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Missing in action: possible effects of water recovery on stream and river flows in the Murray–Darling Basin, Australia

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ABSTRACT

We use published water balance data from irrigated cropping to show that water entitlements acquired for environmental purposes through water infrastructure subsidies in the Murray–Darling Basin, Australia, have resulted in smaller increases in net stream and river flows than is estimated by the Australian Government, and may even have reduced net stream and river flows. Two key policy implications arising from our results are: (1) subsidies to improve irrigation efficiency so as to increase stream and river flows must employ water accounting so that the effects on return flows are known and the volume of water extracted for irrigation is adjusted to achieve desired stream and river flows; and (2) *if* the net increases in stream and river flows in the MDB are much less than estimated by the Australian Government, water infrastructure subsidies to increase irrigation efficiency may have compromised the delivery of key objects of the *Water Act (2007)*.

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Return flows; water accounting; water recovery; environmental flows.

1. Introduction

Since the passage of the *Water Act 2007*, the governance of the Murray–Darling Basin (MDB) has been in the process of major policy reform. This reform process is multifaceted and will not be completed, in full, until 2024. Key aspects of the reforms include: (i) the setting of sustainable diversion limits (SDLs) that will determine the average annual levels of extractions of water from surface and groundwater at a Basin and catchment scale; (ii) the purchase, until 2015, of water rights in the form of water access entitlements for environmental purposes; and (iii) the ongoing use of subsidies for water infrastructure to increase both on-farm and off-farm water-use efficiency.

Several recent studies have reviewed the reform process, in part or in its entirety (Crase, O'Keefe, and Dollery 2012; Young 2014; Grafton and Williams 2017; Williams 2017; Grafton and Wheeler 2018; Grafton and Williams 2018; Grafton, forthcoming). Here, we focus only on the possible net effects on stream and river flows from increased 'water-use efficiency' in the MDB as a result of Australian Government subsidies for water infrastructure. While water-use efficiency is the terminology used by the Australian Government, it is more precisely defined as irrigation efficiency or the volume of water beneficially consumed by irrigation to the volume of water either delivered or extracted to an irrigator's fields (Giordano et al. 2017; Grafton et al. 2018).

Our purpose is twofold. First is to highlight the importance of measuring the effects of increases in irrigation efficiency on recoverable return flows, or the water returned to either surface or groundwater that can be later reused for consumptive or non-consumptive (such as stream flows) purposes. Second, in the absence of actual Basin-wide measures of return flows from increased irrigation efficiency, we provide a possible range of the net effect on the volume of stream and river flows in the MDB as a result of the Australian Government water infrastructure subsidies.

Our estimates of the net effect of water recovery on stream and river flows provide a benchmark to evaluate the effectiveness of the Australian Government's subsidies to increase irrigation efficiency in relation to key objects of the *Water Act 2007*. Namely, '3d(i) to ensure the return to environmentally sustainable levels of extraction for water resources that are over allocated or overused'; and '3d(ii) to protect, restore and provide for the ecological values and ecosystem services of the Murray-Darling Basin …'.Our work further re-enforces the critical need for robust water accounting as set down in Article 80 of the Council of Australian Governments (COAG) National Water Initiative (2004) which states:

> The Parties agree that the outcome of water resource accounting is to ensure that adequate measurement, monitoring and reporting systems are in place in all jurisdictions, to support public and investor confidence in the amount of water being traded, extracted for consumptive use, and recovered and managed for environmental and other public benefit outcomes.

Our key conclusion is that the expenditures to date of some $3.5 billion for on- and off-farm water

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Supplementary material for the article can be accessed here

infrastructure to increase irrigation efficiency, and with the stated intent to recover water for the environment, appears to have resulted in a much smaller net increase in stream and river flows than is estimated by the Australian Government (Department of Agriculture and Water Resources 2017; Murray–Darling Basin Authority 2018).

2. Water balance and return flows

A key issue of water reform in the MDB is to reduce the overall level of water extractions and diversions and to increase stream and river flows, especially at the lower reaches of the Basin (Williams 2017). One method employed to achieve this objective has been to provide Australian Government subsidies for both on- and off-farm water infrastructure to increase irrigation efficiency. To date, expenditures on such subsidies are some $3.5 billion (Grafton and Wheeler 2018). In return for accepting the subsidies, irrigators are obliged to provide a portion of the water that is ‘saved’, typically 50%, to the Australian Government in the form of water entitlements. These water entitlements provided by irrigators are included in the water entitlements held by the Commonwealth Environmental Water Holder (CEWH) and are to be used to increase environmental flows.

