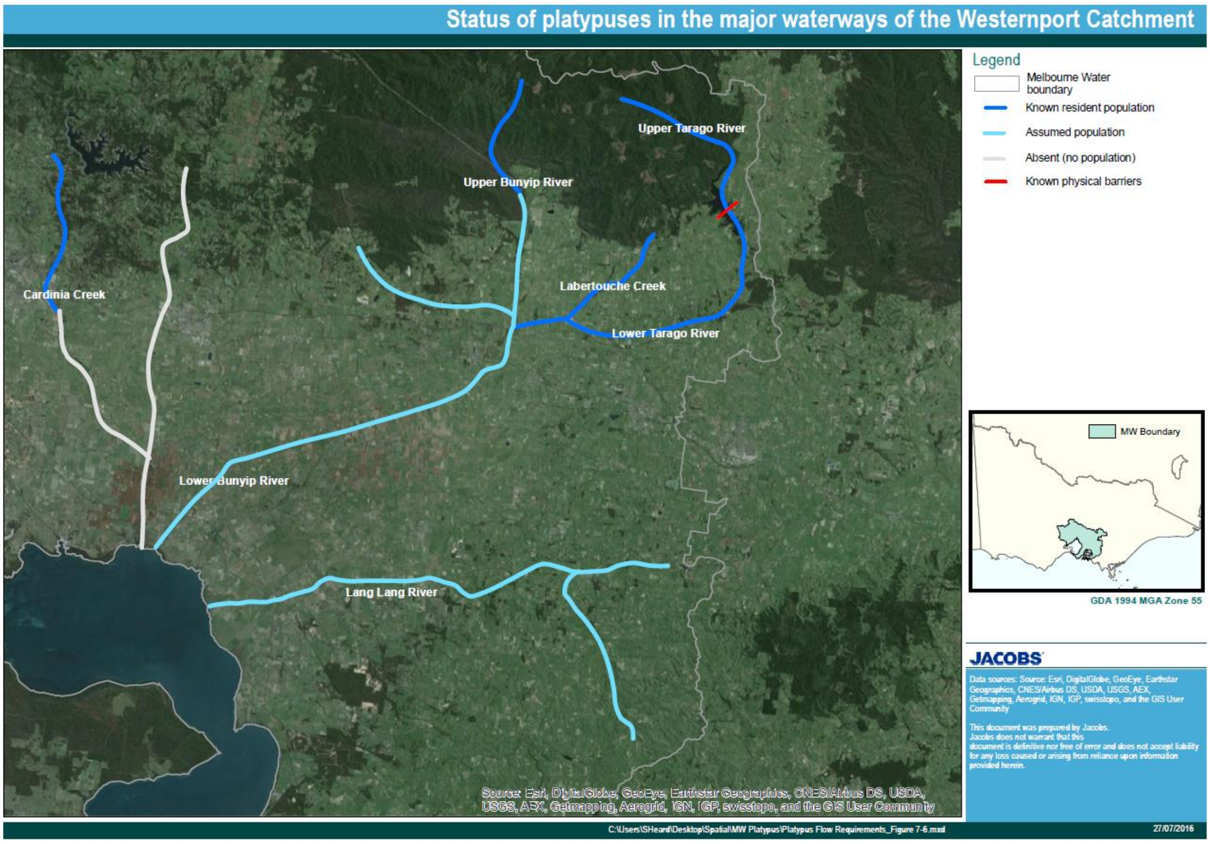

Figure 7-6 Status of platypus in the major waterways of the Westernport Catchment: known resident population (blue), assumed presence (light blue), absence (grey). Known physical barriers indicated in red.

8. Part B: Key complementary actions to conserve platypus in the Melbourne area and knowledge gaps

8.1 Complementary conservation actions

Addressing the environmental water requirements of platypus is vitally important if populations are to survive and thrive in the Melbourne Water region. However, flow-related action will be most effective if it forms part of an integrated management approach that also aims to improve platypus habitat quality, address connectivity issues and reduce direct threats from human activities and natural predators. Recommended complementary actions are listed in this section.

