# Maximising Water Storage in South-East Queensland Reservoirs: Evaluating the Impact of Runoff Interception by Farm Dams

David McJannet, Freeman Cook, Mick Hartcher and Stewart Burn

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The Urban Water Security Research Alliance (UWSRA) is a $50 million partnership over five years between the Queensland Government, CSIRO's Water for a Healthy Country Flagship, Griffith University and The University of Queensland. The Alliance has been formed to address South-East Queensland's emerging urban water issues with a focus on water security and recycling. The program will bring new research capacity to South-East Queensland tailored to tackling existing and anticipated future issues to inform the implementation of the Water Strategy.

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Enquiries should be addressed to:

The Urban Water Security Research Alliance
PO Box 15087
CITY EAST QLD 4002

Ph: 07-3247 3005; Fax: 07-3405 0373
Email: Sharon.Wakem@qwc.qld.gov.au

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# FOREWORD

Water is fundamental to our quality of life, to economic growth and to the environment. With its booming economy and growing population, Australia's South-East Queensland (SEQ) region faces increasing pressure on its water resources. These pressures are compounded by the impact of climate variability and accelerating climate change.

The Urban Water Security Research Alliance, through targeted, multidisciplinary research initiatives, has been formed to address the region’s emerging urban water issues.

As the largest regionally focused urban water research program in Australia, the Alliance is focused on water security and recycling, but will align research where appropriate with other water research programs such as those of other SEQ water agencies, CSIRO’s Water for a Healthy Country National Research Flagship, Water Quality Research Australia, eWater CRC and the Water Services Association of Australia (WSAA).

The Alliance is a partnership between the Queensland Government, CSIRO’s Water for a Healthy Country National Research Flagship, The University of Queensland and Griffith University. It brings new research capacity to SEQ, tailored to tackling existing and anticipated future risks, assumptions and uncertainties facing water supply strategy. It is a $50 million partnership over five years.

Alliance research is examining fundamental issues necessary to deliver the region's water needs, including:

- ensuring the reliability and safety of recycled water systems.
- advising on infrastructure and technology for the recycling of wastewater and stormwater.
- building scientific knowledge into the management of health and safety risks in the water supply system.
- increasing community confidence in the future of water supply.

This report is part of a series summarising the output from the Urban Water Security Research Alliance. All reports and additional information about the Alliance can be found at http://www.urbanwateralliance.org.au/about.html.

**Chris Davis**
Chair, Urban Water Security Research Alliance

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# 1. INTRODUCTION

Unprecedented drought conditions and a growing population are putting pressure on the water supplies in south-east Queensland (SEQ) and water management authorities are assessing all possible means by which to create a sustainable water supply in the region. This report has been prepared for the SEQ Urban Water Security Research Alliance for the purposes of assessing the potential effects of farm dams on the major water storages of SEQ. This report will also assess whether reduction of evaporation from these dams could assist in increasing runoff to the reservoirs. This report forms one of a group of reports which each assess the applicability of different evaporation mitigation techniques to water supply systems.

# 2. MECHANISM FOR MAXIMISING WATER STORAGE IN RESERVOIRS

Farm dams and their proliferation are landscape features that may significantly effect the water generation capacity of a major catchment area. Farm dams represent storage within the catchment and are possible sinks for runoff water that may otherwise reach the reservoirs. Water will evaporate from the open water surface of these dams much faster than the surrounding landscape, hence much of the runoff received by these farm dams will not make it to the larger reservoir. Additionally, research has also shown that smaller water bodies evaporate at a faster rate than large water bodies in the same climatic conditions due to turbulence and edge effects (Harbeck, 1962; McJannet *et al.*, In Prep; Sweers, 1976), therefore, evaporative loss per unit area is also greater from farm dams when compared to reservoirs. It is important to note that the impact of farm dams on storages will be greatest during times of drought. This is because during drought farm dams are likely to be empty or at low capacity, therefore their potential to intercept any runoff generated is at its greatest.

Strict management of further dam construction and application of hard covers, wind breaks or monolayers to farm dams have the potential to reduce that evaporation and maximise runoff to reservoirs. The question that then needs to be answered is ‘what impact do farm dams have on reservoir storages in SEQ?’

# 3. REVIEW OF EXISTING STUDIES

Most of the research into the impact of farm dams on runoff is in relation to streamflow, however, the concept of water being intercepted and evaporated in the landscape is directly applicable to reservoir catchments.

Working within catchments in the Murray Darling Basin, Schreider *et al.* (1998; 1999) undertook an analysis of the impacts of farm dams on streamflow and showed that there were significant trends in decreasing streamflow in a number of catchments. Their analysis utilised the IHACRES model which enabled the impacts of farm dams to be isolated from changes due to climate for the analysis period. They conclude that extensive increases in farm dam development over the previous two decades could be considered a major land use factor contributing to reduced stream flows.

