# Cardinia Creek fish risk assessment amendment

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# Executive summary

Jacobs (2021) assessed the impacts of proposed urban development on flows in the Cardinia Creek with specific reference to risks to native fish and habitat quality. That study showed that outfalls from the Officer South and Cardinia South PSPs had the potential to increase the frequency and duration of flows that could increase erosion risk, especially downstream of inflows from the Officer South PSP (assessed at Chasemore Road). In particular, there was an increase in the number of flow events that occur at a sub-daily (i.e. hourly) duration that exceed critical bed mobilisation flows which could contribute to increased channel erosion and scour of vegetation. This has the potential to impacts on the quality of habitat through the reach and may also interrupt movement cues for Australian grayling that need to move through this reach for downstream spawning and upstream juvenile migration in autumn and spring respectively.

The assessment recommended that the Officer South PSP drainage design be reviewed with the intent of identifying opportunities to reduce peak flow rates, maintain the current frequency and duration of flows in Cardinia Creek that exceed bed mobilisations flows (370 ML/d at Chasemore Road) and limit where possible the increase in magnitude of the 1:1-1:5 year Average Recurrence Interval (ARI) events.

Melbourne Water reviewed the old PSP designs and provided updated MUSIC models for new designs (Jacobs 2023). The updated full development designs were re-run through the Jacobs (2021) risk assessment analysis and compared with flow recommendations for native fish and hydrological metrics related to erosion risk.

The results showed that for the new full development scenario there is a reduction in the risk compared to the old full development scenario. Notably:

- Peak daily flows more closely match current flows.
- Flow recommendations for Australian grayling migration, spawning and access to habitat are maintained.

- There is a decrease in the percentage of time that flows are in the moderate to very high risks categories for bed shear stress and an increase in the percentage of time that flows are in the low risk category for bed shear stress.

- There is a reduction in the percentage of time that daily flows exceed the bed mobilisation flow. Furthermore, the daily flow variation and the frequency and duration of high flows is substantially reduced and close to the current.

- There is a reduction in the peak daily and hourly flow magnitudes. Notably there is a reduction in the frequency and duration of peak hourly flows in the low flow summer and autumn period – hence minimising excessive disturbance during low flow periods.

- The Average Recurrence Intervals more closely match current.

Overall, the redesigned Officer South PSP meets the recommendations of Jacobs (2021) to minimise the increase in peak flows, limit an increase in the duration of flows that exceed the bed mobilisation flow and maintain the current magnitude of 1:1-1:5 year ARI events.

Based on the modelled flows associated with the redesigned Officer South PSP, it is expected that the existing ecological values of Cardinia Creek would be maintained, provided the as constructed flows comply with the design flows.

To ensure the desired outcomes are met it is recommended that an implementation, monitoring and evaluation plan be developed that could include details specifying how flow requirements are to be considered in the DSS, requirements for interim works to maintain DSS design parameters, flow monitoring upstream and downstream of critical outfalls, fish and habitat condition (erosion) monitoring upstream and downstream of critical outfalls and complimentary works, such as weed control and revegetation works to improve overall waterway values.

# 1. Introduction

## 1.1 Background

The Cardinia Creek fish risk assessment study (Jacobs 2021) investigated the potential impacts to two protected fish species (Australian grayling and dwarf galaxias) as a result of proposed development of the Cardinia Creek South, Minta Farm and Officer South Precinct Structure Plan (PSP) areas in Melbourne's outer south-east (Figure 1-1). The assessment involved hydrological and hydraulic modelling to predict changes to the flow regime of Cardinia Creek as a result of altered stormwater inflows from the developed PSP areas. The potential for the predicted flow changes to have an adverse impact on Australian grayling and dwarf galaxias within the Cardinia Creek Conservation Area were then assessed.