8.1.1 General waterway management

- Protect and/or restore corridors of native riparian vegetation along stream and river banks and within wetland systems.
- Remove willows and other invasive woody weeds from stream and river banks (as long as due consideration is paid to preventing bank erosion and maintaining adequate protective cover from predators).
- Reduce adverse impacts of stock access along water courses by working with landowners to fence off waterways and create off-stream watering points.
- Retain and potentially augment the amount of instream woody habitat (logs and large branches) present in stream and river channels and pondages.
- Ensure that the amount of urban stormwater runoff conveyed by conventional drainage systems (directly connected imperviousness, DCI) does not increase in catchments subject to substantial urban development, and that DCI is progressively reduced in established urban environments.
- Treat urban stormwater and agricultural runoff as needed before it enters natural water courses to reduce concentrations of sediment and chemical pollutants.
- Ensure that new control structures located along natural channels or associated man-made earthen channels (including weir walls, culverts, pipes, grates, grilles, etc.) do not hinder or discourage safe passage by platypus; alter or amend problematic existing structures – e.g. by installing platypus and fish ladders at weir walls – as opportunities arise to do so.
- Ensure that contractors operating heavy equipment on or near stream or river banks do not carry out activities in places and at times of year that could compromise successful platypus reproduction in nesting burrows.
- Ensure that all instream pumps, mini-hydroelectric turbines, etc. are fitted with appropriate guard structures around intake points to prevent platypus being drawn into the mechanism while it is being operated.
- Reduce the impact of introduced predators on platypus by implementing control programs for foxes/feral cats and by restoring/maintaining a dense band of plant cover along the edges of waterways to discourage easy access by foxes, dogs and cats, especially in places where water is shallow (seasonally or throughout the year).

8.1.2 Community education

- *General public awareness of urban platypus populations*. Continue to foster community awareness that platypus live in Melbourne’s waterways, to promote positive and informed community attitudes to waterway and platypus conservation activities.
- *Litter*. Work vigorously to raise awareness of high rates of platypus entanglement in litter and its adverse consequences for the animals.
- *Impacts of recreational angling*. Work vigorously to raise awareness of platypus-friendly angling practices and how to deal most humanely and safely with a platypus that is hooked accidentally.
- *Illegal use of nets and traps*. Work vigorously to raise awareness of the rules governing use of fish nets and yabby traps in Victoria, and the problems that their illegal use poses to platypus and other aquatic wildlife (such as turtles).

- *Pet management*. Continue to remind pet owners about the importance of controlling the movement of dogs and cats near lakes, rivers and streams.

8.2 Knowledge gaps and research priorities

A number of knowledge gaps were identified during the technical panel workshop in relation to future flow management and two allied topics: how to develop an effective network of platypus drought refuges, and how best to manage populations deemed to be at risk due to small population size and/or the isolated nature of their habitat. Whereas in some cases further studies are needed to fill a specific knowledge gap, in other cases a large body of relevant information exists but simply hasn't yet been assembled into coherent conclusions and recommendations (e.g. via an appropriately structured workshop) to assist practical application by Melbourne Water managers. This section aims to (1) identify the research activities and/or workshops that will contribute most effectively to addressing leading platypus management priorities in the Melbourne region, and (2) assess their relative priority (summarised in Table 8-1).

8.2.1 Management priority: developing a long-term strategy for managing small and/or fragmented urban platypus populations

Many platypus populations in the Melbourne urban area have declined in size or become fragmented over time (see Section 7.2). From the viewpoint of management, this is important because size matters in platypus populations: small populations are much more vulnerable to extinction than large populations (see Section 7.1). To help provide an overarching framework to manage platypus extinction risk in the Melbourne urban area, it is recommended that a workshop be convened, comprising persons with expert knowledge in the following areas:

- Platypus distribution and status (including genetic status) in the Melbourne region
- Platypus ecological requirements, particularly in habitats near Melbourne
- Platypus translocation and monitoring protocols
- The projected degree of medium-term change (i.e. over the next several decades) in rainfall and streamflow patterns in catchments where platypus currently occur in the Melbourne region
- The projected degree of land use change around Melbourne in coming decades, particularly with respect to how this is predicted to affect direct connected imperviousness (see Section 3.1.1)

The workshop should aim both to prioritise populations for future management action and to identify actions that are most likely to contribute to longer-term population sustainability, by considering the following questions:

- What is the current population status of platypus across the greater Melbourne region? Considered on a catchment or sub-catchment scale, which populations are deemed to be currently self-sustaining and which are deemed to be potentially at risk of extinction?
- Are any of the populations deemed to be at risk likely to be affected by catchment-scale changes in land use, allocation of water resources or stream flow in coming decades? If so, are populations predicted to increase or decrease in size?
- What range of management actions can contribute most effectively to conserving isolated platypus populations deemed to be at risk? What specific mix of actions is recommended with respect to each of the at-risk populations identified in the greater Melbourne area?
- What is the scope (benefits and limitations) for using translocation as a tool to bolster the demographic or genetic integrity of populations deemed to be at risk?
- What level of monitoring is needed to track the progress of at-risk populations?