The Murray Darling Basin Commission ranks the impacts of farm dams as one of the major factors impacting on the shared water resources of the basin. A report on the impact of farm dams (Van Dijk *et al.*, 2006) in the Murray Darling Basin estimates that they cause a 1900 GL reduction in stream flow per year. The report also shows that impacts of farm dams can be expected to be greatest during low flow or drought periods where a greater proportion of runoff can be intercepted. This report ranks farm dams as the biggest threat to water resources of the basin after climate change.

A recent study estimated that on average 9% of the total flow in the sub-catchments of the Mt Lofty ranges is diverted into farm dams (CSIRO, 2007). Realisation of the impact of farm dams in the Mt Lofty ranges has even led the local water management authority to restrict farm dam development to a volume equivalent to 30% of the May to November runoff (SAMDBNRM, 2006).

A simulation model aimed specifically at determining the effects of farm dams on stream flows has been developed by Sinclair Knight Merz (Nathan *et al.*, 2006). The model called the 'Tool for Estimating Dam Impacts' (TEDI) has been used in a number of study catchments (Egis, 2002a; Egis, 2002b) to gauge existing impacts and to assess the impacts of increases in farm dam area in the future. This model and others like it provide a means by which to assess the impacts of farm dams on stream flows or runoff to reservoirs.

# 4. DESKTOP ANALYSIS DESCRIPTION

To analyse the impact of farm dams on reservoir storages we will consider the volume of water stored in the dams and calculate in this case what this volume represents in terms of the surface runoff required to fill them. The analysis was undertaken for Wivenhoe Dam, Somerset Dam and North Pine Dam but the same procedure could be applied to any catchment.

The ESRI ArcGIS, version 9.2, software product was used to develop spatial entities and perform analysis of farm dam volumes in the Wivenhoe, Somerset, and North Pine reservoir catchments. The data sets used were all obtained from the Queensland Department of Natural Resources and Water (NRW) (see Table 1). Two sources of farm dam mapping were available for this region; NRW water bodies data (Muir and Danaher, 2008) and Queensland land use mapping program (QLUMP) water bodies data (Witte *et al.*, 2006). Comparison of these two products showed that although the location, number and size of farm dams identified varied, the total area of farm dams identified in the three catchments of interest was almost identical. The decision was made to use the QLUMP data because it had better shape representation for water bodies, particularly the larger storages. The differences in farm dam mapping are believed to be unlikely to influence final results.

The farm dams and catchment reservoir water bodies were extracted from an ESRI shape file from the QLUMP (1999) landuse dataset. The reservoir catchment boundaries were extracted from a shape file of Queensland drainage subdivisions (QLD Basinsubarea). These boundaries were then used to clip out the south-east Queensland, 25 metre resolution, digital elevation model (SEQDEM). The clipped DEM was then used as inputs to the SedNet catchment modelling software, obtained from the Catchment Modelling Toolkit (http://www.toolkit.net.au/cgi-bin/WebObjects/toolkit), in order to generate sub-catchments and stream networks for each catchment. The sub-catchments and streams were then used to delineate the areas of each catchment, which potentially drained into each reservoir, and the farms dam polygons which were present within this drainage area.

**Table 1: Spatial data used to obtain farm dams, catchments, and reservoirs.**

| Dataset Name | Year | Purpose | Source | Scale |
|---|---|---|---|---|
| SEQ DEM | Supplied 2008 | Definition of sub-catchments and stream networks | Qld NRW | 25m grid cells |
| QLUMP landuse | 1999 | Identification of farm dams and reservoirs | Qld NRW | 1:100,000 |
| Qld Basinsubarea | 2006 | Demarcation of analysis regions | Qld NRW | 1:100,000 |

Each of the three reservoirs and the farm dams within their catchments are shown in Figure 1, 2 and 3. From these figures it can be observed that farm dams identified from the data source are very sparse. The size of water bodies identified in the QLUMP data set is limited by the resolution of the Landsat imagery used to produce it. This type of imagery has a minimum mapping unit of one hectare. We believe that there are likely to be many more small farm dams in these catchments, however this is the best dataset with full coverage that is currently available. Farm dam mapping products that are currently under development will be discussed below. The exclusion of many small farm dams in the dataset used should be kept in mind when assessing the results below.

