Pilot model comparing evaporation from a weir pool vs a natural flowing river

WRL TR 2024/11, April 2024

By L Montano and B M Miller

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Executive summary

The Water Research Laboratory (WRL) of the School of Civil and Environmental Engineering at UNSW Sydney was engaged by the NSW Department of Primary Industries – Fisheries (DPI Fisheries) to numerically assess the potential for reduced evaporation and subsequent water savings by removal of Weir 20A in the Darling River. Water savings opportunities in the Murray Darling Basin have been identified in leading to both ecological and economic benefits (i.e. potentially reducing the need for government-funded water buyback initiatives (Wheeler, 2023)).

The assessment comprised:

i. Input data from 1967-2009 of:
    a. flow (Louth gauge 425004)
    b. water surface area
    c. evaporation (Bourke 480013, 48239) (Note: evaporation data was the limiting timeseries)
ii. An estimation of flow depths upstream of Weir 20A along the river every 1.25 km, with and without the weir, based on a one-dimensional numerical model (RMA-2) and a constant river gradient (Section 3.3)
iii. An estimation of the weir pool length (based on the RMA-2 model results) (Section 3.3)
iv. An estimation of the water surface area in the river, with and without the weir (calculated as the product between the weir pool length and the river width) (Section 3.4)
v. Estimation of the evaporation volume (without and without the weir) based on the surface area in the river and the rate of evaporation expected in Bourke (Section3.5)
vi. Sensitivity analysis of evaporation volumes for a wide range of bathymetric parameters (Appendix A)

Based on the numerical assessment, weir removal would decrease the flow depths along the river and the surface area of the weir pool, thereby reducing the evaporation volume upstream of the weir. The reduction of flow depths and surface area only occurs within the weir pool area (defined as the region upstream of the weir where the hydraulic gradient of the water surface is relatively flat). Upstream of the weir pool, flow depths and water surface area will remain the same as the natural flowing river, as presented in the example in Figure ES1. The length of the weir pool is a function of the flow rate, channel roughness, river bathymetry and river slope. Figure ES1 presents an example of flow depths in the river for a flow rate of 10m^3/s (~ 50%ile). For this flow rate, the weir pool length is approximately 20 km, indicating no impact on the flow levels or water surface area, for the areas located upstream.

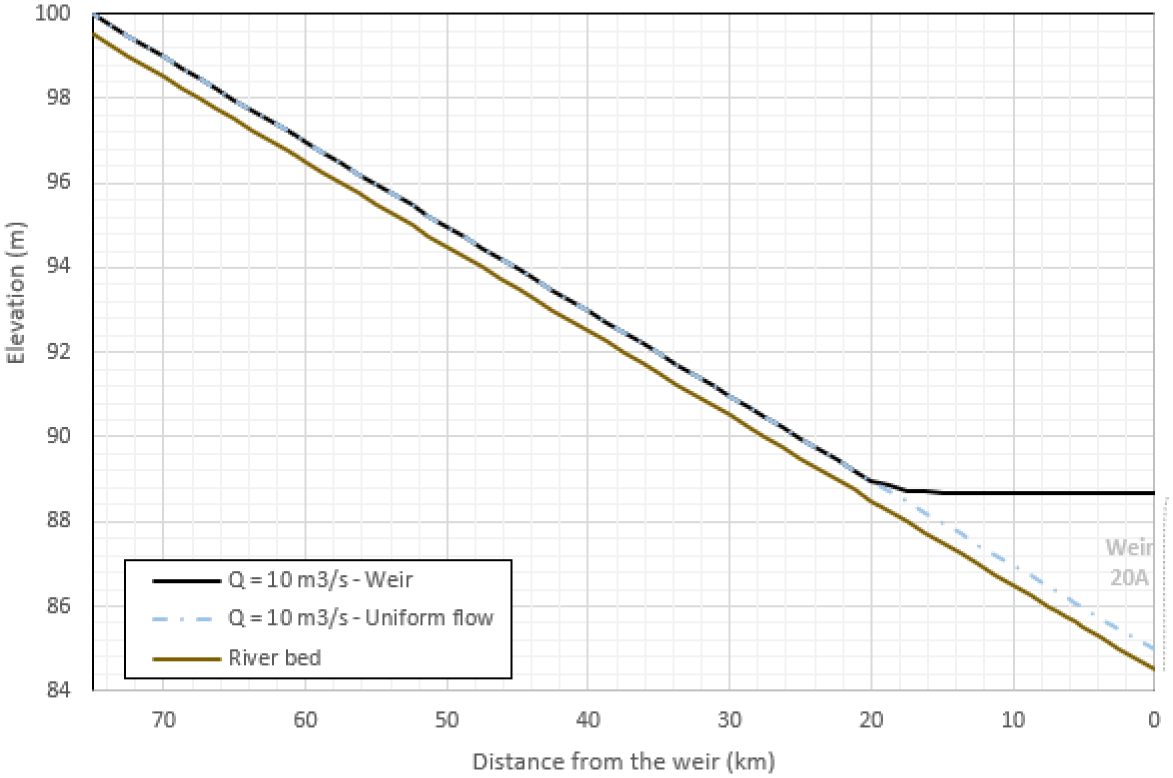

Figure ES1 Example of estimated flow depths for a flow rate of 10^{3}m/s (approximately median conditions) and a river slope of 0.02%

Figure ES2 presents the average of the daily evaporation volume difference between current condition (weir) and the natural flowing river condition (for a river slope of 0.02%). As observed in Figure ES2, the change in daily evaporation volume between current condition and natural flowing river had a high difference observed during the Millenium Drought (2001 – 2009). In some cases, larger flows correlated with lower differences in evaporation volume. However, this was not consistently observed for all the time series analyses.

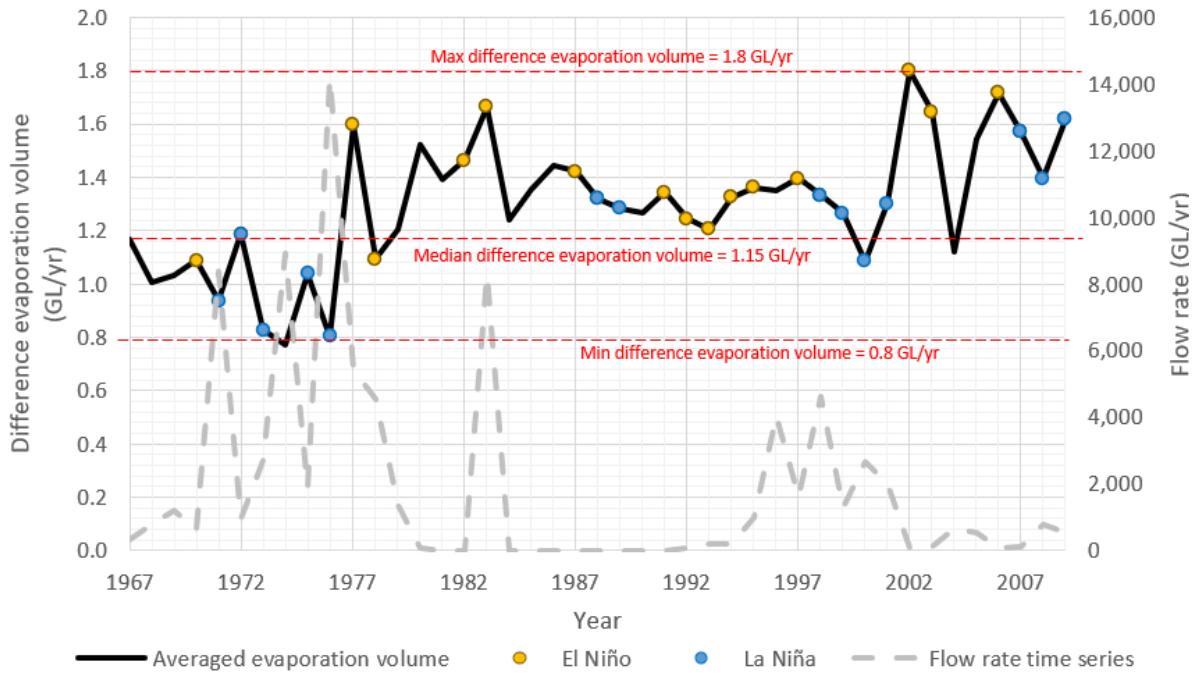

Figure ES2 Yearly difference of evaporation volume with and without the weir, plotted with annual flow.

Figure ES3 presents a box plot of the monthly difference in the evaporation volume. The monthly analysis showed higher evaporation volumes during warm months, highlighting higher water-saving opportunities would occur during the summer periods. Higher variability was also observed during the warmer months, while winter months presented more constant values.

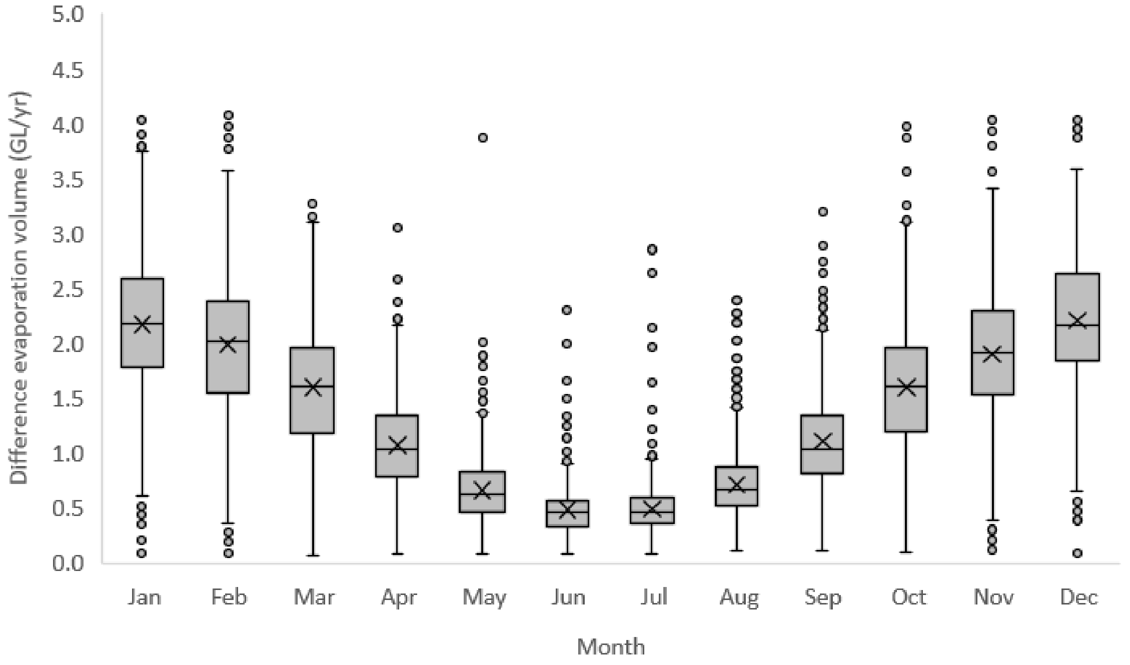

Figure ES3 Box plot of volume of evaporation difference per month, including mean (X), median (horizontal line), 25th and 75th percentiles (rectangle limits)

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1 Background

The analysis was conducted in Weir 20A, located in the Darling River, upstream of Louth town (- 30.4766 S, 145.2594 E). It has a width of 60 m and a height of 4 m. The crest of the weir is located at 88.5 m AHD, and the upstream river bed is at 84.5 m AHD (WaterNSW, 2020). There are no bathymetric surveys in the Darling River and no information on flows, flow depths and evaporation at Weir 20A. Therefore, the data provided in this letter report is based on the information identified in nearby stations or estimated based on DEM data (as indicated in Section 3).