An important public policy, and also environmental, question is: what are the possible effects of Australian Government water infrastructure subsidies on recoverable return flows (surface and groundwater)? This demands a response because what happens to these recoverable return flows, and that contribute to stream flows, determines the net effect on environmental flows (water entitlements acquired by the Australian Government for environmental purposes less reductions in recoverable return flows) of water infrastructure subsidies.

Increases in irrigation efficiency can, and frequently do, reduce return flows (Grafton et al. 2018). This is long established in the international literature (Jensen 2007; Perry 2007; Ward and Pulido-Velazquez 2008; Qureshi et al. 2010; Batchelor et al. 2014; FAO 2017; Grafton et al. 2018). Importantly, insights from this literature were drawn to the attention of Australian Government agencies during the early analysis of the water reform in the Murray–Darling Basin Plan (Young et al. 2002; ACIL Tasman 2003; CSIRO 2005), clearly stated by Crase and O’Keefe (2009), and acknowledged by the Productivity Commission (2010).

Figure 1 illustrates the Conservation of Mass associated with on- and off-farm irrigation infrastructure when water is extracted for irrigation purposes. The intent of irrigation is to increase crop yields through beneficial transpiration. Concomitant with the delivery of water to crops, there may also be non-beneficial transpiration by weeds and non-beneficial evaporation (both on- and off-farm) that represent water losses to an irrigator and that are consumed for non-beneficial purposes. In addition, a proportion of the water extracted for irrigation is not consumed and returns back as return flows through either seepage to groundwater and/or surface runoff to streams. Return flows that are later recovered and reused and become available for stream and river flows comprise a proportion of the ‘recoverable return flows’. The reduction in recoverable return flows to groundwater, streams and rivers must be accounted for when assessing the net effects on stream and river flows as a result of subsidised changes or upgrades to irrigation infrastructure intended to increase irrigation efficiency.

To provide an estimate of the possible effects on recoverable return flows from increased irrigation efficiency, the total water ‘savings’ (S) at a farm scale that are wholly attributable to an increase in irrigation efficiency must come from:

- Item (ii) and (iii) in Figure 1, namely, a reduction in evaporation from soil and/or water surfaces in

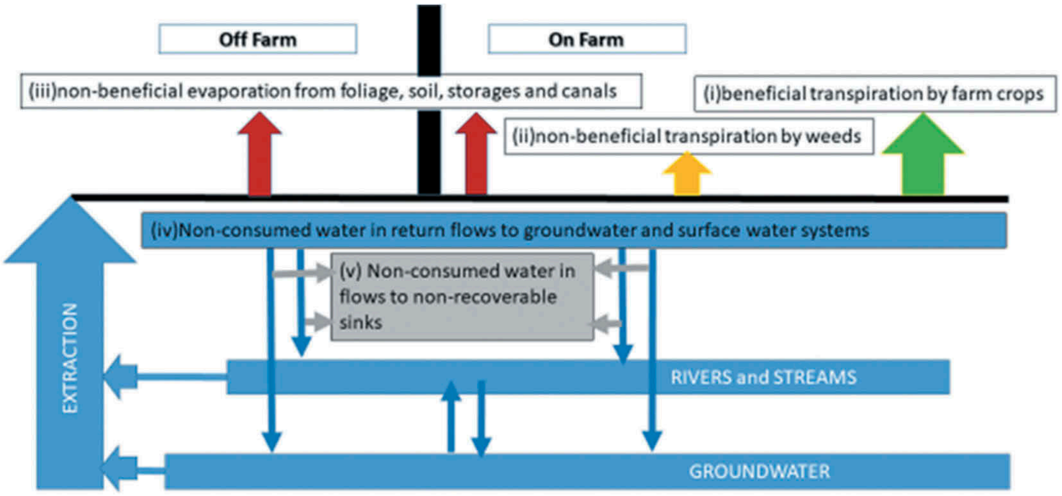

Figure 1. Water flows associated with irrigation.

storages or channels, plus a reduction in evapotranspiration from weeds or other non-crop plants. We designate these reductions as ΔET.