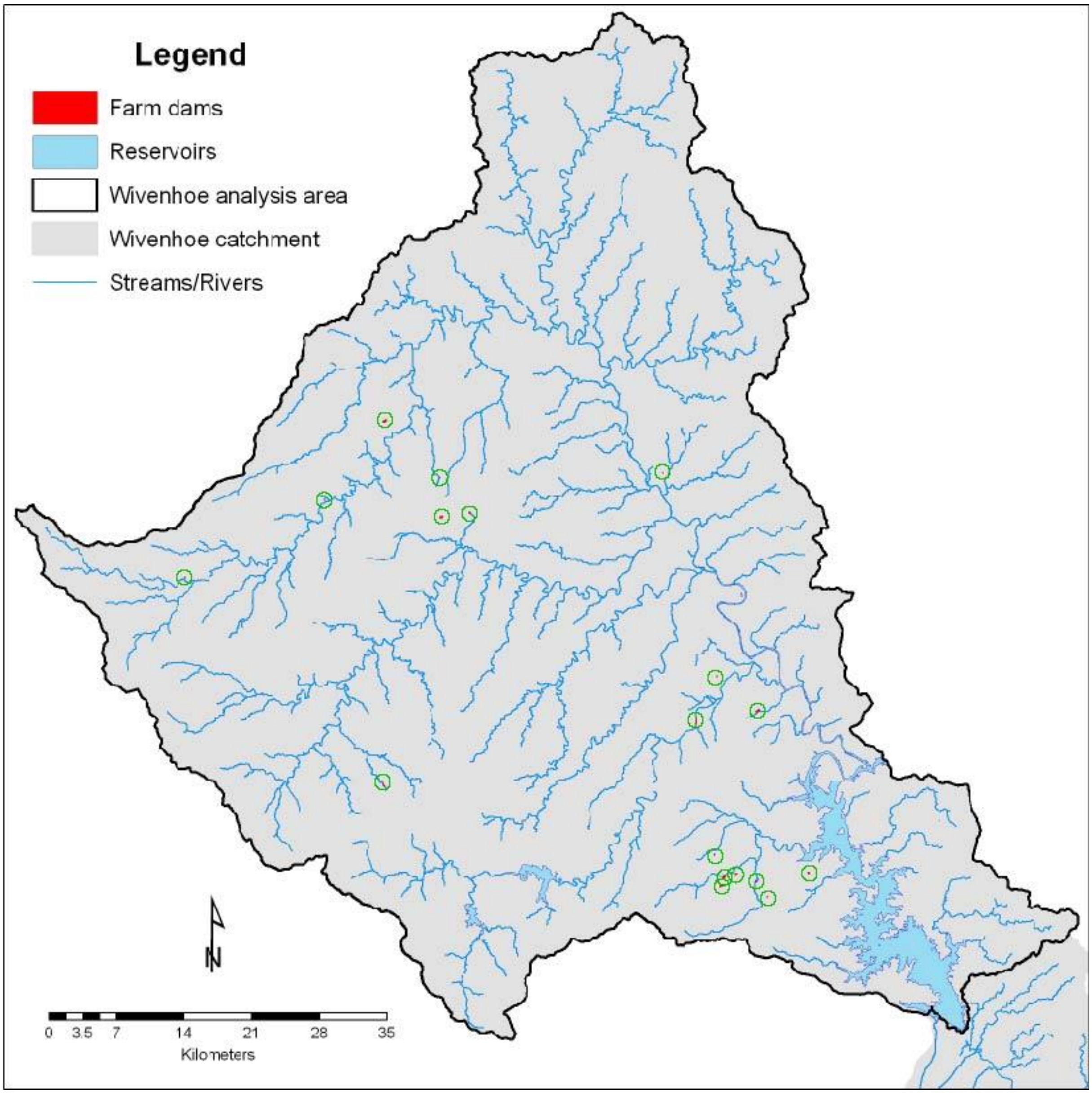

**Figure 1:** **Map of Wivenhoe Dam catchment showing size (red) and location (green rings) of farm dams.**

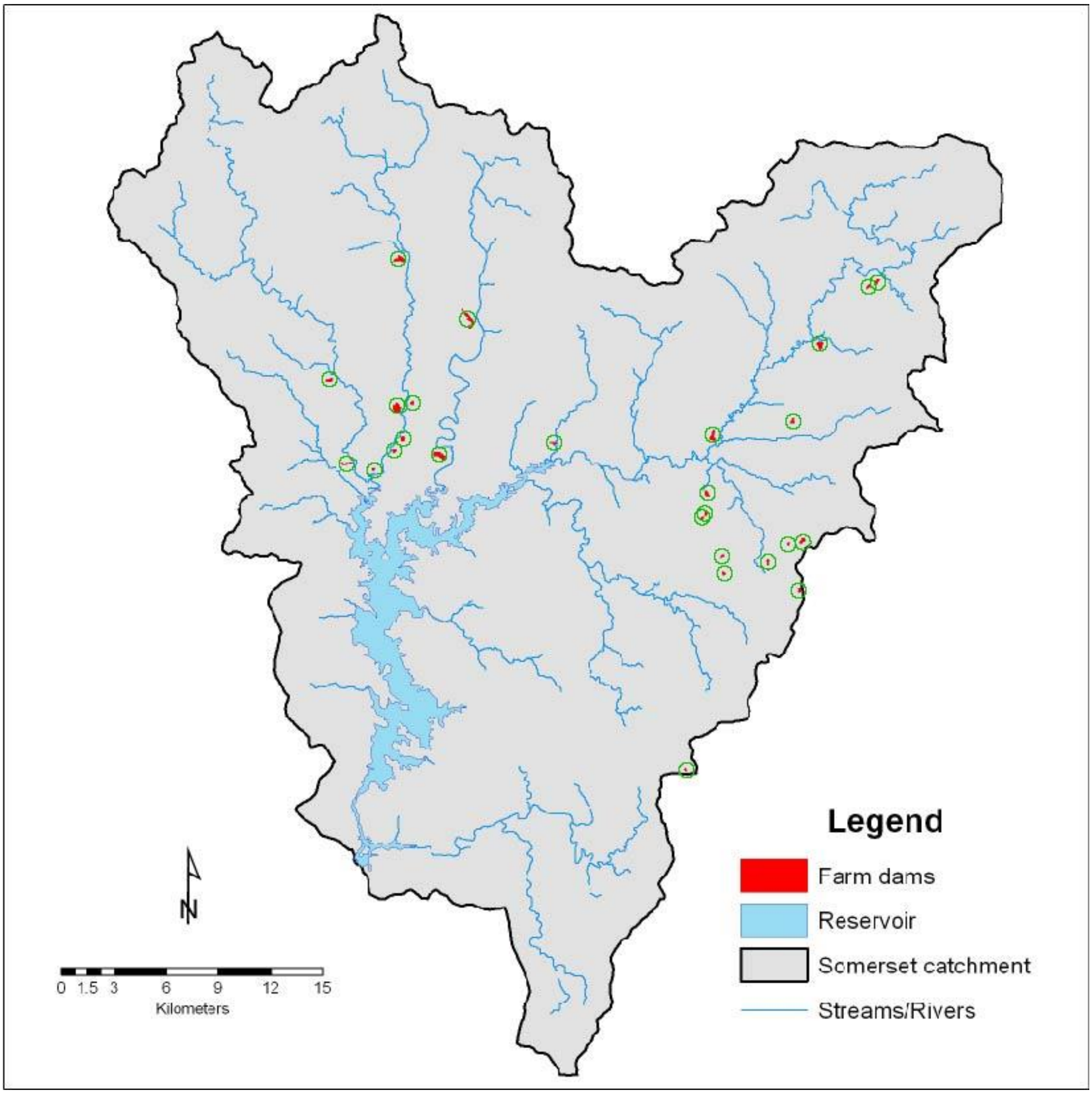

**Figure 2:** **Map of Somerset Dam catchment showing size (red) and location (green rings) of farm dams.**

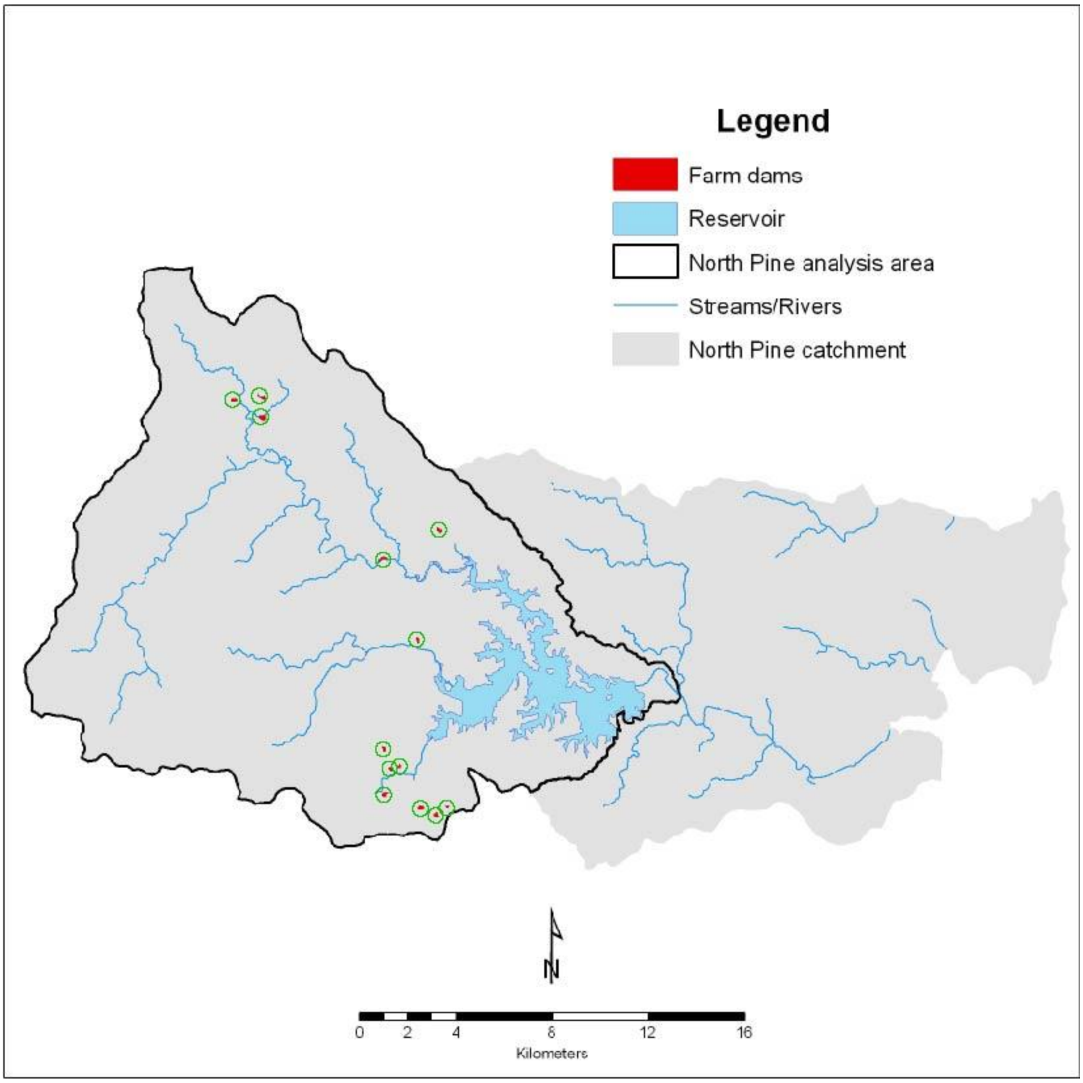

**Figure 3:** **Map of North Pine Dam catchment showing size (red) and location (green rings) of farm dams.**

The area and perimeter length of each farm dam identified within each of the reservoir catchments (Wivenhoe, Somerset and North Pine) was determined using ESRI ArcGIS. From this we estimated an equivalent radius for these dams assuming they were circular in shape using:

Equation 1

$$r_A = \sqrt{\frac{A}{\pi}}$$

$$r_P = \frac{P}{2\pi}$$

where -

$A$ (m2) is the area of the farm dam,