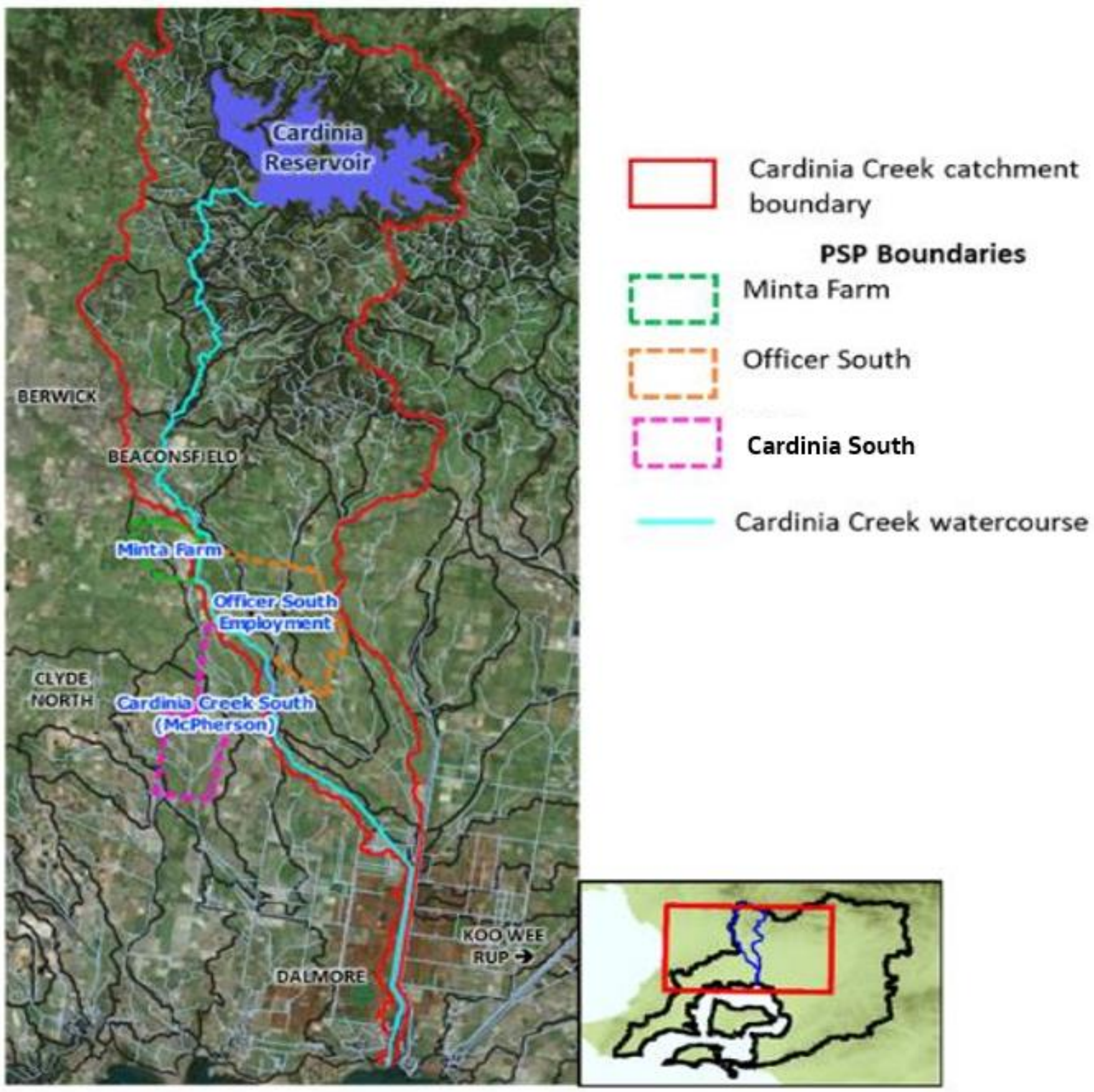



**Figure 1-1. Time series of modelled daily flow at Chasemore Road for old and new full development scenarios for Officer South and Cardinia South PSPs**

Risks were assessed by identifying ecologically relevant flow criteria and metrics and comparing criteria and metrics between flow scenarios under current and modelled full development flows. Criteria and metrics included preferred flow regime requirements for Australian grayling and dwarf galaxias and a range of ecologically and geomorphologically relevant hydrological metrics. The derivation of metrics is documented in Section 4.3 of Jacobs (2021) and summarised in Appendix A.

The analysis of potential risks indicated there was no increase in risk from the Minta Farm (north and south) PSP designs. This is because the Minta Farm development area is small relative to the upstream Cardinia Creek catchment. However, there was potential for an increase in the frequency and duration of flows that could increase erosion risk, especially downstream of inflows from the Officer South PSP (assessed at Chasemore Road). In particular, there was an increase in the number of flow events that occur at a sub-daily (i.e. hourly) duration that exceed critical bed mobilisation flows which could contribute to increased channel erosion and scour of vegetation. This has the potential to impacts on the quality of habitat through the reach and may also interrupt movement cues for Australian grayling that need to move through this reach for downstream spawning and upstream juvenile migration in autumn and spring respectively. Further downstream of Chasemore Road risks were mitigated, even under the old full development scenario, due to the larger channel capacity of the Cardinia Outfall through the Koo Wee Rup Flood Protection Area (as modelled by flows at the Westernport Bay outlet).

The assessment recommended that the Officer South and Cardinia South PSP drainage designs be reviewed with the intent of identifying opportunities to reduce peak flow rates, maintain the current frequency and duration of flows in Cardinia Creek that exceed bed mobilisations flows (370 ML/d at Chasemore Road) and limit where possible the increase in magnitude of the 1:1-1:5 year ARI events.

For full details of the previous assessment see Jacobs (2021)

## 1.2 This memorandum

In response to the recommendations, Melbourne Water has reviewed the Officer South and Cardinia South PSPs and developed new designs that aim to reduce the frequency of peak flows entering Cardinia Creek. For the Officer South PSP, design features include retention basins and wetlands to retain rainfall events and slow flow down – reducing flow peaks. Runoff from the upper catchment (Officer PSP), that was initially modelled to enter Cardinia Creek via the Officer South PSP, is now proposed to be diverted to Lower Gum Scrub Creek. More details of the drainage design are provided in Jacobs (2023). An updated drainage scheme was also developed for the Cardinia South PSP (Alluvium 202x)

MUSIC models of the new drainage designs were used to create new full development flow scenarios in Cardinia Creek following the methods described in Jacobs (2021). Hydrological metrics were recalculated and are compared with the outcomes of the old full development models. Results are assessed for Cardinia Creek at Chasemore Road, which represent a site downstream of the Officer South and Cardinia South PSP outflow locations. The updated assessment does not result in a change in risks associated with development at Minta Farm, so the assessment is restricted to changes in flow as modelled at Chasemore Rd.

