EXPLORING A FLOW REGIME AND ITS HISTORICAL CHANGES DOWNSTREAM OF AN URBANISED CATCHMENT

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ABSTRACT: The rapid growth of Ballarat's urban area, an inland city of approximately 100,000 people in south-eastern Australia, suggests that it is suitable for stormwater capture and reuse. With a threefold increase in the number of dwellings in recent decades, along with a 90% increase in their average size, it should follow that there is evidence of more flow being generated from the urban areas. However, while additional runoff from the growth of impervious areas may be occurring, the overall flow in the receiving river has dramatically reduced with a 60% decrease in the rainfall-runoff relationship since 1997. This reduction in river flow seems disproportionate to any association with the millennium drought which occurred during 1997 to 2009. The evidence of river flow has been complicated by other changes in the catchment. A change in the rainfall-runoff relationship has been identified in other similar catchments, and may lead to significant impacts on water resource management over the long term. To better understand the impacts on river flow downstream of an urbanised catchment, the flow has been partitioned into various components over time using the daily stream flow data available from 1957. Base flow, calculated as the stream flow after periods of four or more days without rain, has decreased. Transfers, predominantly from other catchments for use as potable supply and entering the river via the waste water treatment plant, have remained steady, but now make up the vast majority of dry weather flow. While climatic variations have impacted the river significantly the actual streamflow reduction has been twice that predicted by data from the Australian Water Resources Assessment. A significant increase in the number of small farm dams due to the expansion of peri-urban living around Ballarat explains a further portion of the flow reduction. This paper highlights multiple factors which influence river flow and demonstrates how increases in urbanised area do not necessarily create additional river flow at larger aggregate scales. The investigation therefore provides a cautionary tale around assumptions of stormwater harvesting and any perceived benefit to river flow, and provides insights into the importance of collecting water information of the correct type and scale to help inform future integrated urban water management efforts.

KEYWORDS: Integrated Urban Water Management, stormwater, alternative supply, urbanisation

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1 INTRODUCTION

Increasing urbanisation and the expansion of impervious surfaces is known to have a significant effect on the flow regime of receiving waterways [1], however the impact on annual average runoff is less clear [2]. While runoff coefficients will increase, there will be less infiltration [3] and higher evaporation may result from increased temperatures due to the heat island effect [4]. Integrated Urban Water Management (IUWM) is being actively encouraged in Australia with the Victorian Government Integrated Water Management Framework for Victoria one example [5]. Studies regularly assume that the increased impervious surfaces will result in additional annual average stormwater compared with the pre-development state, which can then be available for capture and use while protecting the receiving waterway from environmental damage [6-8]. While the effects of urbanisation on the flow regime is an area of considerable research, and urban water balances have been studied to determine the potential resource availability, it is rare for the streamflow of the receiving waterway to be included, so the water balance is not closed, and the total impact of IUWM cannot be assessed.

To enhance the understanding of the impact on a river downstream of a growing, inland city in a temperate climate, a 60 year annual water balance was completed for Ballarat, a city of 100,000 people in south eastern Australia. This found that despite population doubling and a tripling of dwellings, there was no discernible increase in the downstream river flow for the first forty years, with the river flow subsequently reducing significantly. River flow over this period has reduced from 58,000 ML/year to 23,000 ML/year. While some of the decrease can be attributed to the 1997 to 2009 millennium drought, the reduction observed was greater than shown by modelling from the Australian Water Resources Assessment Modelling System (AWRAMS) [9] and the runoff did not return following substantial rainfall and generally wetter conditions in 2011 and 2012. A significant change was also evident in the dry weather flow characteristics of the river, with non-storm flow during the driest three months now almost entirely consisting of discharge from a waste water treatment plant.