$P$ (m) is the perimeter length of the farm dam,

$r_A$ (m) is the equivalent radius of a circle based on the area of the farm dam, and

$r_P$ (m) is the equivalent radius of a circle based on the perimeter length of the farm dam.

If the farm dam was a perfect circle then $A/(r_A P) = 0.5$. We can use this value as a shape factor to assess the deviation of farm dam shape from a perfect circle. As the farm dam becomes more elliptical the shape factor, $A/(r_A P)$, will decrease from the value of 0.5. From the three reservoir catchments the average shape factor determined for all farm dams is 0.4 (±0.1).

In order to determine the volume of the dam we assume that it is an oblate hemi-spheroid in shape with the major axis given by the radius and the minor axis given by the maximum depth. The depth of the farm dams is not known but generally the maximum depth is unlikely to be greater than 5m. The volume of each farm dam is thus estimated using:

$$V_x = 2\pi r_x^2 D / 3 \qquad \text{Equation 2}$$

where -

$r_x$ (m) is the radius and x is either $A$ or $P$,

$D$ (m) is the maximum depth of the farm dam (taken to be 5m), and

$V_x$ ($m^3$) is the estimated volume of the farm dam determined from either $r_A$ or $r_P$.

These individual farm dam volumes were summed in each reservoir catchment. The catchment area of each reservoir was estimated and this area was used to determine the amount of surface runoff needed to fill the farm dams from empty. The following equation was used for this:

$$I_x = \sum V_x / A_R \qquad \text{Equation 3}$$

where -

$I_x$ (m) is the runoff depth required to fill farm dams in the reservoir catchment area, and

$A_R$ ($m^2$) is the catchment area for reservoir.