The outcomes of this memorandum are to be read in conjunction with Jacobs (2021)

# 2. Results

## 2.1 Flow

Figure 2-1 shows a timeseries of modelled flow (MUSIC model for the ten-year climate period 1/1/1984-31/12/1993) at Chasemore Road under current and the old and new full development scenarios. Overall there is a reduction in the mean daily flow under the new full development scenario, and particularly a reduction in the peak mean daily flows. Indeed, across the modelled time series, the flow duration curve shows the new full development scenario is much lower than the old full development scenario and slightly lower than the current flow, except for peak flows (Figure 2-2). This is because the new full development design diverts the Officer PSP outflows to Lower Gum Scrub Creek, whereas the current modelled flow includes that part of the catchment outflows entering Cardinia Creek.

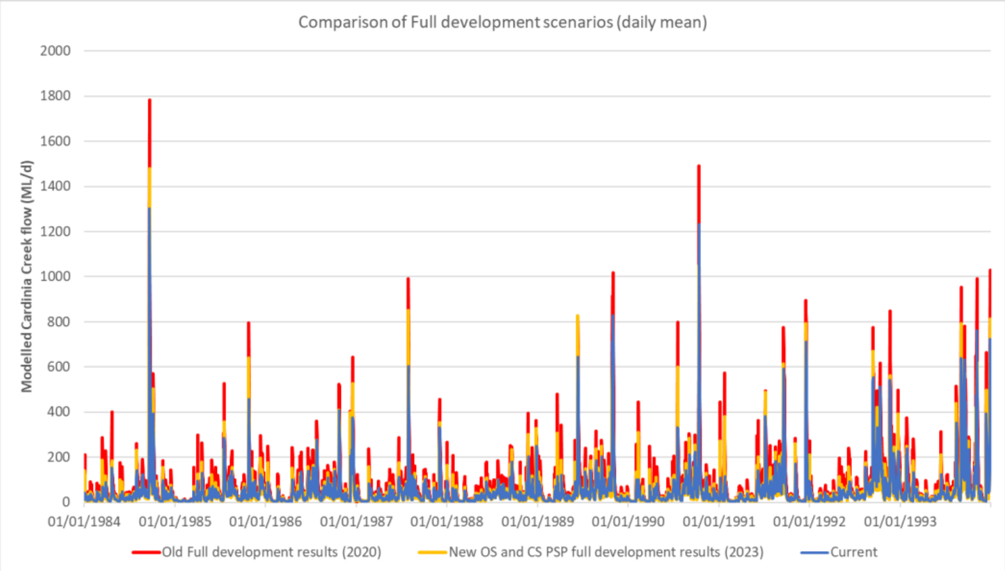



**Figure 2-1. Time series of modelled daily flow at Chasemore Road for old and new full development scenarios for Officer South and Cardinia South PSPs**

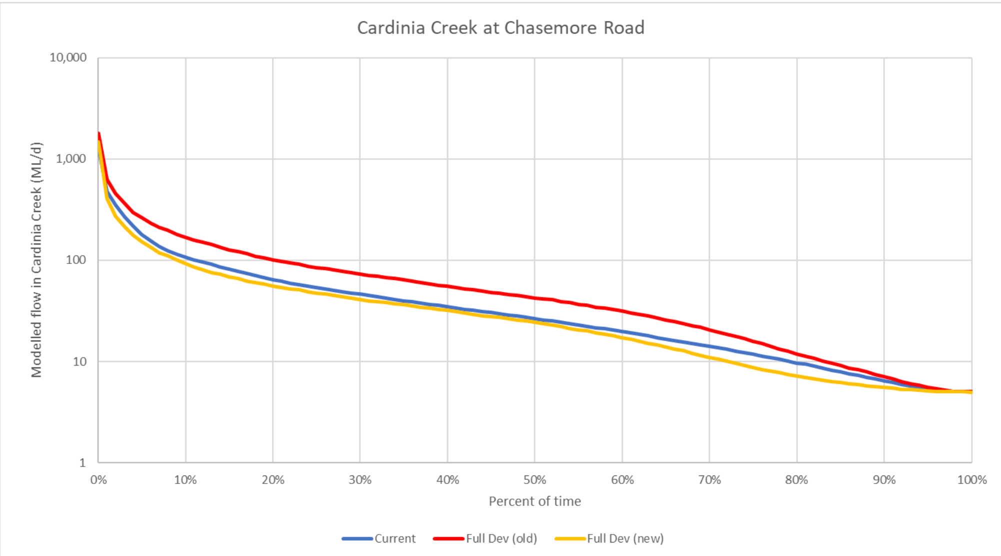



**Figure 2-2. Flow duration of modelled daily flow at Chasemore Road for current, old and new full development scenarios for Officer South and Cardinia South PSPs**

## 2.2 Risk to Australian grayling

Flow recommendations to support Australian grayling include suitable low flows to maintain access to habitat, higher flows in autumn to trigger migration and spawning and higher flows in spring to facilitate the migration of juveniles from the marine environment (Table 2-1). Under the old full development designs there was an increase in the duration of higher flows in autumn as a result of increased runoff from PSP areas contributing to flows already occurring from upstream areas. Under the new full development design this increase in duration of autumn freshes is less evident and the new full development conditions more closely match the current conditions. However, under the new full development conditions, there is a slight decrease in the duration of high flow in winter/spring, although the number of events increases such that the total number of days above high flow thresholds is similar.