A range of impacts on the average annual runoff from an urban catchment in addition to climate were identified, and this paper analyses which of these factors may be most significant in contributing to the observed change in river flow. They are:

- Additional runoff due to increased urban impervious areas
- Changes to the broader catchment character
- Increased use of rainwater tanks in urban areas
- Increased number of farm dams
- Changes to groundwater levels

Changes in runoff due to impervious surfaces has long been understood and has been the foundation of the work on urban hydrology [10]. As this underlies the hypothesis of additional potential water from an urban catchment, it is useful to calculate how much extra water might be available due to the growth of Ballarat's urban area. Similarly, changes in the urban environment will alter the rainfall-runoff relationship [11], so this portion of the catchment must also be considered. While no large storage reservoirs have been constructed within the catchment during the period of this study, there has been a significant increase in peri-urban development with an increase in small farm dams which will change the depression storage and influence runoff characteristics. Rainwater tanks are installed to explicitly capture roof runoff, prevent it becoming stormwater reaching the receiving stream. Sophocleus reminds us of the complexity of the surface and ground water interactions [12] and changes in groundwater are a potential cause of the non-stationarity in the rainfall-runoff relationship observed after lengthy dry periods [13]. It is known that infiltration will be reduced by increased paving [14], and while runoff responds quickly to storm events, a high proportion (up to 75%) of the 'quickflow' may be 'old' water from the soil. This has been called the 'rapid mobilisation of old water paradox' [15]. Changes in groundwater around Ballarat have been included in this analysis to aid the understanding of this dimension to urbanisation and its effects on river flow.

A case study approach inherently concentrates on one situation, and Ballarat may be unique in the rainfall-runoff change and the reduction in river flow which has been observed. Therefore, the method was applied to similar cities to identify if similar changes could be observed.

For each of these factors, which are known to impact streamflow, the potential contribution to the change in river flow has been quantified. While definitive conclusions cannot be drawn on this basis alone, the study does show the complexity of the urban water balance, and the care which therefore must be taken to ensure that IUWM does not lead to unintended consequences. The absence of water information, of the correct type and scale, makes these types of investigations difficult.

2 METHOD

The magnitude of the change due to transfers to and from the river, the effect of climate using AWRAMS [9] results, and the reduction in dry weather flow were explored in an accompanying piece of work [16]. Here, the five additional potential causes of a change in the rainfall-runoff are considered.

2.1 WATER FROM URBANISATION

The increase in roof area due to more dwellings, and the coinciding paved areas such as roads, pathways, driveways, sheds and parking areas have increased the area of impervious surfaces in Ballarat. The number of dwellings has been estimated from connection data in water utility annual reports [17]. Average new dwelling size over time is available from ABS every year from 1986 and for single years in the 1950's [18]. A constant percentage increase per year in dwelling numbers was assumed between 1957 and 1986 due to relatively steady increase over this period. The number of new dwellings each year multiplied by the average size of new dwellings gives the increase in roof are per year. The ratio of total impervious area (roads, driveways, carparks and houses) to residential dwellings in other research have been estimated to be 3:1 [14], however aerial imagery accessed via Google Maps indicated that within Ballarat, this ratio was 2:1 due to the lower density of urban development compared with major cities. Therefore, the ratio of 2:1 was used to calculate the increase in total impervious area over time. It does not include all the non-residential changes (shopping centres, industrial development) and will therefore give a conservative estimate of the additional water available over time.

The average annual runoff was 13.2% of the catchment rainfall over the period 1957 to 1996. It has been calculated that impervious surfaces can result in 95% of rainfall becoming stormwater [19]. For a conservative estimate of the additional stormwater runoff due to urbanisation in this study, an increase in runoff coefficient to 0.9 was assumed in equation (1).

$$ARO_n = (RA_n - RA_{1957}) \text{ x } 2 \text{ x } Rainfall_n * (0.9-0.14) \quad (1)$$

Where
ARO_n = Additional Runoff in year n (ML)
RA_n = Roof Area in year n (m^2)
RA_{1957} = Roof Area in 1957 (m^2)
$Rainfall_n$ = Annual Rainfall in year n (mm)

2.2 CHANGES TO CATCHMENT

The Yarrowee catchment upstream of the gauging station at Mt Mercer is a mixture of farmland, forest, peri-urban and urban development. The extent of urban development was determined by tracking the change in zoning of land over time. Aerial photographs are available for the Yarrowee catchment from the 1950's [20] and were used to determine the extent of changes in forested and farmland area. While the forested areas have predominantly been maintained, the aerial photography indicates they are reducing if anything although a trend could not be observed over this time period. Lower afforestation would result in higher runoff [11], contrary to the observations made. To take the conservative case in this scenario, it has been assumed that no change in runoff has occurred due to afforested area. Aerial photography could also be used to determine changes in farming practice between cropping and grazing. However, this can be difficult to differentiate from a single photograph [20] at ten year intervals. Personal communication with the largest and long standing land holders in this portion of the Yarrowee catchment [21]have been used to confirm assumptions around land use for farming, and ultimately this change was assumed to be small compared to other observed changes.
Given the relatively small change in afforestation and the assumed small effect of farming use, no further results are presented for the broader catchment impacts on river flow.