Figure 1.1 Upstream view of Weir 20A (WaterNSW, 2020)

2 Methodology

The estimation of the evaporation difference between the current condition (weir) and the natural flowing river (without the weir) was undertaken following the next steps:

- **Step 1:** Identify the river banks and river slope using the most recent Digital Elevation Model (DEM). The study was conducted using a 5 m DEM obtained from NSW Government with a horizontal accuracy of ±1.25 m and vertical accuracy of ± 0.9 m. Note that DEM data was used due to the missing bathymetric information for the Darling River.
  Based on the 5 m DEM, a constant river slope and one cross-sectional section (assumed trapezoidal) were selected based on the average of three transects along the river channel. The single trapezoidal cross-section in the river was extrapolated to estimate the bathymetry not detected by LiDAR. While it is understood that the slope and river banks will not be constant, this simplified version provides an approximate estimation of the flow conditions. An updated bathymetric survey would provide more precise information on the river hydrodynamics.

- **Step 2:** Time series and statistical analysis of daily historical data of flow rates and flow depths. The information was obtained from the WaterNSW historical information at the Louth Weir.

- **Step 3:** Time series and statistical analysis of daily historical data of evaporation. The information was obtained from the Bureau of Meteorology at Bourke Station (Station 048013, 048239).

- **Step 4:** Estimate flow depths for both conditions (with and without the weir). The flow depths were calculated by setting up a one-dimensional numerical model. The model used in this study was the finite element hydrodynamic model (RMA-2) (King, 2015) which can model the system's hydrodynamics in well-defined channels. The model resolves the flow depth by considering gradually varied flow conditions (backwater calculations) and the Manning equation (Equation 1).

$$\boldsymbol{Q = \frac{A_w}{n} R_h^{2/3} S^{0.5}} \tag{1}$$

  Where Q is the flow rate, A_w is the wetted area, n is the Manning coefficient, R_h is the hydraulic radius and S is the river slope.

- **Step 5**: Estimation of surface area based on the flow depth estimated in Step 4 and the channel bathymetry. The surface areas were calculated as the product between the length of the weir pool and the channel width.

- **Step 6**: Estimation of the difference in evaporation volume between the current condition and the naturally flowing river. The evaporation volume was calculated as the product between the surface area and the evaporation. Note the present study considered as negligible the impact of flowing water on the evaporation rate. However, under flowing conditions, evaporation rates could be larger compared to stagnant flows (e.g. lakes) (Maheu et al., 2014).

The data sources, type of data, dates and location are summarised in Table 2-1.

Table 2-1 Data sources used in the analysis of weir pool evaporation

Data	Type	Date	Location	Source
5m DEM	DEM	2015 and 2017	Louth and Toorale	NSW Government
Flow rates	Daily time series	1904 - 2024	Louth Weir*	WaterNSW
Flow depths	Daily time series	1904 - 2024	Louth Weir*	WaterNSW
Weather data	Daily time series	1967 - 2009	Bourke	Bureau of Meteorology

* Flow depth and flow rate data are also available for other weirs along the Barwon River. Louth Weir was selected as it is the closest to Weir 20A.

3 Results

3.1 Daily historical data of flow rates and flow depths

The flow duration curve and the statistical assessment of daily flow rates at Louth Weir are presented in Figure 3.1 and Table 3-1. Flow rates at the Louth Weir have a median value of 1302 ML/day, with an increase to 2,751 ML/day during summer months and a drop to 733 ML/day during winter months.

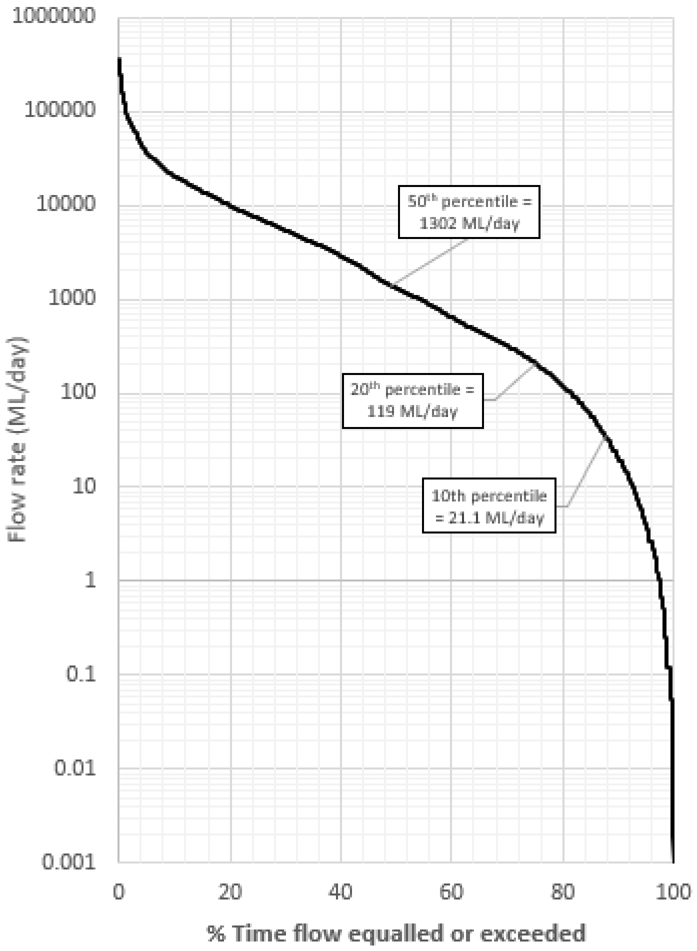

Figure 3.1 Flow duration curve at Louth Weir (Data from 1904 to 2024)

Table 3-1 Statistical data of flow rates in ML/day at Louth Weir (Data from 1904 to 2024)

Percentile	All year	Summer (Dec - Feb)	Winter (Jun - Aug)
5th	3.8	14.2	1.8
10th	21.1	78.2	10.8
20th	119.0	284.2	67.7
30th	318.3	578.1	185.2
40th	639.4	1,353.0	394.3
50th	1,302.2	2,751.2	733.5
60th	2,874.2	4,728.8	1,229.2
70th	5,361.9	8,155.0	2,726.5
80th	9,853.9	14,358.5	5,843.7
90th	20,300.8	26,593.1	13,390.8
100th	359,979.9	327,034.9	260,786.3

The statistical assessment for the flow depth is presented in Figure 3.2 and Table 3-2. Median flow depths at Louth Weir are 3.2 m. Similar flow depths are observed for the summer and winter months.

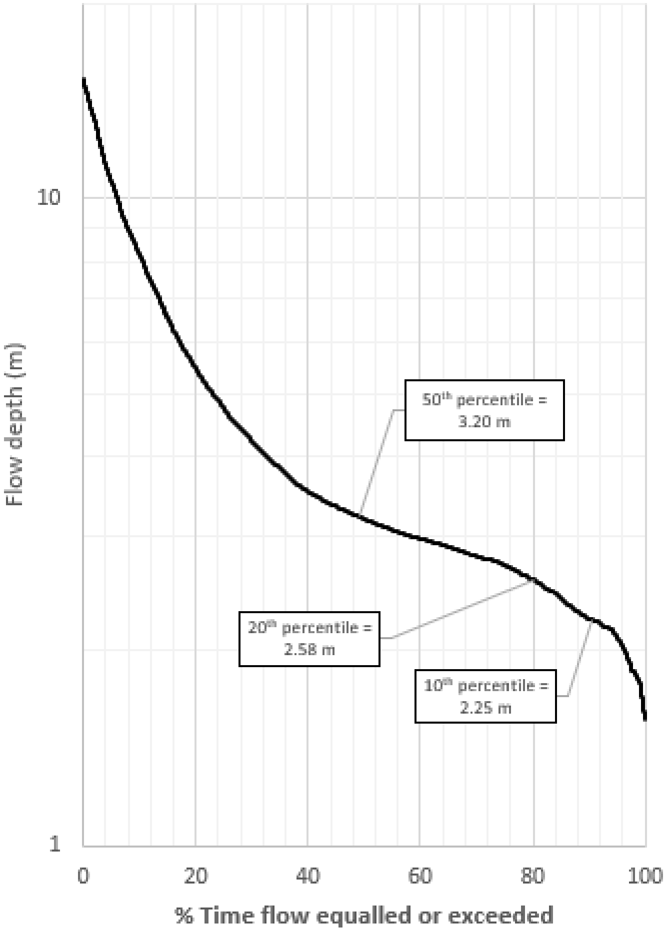

Figure 3.2 Flow depth duration curve at Louth Weir (Data from 1904 to 2024)

Table 3-2 Statistical data of flow depths at Louth Weir (Data from 1904 to 2024)

Percentile	All year	Summer (Dec - Feb)	Winter (Jun - Aug)
5th	2.1	2.0	2.1
10th	2.3	2.2	2.3
20th	2.6	2.6	2.6
30th	2.8	2.8	2.8
40th	3.0	3.0	2.9
50th	3.2	3.2	3.1
60th	3.5	3.5	3.3
70th	4.2	4.2	3.6
80th	5.5	5.5	4.4
90th	8.2	8.2	6.3
100th	15.3	15.3	15.0

3.2 Daily historical data of evaporation

The daily evaporation time series were obtained from the Bureau of Meteorology station at Bourke. The daily evaporation statistical data is presented in Figure 3.3 and Table 3-3. Considering all year data, the median daily evaporation rate is 4.8 mm. Significant differences in the daily evaporation rate between summer and winter seasons are observed with 8.6 mm/day for summer and 2 mm/day for winter.