We consider this approach to be a first cut assessment as to the potential for farm dams to impact on the volume of water held within the storages of SEQ. We do not attempt to assess the impact of the spatial distribution of farm dams on runoff, nor do we assess the cumulative impacts of runoff interception when moving down the landscape or the spatial distribution of rainfall in relation to dams. We also do not take into account the temporal variability in rainfall intensity and the impacts of this on surface runoff. All of these factors would require the development of a highly complex and spatially distributed rainfall-runoff model. Our interest here is to make the first assessments as to whether the area and volume of farm dams is of significant size to have a major impact on water stored in the major SEQ storages.

We also used the water balance model developed for assessing the potential for runoff enhancement to maximise water storage in SEQ (McJannet *et al.*, 2008) to include the loss to farm dams. This was initiated with the dams assumed to be empty. The surface runoff into the farm dams was calculated by:

$$\begin{aligned} SROf(t) &= FDS(t)/CA \text{ if } SRO(t) \geq FDS(t)/CA \qquad \text{Equation 4} \\ SROf(t) &= SRO(t) \text{ if } SRO(t) < FDS(t)/CA \end{aligned}$$

where -

$SRO$ (mm) is the surface runoff from the soil assuming no farm dams,

$SROf$ (mm) is the runoff captured by the farm dams,

$CA$ ($km^2$) is the catchment area,

$t$ is time (days), and

$FDS$ ($m^3$) is the farm dam storage given by:

$$FDS(t+1) = FDS(t) + \left[Et(t) - SROf(t)\right].FA$$ Equation 5

$$\text{if } FDS(t+1) \geq FDC, \text{then } FDS(t+1) = FDC$$

where –

*Et(t)* (mm) is the potential evaporation from a water body on day *t*,

*FA* (km$^2$) is the surface area of farm dams in the catchment, and

*FDC* (m$^3$) is the maximum farm dam capacity.

The ten-year long record of daily rainfall and potential evaporation data required to run the model were sourced from the SILO database (Jeffrey *et al.*, 2001) for the Wivenhoe area.

# 5. DESKTOP MODELLING RESULTS

The results for the analysis of the potential impact of farm dams on reservoir storage for Wivenhoe, Somerset and North Pine Dams are summarised in Table 2. The first observation is the very small number of farm dams in each catchment and the small area of farm dams relative to the total catchment area. The percentages of each catchment identified as farm dams for each reservoir are: 0.01% for Wivenhoe, 0.1% for Somerset and 0.08% for North Pine. It is worth reiterating that the farm dam mapping data available may not include smaller farm dams because of the resolution of the data sources used to create it (we will discuss this further below).

The results suggest that the maximum volume of water held within farm dams is only a very small percentage of water held in each reservoir (range 0.2 – 3.1%). Even if farm dams were completely empty the runoff required to fill them would be less than 0.8 mm, 8.0 mm and 5.4 mm from the entire Wivenhoe, Somerset and North Pine catchments, respectively. Thus, it appears from this analysis that the area and volume of farm dams in these catchments are so small that they will make very little difference to the amount of water held in the reservoirs.

**Table 2: Catchment area, reservoir volume, number of farm dams, area and volume of farm dams, farm dam volume as a percentage of reservoir volume and runoff required to fill farm dams for the three major storages in SEQ. Values are presented for calculations using both area (*A*) and perimeter (*P*) methods. NB A maximum dam depth of 5 m is used in these estimates.**

| | | Wivenhoe | Somerset | North Pine |
|---|---|---|---|---|
| Catchment area | | 5360 km$^2$ | 1490 km$^2$ | 333 km$^2$ |
| Maximum reservoir volume | | 1165 GL | 380 GL | 215 GL |
| Number of farm dams identified | | 18 | 26 | 13 |
| Total area of farm dams | | 0.68 km$^2$ | 1.56 km$^2$ | 0.27 km$^2$ |
| Farm dam area as % of catchment area | | 0.01 % | 0.1 % | 0.08 % |
| Total volume of farm dams | *A* | 2.3 GL | 5.2 GL | 0.9 GL |
| | *P* | 4.5 GL | 11.9 GL | 1.8 GL |
| Farm dam volume as % of reservoir volume | *A* | 0.2 % | 1.4 % | 0.4 % |
| | *P* | 0.4 % | 3.1 % | 0.8 % |
| Runoff required to fill farm dams | *A* | 0.4 mm | 3.4 mm | 2.7 mm |
| | *P* | 0.8 mm | 8.0 mm | 5.4 mm |

We have also assessed surface runoff for different soil types across these catchments for a companion report on catchment runoff enhancement (McJannet *et al.*, 2008). In this report, the surface runoff in the three water storage catchments over a 10 year period was calculated for 14 soil types. Surface runoff (SRO) was shown to be similar for 13 of the soil types (Soils 1 -13) with only one soil showing different runoff characteristics (Soil 14). Using this dataset we can determine the effect of the farm dams on the total amount of surface runoff. Over this 10 year period the reduction in runoff was less than 3% for Soils 1 to 13 and less than 7% for Soil 14. However, soil type 14 constitutes only a small percentage of the catchments. Regardless of the soil type distribution the impact of runoff interception is likely to be small. These results support findings from the analysis of farm dam volume, however, it should be noted that this result is predicated on the basis of the farm dam dataset available at the time of this study.