Peri-urban development has been a significant change in land use surrounding the city. Allotments from 0.5 hectare to 10 hectares have increased significantly, with many residents installing dams to water horses, gardens or for aesthetic purposes. This is discussed in more detail in Section 2.5.

2.3 RAINWATER TANKS

The use of rainwater tanks, which had been discouraged for many years due to the risk of contaminated supply [22], was encouraged during the Millennium Drought [17], particularly for garden watering and toilet flushing. Water captured in tanks and then used externally has been assumed to evaporate or infiltrate and not end up as river flow. Any rainwater used for toilet flushing will however, go via the sewage treatment plant and discharge to the same catchment, and so will act as a substitute for water that would have otherwise been imported into the catchment for potable supply. Therefore, the effect of all rainwater captured and used is to reduce stream flow. It is difficult to determine the extent of the penetration of the use of rainwater tanks. Research has been undertaken elsewhere into how widespread rainwater tanks have become and the effect this has on water consumption [22, 23], but confirming these results in Ballarat proved difficult. The tendency to install tanks under house eaves prevents the methodology of using satellite imagery to gain an accurate estimate.

A proportion of the actual reduction in internal and external water use per person in Ballarat between 1996 and 2010 has been assigned as the impact of rainwater tanks. This estimate is compared to previous reports into the effect of rainwater tanks and the impact they would have on total water use in Ballarat[24, 25].

2.4 FARM DAMS

The number of farm dams in the catchment has been calculated using visual counts from aerial photographs [20], Google Earth, and current data confirmed using the Victorian Water Asset Database [26]. This also provided details on the surface area for all dams estimated to be over 0.3ML. For smaller dams, which make up 10% of the total dam volume in the catchment, a linear size distribution has been assumed.

STEDI (Spatial Tool for Estimating Dam Impacts) is modelling software that calculates the impact on runoff due to dams [27]. It was initially developed for the Victoria Government Department of Natural Resources and the Environment (DNRE) in 2002 by SKM and has been upgraded over time. It calculates a water balance around each dam, each time step, accounting for inflow, rainfall, evaporation, removals and bypass. The model can be run to predict the impact of future dams or effect of previously installed dams. Time steps can be daily, monthly or annual. The requirements of STEDI software are:

- Stream flow at the desired time step
- Rainfall at the desired time step
- Evaporation at the desired time step
- Dam size
- Dam catchment (% impacted)
- Usage (% storage used annually)

Stream flow, rainfall and evaporation are all available at daily time steps from the Bureau of Meteorology (BOM).

Estimates are required on what portion of the catchment is affected by dams. While GIS data indicates this might be as high as 68% for the study catchment, with only urban and forested areas unaffected, STEDI documentation indicates it is unlikely for catchments to have more than 50% affected area. To determine the sensitivity of this input, cases have been run with the affected catchment area being varied from 30% to 70% in 10% increments.

The water used from each farm dam is difficult to determine with published estimates suggesting 20% of the dam volume may be used each year if it was primarily aesthetic with low use, and up to 70% may be used if it was for irrigation. It is also dependent on rainfall, however the parameter cannot be varied in the model for different time steps. As there is no reliable data for determining usage, cases have been run varying use between 20% and 80%, at 10% increments. The combination of affected area and usage results in 35 different cases being assessed.

While the quantity of dams increased over time, the objective is to determine how significant the increasing number of farm dams is compared with the change in the rainfall-runoff relationship which occurred post 1997 and which did not recover with higher precipitation in latter years. Therefore, it has been assumed that the 1957 – 1996 is the ‘pre-dam’ period and 1997 – 2016 is ‘post-dam’. The model was then used to predict the impact of dams on the 1957 – 1996 river flow data, and the effect of removing all dams was tested against the 1997 – 2016 data.