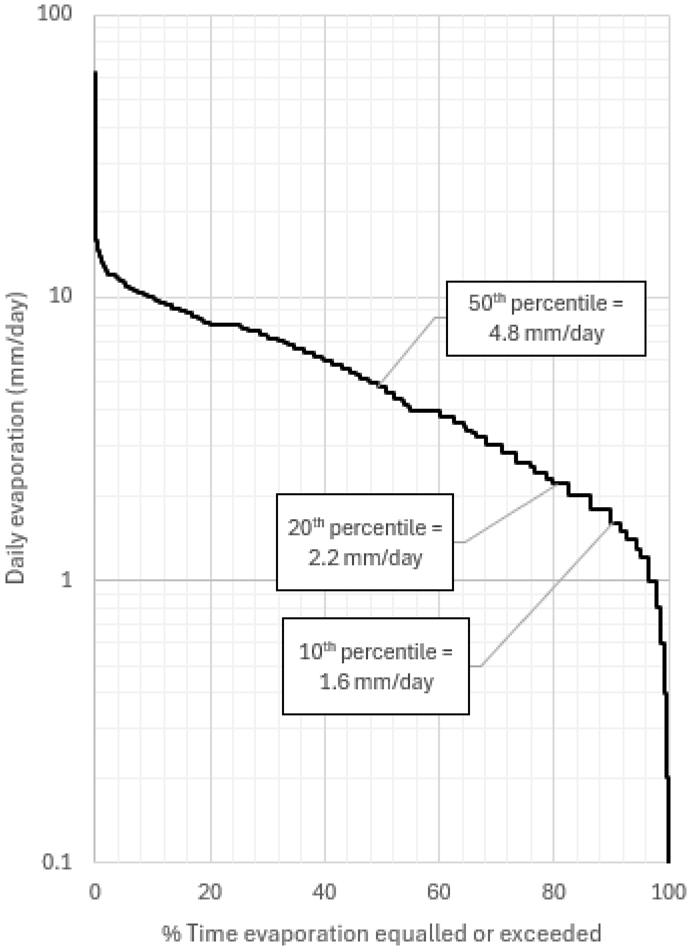

Figure 3.3 Daily evaporation duration curve at Bourke station (Data from 1967 to 2009)

Table 3-3 Statistical data of daily evaporation at Bourke station (Data from 1967 to 2009)

Percentile	All year	Summer (Dec – Feb)	Winter (Jun – Aug)
5th	0.6	1.8	0.4
10th	1.6	5.3	1.2
20th	2.2	6.8	1.4
30th	3.0	7.6	1.8
40th	4.0	8.0	2.0
50th	4.8	8.6	2.0
60th	6.0	9.2	2.4
70th	7.2	10.0	2.6
80th	8.0	10.8	3.0
90th	10.0	12.0	3.8
100th	13.8	15.0	6.6

A comparison between the evaporation data and the flow rates is shown in Figure 3.4. Note the weather data (evaporation data) was collected at Bourke station, and it may not represent the weather data at the location of the flow gauge in Louth. The higher evaporation rates (evaporation higher than 20 mm/day) were observed for the lower flow conditions (flow rates lower than 3,600 ML/day). Most of the higher peak flows (flow rates larger than 4,300 ML/day) occurred for evaporation rates below 10 mm/day (Figure 3.4).

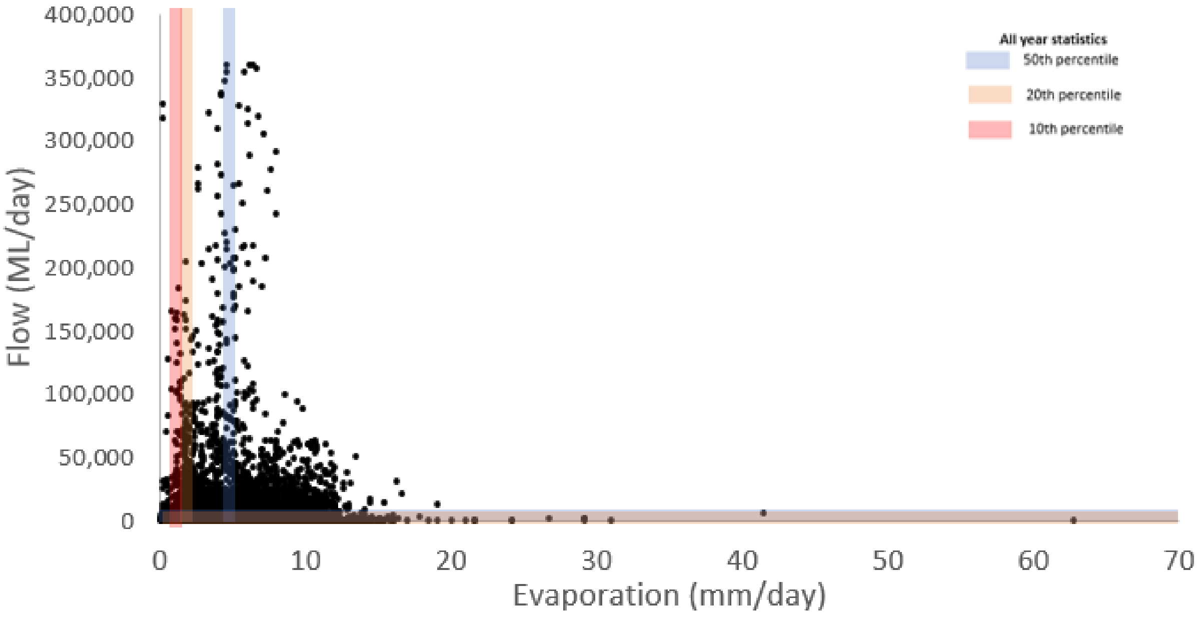

Figure 3.4 Correlation between daily evaporation data an daily flow rates

3.3 Flow depth and weir pool estimation

Weirs are artificial barriers across rivers impacting the hydraulics of the riverine system, such as flow depths and velocities. For certain flow rate conditions, the flow depth could be flat some kilometres upstream of the weir. This region is defined as the weir pool. The length of the weir pool is a function of the flow rates, channel roughness, river bathymetry and river slope. Figure 3.5 presents the elevations upstream of Weir 20A for a flow rate of 864 ML/day and a river slope of 0.02%, including the current condition (Weir 20A) and the natural flowing river condition (considering uniform flows). For this condition, the weir pool is extended approximately 20 km upstream. The weir pool area is characterised by slower flow velocities, deeper flow depths, larger surface area and therefore, higher evaporation potential. An approximated weir pool length for different flow rates is included in Figure 3.6. For the flow rates analysed in the present study, weir pool length are between 20 km for typical flow rates and up to 30 km for extreme flood conditions.

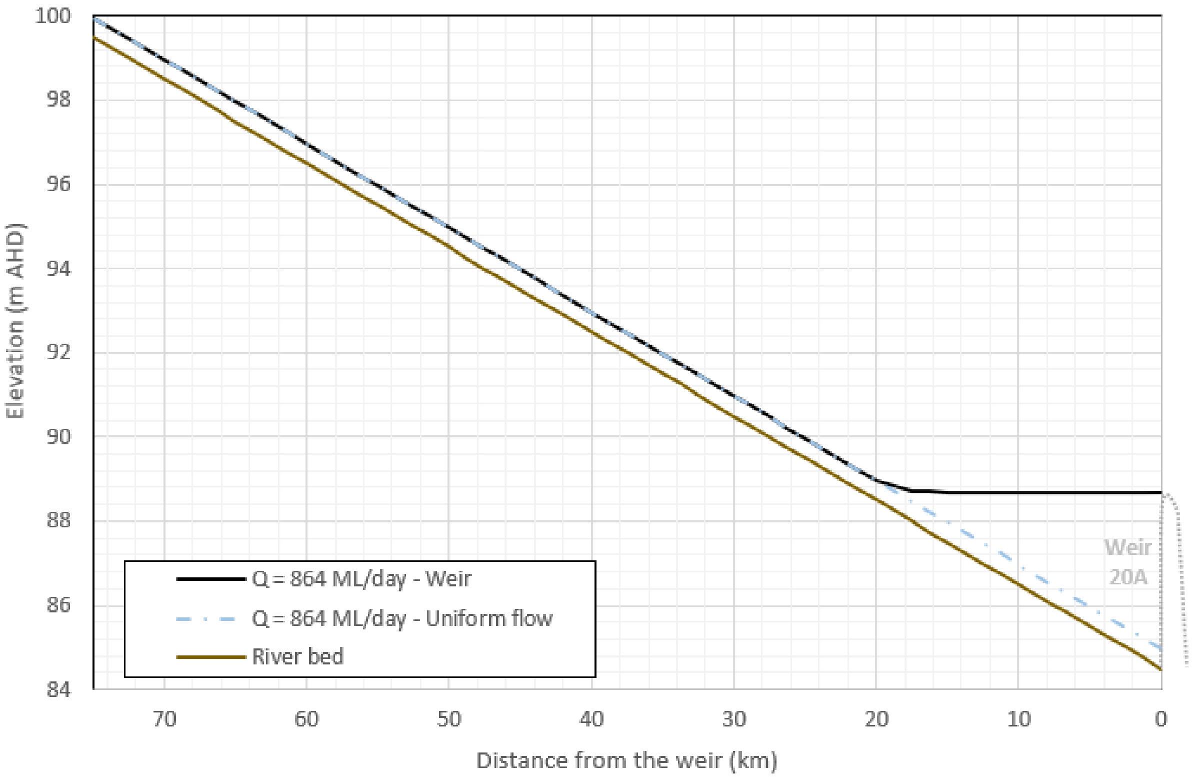

Figure 3.5 Estimated flow depths for a flow rate of 864 ML/day and a river slope of 0.02%

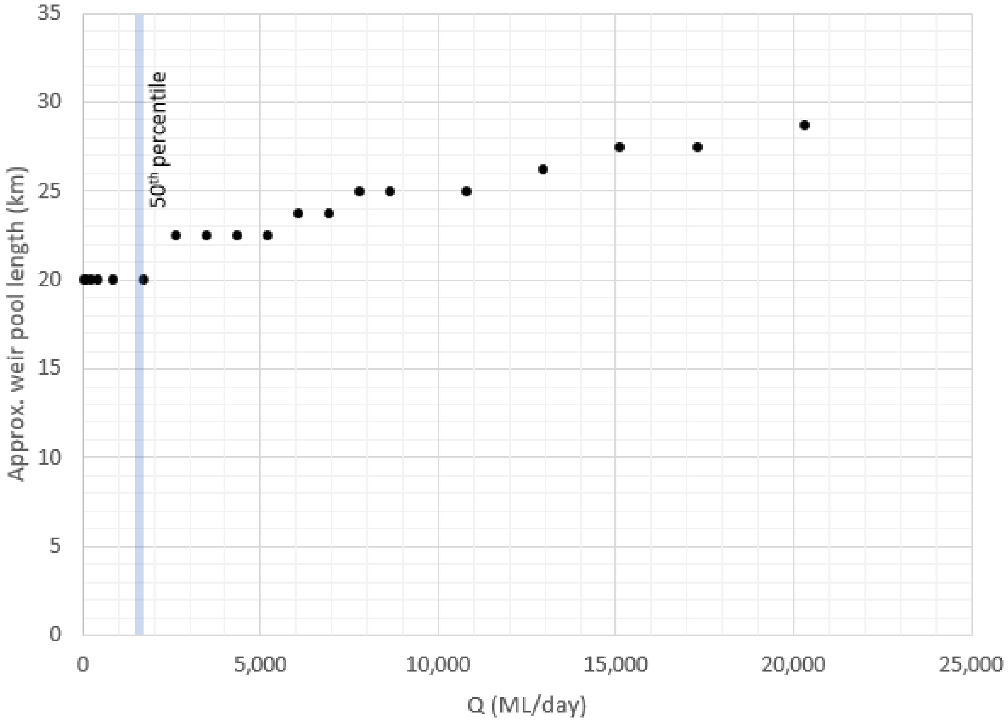

Figure 3.6 Weir pool lengths as a function of flow rates

3.4 Surface area estimation

The surface area was estimated as the product between the width of the river (function of the flow depth and the flow rate) and the weir pool length. Figure 3.7 present the surface area change between current conditions (weir) and naturally flowing rivers as a function of the flow rates. The difference in the surface area decreases with increasing the flow rate as a result of the higher surface area (higher flow depths) for larger flow rates under the natural flowing river condition. Figure 3.7 also shows the 10th, 20th and 50th flow rate percentiles. A sensitivity analysis with smaller slopes showed larger surface area with flatter river beds (Appendix A).