**Table 3: Potential reduction in surface runoff as a result of farm dams for Soils 1 to 13 and Soil 14 for the period 1997-2007. The value in brackets after the reservoir name is the percentage of Soil 14 in that catchment. The figure in brackets in the total SRO column is the value for Soil 14.**

| **Reservoir** | | **Soil 1 to 13** | | | **Soil 14** | | |
|---|---|---|---|---|---|---|---|
| | Total *SRO* (mm) | *SRO* reduction (mm) | *SRO* reduction (%) | Volume (GL) | *SRO* reduction (mm) | *SRO* reduction (%) | Volume (GL) |
| Wivenhoe (<1%) | 667 (144) | 2.2 | 0.3 | 11.8 | 1.2 | 0.8 | 6.5 |
| Somerset (~6%) | 667 (144) | 18.0 | 2.7 | 26.8 | 10 | 6.9 | 14.9 |
| North Pine (~1%) | 667 (144) | 18.0 | 2.7 | 6 | 8.0 | 5.5 | 2.6 |

It is highly likely that there are many small farm storages that are not identified in the utilised dataset (or the alternative NRW water bodies data set) (see Figure 4). However, a new farm dam mapping product based on much higher resolution SPOT imagery is currently under development by Geosciences Australia. A small section of the images for the Wivenhoe Dam catchment has been processed and Geosciences Australia allowed access to the data for the purposes of illustrating the difference between existing mapping and that currently being undertaken.