The Jacobs (2021) concluded the increase in duration of flow events under the old full development scenarios was unlikely to represent a risk to life history ques for Australian grayling. However, there was the potential for the peak magnitude of these events to also increase, which poses a risk to habitat conditions. The new full development scenarios results in an overall reduction in the peak flows and similar represents a low risk to life history ques for Australian grayling.

Risks to habitat conditions is discussed in Section 2.3.

**Table 2-1 Current and modelled old and new full development flows thresholds for components relevant to Australian grayling at Chasemore Rd**

| | **Flow component** | | | **At Chasemore Rd** | | |
|---|---|---|---|---|---|---|
| Season | **Component** | **Requirement** | **Thresholds** | **Current** | **Old** | **New** |
| Summer low flows (Dec-May) | Magnitude (percentage of time above specific magnitudes) | Sufficient to maintain depth over riffle habitats and pool depths (~40-100 cm deep). The current low flow recommendation is 5 ML/d (as specified in Doeg, 2012) | **5 ML/d** for fishway operation | 100% of time | 100% of time | 100% of time |
| | | | **10 ML/d** (10-20 cm over ~90% of cross sections | 65% of time | 70% of time | 55% of the time |
| Autumn spawning freshes (April-June) | Autumn fresh of sufficient magnitude and duration to enable spawning life cycle event to be completed. Typically 10-15 days or longer is required based on research from other rivers. | A range of event magnitudes have been selected and the duration and number of events per season are compared between current and developed conditions. (Calculated as mean duration of event above threshold) | **75 ML/d** | 3.6 days 1.7 per season | 5.7 days 3.5 per season | 2.9 days 2.5 per season |
| | | | **40 ML/d** | 8.5 days 2.7 per season | 14.4 days 3.2 per season | 6.6 days 3.5 per season |
| | | | **30 ML/d** | 11.4 days 3 per season | 24.7 days 2.7 per season | 11.2 days 3.3 per season |
| | | | **25 ML/d** | 13.3 days 3.2 per season | 30.4 days 2.6 per season | 17.8 days 2.9 per season |
| Winter low flows (June-Nov) | Magnitude (% of time above specific magnitudes) | Sufficient to maintain depth over riffle habitats and pool depths. (40 cm over 50% of cross sections) | **30 ML/d** | 28% of time | 43% of time | 28% of time |
| Winter / spring High flows (Sep-Dec) | High flows September-December to facilitate juvenile migration from marine environment | A range of event magnitudes have been selected and the duration and number of events per season are compared between current and developed conditions | **75 ML/d** | 10.4 days 3.4 per season | 14.1 days 4.1 per season | 6.3 days 4.2 per season |
| | | | **150 ML/d** | 6.0 days 2.7 per season | 6.7 days 3.7 per season | 3.6 days 3.3 per season |
| | | | **250 ML/d** | 5.5 days 1.9 per season | 4.7 days 2.8 per season | 2.7 days 2.9 per season |

## 2.3 Chanel stability risks

A range of channel stability metrics were derived related to erosion risk (measured as shear stress), flows sufficient to initiate bed mobilisation and flows that represent a high potential for overall channel disturbance (Table 2-2). The old full development scenarios were modelled to increase the duration of time that flow was within moderate and high shear stress (erosion risk) categories and exceeded bed mobilisation, daily flow variation and high disturbance thresholds for longer than current conditions. The new full development scenario is characterised by overall lower flows (compared to both the old full development and current flow scenarios), however the highest peak flows, when they do occur, are still greater than current peak flows (although less than the old full development peak flows). In this regard the new full development scenarios represent a lower level of risk than the old full development scenarios.

Given the reduction in risks at Chasemore Road associated with the new full development scenario, risks would be further mitigated downstream of Chasemore Road due to the larger channel capacity of the Cardinia Outfall through the Koo Wee Rup Flood Protection Area (as modelled by flows at the Westernport Bay outlet) and are not assessed further.

**Table 2-2 Current and modelled future channel stability risks (daily modelled flow)**

| Component | Function / effect | Threshold | Chasemore Road | | |
|---|---|---|---|---|---|
| | | | Current | Old full dev | New full dev |
| **Shear stress rankings** | Different bed material mobilise at different shear stresses. Flow magnitudes that correspond the shear stress risk categories has been determined for the Cardinia Creek channel. Assessment is against percent of time that flow exceeds various risk categories under current and full development | **< 5 ML/d (very low risk)** | 0% of time | 0% of time | 0% of time |
| | | **5.1-30 ML/d (low risk)** | 55% of time | 39% of time | 58% of time |
| | | **30.1-200 ML/d (mod. risk)** | 41% of time | 53% of time | 39% of time |
| | | **200.1-750 ML/d (high risk)** | 4% of time | 7% of time | 3% of time |
| | | **>750 (very high risk)** | 0% of time | 1% of time | 0% of time |