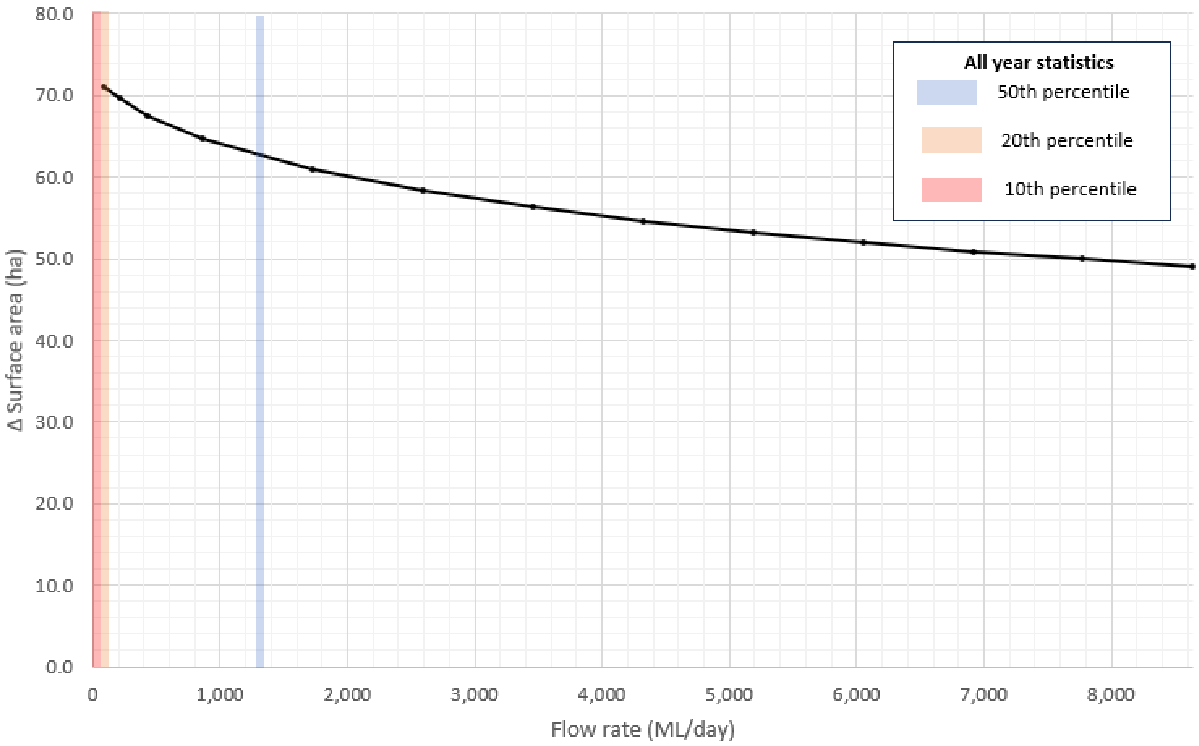

Figure 3.7 Surface area difference between current condition (weir) and natural flowing river (For a river slope of 0.02%)

3.5 Evaporation volume difference

The annual evaporation difference between the current condition and the natural flowing river represents the potential of water savings during a year in the scenario of weir removal. Figure 3.8 presents the annual evaporation difference for different flow and evaporation rates considering a river slope of 0.02%. The evaporation difference is higher for lower flow rates and higher evaporation rates. The annual evaporation difference was 1.15 GL/year for the median flow rate and evaporation conditions. The difference in evaporation is also illustrated in an extreme drought condition in 2019 in Figure 3.8. The reduction in the evaporation volume would have been 2.1 GL/year when considering the period between September and December in 2019. Note that this value is only representative of extreme conditions lasting a couple of months and do not capture the water savings for a whole year. Based on the sensitivity analysis presented in Appendix A, the flatter the river slope, the higher the water savings. Note the analysis was undertaken considering only the daily evaporation data, without considering wind or evapotranspiration. The effect of the latter variables may influence the total amount of evaporation difference in the system.

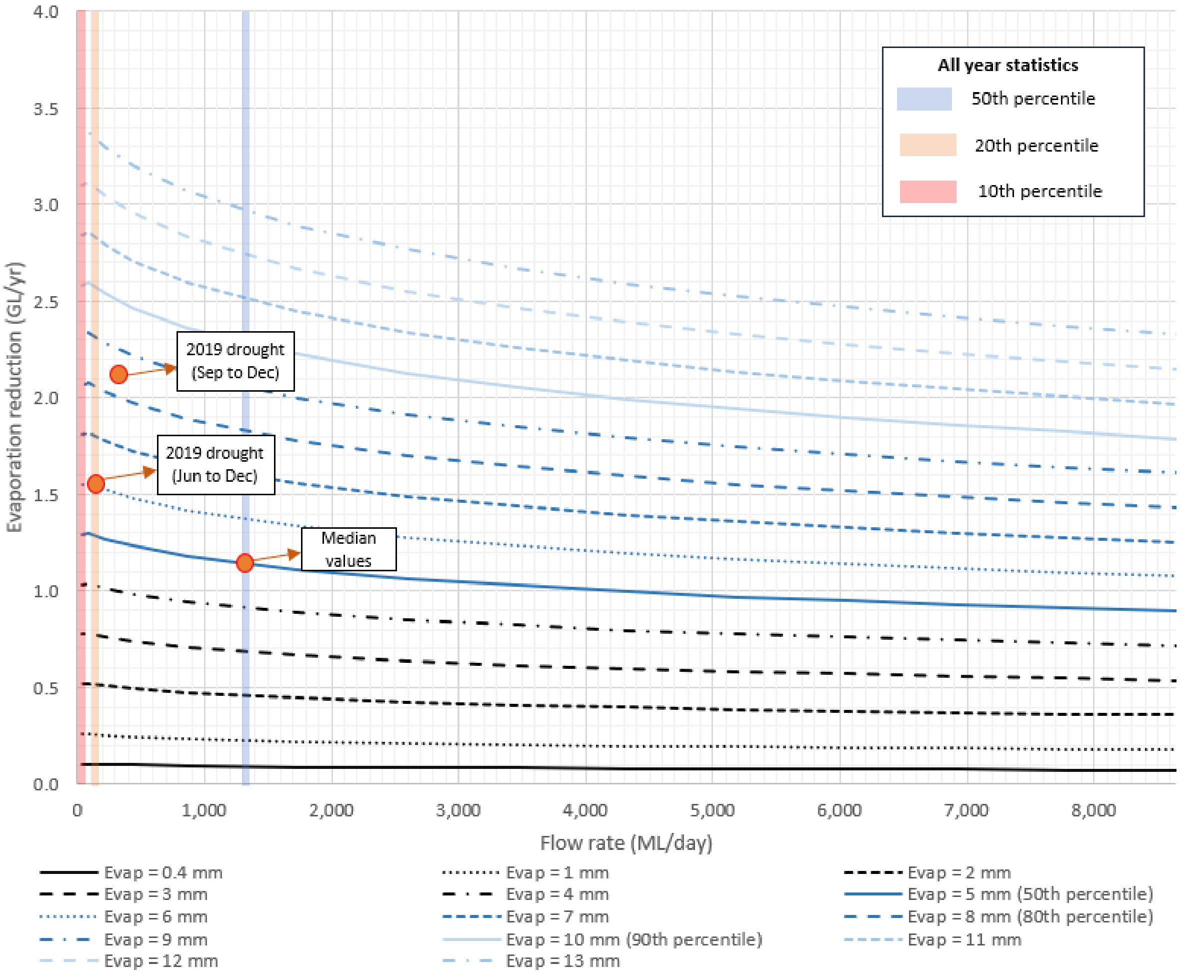

Figure 3.8 Annual evaporation difference between current condition (weir) and natural flowing river (For a river slope of 0.02%)

Based on the information provided in Figure 3.8, a potential evaporation time series was estimated based on the flow rate and evaporation historical data (Figure 3.9). The median volume of evaporation differences between current condition and natural flowing river conditions was 3.1 ML/day. Figure 3.9 also presents a periodical increase in the evaporation difference matching in most of the cases with the summer season.

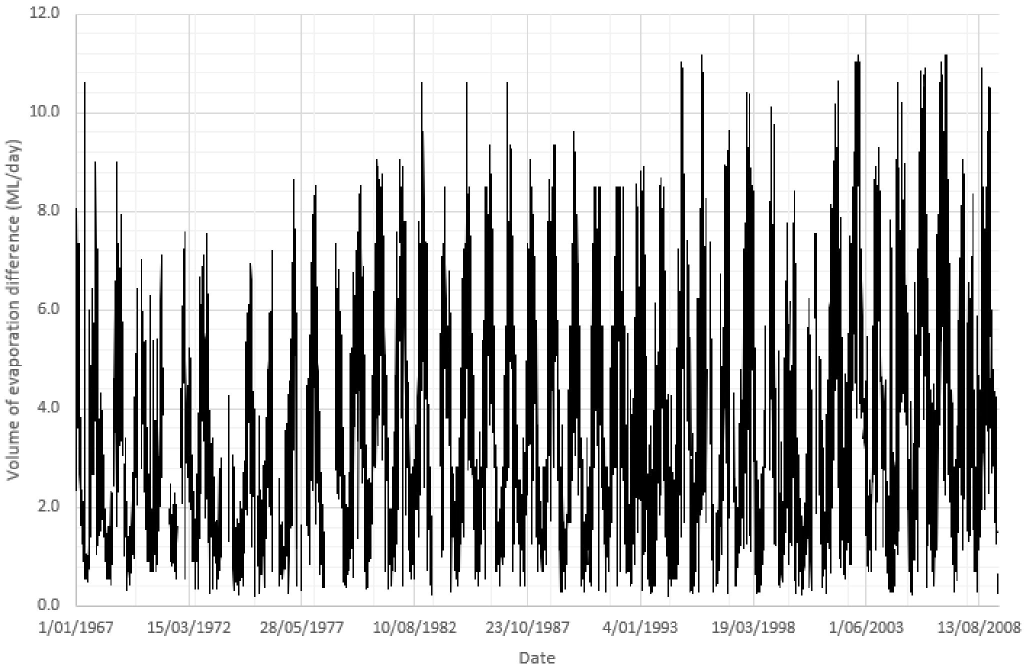

Figure 3.9 Time series of evaporation difference between current condition and natural flowing river based on historical flow and evaporation data (for a river slope of 0.02%)

A temporal assessment of the average daily volume of evaporation difference between the current condition and the natural flowing river is presented in Figure 3.10. Based on the historical data, the change in daily evaporation volume between current condition and natural flowing river oscillated between 0.8 GL/yr to 1.8 GL/yr (Figure 3.10a). During the 60s and 70s, the change in daily evaporation is estimated at approximately 1.0 GL/yr. In contrast, the estimated change in evaporation volume is approximately 1.5 GL/yr in the 2000s, which corresponds to the Millenium Drought. The majority of the peaks in the change in evaporation volume correlate to El Niño events, which is expected due to the strong droughts.

