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Queensland Government

Department of Environment and Resource Management

Improved Assessment of the Impact of Stock and Domestic Farm Dams in Queensland

STATEWIDE ASSESSMENT: REPORT 1

- Methods and Inputs
- Final
- 28 March 2012

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Australian Government

National Water Commission

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Executive Summary

Queensland is home to a number of high value agricultural activities and for many of these activities water is supplied either through large irrigation schemes, floodplain storages and water harvesting, or by direct pumping from waterways. These major water sources have historically been managed to ensure impacts on the waterways are kept to acceptable levels, and that other water users' reliability is maintained.

For the purposes of water resources planning, farm dams for stock and domestic use have not generally been viewed as a significant issue. This is most likely because each dam in itself is quite small, typically less than 20ML. However, these dams exist in staggeringly large numbers. While each individual dam may have minimal impact on the environment and other water users, the combined impact is significant, especially in particular locations where the density of farm dam development is high.

The purpose of this project was to develop and test a method which could be used by DERM to assess the hydrologic impact of stock and domestic farm dams in Queensland and to develop a method to assess the trends in stock and domestic farm dam development. This project was carried out in three stages; a Scoping Study, Pilot Study and Statewide Assessment. The Scoping Study and Pilot Study have been completed and this report presents, in part, the outcomes of the Statewide Assessment.

The Statewide Assessment of the impact of stock and domestic farm dams has been completed for all of Queensland, applying the methods developed and tested during the Pilot Study. Several of the methods developed for the Pilot Study were also revised for the Statewide Assessment, using additional data which only became available after the completion of the Pilot Study.

The Statewide Assessment used the improved understanding of stock and domestic farm dams to create STEDI models for a number of modelling catchments and then regionalise the results to the rest of Queensland. The outcomes from the Statewide Assessment are presented in two reports:

- *Statewide Assessment: Report 1 – Methods and Inputs* (this report)
- *Statewide Assessment: Report 2 – Hydrological assessment of stock and domestic farm dams in Queensland.*

This report presents the final inputs and methods developed for this Project, in order to facilitate the estimation of the hydrologic impact of stock and domestic farm dams in Queensland. Where practical, alternative methods have been proposed and discussed with respect to their relative advantages and with a view to improving the adopted methods.

Modelling used a piece of software called STEDI, which stands for the Spatial Tool for Estimating Dam Impacts. For this study the STEDI models require the following inputs:

1. Climate inputs – rainfall, streamflow and evaporation;
2. Estimate of use or the demand factor for each dam – representing the annual volume taken extracted from the dam as a proportion of the storage capacity of the dam ;
3. Catchment areas – total catchment area and the sum of the catchment areas that are upstream of all of the farm dams in the catchment; and
4. Estimate of the number and volume of farm dams in the catchment.

The streamflow, rainfall and evaporation data adopted for this study is considered to be of very good quality and does not need to be updated or improved. This data is currently routinely developed and maintained as part of other ongoing work by DERM and further investigation is not required for these inputs.

The demand factor, used to estimate the direct usage from the dams has been derived from an analysis of phone survey responses and farm dam design sheets. The sample size of this analysis is quite small and it is therefore recommended to either revise the demand factor based on an expanded phone survey or based on a long term metering project.

The catchment area upstream of farm dams within each catchment was determined from detailed digital terrain model data for five small representative catchments and then was regionalised, for the purposes of modelling, using a regression relationship. The regression relationship relates the total catchment area upstream of the farm dams with the total catchment area, mean catchment slope and dam density. While the relationship shows a very good fit to the observed data there is some uncertainty associated with it due to the relatively small sample size and the limited geographic range represented in the digital terrain models that were used to derive the relationship. This relationship could be improved through further spatial analysis, over a wider geography.

A farm dam surface area to volume relationship was developed based on a sample of 73 dams in the Moreton, Lockyer and Sothern Downs reporting regions. The adopted relationship was also relatively consistent with similar relationships that were derived from samples of farm dams in Victoria, southern New South Wales, South Australia and south west Western Australia, which indicates that regional variations in the surface area to volume relationship are not too large. The adopted relationship has a strong correlation and level of confidence; however this could be improved through ground survey or additional LiDAR analysis. The LiDAR analysis is more likely to improve the current approach than the ground survey and is likely to provide better value for money.

Stock and domestic farm dams are currently identified through spatial analysis, using a landuse exclusion process. This method can be applied over large areas where little other information is available. There is a high level of uncertainty around this method, which is difficult to verify or quantify with currently available information. It would be worthwhile for DERM to investigate this area further and to consider testing the results from the landuse based analysis by investigation using field officers.

Overall, additional digitisation over a large area would seem to provide the most benefit to DERM. This could be used to directly identify individual dams for modelling (removing the need to use the regional volume estimate approach for the digitised areas) and as an input to improve the local catchment area regression relationship. Any additional digitisation should consider the need to incorporate geographic diversity, in order to account for the likely regional differences due to factors such as rainfall, evaporation, terrain and landuse.