- Item (iv) in Figure 1, namely, a reduction in recoverable return flows from both surface returns to streams and subsurface returns that includes seepage beneath the root zone to groundwater systems, which contribute to stream and river flows (Van Dijk et al. 2006, 23). We designate these surface and subsurface flows as ΔRF.
- Item (v) in Figure 1, namely, a reduction in non-recoverable flows (often saline) to surface lakes, reservoirs and evaporative discharge sites plus non-recoverable seepage beneath the root zone to groundwater disconnected from regional groundwater and streams. We designate these flows as ΔNRF.

The water savings, so described, represent the change in water flows at the farm level that need to be accounted for when evaluating the effects of increases in irrigation efficiency on the net changes in stream and river flows.

Formally, we define the total water savings at a farm scale from an increase in irrigation efficiency as

$$S = \Delta ET + \Delta RF + \Delta NRF \tag{1}$$

It follows that the change in recoverable return flows (ΔRF) can be expressed as

$$\Delta RF = S - (\Delta ET + \Delta NRF) \tag{2}$$

The net effect on stream and river flows (ΔWF) includes changes in conveyance flows (water volumes needed to deliver water for downstream diversions) and environmental flows (water volumes to support freshwater and riparian ecosystems)[1]. The net effect on stream and river flows must account for: (i) the proportion of the water savings that have to be transferred as water entitlements to the Australian Government (V) in return for water infrastructure subsidies and (ii) the average utilisation rate (U) for diversion purposes of water entitlements transferred from irrigators to the Australian government. Thus, the net change in stream and river flows is

$$\Delta WF = S * V * U - \Delta RF \tag{3}$$

where S*V*U is the net reduction in irrigation diversions associated with infrastructure investments to improve irrigation efficiency.

We can simplify the expression in Equation (3) if we define the parameter $F = \Delta RF/S$ such that:

$$\Delta WF = S*(V * U - F) \tag{4}$$

Under the National Plan for Water Security (Howard 2007, 1) the expected reduction in diversions in terms of water entitlements provided to the Australian Government (V) from water infrastructure subsidies is 50% of the estimated water savings, but Wang et al. (2018, vi) state that 64% of the estimated water savings have been provided to the Australian Government. Thus, estimates of ΔWF are provided for both these values of V. Our estimate of the average utilisation rate (U) of water entitlements is from the Murray–Darling Basin Authority (2017, 84, Table 20) and is 0.80[2], but for comparison purposes we also provide calculations where U = 1.0.

Given that we have two possible parameter values for V (0.5 and 0.64) and U (0.80 and 1.0), we have four possible net effects on stream and river flows for a given value of F.

$\underline{V = 0.50}$

$$\Delta WF1 = S*(0.4 - F) \text{ given } U = 0.8 \tag{5}$$

$$\Delta WF2 = S*(0.5 - F) \text{ given } U = 1.0 \tag{6}$$

$\underline{V = 0.64}$

If we assume that 64% of the water savings have been provided in the form of water entitlements, as stated by Wang, Walker, and Horne (2018, vi), then:

$$\Delta WF3 = S*(0.512 - F) \text{ given } U = 0.8 \tag{7}$$

$$\Delta WF4 = S*(0.64 - F) \quad \text{given } U = 1.0 \tag{8}$$

Thus, from Equations (5–8), if all the water savings from an increase in irrigation efficiency are from ΔET and ΔNRF, such that F = 0, then the net change in stream and river flows (ΔWF) is between 0.4S (V = 0.5, U = 0.8) and 0.64S (V = 0.64, U = 1.0). Thus, positive (+) 0.64S represents a net *increase* in stream and river flows and is the best case in terms of the effects on stream and river flows. Conversely, if all of the water savings are from recoverable return flows (ΔRF), such that F = 1, then the water recovery or the net change in stream and river flows is between −0.6S (V = 0.5, U = 0.8) and −0.36S (V = 0.64, U = 1.0), or equal to a 60% or 36% reduction of the total water savings. Thus, negative (−) 0.6S represents a net *reduction* in stream and river flows and is the worst case in terms of the effects on stream and river flows.

Equations (5–8) show that it is not possible to determine the net effect on stream and river flows arising from subsidies for water infrastructure to increase irrigation efficiency without knowing the magnitude of the effect that irrigation efficiency has on recoverable return flows. The only publicly available information on the measured effects of recoverable return flows is a 2010 consultant's report found on the Murray–Darling Basin Authority's website in November 2017. This report gives attention to only surface return flows and does not include sub-surface seepage return flows to groundwater and streams. This 2010 report concludes that while there is a paucity of measurement across the MDB, estimates of end-of-channel flows in 2008–2009 were just 3% of what they were in 1993–1994 (URS Australia 2010), noting that the year 2008–2009 was during the Millennium Drought when water diversions were lower than normal and this would also have reduced return flows.