For each of the 35 scenarios, the measured stream flow was compared with the predicted stream flow from STEDI and linear regression used to determine farm dam impact. In all cases the R^2 value was greater than 0.95. A frequency analysis of flow days was used to select flows at 10% increments from 10% to 90% of expected flow. For these ten daily flows the impact of dams was calculated using each of the 35 scenarios. A maximum and minimum prediction on the impact of dams was then made and applied to the actual daily flows.

2.5 GROUNDWATER

To estimate the base flow of the Yarrowee River the streamflow after 4 or more consecutive days of no rain has been calculated [16] with the contribution from the Ballarat South WWTP removed. Daily flow data from the WWTP is not available for the complete period of study, so for these years annual flow has been divided by the number of days (Equation 2).

$$BF_{daily} = DWF_{daily} - WWTPF_{annual}/365 \qquad (2)$$

Where BF_{daily} is the calculated daily average base flow (ML/day), DWF_{daily} is the average daily river flow (ML/day) after 4 or more consecutive days of no rain and $WWTPF_{annual}$ is the annual sewage treatment plant flow (ML/year). While sewerage flow is reasonably stable, stormwater is known to impact treatment plant loading through inflows and infiltration, with treatment plants typically accommodating these types of flows with wet weather storages and holding lagoons, so this will introduce some errors.

Groundwater data was accessed via the Victorian Water Measurement Information System (WMIS) [28]. These records do not have as long a history as those for the surface water monitoring. Fifteen monitoring and observation groundwater bores were identified in the Yarrowee catchment which have data pre- and post-1997 with the earliest data being available from 1987. For each of these bores, the groundwater level over time was investigated, and a difference in mean level before and after 1997 was calculated to determine if there was a statistically significant change. This does not enable any calculation of the impact on river flow, however, if changes in groundwater level could be related to catchments where rainfall-runoff relationships have been shown to change, this may inform of the importance of groundwater on influencing the non-stationary character of catchments.

2.6 COMPARSION WITH OTHER CITIES

To ensure similar data sets and climatic conditions, comparisons were limited to other cities in Victoria, Australia. The top 50 cities by population were determined, however, there is a very rapid decrease in the size of cities in Victoria when ranked by population. Melbourne, the capital, has over 4.5 million people while Ballarat is the third largest city. The tenth largest city has less than 30,000 people, so urbanisation and impervious surfaces here and in the smaller centres are not easily comparable to major urban areas. Within the Melbourne area, there have been gauges both on the Yarra River, which receives a significant portion of stormwater flow from the suburbs, and a number of tributary streams. However, monitoring has been discontinuous and sporadic, with little or no consistent data for the past twenty years.

There were 23 gauging stations identified downstream of an urban area, but many of these are small towns which would not generally be described as suffering the full-scale impacts of urbanisation. While some data is presented for comparison, the inadequacy of available information highlights the difficulty in completing the water balance and meaningfully assessing the impact of Integrated Urban Water Management.

3 RESULTS AND DISCUSSION

3.1 WATER FROM URBANISATION

The number of dwellings in Ballarat increased from 17,000 to 50,000 [17] and the size from 110 m^2 to 210 m^2 [18] between 1957 and 2016. This resulted in predicted additional stormwater runoff of over 6,500 ML per year by 2016, or about half of Ballarat's total potable water use per year, and is similar to the net import of water from other catchments to the flow of the Yarrowee River. It is 11% of the 1957 – 1996 average river flow and 28% of the post 1997 average.