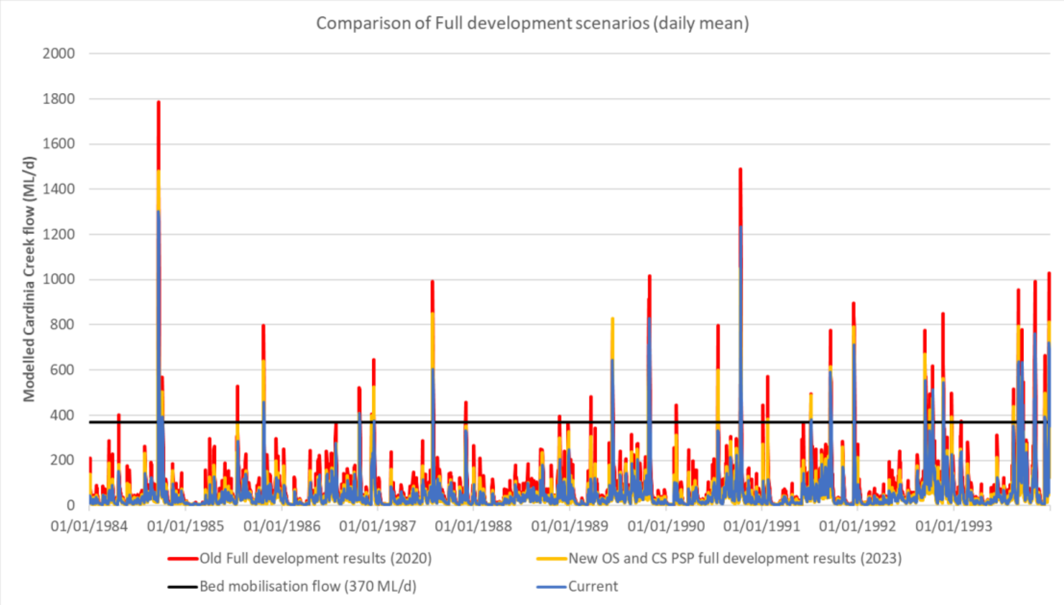
| | | | | | |
|---|---|---|---|---|---|
| **Bed mobilisation** | Represents a natural disturbance event that transports sediment and organic material, maintains channel form, flushes riffles etc. Metric is expressed as the fraction of time > $Q_{2yrARI}/2$ (Duncan *et al.*, 2014). Threshold is determined for the current condition and change in duration compared between current and full development | % of time the flow exceeds $Q_{2yrcurrentARI}/2$ Chasemore Rd (370 ML/d) | 1.8% | 3% | 1.2% |
| **Variation in daily flow** | Large variations in day to day (and within day) flows (i.e. flashy flows) create excessive disturbance that impact on the ability of biota to persist in highly variable habitats. Highly variable flows can also result in bank slumping. | Unitless metric, a larger number means a higher flow variation and hence greater flow 'flashiness' | 108.5 | 137.6 | 118.4 |
| **High flow frequency and duration** | Similar to the bed mobilisation metric but is based on the number of times and the duration that a high flow threshold is exceeded. The high flow frequency metric is typically defined as the number of events per year greater than 3 times the median flow and the high flow duration is the fraction of days that daily mean flow is greater than the annual mean flow (Duncan *et al.*, 2014). | **High flow frequency** Mean number of events per year that exceed 3x the median flow at Chasemore Rd (79.4 ML/d) | 11.1 | 20.1 | 15.6 |
| | | **High flow duration** % of days across record that flow is > annual mean flow at Chasemore Rd (52 ML/d) | 26% | 42% | 22% |

## 2.4 Daily versus sub daily flows

The channel stability risks noted above are based on the modelled increase in average daily flows from the various PSPs. However, it doesn't account for any sub-daily flow variation. For example, a storm event that generates runoff from the new urban areas might only last for a few hours so the peak flows to Cardinia Creek from these events might be quite high for a few hours, but when averaged across a day the daily average flow will be lower. Hence risks associated with sub-daily peak flows may be overlooked.

To explore this issue further the daily and sub-daily flows (as the maximum peak hourly flow from MUSIC models) were compared between the old and new full development scenarios. The results show that the daily flow and the maximum peak hourly flow is reduced under the new full development scenario (Figure 2-3).

The reduction in peak daily and hourly maximum flows support the reduction in the frequency and duration flow exceeds the bed mobilisation and high flows under the new full development scenario (from Table 2-2). The reduction is further demonstrated in Figure 2-4, which shows a reduction in the number and duration of daily flows above the bed mobilisation flow (compare panels And B) and then number and duration of peak hourly flows above the bed mobilisation (compare panels C and D). Of note is the a near halving in the number of peak hourly flow events that occur in the otherwise low flow summer and autumn season. This is important because it reduces the frequency of disturbance during low flow conditions.