There is a dearth of publicly available information, based on actual measurements and at a Basin scale, relating to recoverable return flows associated with changes in irrigation efficiency. This is despite the fact that attention was drawn to the potential magnitude of return flows in ACIL Tasman (2003, Section 6), and that Van Dijk et al. (2006, 23–24) and Kirby et al. 2010, 3) both highlighted the critical need to quantify return flows in the Basin.

3. Estimates of water recovery on net stream and river flows in the Murray–Darling Basin

In the absence of publicly available information on recoverable return flows, Figure 2 represents the possible net changes in stream and river flows (ΔWF) in the MDB and that include both conveyance flows and environmental flows. This is based on Equations (5) and (6) and the stated volume of water recovered by the Australian Government, as of 30 September 2018 (Murray–Darling Basin Authority 2018), from subsidies for water infrastructure of some 700 GL/year.[3] Assuming that irrigators provided 50% of the estimated water 'savings' (V = 0.50) to the Australian Government from water entitlements, then the estimated total water savings from subsidies for water infrastructure to increase irrigation efficiency are, thus, some 1400 GL/year.

From Figure 2, under the assumptions given in Equation (6) (V = 0.5, U = 1.0, F = 0) such that there is no reduction in recoverable return flows, the water recovered for stream and river flows is a positive 700 GL/year or 0.5 × 1400 GL/year. By contrast, under the assumption given in Equation (6) (V = 0.5, U = 0.8, F = 1.0) such that all water recovered is from a reduction in recoverable return flows, the net water recovered for stream and river flows is a negative (a *reduction*) 840 GL/year or −0.6 × 1400 GL/year.

To establish a more concise range of the estimated water recovery for the net change in stream and river