Following on from this report, the STEDI modelling results and outcomes of the trends assessment are provided in the *Statewide Assessment: Report 2 – Hydrological assessment of stock and domestic farm dams in Queensland*. This report also presents the outcomes of an assessment of the sensitivity of the model to changes in the input parameters. This has been used to further evaluate the benefit of improving the input estimation methods. Final recommendations with respect to improving these methods are provided in Report 2.

1. Introduction

There are three phases in the investigation into the impacts of stock and domestic dams in Queensland; a Scoping Study, Pilot Study and Statewide Assessment. The Scoping Study and Pilot Study have been completed and this report presents in part the outcomes of the Statewide Assessment.

The Scoping Study was carried out as a planning activity, scoping the activities and methods to be used in the Pilot Study and Statewide Assessment. The Pilot Study involved assessing the data available in Queensland to better understand the characteristics of stock and domestic dams. The impacts of farm dams were then modelled in five pilot catchments, the Condamine-Balonne, Burnett, Burrum, Kolan and Warrego catchments. Modelling used a piece of software called STEDI, which stands for the Spatial Tool for Estimating Dam Impacts.

The Statewide Assessment of the impact of farm dams has been completed for all of Queensland, applying the methods developed and tested during the Pilot Study. The Statewide Assessment used the improved understanding of stock and domestic farm dams developed during the Pilot Study to create STEDI models for a number of modelling catchments and then regionalise the results to the rest of Queensland.

1.1. Scope of this report

This report presents the final inputs and methods developed for this Project. Alternative methods are also proposed and discussed with respect to their relative advantages and with a view to improving the adopted methods.

The modelling outcomes and results of the trends assessment are provided in the *Statewide Assessment: Report 2 – Hydrological assessment of stock and domestic farm dams in Queensland*. This report also presents the outcomes of an assessment of the sensitivity of the model to changes in the input parameters. This has been used to further evaluate the benefit of improving the input estimation methods.

1.2. Format of the report

The format of this report is as follows:

Section 2 Provides an overview of farm dams.

Section 3 Describes the STEDI model and required inputs.

Section 4 Details each adopted method and discusses potential alternatives.

Section 5 Provides an assessment of the proposed alternative methods against key criteria.

Section 6 Presents conclusions and recommendations for further work.

Section 7 Discusses the limitations of the study.

2. Overview of farm dams

Queensland is home to many high value agricultural activities. For many of these activities, irrigation is supplied either through large irrigation schemes, large floodplain storage and harvesting, or direct pumping from waterways. These major water sources have historically been managed to ensure impacts on the waterways are kept to acceptable levels, and that other water users' reliability is maintained.

For the purposes of water resources planning, farm dams for stock and domestic use have not generally been viewed as a significant issue. This is most likely because each dam in itself is quite small, typically less than 20ML. However, these dams exist in staggering large numbers. Throughout the MDB, Geoscience Australia (2008) identified approximately 500,000 man-made water bodies and most of these are likely to be stock and domestic farm dams. Since the state of Queensland covers an area that is almost double the area of the Murray Darling Basin, it could reasonably be expected that there are hundreds of thousands of farm dams in Queensland. While each individual dam may have minimal impact on the environment and other water users, the combined impact is significant, especially in particular locations where the density of farm dam development is high.

Farm dams are earth structures designed to capture and store water for irrigation, aquaculture, stock watering, domestic supply or aesthetic purposes (Lewis, 2002). It can be used to encompass both on-stream and off-stream storages. The distinction between an on-stream and off-stream storage depends on the definition of the watercourse itself. In the context of this report, a farm dam refers to a private dam that:

- intercepts catchment runoff (or overland flow); and
- is primarily not filled using extractive water access rights from other water resources.

Farm dams differ from one another with respect to a number of characteristics. These characteristics determine the benefit that can be derived from having a farm dam (i.e. the volume of water that is generally available for use) and the reduction in the volume of water available for others (either other users or the environment). Conceptually, the characteristics could be placed into the following broad categories:

- The location of the farm dam;
- The size of the farm dam;
- The purpose for which the dam is used;
- The volume of water harvested by the farm dam; and,
- The timing when the farm dams can harvest water.

The nature of these characteristics is discussed throughout this section.

The **location** of a farm dam can be defined in terms of its geographical location and its location with respect to a waterway. The geographical location of the farm dam is important as it will influence the volume of water harvested by the farm dam and this will be discussed further below. The location of the dam in relation to other dams will also affect its ability to harvest water and the extent to which it is connected to other water users downstream.

Farm dams vary substantially in **size** and shape. The factors influencing the size of a farm dam include method of construction, the intended use of the farm dam, the magnitude and variability of the catchment runoff at the site of the farm dam and site topography.

The main categories used to define the **purpose** of a farm dam are domestic and stock, irrigation and commercial purposes. Farm dams can also be used for other purposes, such as for aesthetic reasons, erosion control, flood control, water quality control or environmental purposes. A survey undertaken by Lowe et al (2005) indicated that small dams are typically used for domestic and stock purposes and larger dams are used for either irrigation or commercial purposes.