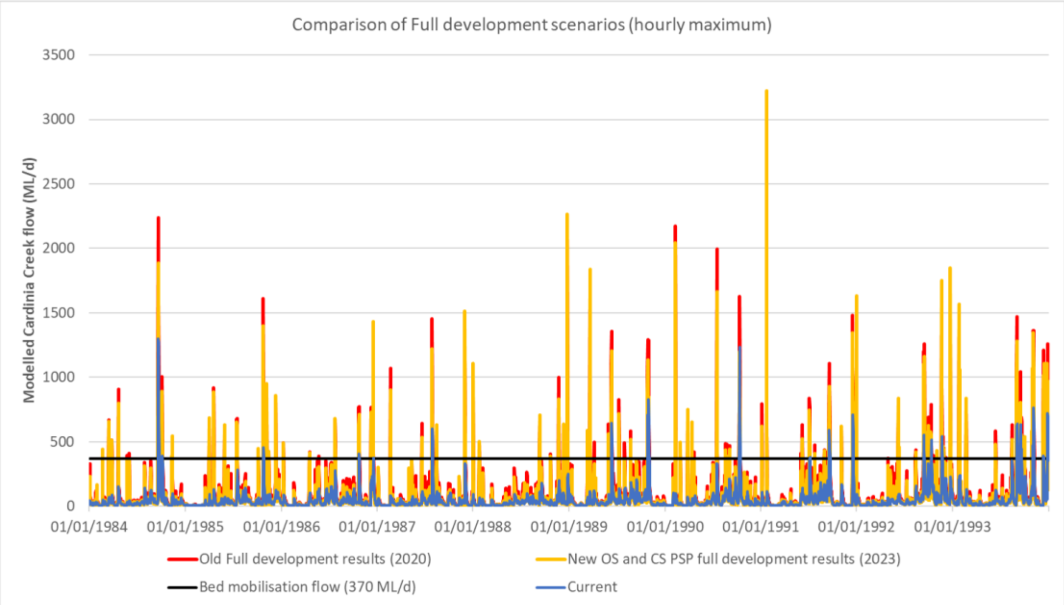




**Figure 2-3. Differences between the old and new full development scenarios for daily (upper panel) and hourly maximum (lower panel) flows at Chasemore Road. Peaks are compared to the bed mobilisation threshold (370 ML/d at Chasemore Road).**

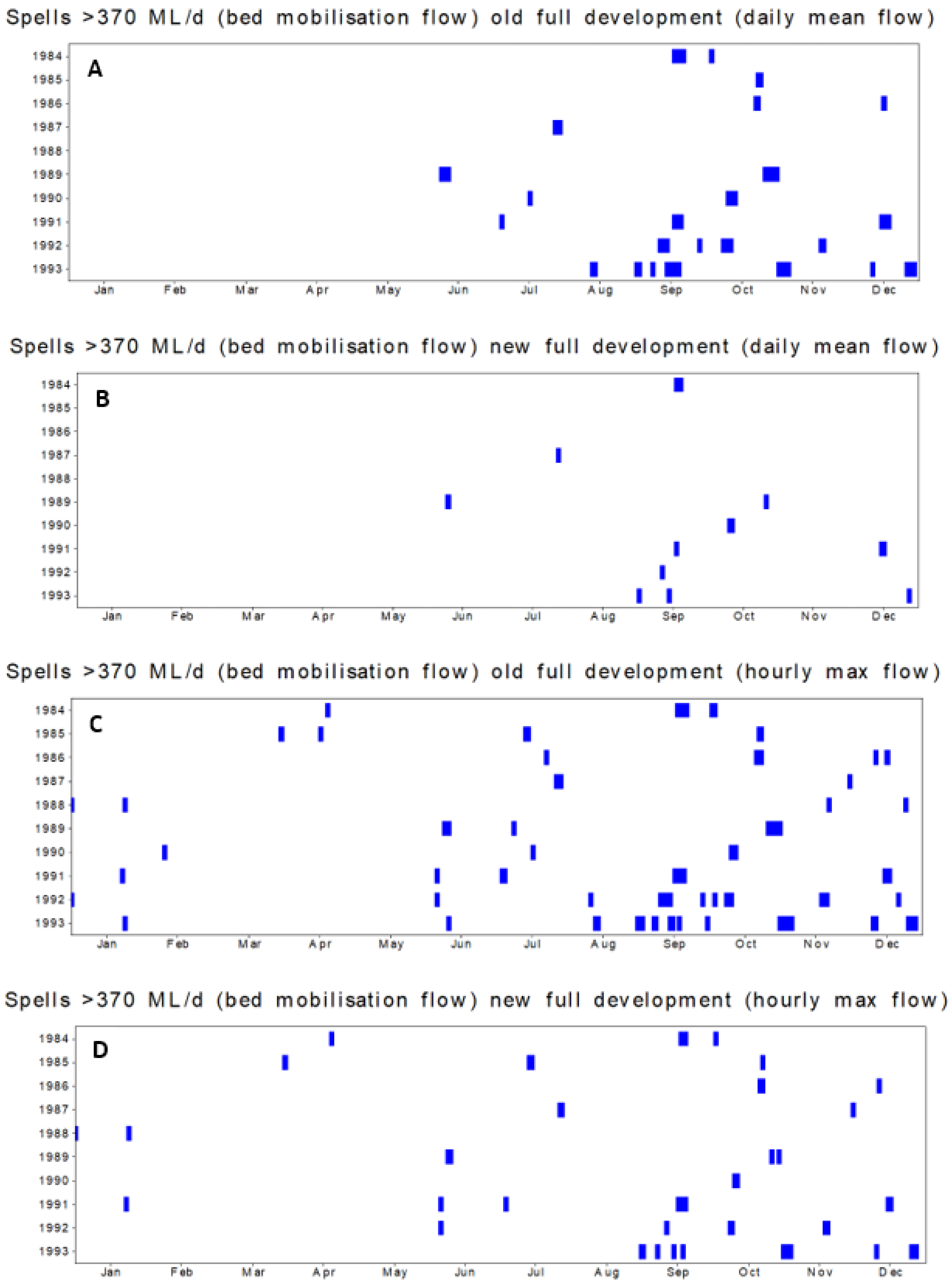



**Figure 2-4. Spells above the bed mobilisation flow (370 ML/d) at Chasemore Road under old and new full development (peak daily and peak hourly) conditions**

To further demonstrate the change in flow associated with the cumulative impact of all proposed PSPs outfalls, Figure 2-5 shows the change in the Average Recurrence Interval (ARI) under current and old and new full development conditions. Under the old full development conditions the 1:1 year event changes from a flow of ~550 ML/d to a flow of ~800 ML/d (what was the 1:1 year flow now occurs twice per year). Moreover, flows that would have occurred once every 5 years (~1000 ML/d) were predicted to occur around once every 2.5 years. However, under the new full development conditions the Annual Recurrence Interval is very similar to current conditions. This represents a substantial risk reduction compared to the old full development conditions.