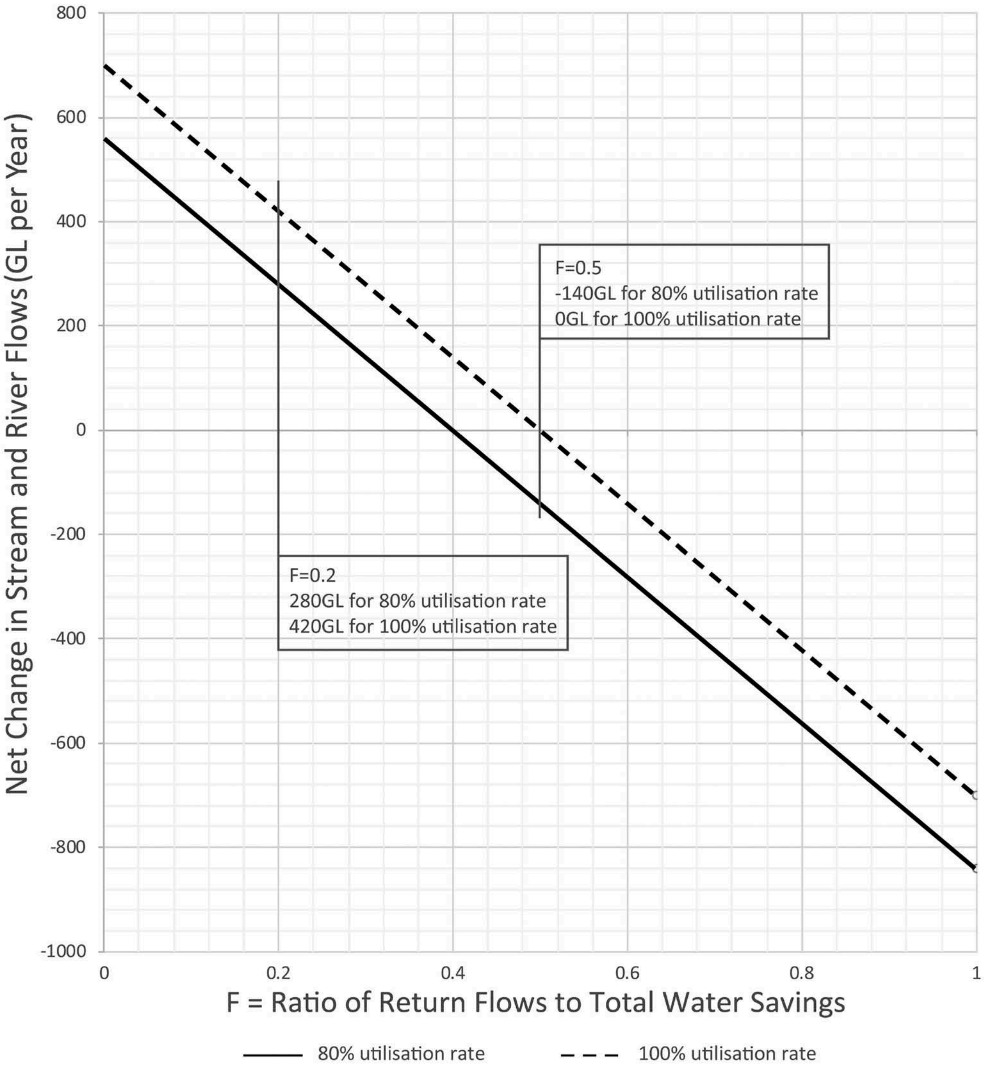

Figure 2. Net change in stream and river flows adjusted for possible changes in recoverable return flows, arising from Australian Government subsidies for water infrastructure to increase irrigation efficiency in the Murray–Darling Basin at two utilisation rates of water entitlements transferred to the Australian Government, namely, 100% (where U = 1.0) and 80% (where U = 0.8).

flows, we have used data from the published academic literature of measures of water balances under irrigation within the Murray–Darling Basin. Roth et al. (2013) provide three water balances. In their Table 4, F can be estimated from the total losses; the proportion of those losses from return flows in seepage and runoff is such that the mean of three estimates is F = 0.35. CSIRO (2005) provides water balances from the Murrumbidgee Irrigation Area (MIA) and Coleambally Irrigation Area (CIA). From the root-zone water balance for the CIA (CSIRO 2005, 15), seepage loss is small (Silburn et al. (2013) and runoff loss is considered to be zero. Applying the change in water balance terms for this root zone water balance when moving from flood to drip irrigation (Grafton et al. 2018, Figure 1), and for two cases, we estimate that F has a value between 0.1 and 0.25 (see supplementary material for calculation details).

If we refer to the international literature, such as Evans and Zaitchik (2008) and their field work in Turkey, we can provide a regional water balance under both flood and drip irrigation. Based on their findings, we estimate F = 0.33 from the savings in both evaporation and seepage return flows when flood and drip irrigation are compared. These estimates of F are in the range 0.3 to 0.35 when savings of losses are dominated by a larger reduction in evaporation rather than runoff or seepage return flows.

The MIA and CIA studies reported by Meyer (2005, Table 28) and CSIRO (2005, 12–15), which consider both on-farm and off-farm flows in an irrigation region, show that the runoff and seepage flows which contribute to return flows can be a large proportion of potential savings of losses from current irrigation practices. These seepage flows are consistent in magnitude to those reported by Silburn et al. (2013) and Ringrose-Voase and Nadelko (2013). For the MIA, total water losses from both off-farm and on-farm are estimated at 250 GL/year (CSIRO 2005, 12) of which 193 GL/year can be identified as contributing to return flows. In such situations, most of the savings will be attributed to reductions in return flows resulting in F values as high as 0.77.

Droogers and Bastiaanssen (2002, Table 2) provide a useful broad-scale verified simulation for flood irrigated cotton and grapes. Their Table 2 details the water balance components for a region in Turkey. If we apply the changes in the water balance implied by moving from flood to drip irrigation according to the data of Evans and Zaitchik (2008, Table 1), or that of Grafton et al. (2018, Figure 1), to the water balance data by Droogers and Bastiaanssen (2002, Table 2), we can compute the total reduction in water loss and how the reduction in water loss is attributed to evaporation, runoff and seepage. Using the Droogers and Bastiaanssen's (2002) water balance studies and applying the Grafton et al.'s (2018) estimates for drip irrigation, respectively, we calculate F = 0.79 and F = 0.80. In these cases, a large proportion of the reduction in water loss or savings in these cases comes from runoff and seepage return flows. Details of these and all other calculations of F from the existing literature are in the supplementary material available from the journal or on request from the authors.