**Figure 4: Aerial view of farm dam density in a part of the Wivenhoe catchment. Photo courtesy Richard Cresswell.**

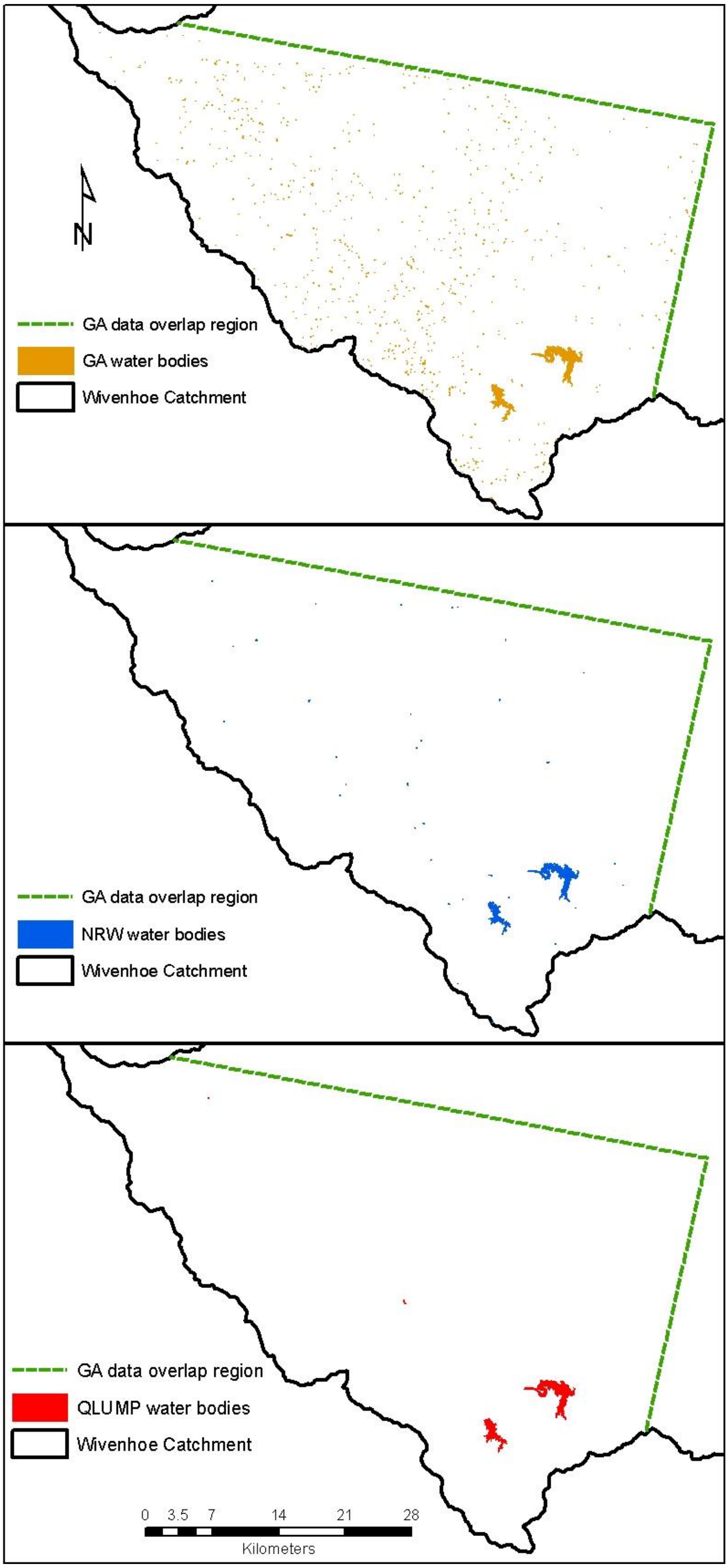

**Figure 5:** **Illustration of the differences in the number of farm dams identified in the overlap zone of the QLD NRW and QLUMP water bodies datasets (Landsat based) and Geosciences Australia water bodies data (SPOT imagery).**

The vast differences in the two products currently available and the product being developed are shown in Figure 5 which shows a small overlap zone for the Wivenhoe catchment. For the overlap zone there are many more water bodies identified in the Geosciences Australia dataset (n = 971) than in the NRW dataset (n = 34) and the QLUMP dataset (n = 2). (N.B the QLUMP dataset is particularly poor in this area but better in others). In terms of the farm dam area identified, there is 13 times more area identified in the Geosciences Australia dataset (2.21 $km^2$) than in the NRW dataset (0.17 $km^2$) and 44 times more than the QLUMP dataset (0.05 $km^2$). Assuming the mapping difference is similar across the Wivenhoe Dam catchment, then the impact of farm dams is likely to be much larger than predicted in the desktop exercise above. Taking Somerset catchment as an example, a 13 times increase in farm dam area would result in an approximate increase in farm dam volume from 5.2 GL to 68 GL, or ~20% of reservoir volume. Such a volume could abstract a large fraction of runoff in drought years. Unfortunately, the Geosciences Australia farm dam data set is still in developmental stage for this region and cannot be released for analysis purposes until further ground truthing and testing is undertaken. A repeat of this exercise when the final Geosciences Australia product is released is advisable. If farm dams are found to significantly reduce runoff, then an assessment of the means by which to reduce evaporation losses from farm dams should be attempted, undertaking such an analysis based on the existing data would be misleading.

# 6. SUGGESTIONS FOR FURTHER RESEARCH

Based on available datasets the results of the farm dam analysis suggest that farm dams have very little impact on runoff to Wivenhoe, Somerset and North Pine Dams. It should be noted, however that the existing farm dam mapping only shows storages larger that 0.1$km^2$ and that our comparison with products currently being developed shows that there are many farm dams that have not been mapped. Research from other parts of Australia shows significant impact on runoff, therefore further analysis is suggested for these catchments and others in SEQ when the new data sources become available. For reservoir catchments where farm dams are much more widespread there may be justification for the use of more detailed water balance modelling studies such as that carried out by Egis (2002b), and Schreider (1998). Some of these studies use spatially distributed rainfall-runoff models and climatic time series data to more accurately assess farm dam impacts. The results from our simple analysis for these three reservoirs does not justify the utilisation of more complex modelling approaches until better data sources are first assessed. If farm dams are found to significantly reduce runoff after utilising the new data then an assessment of the means by which to reduce evaporation losses from these storages (e.g. monolayers, hard covers) should be attempted.

# 7. KEY MESSAGES

The main conclusions from this analysis are:

1. Based on best available data sets for the region it appears that farm dams make up a very small percentage (<0.1%) of the total catchment area supplying Wivenhoe, Somerset and North Pine Dams.
2. Using this data, the combined volume of these farm dams is estimated to hold the largest percentage of reservoir capacity in the Somerset catchment (<3.1%) with smaller percentages in the Wivenhoe (<0.4%) and North Pine catchments (<0.8%).
3. Available data suggests that runoff to the three storages is reduced by less than 3% as a result of farm dams.
4. Desktop modelling is severely limited by the lack of high resolution farm dam mapping products. Many more dams than those identified in existing data sources are known to exist.
5. Desktop modelling suggests that no further work is justified on this topic for the Wivenhoe, Somerset and North Pine dams until much better resolution farm dam mapping becomes available.
6. More detailed investigations for other reservoirs may be justified where farm dams are known to be prevalent.

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