**Figure 2-5. Change in Annual Recurrence Interval for flows at Chasemore Road (cumulative impact of all PSPs) under current and old and new full development conditions.**

# 3. Conclusions and recommendations

Jacobs (2021) assessed the impacts of proposed urban development on flows in the Cardinia Creek with specific reference to risks to native fish and habitat quality. That study showed that outfalls from the Officer South and Cardinia South PSPs had the potential to increase the frequency and duration of flows that could increase erosion risk, especially downstream of inflows from the Officer South PSP (assessed at Chasemore Road). In particular, there was an increase in the number of flow events that occur at a sub-daily (i.e. hourly) duration that exceed critical bed mobilisation flows which could contribute to increased channel erosion and scour of vegetation. This has the potential to impacts on the quality of habitat through the reach and may also interrupt movement cues for Australian grayling that need to move through this reach for downstream spawning and upstream juvenile migration in autumn and spring respectively.

The assessment recommended that the Officer South PSP drainage design be reviewed with the intent of identifying opportunities to reduce peak flow rates, maintain the current frequency and duration of flows in Cardinia Creek that exceed bed mobilisations flows (370 ML/d at Chasemore Road) and limit where possible the increase in magnitude of the 1:1-1:5 year Average Recurrence Interval (ARI) events.

Melbourne Water reviewed the old PSP designs and provided updated MUSIC models for new designs (Jacobs 2023). The updated designs were re-run through the Jacobs (2021) risk assessment analysis and compared with flow recommendations for native fish and hydrological metrics related to erosion risk.

The results showed that for the new full development scenario there is a reduction in the risk compared to the old full development scenario. Notably:

- Peak daily flows more closely match current flows.
- Flow recommendations for Australian grayling migration, spawning and access to habitat are maintained.
- There is a decrease in the percentage of time that flows are in the moderate to very high risks categories for bed shear stress and an increase in the percentage of time that flows are in the low risk category for bed shear stress.
- There is a reduction in the percentage of time that daily flows exceed the bed mobilisation flow. Furthermore, daily flow variability and the frequency and duration of high flows is substantially reduced and close to the current.
- There is a reduction in the peak daily and hourly flow magnitudes. Notably there is a reduction in the frequency and duration of peak hourly flows in the low flow summer and autumn period – hence minimising excessive disturbance during low flow periods.
- The Average Recurrence Intervals more closely match current.

Overall, the redesigned Officer South PSP meets the recommendations of Jacobs (2021) to minimise the increase in peak flows, limit an increase in the duration of flows that exceed the bed mobilisation flow and maintain the current magnitude of 1:1-1:5 year ARI events.

Based on the modelled flows associated with the redesigned Officer South PSP, it is expected that the existing ecological values of Cardinia Creek would be maintained, provided the as constructed flows comply with the design flows.

To ensure the desired outcomes are met it is recommended that an implementation, monitoring and evaluation plan be developed that could include details specifying how flow requirements are to be considered in the DSS, requirements for interim works to maintain DSS design parameters, flow monitoring upstream and downstream of critical outfalls, fish and habitat condition (erosion) monitoring upstream and downstream of critical outfalls and complimentary works, such as weed control and revegetation works to improve overall waterway values.

# 4. References

Alluvium (202x) Cardinia South PSP drainage design update. Report by Alluvium for Melbourne Water

Jacobs (2021) Cardinia Creek hydrological and fish risk assessment. Report by Jacobs for Melbourne Water

Jacobs (2023) Officer South PSP drainage design update. Report by Jacobs for Melbourne Water

# Appendix A Ecological metrics

### Flow components for dwarf galaxias life history and habitat requirements

| Season | Flow component | Rationale | Threshold (at Minta Farm and Cardinia Drop Structure) |
|---|---|---|---|
| **Summer and winter low flows** | Magnitude (percentage of time above specific magnitudes). | Low flows that disconnect floodplain wetland habitats and anabranch systems so that seasonal drying occurs, but sufficient to maintain moisture in the sub soils and in crayfish burrows (percentage of time below specific magnitudes). Minimum flows as per Australian grayling (see **Error! Reference source not found.**). Maximum flow 100 ML/d to prevent excessive inundation of potential habitats. | **10 ML/d summer**<br>**30 ML/d winter**<br>**100 ML/d max to minimise excessive inundation of backwater habitats** |
| **High flows (anytime)** | Frequency and duration of time above critical thresholds for inundating dwarf galaxias habitat | Hec Ras modelling has identified anabranches and backwater areas along Cardinia Creek from Minta Farm to the Cardinia Drop Structure and determined the flow magnitudes that commence to inundate these habitats. Thresholds range from 150-1000 ML/d with most potential habitats inundated at between 250 and 500 ML/d. | **Range of flows from 150-1000 ML/d** |