Addressing these knowledge gaps is deemed to be a very high priority, given that it represents the logical first step towards (1) deciding how best to allocate resources to future platypus studies across the Melbourne region, and (2) identifying platypus management priorities on a catchment-by-catchment basis (including those related to flow).

8.2.2 Management priority: building resilience of platypus populations to drought

During extended dry periods, the existence of large permanent pools is likely to be critical to platypus survival along any water course where flow becomes intermittent or nearly so (see Section 6.1). Although the presence of platypus was used to help establish the importance of high priority drought refuge areas in Melbourne

Water's (2014) Drought Refuge Management Plan, platypus-specific refuge requirements were not considered in detail in that document, To help fill this knowledge gap, consideration should be given to (1) mapping the distribution of existing platypus drought refuges, particularly in places where this is deemed to be a priority for population survival in the medium-term (ideally following completion of the workshop process outlined in Section 8.2.1), and (2) identifying opportunities for augmenting the number and quality/carrying capacity of platypus drought refuges, again particularly in places where this is likely to assist population survival. In both cases, field work will be required to help map and describe sites.

8.2.3 Management priority: increasing the natural rate of platypus migration to otherwise isolated populations

Barriers to gene exchange between platypus populations are most likely to be bridged by adult males seeking mates in late winter or spring, or juvenile males dispersing from their natal home range in autumn. In both cases, long-range travel is most likely to be successful when stream and river flow is reasonably substantial (see Section 2.5). Could it therefore be possible to use a managed flow regime to trigger and support successful travel past barriers by breeding males and/or dispersing juveniles, e.g. by increasing flow from a low base level at the appropriate time of year? In theory, this could be mediated by biological pull factors ('I might find some suitable unoccupied habitat/receptive females if I follow this promising flow upstream') and/or push factors ('It might be a good time to disperse/look for mates now that flow has increased'). Field studies will be needed to fill this knowledge gap, ideally by using acoustic tags and automated receivers to monitor animal movements in response to experimental changes in flow. It should be recognised that fieldwork will almost certainly need to be staged over two or (probably) more years to enable adequate replicated sampling to occur.

8.2.4 Management priority: identifying the most critical barriers to platypus migration in the greater Melbourne area

Modern genetic techniques can provide useful inferential information relating to how barriers affect population exchange. Currently the best way to improve understanding of the impact of manmade and natural barriers on connectivity of platypus populations in the Melbourne region will be to use Next Generation Sequencing (NGS) to define discrete populations, level of connectivity between populations, and genetic diversity at a much finer scale than previously achieved. An NGS investigation such as this would benefit from the extensive library of platypus tissue samples collected through the MWUPP (*n* = 340; Weeks (2014) plus additional samples collected since 2013).

8.2.5 Management priority: predicting how the effects of flow regime on platypus population status are influenced by other catchment characteristics, e.g. habitat quality and amount of connected imperviousness

Given the large number of potentially relevant independent factors affecting platypus numbers and reproductive success, this knowledge gap is likely to be best addressed through sophisticated computer modelling incorporating a wide range of databases.

Table 8-1 Management priorities, associated actions and contributions made to management.

Management priority	Actions to address knowledge gap	Contribution made to management	Priority
Developing a long-term strategy for managing small and/or fragmented urban platypus populations	Workshop to develop a management strategy for small/fragmented populations	Provide a sound basis for identifying future research and management priorities and allocating resources	Very high
Building resilience of platypus populations to drought	Field studies to support map production	Field studies to map existing and potential platypus drought refuges	High (isolated small populations) Medium-low (other populations)
Increasing the natural rate of platypus migration to otherwise isolated populations	Experimental field studies to determine if managed flows can be used to trigger long-range platypus movements	Develop a cost-effective tool to promote natural migration to isolated populations	High (isolated small populations)
Identifying the most critical barriers to platypus migration in the greater Melbourne area	Next Generation Sequencing (NGS) analysis of accumulated platypus tissue samples	Help to identify/confirm where substantial barriers to platypus migration exist	Medium-high (similar but less sophisticated analysis was carried out in 2014)
Predicting how the effects of flow regime on platypus population status are influenced by other catchment characteristics, e.g. habitat quality and amount of connected imperviousness	Modelling the environmental factors affecting platypus population density	Improve basic understanding of how to manage platypus most effectively	Medium-high

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