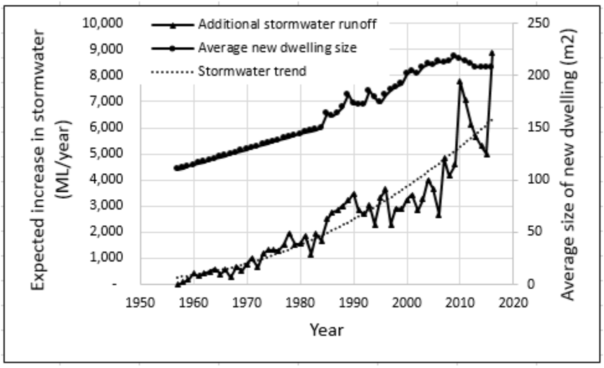

Figure 1: *Increase in predicted stormwater runoff*

3.2 RAINWATER TANKS

A report for the Ballarat City Council determined that between a 20% and 40% reduction in potable water demand could be achieved if there was an 80% penetration of rainwater tanks of 3kL or greater [24]. While the actual installation rate has not been exactly determined, the staged water restrictions between 2000 and 2010, which resulted in the use of potable water outside the home being banned, encouraged the use of tanks for garden watering [17]. New houses are increasingly likely to have tanks installed for garden use and toilet flushing in an attempt to achieve a higher sustainability rating [29]. Average per person water use reduced from 290 litres per capita per day (Lpcd) in Ballarat in 1994 to 200 Lpcd in 2010 [30], with 70 Lpcd of this reduction due to outside water use. Toilet use has been estimated to contribute 35 Lpcd to overall water use in Australian cities [31]. Assuming 50% of the external water use reduction and toilet flushing has been achieved through the use of rainwater tanks as distinct from reductions in total water use, the estimated impact is 60 Lpcd. Given two thirds of homes in Ballarat are within the Yarrowee River catchment, this results in an estimated reduction to annual stream flow of 1,500 ML/year. This is equivalent to 16 % of the total reduction in water use in Ballarat which is comparable with the estimates due to tanks. However, it is just 4% of the observed streamflow reduction that has occurred. While the increasing use of rainwater tanks can have a significant and important impact on the demand for potable water, it is only a minor cause of the reduction in the flow of the Yarrowee River.

3.3 IMPACT OF FARM DAMS

There are currently 5107 identified farm dams within the Yarrowee catchment upstream of the Mt Mercer gauge (Figure 2).

While the assumption used was that these farm dams were all constructed in 1997, it is still useful for the purpose of this study. There has been a major increase in peri-urban development around Ballarat in the past 30 years evidenced by the increase in dams, and this coincided with the Millennium Drought. At the end of the drought, the majority of dams, new and old, were empty or near empty, resulting in much higher surface and depression storage available than had ever been the case. The recovery in the rainfall-runoff relationship may have been impacted at this time in a manner analogous to the assumption of all dams being constructed in 1997.

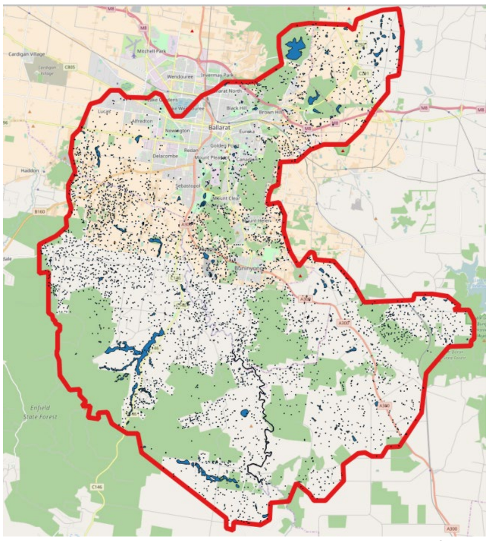

***Figure 2:** Yarrowee catchment showing farm dams*

For each of the 35 scenarios described the actual flow and the predicted flow for both 1957 – 1996 and 1997 – 2016 data was used to calculate a prediction of the impact of dams. The particular example shown in Figure 4 is just one of these 70 cases, using the latter data period with 50% of the catchment impacted by dams, and 60% of the dam volume used each year.

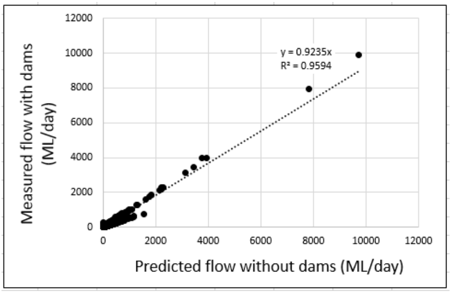

***Figure 3:** 1997 – 2016 daily flow data actual versus predicted flow with 50% catchment area affected by dams and 60% dam volume usage*

The frequency analysis of flow results are shown in Table 1, where the percentage represents the frequency of days on which the flow was at or below the stated value.