### Flow components for Australian grayling life history and habitat requirements

| Season | Component | Rationale | Thresholds (at Cardinia Drop Structure, Chasemore Road and WPB outlet) |
|---|---|---|---|
| **Summer low flows (December-May)** | Magnitude (percentage of time above specific magnitudes). Sufficient to maintain access to riffle and pool habitats and movement through fishways. | The current low flow recommendations for Cardinia Creek is 5 ML/d (as specified in Doeg, 2012).<br>Hec Ras modelling identified 10 ML/d is sufficient to maintain a depth of 10-20 cm over 90% of cross section).<br>Current fishway operational range is predicted to be 5-350 ML/d (Ivor Stuart, DELWP, Pers. Com.). | **5 ML/d for fishway operation**<br>**10 ML/d (10-20 cm over ~90% of cross sections** |
| **Autumn spawning freshes (April-June)** | Autumn fresh of sufficient magnitude and duration to enable spawning life cycle event to be completed. Typically10-15 days or longer based on research from the nearby Bunyip River (Koster *et al.*, 2013). | A range of event magnitudes have been selected and the duration (above threshold) and number of events per season are compared between current and developed conditions. These include events that range in duration from 5 days through to 15 days as per the duration suggested by Koster *et al.* (2013). | **25 ML/d**<br>**30 ML/d**<br>**40 ML/d**<br>**75 ML/d** |
| **Winter low flows (June-November)** | Magnitude (% of time above specific magnitudes). Sufficient to maintain access to riffle and pool habitats and movement through fishways- winter low flow is typically higher than summer low flows. | Hec Ras modelling identified 30 ML/d is sufficient to maintain a depth of 40 cm over 80% of cross sections in reach 1 and 50% of cross sections in reach 2. | **30 ML/d** |
| **Winter / spring High flows (Sep-Dec)** | High flows September-December to facilitate juvenile migration from marine environment. Flow needs to be sufficient to provide fish passage. | Event magnitudes (within the operational range of fishways and higher than the low flow thresholds) and the duration and number of events per season are compared between current and developed conditions. | **75 ML/d**<br>**150 ML/d**<br>**250 ML/d** |

**Flow components for habitat quality – these flows are to maintain instream habitat conditions for fish and other values and to minimise habitat/channel degradation**

| Component | Function / effect | Threshold |
|---|---|---|
| **Shear stress rankings** | Different bed material mobilise at different shear stresses. Flow magnitudes that correspond the shear stress risk categories has been determined for the Cardinia Creek channel from the Hec Ras modelling of channel characteristics and using criteria from Gordon *et al.* (2004) (see Jacobs (2020) for details of shear stress risk categories). Assessment is against percent of time that flow exceeds various flow threshold / risk categories under current and full development scenarios. | <5 ML/d (very low risk, minimal movement of unconsolidated bed material) |
| | | 5.1-30 ML/d (potential movement of unconsolidated bed material, limited movement of consolidated / shielded fine bed material) |
| | | 30.1-200 ML/d (moderate risk, potential movement of shielded bed material) |
| | | 200.1-750 ML/d (high risk, likely movement of shielded bed material) |
| | | >750 (very high risk, scour of stiff clay, cobbles and potential impacts on in-channel vegetation) |
| **Bed mobilisation** | Represents a natural disturbance event that transports sediment and organic material, maintains channel form, flushes riffles etc. Metric is expressed as the fraction of time flow is >$Q_{2yrARI}$/2 (Duncan *et al.*, 2014). The threshold is determined for the current flow condition and the change in duration is compared between current and full development flow scenarios. | $Q_{2yrcurrentARI}$/2<br>Cardinia Drop Structure (376 ML/d)<br>Chasemore Rd (370 ML/d)<br>WPB outlet (638 ML/d)<br>Note the bed mobilisation flows fall within the high shear stress risk category. |
| **Variation in daily flow** | Large variations in day to day (and within day) flows (i.e. flashy flows) create excessive disturbance that impact on the ability of biota to persist in highly variable habitats. Highly variable flows with rapid changes can also result in bank slumping. Increases in flow variability can occur post development due to more rapid runoff from impervious surfaces.<br>Variation can be expressed as the sum of the absolute values of change in mean daily flows divided by the sum of the mean daily flows (Duncan *et al.*, 2014). This provides a measure of the variability of flows as an indicator of the duration of 'disturbance events' and stream flashiness. | Unitless metric: full development compared to current scenarios, a larger number means a higher flow variation. |
| **High flow frequency and duration** | Similar to the bed mobilisation metric but is based on the number of times and the duration that a high flow threshold is exceeded. The high flow frequency metric is typically defined as the number of events per year greater than 3 times the median flow and the high flow duration is the fraction of days that daily mean flow is greater than the annual mean flow (Duncan *et al.*, 2014). | **High flow frequency**<br># events that exceed 3x the median flow<br>Cardinia drop structure (66 ML/d)<br>Chasemore Rd (79.4 ML/d)<br>WPB outlet (173 ML/d) |
| | | **High flow duration**<br>% of days flows is >annual mean flow<br>Cardinia drop structure (46 ML/d)<br>Chasemore Rd (52 ML/d)<br>WPB outlet (107 ML/d) |