It is important to recognise that the reduction in return flows in these water balance analyses are from both runoff and seepage losses. This is represented in Equation (1) as a combination of reduction in recoverable return flows (ΔRF) to streams and groundwater and non-recoverable return flows (ΔNRF) (often saline) to surface lakes, reservoirs and evaporative discharge sites plus non-recoverable seepage beneath the root zone to groundwater disconnected from regional groundwater and streams. The fact that a recoverable return flow may have a level of salinity as it flows to groundwater or a stream is not necessarily a hazard if the flows of the streams and groundwater are able to dilute these salts and remove them to the ocean (Williams et al. (2002, 461).

The long-term sustainability of an inland irrigation region like those in the MDB is dependent on having sufficient flows in the streams and the groundwater systems to transport the salt to the oceans. This key point is highlighted by Van Dijk et al. (2006, page 6): 'The impact of the risks on river salinity is the balance result of changes in salt mobilisation and changes in stream flow'. Thus, while the identification and quantification of saline non-recoverable flows and its management are important issues across the MDB, this should not be confused with the matter of recoverable return flows that are needed for environmental and water conveyance purposes and contribute to salt export from the basin (Meyer 2005, 26; Khan et al. 2006, 94).

We employ in our analysis a range for F from 0.2 to 0.5, with a mid-point of 0.35 that is consistent with observations in the MDB and international literature. We acknowledge that F will vary from locations across the Basin and that the average value for the Basin may lie outside this range. Further, we highlight that both the nature and magnitude of recoverable return flows and non-recoverable return flows are poorly understood (Van Dijk et al. 2006, 23–24).

From Figure 2 and based on Equation (5) and assuming F = 0.2, the net change in stream and river flows is 280 GL/year (V = 0.5, U = 0.80); while using the value of F = 0.5, the net water recovery for stream and river flows is −140 GL/year (V = 0.5, U = 0.8). If we use Equation (6) and assume the value of F = 0.2, the net water recovery for stream and river flows is 420 GL/year (V = 0.5, U = 1.0); and for F = 0.5, the net water recovery for stream and river flows is zero (V = 0.5, U = 1.0).

If we employ the assumptions of Wang, Walker, and Horne (2018, vi), namely: (i) water entitlements equivalent to 64% (rather than 50%) of water savings have been made available to the Australian Government; (ii) water savings are 1179 GL/year (rather than 1400 GL/year), then the worst case (U = 0.80, F = 0.5) for the increase in stream and river flows is 14 GL/year and in the best case (U = 1.0, F = 0.2) it is 519 GL/year.[4] Wang, Walker, and Horne (2018, vi), however, calculate a lower value of F = 0.10 (adjusted for groundwater and river connectivity factor with an unadjusted value of around F = 0.5) and estimate the *reduction* in return flows to be 121 GL/year with an uncertainty range (assumed to be + and – 10%) from 90 GL/year to 150 GL/year associated with infrastructure intended to increase irrigation efficiency. Further comparisons between Wang, Walker, and Horne (2018) and our estimates is not possible because the justifications for their assumptions (see their Appendix E in relation to information provided to them by the Department of Agriculture and Water Resources) are not available so we are unable to replicate their calculation that F = 0.10 (adjusted for a groundwater and river connectivity factor).

We readily acknowledge there remains a great deal of uncertainty about the actual effect on return flows from increases in irrigation efficiency in the MDB. Notwithstanding this uncertainty, whatever assumptions are employed (F is in the interval 0.2 to 0.5, U = 0.8 or 1.0), including those of Wang, Walker, and Horne (2018), where we interpret V to be 0.64, U to be1.0 and F = 0.1 (adjusted for a groundwater and river connectivity factor), the estimates are that there has been a material *reduction* in return flows associated with on- and off-farm water infrastructure intended to increase irrigation efficiency in the MDB. Importantly, these reductions have not been accounted for in the Australian Government's estimated increase in stream and river flows attributable to water recovery for the purposes of the 2012 Basin Plan.

4. Discussion and conclusions

Our focus has been on the net effect on stream and river flows, but we acknowledge that the environmental water entitlements acquired through water-use efficiency subsidies and that are held by the CEWH can, and do, provide benefits when released from storages in the form of increased base flows and inundation of targeted wetlands (Stewardson and Guarino 2018). Further, we accept that the restoration of ecological values and ecosystem services, as per 3d(ii) of the *Water Act 2007*, are not solely determined by environmental flows (Crase, O'Keefe, and Dollery 2012). Nevertheless, stream and river flows are a key driver of environmental outcomes in the MDB.