The predictions for each scenario were then used for these flows to produce a chart as shown in the Figure 5 example to produce the range of possible impacts from farm dams. Figure 5 shows the median example from 1957 – 1996 with 38 ML/day, and the range of impacts predicted based on the percentage of catchment affected and volume used.

***Table 1:** Daily flow frequency table*

% of Days	Daily Flow (ML/day)	
	1957 - 1996	1997 - 2016
10%	14.1	13.8
20%	18.8	16.8
30%	23.6	20.0
40%	29.4	23.9
50%	38.2	28.9
60%	53.5	35.8
70%	81.4	48.2
80%	142.6	70.7
90%	335.5	127.3

The smallest impact is a reduction of 5 ML/day, occurring when 30% of the catchment is affected and 20% of the dam volume is used. The greatest predicted impact, with more than a 50% flow reduction, is if 70% of the catchment is affected and 80% of the dam volume is used.

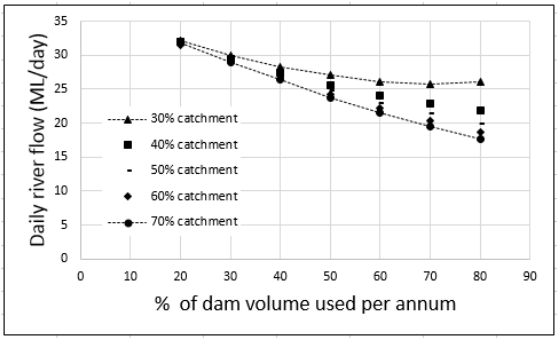

***Figure 4:** Calculated river flow for the 50% flow day 1957 – 2016 of 38 ML/day. 35 scenarios of 30 – 70% affected catchment and 20 -80% volume used per year*

The maximum and minimum impact from the scenarios was then chosen for each of the flows to produce the possible range of impact, and a prediction for any given flow day. Unsurprisingly, the minimum dam impact occurs when the least amount of catchment is affected and smallest volume of water used and conversely for the maximum impact, however, the charts give some idea of the sensitivity of the Yarrowee catchment to these variables.

For every day from 1957 to 1996 the minimum, the mode, and maximum expected flows that would occur if all the dams in the catchment were installed were then calculated. The most likely scenario was chosen to be 50% of the catchment affected and 60% of the volume used. Similarly, this was done for all days from 1997 - 2016

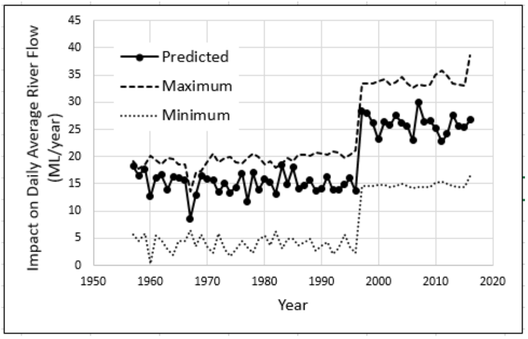

***Figure 5:** Predicted impact of dams on the daily average Yarrowee River flow by year, with minimum and maximum predictions of impact.*

A significant change occurred in the forecast impact occurred when the scenario changed from dams being installed to reduce the 1957 – 1996 flow, compared with removing dams and increasing the 1997 – 2016 flows. The average impact of farm dams on the measured flow from 1957 – 1996 was a reduction of 16 ML/day from 158 ML/day, with the expected range 4 – 19 ML/day. The estimate of the impact on the daily average flow of 65 ML/day from 1997 – 2016 was an increase of 27 ML/day (15 – 32 ML/day). The greater impact of additional storage during times of low flow may be expected, although the step change indicates the change in methodology is significant. Dams will be commensurately emptier when there is lower rainfall and less river flow, and more flow will be subsequently captured within the aggregate farm dam storage following a rain event. Combining the two predictions the estimated effect is a reduction of 21 ML/day (7,500 ML/year) with a range of 3,000 to 12,000 ML/year covering 90% of the possible combinations of affected catchment and use.