The assessment of the average daily evaporation volumes per month (Figure 3.10 b) shows the impact of summer months with the increase in the evaporation difference between current and natural flowing river conditions. During summer months, the difference in evaporation rates is approximately 2.2 GL/yr, while the difference is 0.7 GL/yr during winter months. This result indicates higher water savings potential during summer season.

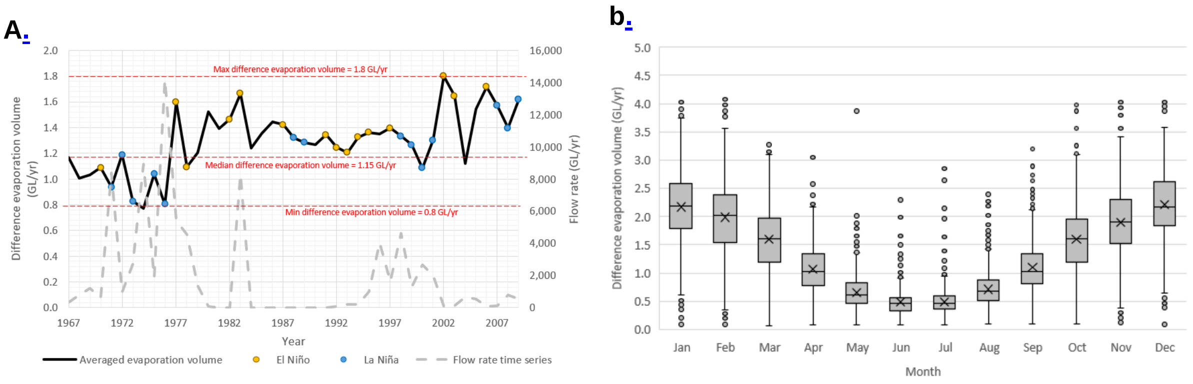

Figure 3.10 Average daily volume of evaporation difference: a. per year; b. per month

4 Summary

The present study estimated the flow depths and evaporation volumes at Weir 20A based on a simplified one-dimensional hydrodynamic model. While this assessment was conducted for Weir 20A, it could be extrapolated to other weirs along the Darling River. The hydrodynamic model generated the flow depth profiles for the current condition (with the weir) and the condition without the weir. Based on the model, flow depths were uniform for both conditions (with and without the weir), but in the region upstream of the weir, the flow depth presented a flat section upstream of the weir, known as the weir pool. The maximum weir pool length identified was approximately 30 km.

The surface area was estimated based on the modelled flow depths and was used to estimate the evaporation volume. The difference in the evaporation volumes between the conditions with and without the weir was a function of the flow rates, river geometry, river bathymetry and river roughness, as well as the evaporation rates. Large evaporation rates on lower flow rates result in higher evaporation volume differences. Therefore, higher differences are expected during the summer season. The water savings in evaporation loss considering median conditions were estimated as 1.15 GL/year.

The values provided in this report are estimates only based on the information on flow and climate conditions nearby. While bathymetric information was estimated based on DEM data, detailed bathymetric data upstream of Weir 20A is required to calculate flow depths accurately in the numerical modelling. Based on a sensitivity analysis considering different river bed slopes, river bed width and bank slopes (Appendix A), river bed slope and bank slopes significantly influence the volume reduction value and should be carefully identified in bathymetric surveys.

Further investigation of volumes required to fill the weir under different weir capacity conditions, and the impact of weir removal on groundwater and surface water interactions are included in Appendix B and Appendix C, respectively.

5 References

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Appendix A Sensitivity analysis

The difference in the evaporation volume is significantly impacted by the river slope and cross-sections. Considering the limited bathymetric information in the Darling River, a sensitivity analysis of different slopes and cross-sections was conducted to identify the change in evaporation volume considering:

- River slope of 0.02%, 0.01% and 0.0036%
- Channel width of 45 m and 73 m
- Bank slope of 4:1 and 9:1 (H:V)

A summary of the sensitivity analysis options and results is presented in Table A-1.

Table A-1 Sensitivity analysis scenarios

Scenario	**River slope (%)**	**Channel width (m)**	**Bank slope (H:V)**	**Roughness coefficient (Manning)**	**Δ Surface area for Q = 43 ML/day (ha)**	**Evaporation reduction median condition (GL/yr)**	**Weir pool (km)**
001	0.02	73	9:1	0.03	70	~1.2	20 to 28
002	0.01	73	9:1	0.03	140	~2.2	40 to 50
003*	0.0036	73	9:1	0.03	> 355	> 5	> 75
004*	0.0036	45	9:1	0.03	> 349	> 4.4	> 75
005*	0.0036	45	4:1	0.03	> 150	> 2	> 75
006	0.02	45	4:1	0.03	31	~0.5	20 to 32.5

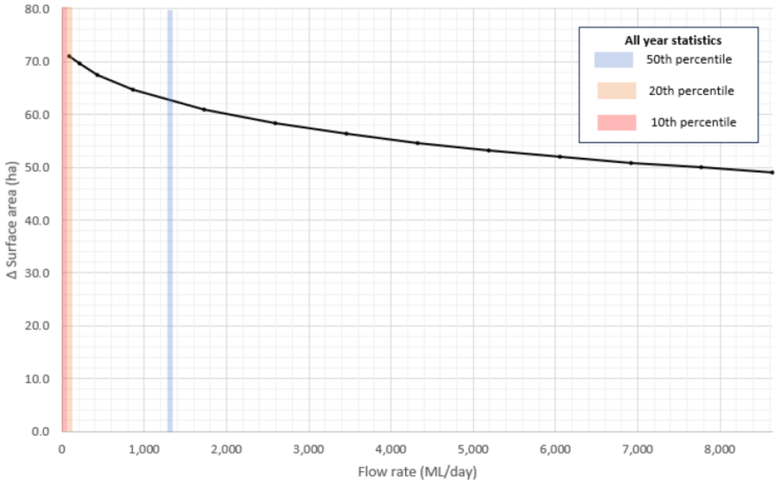
* Flow did not reach uniform flow conditions for the length analysed, so the weir pool length, delta surface area and evaporation reduction would be higher compared to the data presented in this table

Table A-2 and Table A-3 present the sensitivity analysis results for the surface area and volume reduction difference between current conditions (weir) and naturally flowing rivers. Based on the comparison, it can be inferred that:

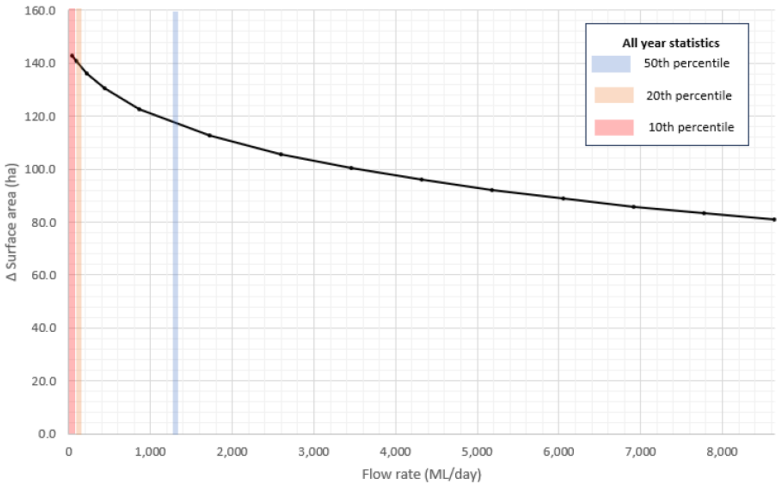
- Evaporation reduction values range between 0.5 GL/yr to more than 5 GL/yr under the bathymetric conditions assessed in Table A-1.
- Decrease in river slope increases the surface area and volume reduction. This is related to the increase in weir pool length for flatter river slopes. For scenarios 003, 004 and 005, no uniform flow conditions were reached for the river length analysed (75 km upstream of the weir).
- Decrease in river bed width resulted in a slight decrease in the surface area and evaporation reduction.
- A bank slope of 9:1 (H:V) represented more than twice the volume of evaporation reduction compared to a bank slope of 4:1 (change was linear). The variation was related to the increase in the width of the river resulting in larger surface evaporation area.

- River slope and bank slope are significantly influencing the surface area and evaporation potential, and should be carefully identified before proceeding with a detailed numerical assessment.

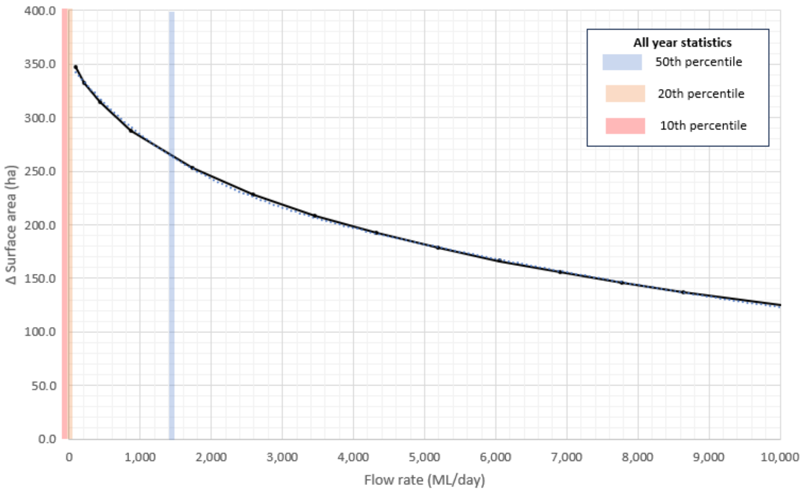
Table A-2 Sensitivity analysis of surface area difference