The benefits of environmental flows are supported by five actions employed by the CEWH in its delivery of environmental water. These actions include: (i) augmentation of flows for non-environmental purposes; (ii) coordination of flows with other environmental water holders; (iii) piggy-backing on unregulated flows to increase flows; (iv) shepherding, or using the same 'parcel' of water for multiple purposes; and (v) assisted delivery by using water infrastructure to deliver the water and increase its effectiveness. Notwithstanding these actions, it is also important to replicate natural flow regimes in streams and groundwater, as shown in the findings of Wallace et al. (2011, 5). This replication of natural flows also applies to the seepage return flows to groundwater from losses under irrigation areas that may have time lags and also may behave differently to the flooding regime and overbank seepage and recharge of groundwater systems. In the MIA, both Meyer (2005) and Khan et al. (2006) show that after over 60 years of irrigation, the groundwater systems are well established and flow regimes are responsive to water management. In our view, this implies a well-established connectivity in the MIA between deep drainage, groundwater systems and/or stream and river flows.

Our analysis is currently the best available and is transparently calculated from a range of estimates of the water recovery for stream and river flows associated with Australian Government subsidies for water infrastructure to increase irrigation efficiency. Our *best-case* estimate of net water recovery for stream and river flows is +420 GL/year when F = 0.2 with 100% utilisation of water entitlements for diversion purposes, and is +280 GL/year with an 80% utilisation of water entitlements that approximates the current Basin average utilisation rates of water entitlements for diversion purposes. By contrast, the Australian Government estimate of water recovery from water infrastructure subsidies is some 700 GL/year with the implicit assumptions that F = 0 and that U = 1.0.

If we assume F = 0.35, our mid-point estimate of F, and which is consistent with field water balance data for the MDB, the net (+) change in stream and river flows is, respectively, +210 GL/year and +70 GL/year for 100% and 80% utilisation of water entitlements, not the approximate 700 GL/year claimed by the Australian Government. To put this into perspective, and using the mid-point estimate of F and an 80% utilisation rate, the difference between what is estimated by the Australian Government to be the increase in stream and river flows and what we calculate to be the net increase in stream and river flows is some 630 GL/year. This is a volume of water that is greater than the SDL Adjustment Mechanism of 605 GL/year that was approved by the Australian Parliament in May 2018 (Australian Government Federal Register of Legislation 2018).

We observe that Wang, Walker, and Horne (2018) also estimate that there has been a material decrease in return flows as a result of water infrastructure investment to increase irrigation efficiency that is equivalent to 121 GL/year. We note, however, that their lower estimate of reduction in returns flows is strongly dependent on their use of an average connectivity factor of between 0.2 and 0.30 (Wang et al. p. v) to represent groundwater–stream and river connectivity such that a CF = 1.0 means groundwater is fully connected to river flows while a CF = 0 means groundwater is completely disconnected from river flows (Wang, Walker, and Horne 2018, 8). From their data on the source of water saving for the various schemes given by Wang, Walker, and Horne (2018, 66–67), we compute their unadjusted (not corrected for CF) F values which range from a low of 0.41 to a high of 0.96, with a mean of 0.80. This indicates that a large proportion of estimated water savings are derived from water that contributes to return flows. Details of these calculations of F are in the supplementary material available from the journal or on request from the authors.

While the connectivity between groundwater beneath irrigation areas and rivers and streams is not well understood, and there is a high degree of uncertainty in relation to CFs as is highlighted by Wang, Walker, and Horne (2018 8), any CF value must satisfy the Conservation of Mass. In other words, a low CF in the MDB implies increasing stores of groundwater in hydrological isolation from the rivers and streams of the Basin, but fed from seepage and leakage from the irrigated landscape. While groundwater levels vary spatially across the Basin and with inflows, which may decline substantially during droughts, there does not appear to be an increasing trend in basin-scale groundwater levels (Le Blanc et al. 2009). Where there are observations and analysis of sub-basin scale groundwater levels, such as in the MIA, both Meyer (2005) and Khan et al. (2006, 94) show that after over 60 years of irrigation, the groundwater systems are well established. In other words, although they find for the MIA that the total outflow of the aquifers is less than the total inflow to the aquifers, the groundwater flow regimes are responsive to water management.

Here, we assume CF = 1.0 which means that our estimates of the net change in stream and river flows can be interpreted as a longer-term effect associated with increases in irrigation efficiency. We contend that our estimates of changes in stream and river flows at a decadal level, rather than at a time scale of a year or less, are appropriate. This is because the Basin Plan will not be fully implemented until 2024 and because of the large inter-annual variability in irrigation diversions and, hence, returns flows.