3.4 GROUNDWATER

The base flow of the Yarrowee River is shown in Figure 6, with the 1957 – 2016 average of 14 ML/day dropping to 4 ML/day in 1997 – 2016.

This reduction of 10 ML/day (4,000 ML/year) is 6% of the 1957 – 1996 average flow and 17% of the post 1997 average flow.

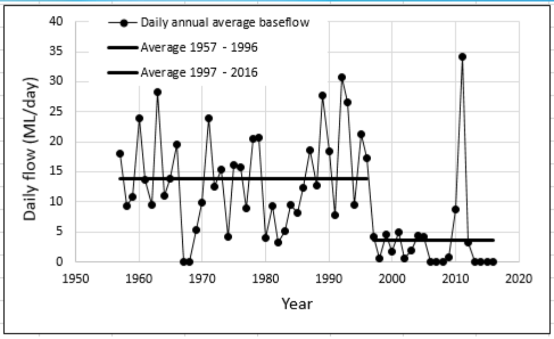

***Figure 6:** Calculated daily base flow of Yarrowee River with 1957 – 1996 and 1997 – 2016 average*

Groundwater levels are shown in Figure 7 for four of the sites within the Yarrowee River catchment. These are considered representative of the range of data. The first bore shows little change over time. The second has a large decrease in level corresponding to reduced rainfall, and then a recovery in level after rain, with a further reduction following. The next chart shows a bore with significantly more variation but a potential reduction in average groundwater depth even after rainfall, and finally a bore which shows a substantial reduction and little recovery.

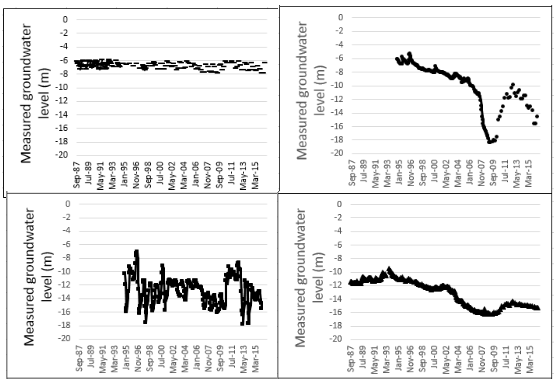

Figure 7: *Groundwater level in four aquifers surrounding Ballarat*

A reduction in groundwater may be expected due to the reduction in infiltration which will occur in an area which has had a significant increase in impervious paving. The reduction in baseflow over time may be attributed, at least in part, to the reduction in groundwater levels. The Ballarat area and the Yarrowee catchment has a number of aquifer systems within the catchment boundary, some of which are exploited for irrigation. This data highlights the variability in the groundwater level. Further work is required to determine the expected decrease in infiltration due to the change in impervious areas and quantifying this impact on base flow. While a reduction in baseflow can be calculated, based on this data no conclusion can be drawn on the degree to which groundwater level has been the cause, or how much of that is due to urbanisation. However, the trend of increased imperviousness, lowering of groundwater and reduction in baseflow all indicate this is worthy of further exploration.

3.5 OTHER CITIES

Streamflow downstream of 23 urban areas or small towns has been collected, and this shows that in every case the average daily flow has reduced in the post 1997-period compared with the pre-1997 period. A student-T test for the comparison of means shows this is a statistically significant change at the 99% Confidence Interval for 22 of these cases, with the other case only having a short data set available prior to 1997.