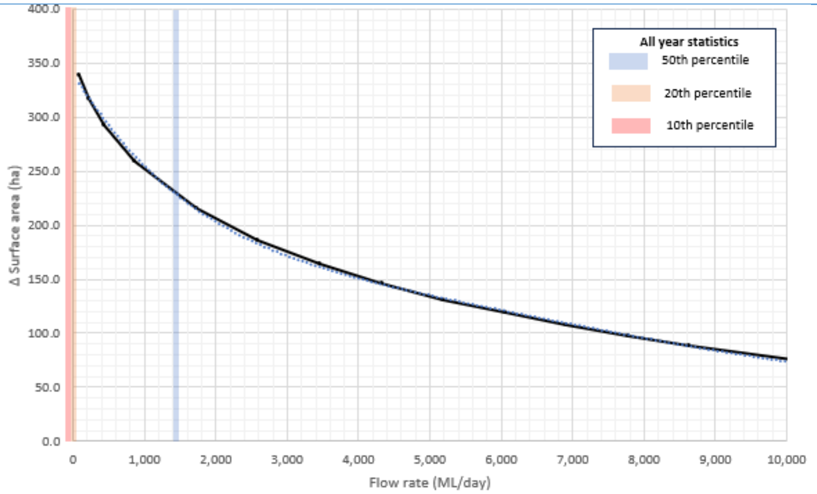
Scenario 001



Scenario 002



Scenario 003



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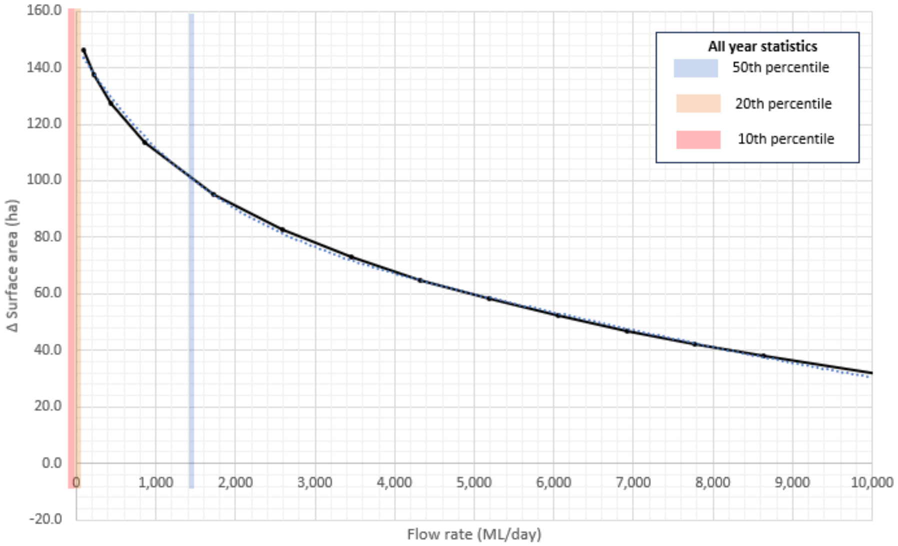

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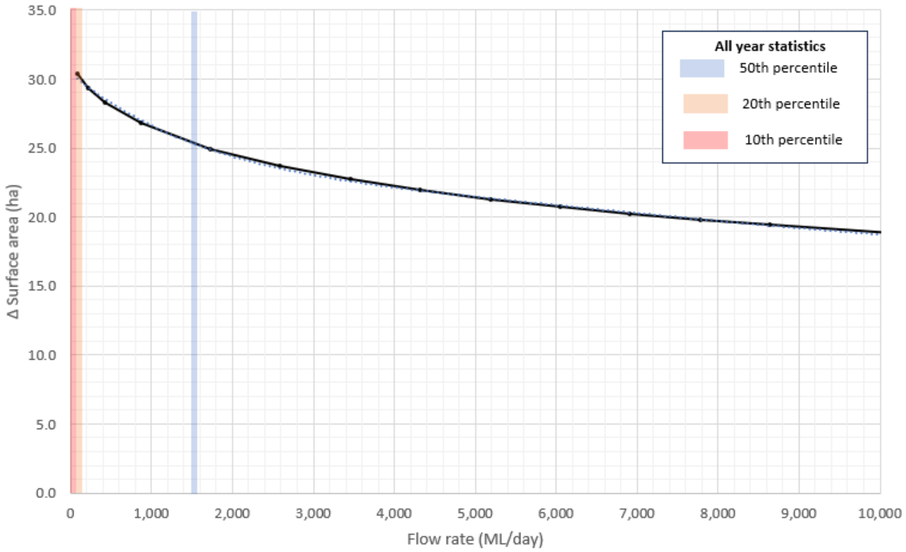
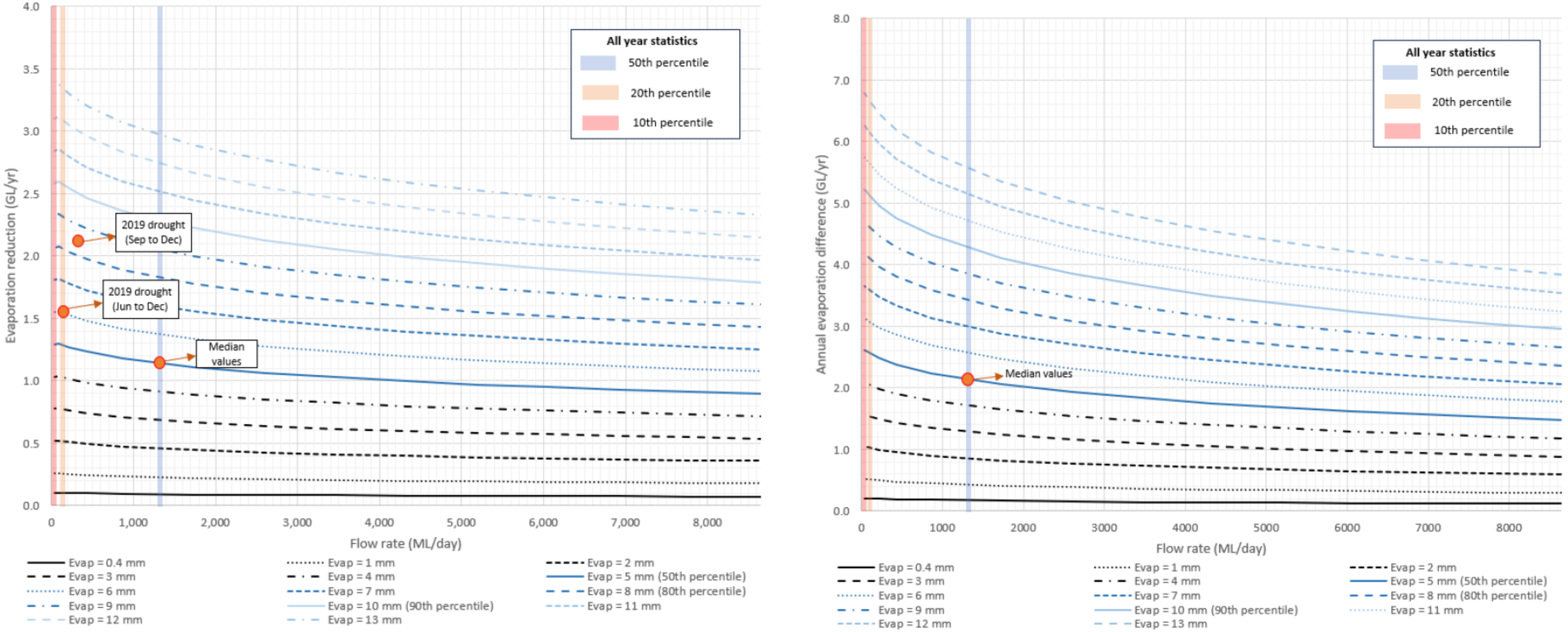