If we use our mid-point estimate of F and an 80% average utilisation rate of water entitlements, the actual average cost of increasing stream and river flows per ML from subsidies to increase irrigation efficiency infrastructure in the MDB would be 10 times more expensive than is estimated by the Australian Government. Indeed, instead of some $5000/ML or about 2.5 times greater than the cost of water recovery through the direct purchase of water entitlements (Grafton and Wheeler 2018), the average cost of water recovery for infrastructure grants and subsidies per ML could be as much as $50,000/ML.[5] Notwithstanding these huge cost differences, and the possibly very large differences in the net increase in stream and river flows between our estimates and those of the Australian Government, there has yet to be a comprehensive measurement based on primary data and an audit of the effects of irrigation efficiency investments on recoverable return flows. Nor is such comprehensive water accounting supported by the current Australian Government, despite its own endorsement and that of all Basin governments (except the Queensland Government) that a comprehensive water accounting be part of the 2004 National Water Initiative. Without a comprehensive, independent and adequate measures of changes in the recoverable return flows at a Basin scale, using the best available science and on primary data and measurements, it is simply not possible to know the net change in stream and river flows and the effect on river hydrology and ecology in the MDB as a consequence of the 2012 Basin Plan.

In summary, our findings provide two key policy implications. First, the critical need to comprehensively measure the effects on recoverable return flows of increased irrigation efficiency based on primary data as a result of water infrastructure subsidies. This is especially important given that 'There is no evidence Department of Agriculture and Water Resources undertakes systematic assessments of return flows in its current programs' (Productivity Commission, 2018, 89). Moreover, the need for comprehensive water accounting was agreed to by the Council of Australian Government in the 2004 National Water Initiative, reiterated by Prime Minister Howard in the National Plan for Water Security in 2007 (Howard 2007), and was part of a key recommendation of the House of Representatives Standing Committee on Agriculture and Water Resources in 2017 (Recommendation 1, p. 60). Most recently, the need to measure what happens to return flows was endorsed by Wang, Walker, and Horne (2018, vii) who argue for '…more intensive and on-going data collection, regular evaluation and review of impacts on river flow from groundwater SDLs, irrigation efficiency projects and other factors'. Second, good public policy requires a halt to any further water infrastructure subsidies in the Murray–Darling Basin to increase irrigation efficiency until it can be scientifically determined by how much, if at all, whether such infrastructure subsidies increase net stream and river flows, and at what cost.

Notes

1. Water flow in streams and rivers provides multiple, and not necessarily rivalrous, benefits. Two principal benefits of stream and river flows are: (i) conveyance

flows that transport or convey water needed for downstream diversions and (ii) environmental flows that support freshwater and riparian ecosystems. Given that conveyance flows can contribute to environmental flows, and vice versa, we are not able to identify the effects of changes in irrigation efficiency and return flows separately for conveyance flows and environmental flows. Thus, we focus on the change in stream and river flows noting that this may affect conveyance and environmental flows differentially.

2. Wheeler et al. (2014, Table A1 p. 80 for years 2006–07 to 2010–11) used irrigator survey data and estimated the average utilisation rate of water entitlements for those surveyed to be 72%.
3. The amount of water recovered by the Australian Government as of 30 June 2018 from water-use efficiency grants and subsidies related to infrastructure was 713.1 GL/year (Murray–Darling Basin Authority 2018).
4. Wang, Walker, and Horne (2018) state that water entitlements acquired through irrigation efficiency projects are 757 GL/year. We observe that the MDBA's (2018) latest available information (as of 12 December 2018), for the period ending 30 September 2018, has the water entitlements from infrastructure projects at 713.1 GL (Murray–Darling Basin Authority 2018).
5. The cost calculation by Grafton and Wheeler (2018, Table 2) of some $5000/ML from water-use efficiency infrastructure projects is based on Australian Government data. It supposes that the volume of water entitlement acquired through water-use efficiency subsidies is 700 GL/year and this is equivalent to the estimated increase in environmental flows. If, in fact, the net increase in environmental flows, after accounting for the reduction in recoverable return flows, is only 70 GL/year (F = 0.35, U =0.8), the average cost per ML of environmental water acquired from water-use efficiency upgrades could be 10 times more expensive, or some $50,000/ML. This cost per ML is some 25 times more than the actual average cost of acquiring water entitlements from willing sellers via direct purchases (Grafton and Wheeler 2018).

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