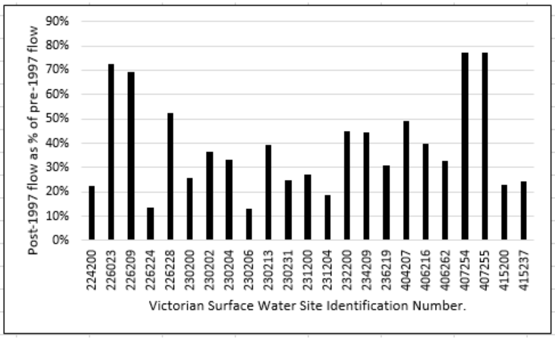

***Figure 8:** Post 1997 daily average streamflow as a % of pre-1997 daily average streamflow for 23 sites downstream of urban areas in Victoria*

The reduction in streamflow for every one of these rivers is consistent with the overall trend of river flow reduction reported in Victoria over this time [13]. It does show that in none of these cases does an increase in urbanisation and additional impervious surface area result in more stormwater flow than has been lost through other changes. This may be expected as the degree of urbanisation in these catchments is generally low. The range in post-1997 flow from 12 to 78% of pre-1997 flow does demonstrate the extent of variation which can occur, and some of this may be due to impervious surfaces. It may be expected that any urbanisation impacts would be proportionally higher in small catchments where there is less non-urban catchment, or larger towns where growth may be greater, but no correlation between these and the percentage change in flow was identified.

The lack of comparative data for streamflows downstream of the major urban areas, such as Melbourne and Geelong, does highlight the difficulty in monitoring the total impact of IUWM. While the additional runoff from impervious surfaces can be calculated, the Ballarat case study has shown that there are other factors which must also be considered, and without incorporating measured streamflow into the total water balance, assessment of the true performance of IUWM is probably incomplete.

3.6 RELATIVITY OF IMPACTS

The relative size of the impacts from the potential causes of the reduction in the Yarrowee River flow are shown in Figure 9. The average river flow for the two periods is after transfers into, and out of the river, have been removed, as described in previous work [16], which also detailed the modelling and predictions for the change in rainfall and temperatures. The solid black bar shows the predicted impact for each variable, while the hashed bar indicates the maximum effect estimated. A minimum effect has also been calculated but for clarity of the Figure has not been shown. In each case the error bar is symmetrical about the predicted value.

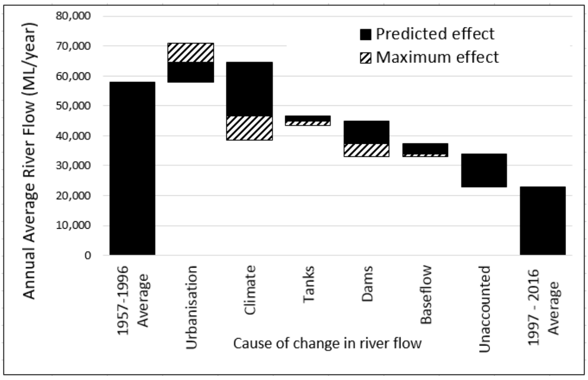

Figure 9: *Annual average flow of the Yarrowee River and impact on flow of various causes.*

Figure 9 clearly shows the biggest impacts are changes to climate and the farm dams in the catchment. While there is some unaccounted reduction in flow, the errors in the estimates are larger than the overall error. The difficulty in accurately predicting each of these impacts and the inability to recreate this in other catchments also prevents more general conclusions being drawn. However, it does indicate the complexity of the urban water balance, and that the cumulative effects of changes to the environment can only be known if the flow of the receiving waterway is appropriately monitored.

4 CONCLUSIONS

Additional water generated from impervious urban catchments is one of the tenets of IUWM, however, studies regularly calculate the additional water available from runoff without confirming this by analysing the downstream river flow. This study has demonstrated a range of complexities when exploring the impacts of urbanisation on the downstream river. The relative impact of the causes identified have been quantified for the Yarrowee River downstream of Ballarat. However, the observations could not be confirmed in other major urban centres in Victoria due to the lack of data availability. This highlights a significant concern in the context of future IUWM efforts. While the complex interactions of the urban water balance are difficult to calculate, the overall effect can be monitored by measuring the flow of rivers downstream of cities, but this data is not readily available. Therefore, the ability to monitor the progress of IUWM is significantly limited. With the increasing importance of identifying alternative water sources and the encouragement of IUWM into day-to-day water resource planning activities, it will be necessary to implement an appropriate monitoring regime to ensure that well intended actions do not lead to unintended consequences. This is not currently possible with the river monitoring arrangements in Victoria, and probably around much of the world, given the historical origins of water resource monitoring and the difficulties usually encountered in changing or adding to government funded monitoring regimes.

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