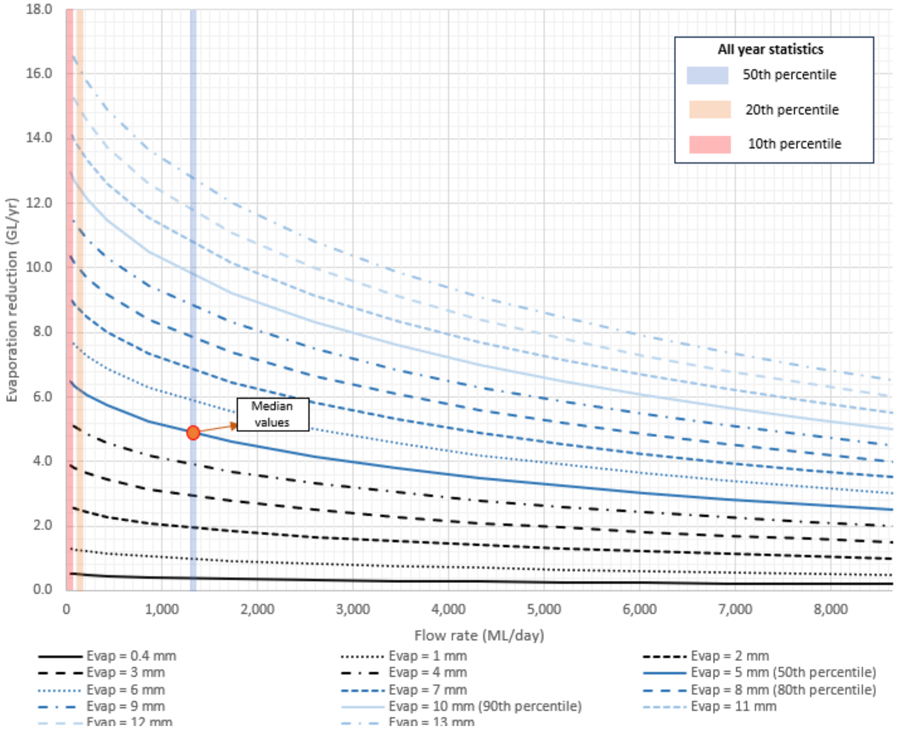
Scenario 006

Table A-3 Sensitivity analysis of volume reduction difference

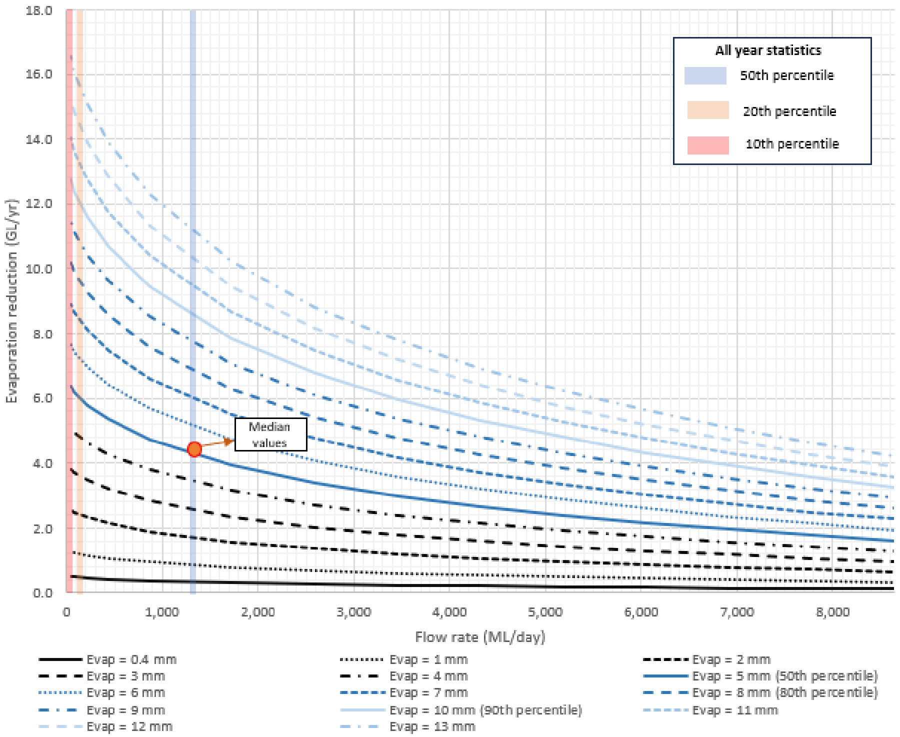


Scenario 001

Scenario 002



Scenario 003



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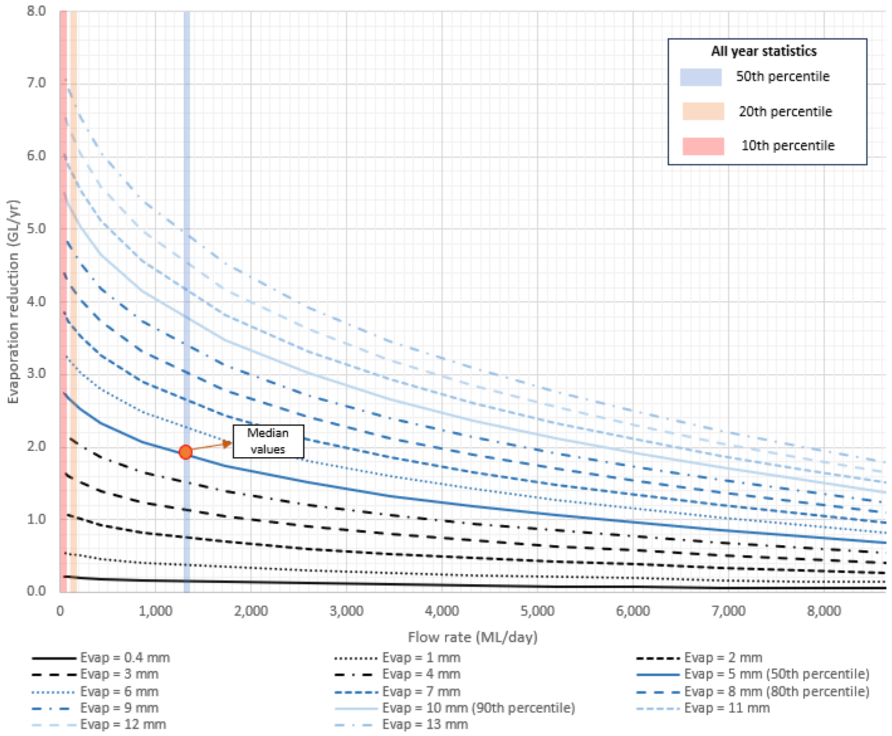

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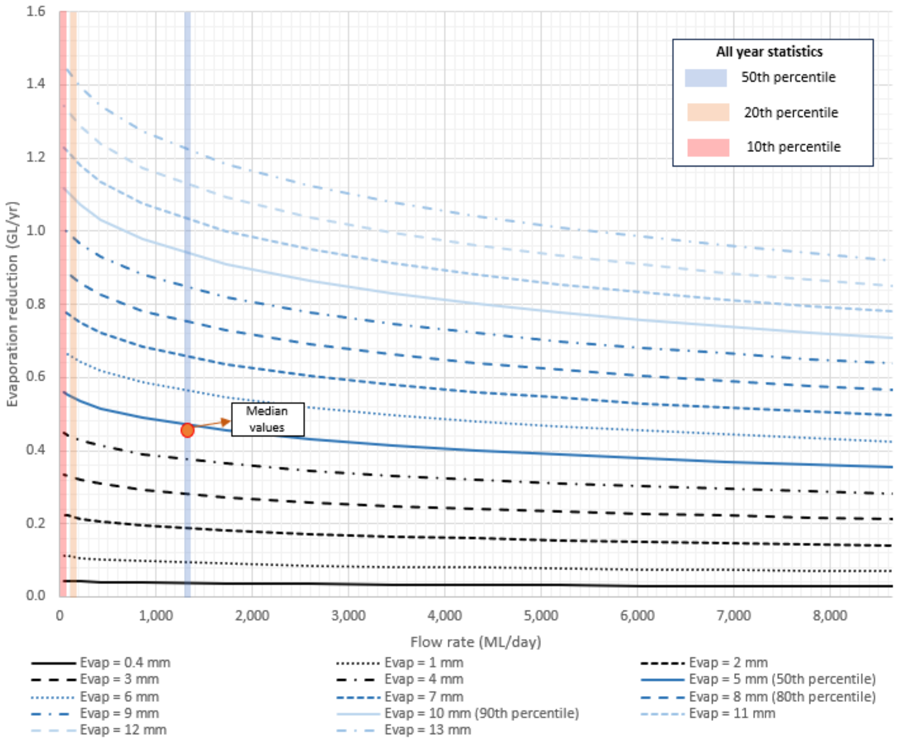

Scenario 006

Appendix B Volume required to fill the 20A weir

This section presents an estimation of the volume required to fill the weir under various initial weir capacity conditions. The volume was calculated considering no inflows (i.e. dry condition) and therefore, the weir pool length corresponds to the distance from the weir to the location where the water elevation extent crosses the river bed (Figure B-1). The volume was estimated as the product between the surface area (surface area = weir pool length x the bank width) and the flow depth elevation. The latter two were estimated based on the bathymetric data (river slope and river banks) identified in Section 4.

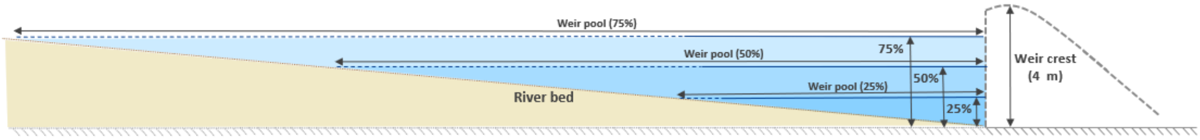

Figure B-1 Conceptual sketch of water level conditions under different weir capacity (Drawing not to scale)

Considering a river slope of 0.02%, the weir pool length is 20 km and the volume required to infill the weir considering fully dry conditions would be 2.9 GL. Table B-1 presents the volume required to infill the weir under different initial weir capacity conditions.

Table B-1 Estimated volume to fill the weir under different weir capacity conditions

Weir capacity (%)	Water depth (m)	Weir crest – water depth (m)	Average bank width (m)	River slope (%)	Weir pool length (m)	Surface area (m^2)	Volume required to infill the weir (ML)
0%	0.0	4.0	73.8	0.02%	20,000	1,476,000	2,952
25%	1.0	3.0	92.3	0.02%	20,000	1,846,000	2,769
50%	2.0	2.0	110.8	0.02%	20,000	2,216,000	2,216
75%	3.0	1.0	129.4	0.02%	20,000	2,588,000	1,294

Appendix C Groundwater (GW) – Surface Water (SW) interactions

C1 Theory SW-GW interactions

There are various processes involved in the interaction between Surface Water (SW) and Groundwater (GW) (Winter et al., 1998), including:

- **Groundwater - surface water exchange**: Streams may either gain or lose water depending on the relative height of the groundwater table compared to the stream's surface. When the groundwater table is higher, streams gain water from groundwater, while they lose water to groundwater when the groundwater table is lower.
- **Stream connectivity**: Streams can be either connected or disconnected based on the saturation of the sediments below the stream. A stream is considered disconnected when the sediments are unsaturated and connected when saturated. In disconnected conditions, changes in the groundwater table do not affect stream water levels (but the stream may still be losing water to the subsurface).
- **Bank storage**: Precipitation, or changes in flow conditions may generate increases in the flow depth, and water will temporarily enter the stream banks. The increase in the stream level will impact the groundwater table surrounding the stream, and the volumetric flow from the stream to the groundwater system. A portion of this water typically re-enters the stream when surface water levels recede after high flow.
- **Human interactions**: Groundwater extraction (pumping) will lower the groundwater table and change the hydraulic gradient between groundwater and stream, which may change the connection and streamwater exchange (i.e. may change the interaction from gaining to losing conditions).
- **Hyporheic exchange**: The hyporheic zone is defined as the area where surface water travels through short segments of subsurface zones until it reaches the stream again. Hyporheic zones are typically observed downstream of a pool in riffle-pool sequences or in strongly meandering streams.
- **Evaporative losses**: In water bodies with slow flow velocities, where the surface area is large, evaporation will also influence the water balance in the system, representing water loses in the system and less available flow for surface-groundwater interactions.
- **Clogging layer due to fine sediments**: Slow water bodies will typically contain a higher volume of low-permeable sediments (i.e. fine grained sediments such as silts and clays) that may lower exchange between surface and groundwater.

Note the interactions between SW-GW are spatially and temporally variable, and therefore, stream gains or losses, flow rates and volumes may vary from location to location, and time to time (Winter et al., 1998).

C2 Potential impacts of SW-GW interactions by removing the weir

The present study also evaluated potential impacts of weir removal on the SW-GW interactions.

C2.1 Long-term impacts

Considering a steady state surface water level (i.e. no temporal effects due to floods), the regional groundwater level will determine the SW-GW interaction. If the weir is removed, the interaction may change according to three possible scenarios. The three scenarios are illustrated in Figure C-1.

1. **Gaining – gaining scenario:** If the steady state groundwater level is above the stream level, the stream would be **gaining** prior to the weir removal. Once the weir is removed, the **gaining** conditions would be maintained and the increasing hydraulic gradient towards the stream (with the lower surface water level) would lead to higher groundwater discharge.
2. **Losing – gaining scenario:** If the steady state groundwater level is below the stream level, the stream would be **losing** prior to the weir removal. Once the weir is removed, if the surface water level falls below the regional groundwater level, the stream would become a **gaining** stream.
3. **Losing – losing scenario:** If the steady state groundwater level is below the stream level, the stream would be **losing** prior to weir removal. Once the weir is removed, if the groundwater level is maintained below the surface water level, the stream would continue as a **losing** stream, but possibly losing surface water at a lower rate due to a smaller gradient.

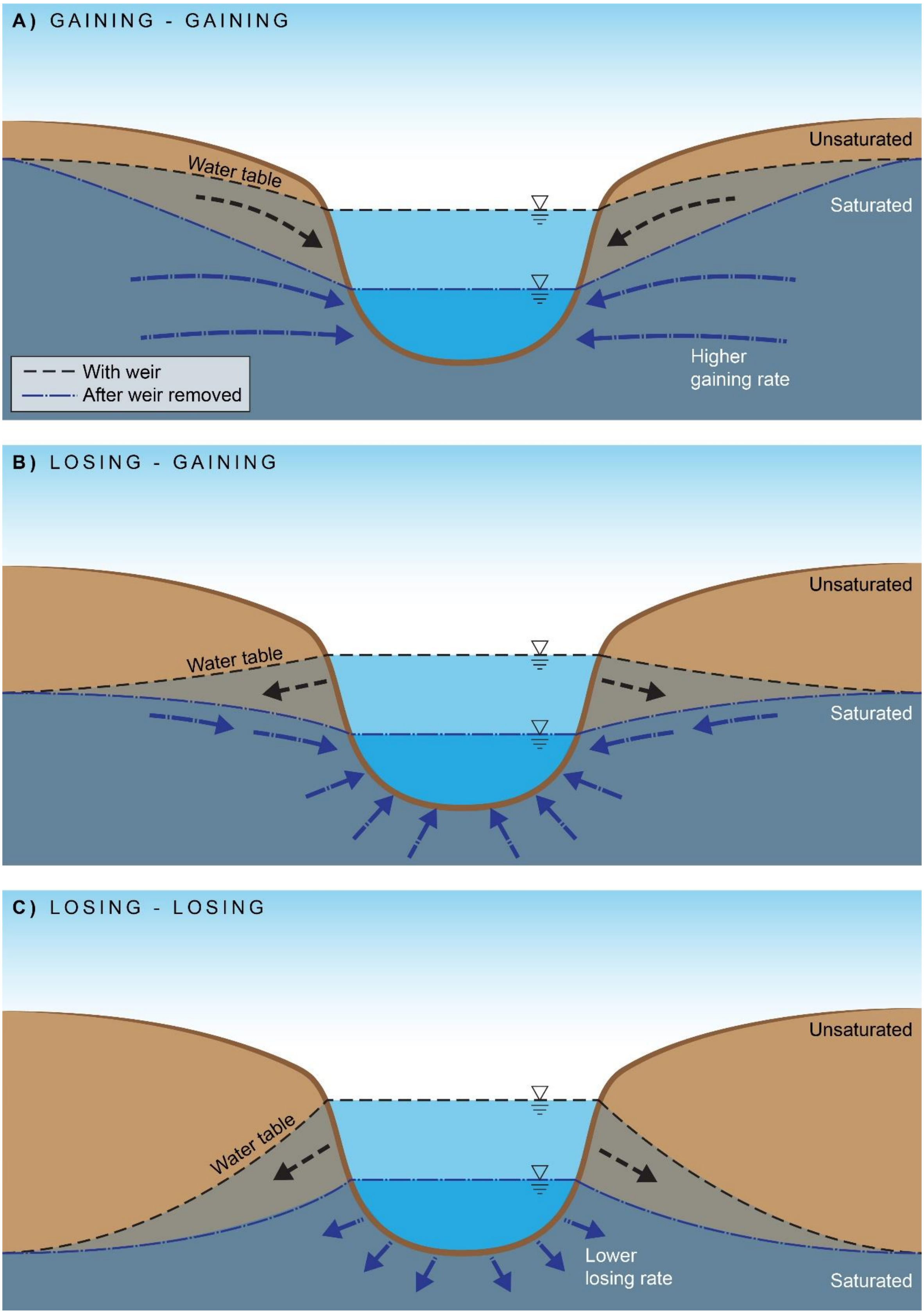

Figure C-1 SW-GW interactions; a. gaining – gaining condition; b. losing - gaining condition; losing – losing condition

C2.2 Transient impacts

Immediately after the weir is removed, the surface water level will decrease rapidly resulting in a transient period of water balance adjustment between the SW-GW levels. This adjustment leads to:

- Increased surface water flow-rates and velocities in the section which used to be the weir pool (i.e. stagnant and slow flows). Such increased flow may lead to erosion of fine grained low-permeable sediments accumulated in the former weir pool section, resulting in an increase in the permeability and hence, an increase in the exchange rate between surface water and groundwater.
- Temporarily or permanently evapotranspiration changes from vegetation near the stream. Since the groundwater level near the stream would decrease, the riparian vegetation, which was able to access the groundwater prior to weir removal, may lose access to groundwater. This will lead to lesser evapotranspiration. The impact in evapotranspiration changes may be temporary (if the vegetation is able to extent their roots deeper over time) or permanent resulting in riparian vegetation decline (if the roots cannot reach the new groundwater level).

C2.3 Comparison surface water loss by groundwater and evaporation

The surface water loss for the losing stream condition could be substantial compared to the water lost by evaporation, depending on the streambed sediment hydraulic conductivity, and the hydraulic gradient. An assessment of the groundwater flow rate considering different water elevations (from 4 m (weir condition) to lower water levels) and sediment types is presented in Table C-1. The groundwater flow rate was estimated using Equation C1:

$$\boldsymbol{Q_{GW} = K \times A_{GW} \times \frac{\Delta H}{\Delta l}} \qquad \textbf{(C1)}$$

where K is the hydraulic conductivity in m/s, A_{GW} is the cross-sectional area in m^2, ΔH is the hydraulic head in m and Δl is the distance in direction of the flow in m ($\Delta H/\Delta l$ is also know and the hydraulic gradient). The assessment assumed a perennial and connected stream with the same sediment type throughout the entire bed, no groundwater extractions along the water table, same river width along the different elevations equal to 100 m and the same hydraulic gradient for different water surface elevations equal to 0.005 (Figure C-2). It is important to note here that the hydraulic gradient ($\Delta H/\Delta l$) will change with a change in the surface water level. It has been kept the same here to illustrate the effect of the changes in surface water level (contact area) and sediment type.

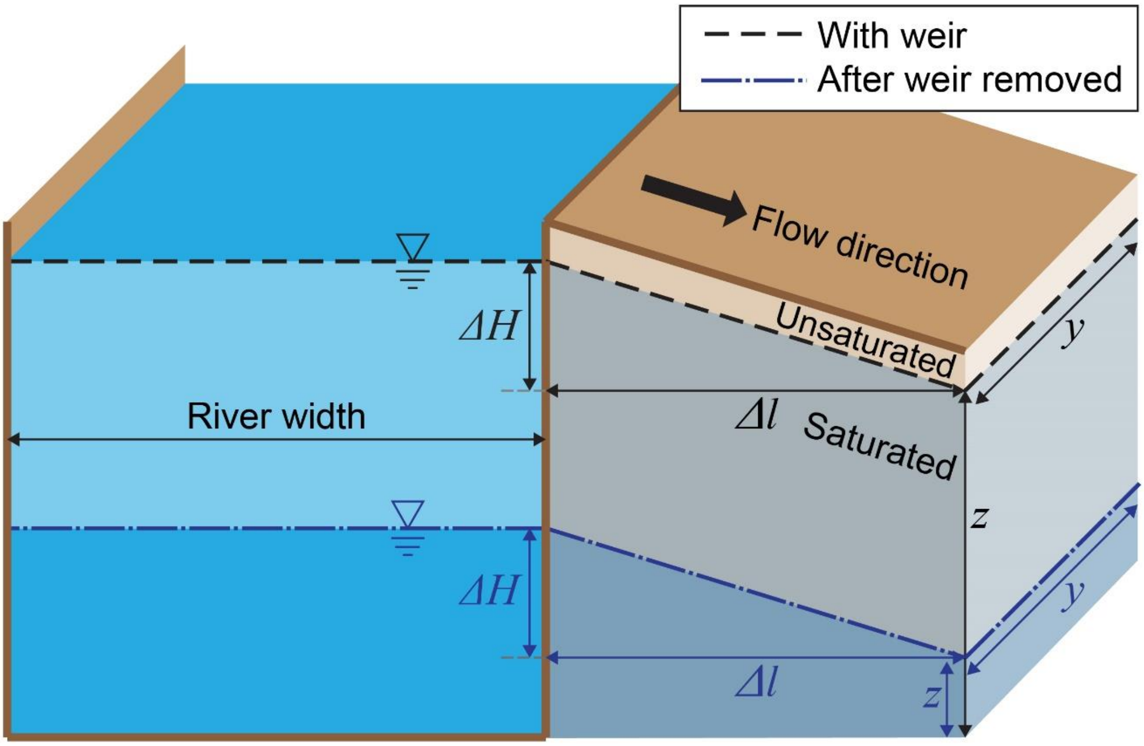

Figure C-2 Conceptual model of impacts on groundwater flow considering higher and lower surface water levels

The assessment involved the comparison between fine sand (high hydraulic conductivity), clayey sand and clay (low hydraulic conductivity). The groundwater flow rate was compared to the evaporation flow rate considering a median evaporation rate of 4.8 mm/day.

For a high conductivity, the groundwater flow rate exceeded the evaporation flow rate by 60% when the surface water level was 4 m (weir condition) while it only represented 5% of the evaporation rate at a surface water level of 0.6 m. This result highlights the substantial influence of surface water level on the groundwater flow rates in environments with high hydraulic conductivity.

In clayey sand, the groundwater flow rate represented 16% of the evaporation flow rate at a surface water level of 4 m, and less than 1% at low surface water levels. For the condition with low hydraulic conductivity, the groundwater flow rate remained lower than 1% regardless of the surface water level, highlighting minor transmission of surface water to groundwater for low hydraulic conductivity sediment types.

Note that sediment types along the rivers in western NSW in some instances are characterised by high hydraulic conductivity sediments (sands and gravel) at the river bottom and low hydraulic conductivity (silts and clay) in the river banks. Hence, an increase in surface water level may have a smaller effect than in our simplified calculations due to the lower hydraulic conductivity sediments higher up the banks. A detailed survey of sediment types along the river banks as well as actual groundwater levels are required for a better quantification of the surface water -groundwater exchange rates along the Darling River.

Table C-1 Comparison groundwater and evaporation flow rates

Surface water level (m)	Sediment type	K (m/s)	ΔH/ΔI (-)	z (m)	River width (m)	A_{GW} (m^2)	Q_{GW} (m^3/day)	Surface area (m^2)	Evaporation rate (mm/day)	Q_{evap} (m^3/day)	Q_{GW}/Q_{evap} (%)
4 (weir condition)	Fine sand	5.1E-04	0.005	3.5	100	3.5	-0.76	149.5	4.8	0.48	159%
3	Fine sand	5.1E-04	0.005	2.5	100	2.5	-0.55	129	4.8	0.48	114%
2	Fine sand	5.1E-04	0.005	1.5	100	1.5	-0.33	111	4.8	0.48	68%
1	Fine sand	5.1E-04	0.005	0.5	100	0.5	-0.11	92	4.8	0.48	23%
0.6	Fine sand	5.1E-04	0.005	0.1	100	0.1	-0.02	85	4.8	0.48	5%
4 (weir condition)	Clayey sand	5.1E-05	0.005	3.5	100	3.5	-0.08	149.5	4.8	0.48	16%
3	Clayey sand	5.1E-05	0.005	2.5	100	2.5	-0.05	129	4.8	0.48	11%
2	Clayey sand	5.1E-05	0.005	1.5	100	1.5	-0.03	111	4.8	0.48	7%
1	Clayey sand	5.1E-05	0.005	0.5	100	0.5	-0.01	92	4.8	0.48	2%
0.6	Clayey sand	5.1E-05	0.005	0.1	100	0.1	0.00	85	4.8	0.48	<1%
4 (weir condition)	Clay	5.0E-09	0.005	3.5	100	3.5	0.00	149.5	4.8	0.48	<1%
3	Clay	5.0E-09	0.005	2.5	100	2.5	0.00	129	4.8	0.48	<1%
2	Clay	5.0E-09	0.005	1.5	100	1.5	0.00	111	4.8	0.48	<1%
1	Clay	5.0E-09	0.005	0.5	100	0.5	0.00	92	4.8	0.48	<1%
0.6	Clay	5.0E-09	0.005	0.1	100	0.1	0.00	85	4.8	0.48	<1%