The **volume of water harvested** by the farm dam is one of the most important characteristics of the water access right as it determines the impact of the farm dam on the environment and other water users. The volume of water captured by the farm dam depends on the following factors:

- *Capacity of the farm dam.* The ability of a farm dam to capture runoff when it occurs depends on its capacity. The larger the capacity, the more water the dam will be able to capture;
- *Inflows.* The volume of water harvested from a farm dam is dependent on the amount of catchment runoff entering the dam. The volume of runoff generated by catchments varies considerably across Queensland, particularly with climate and topography. The volume of water available for harvesting by farm dams differs between catchments and within catchments. A farm dam located on a waterway with a relatively large upstream catchment will be able to receive more inflows than a farm dam which is not located on a waterway and has a small catchment area. In a given catchment the availability of catchment runoff can be estimated using the catchment area of the farm dam;
- *Extractions from the farm dam.* A farm dam will only capture runoff when it is not full. Therefore, the more water that is extracted from the farm dam, the more water it is able to harvest. The extractions from the dam are known to vary considerably between individual users (Lowe and Nathan 2008). The seasonal pattern of extractions can also affect the ability to harvest water at any given time of the year; and,

- *Evaporation from the dam.* As with extractions from the dam, evaporation rates will influence how full a farm dam is and consequently the harvested volume. The volume of evaporation from the farm dam will depend on the rate of evaporation in the region (and this varies considerably across the Queensland) and the surface area of the farm dam. For example, there will be more evaporation from a shallow farm dam with a large surface area than from a deeper farm dam with the same volume.

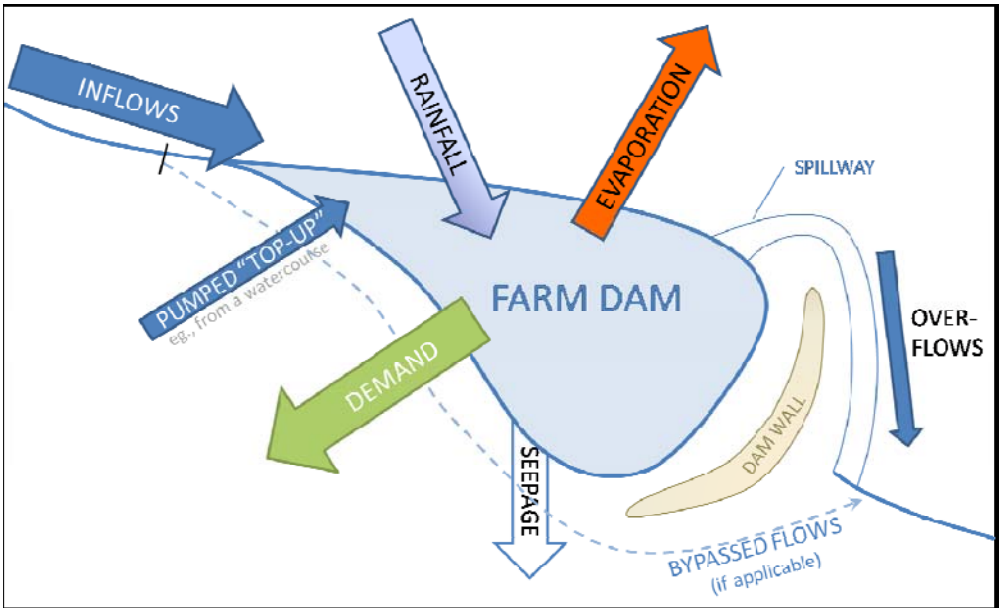
Unlike diversions from a waterway, it is difficult to control the **timing** of when farm dams harvest water. Until it is full, a farm dam will capture all catchment runoff intercepted by the farm dam. Farm dams also intercept the first catchment flows after a dry period, thereby extending the period of time over which a waterway could be experiencing those dry conditions.

It is possible to install a low flow bypass on a farm dam; this is used to divert runoff through or around the dam. The bypass is generally a pipe or channel which diverts low flows around the dam, while large flows are still able to enter the dam. Alternatively, the bypass may be a pipe built into the dam wall. Bypasses are not commonly implemented on farm dams in Queensland, except that where the dam is on a watercourse it will normally have a license condition that releases from the dam are required for downstream users.

3. Modelling the impact of stock and domestic farm dams

The impact of farm dams is estimated using a program called STEDI, Version 1.20 which was developed by SKM and the Department of Sustainability and Environment (DSE) in Victoria and released in 2011. The program is available as Freeware and can be downloaded from the SKM website at http://www.globalskm.com/Markets/Australia/Water--Environment/Natural-Resource-Management/STEDI.aspx.

STEDI stands for the Spatial Tool for Estimating Dam Impacts and uses a water balance approach to simulate the flow of water through a catchment, particularly focussing on the impact that the capture of water in catchment farm dams has on streamflow. The model accounts for direct rainfall and evaporation on the dams, seepage, catchment runoff, demand, pumping to the dams, overflows and bypassed flows, as shown in Figure 1.



▪ **Figure 1 Simplified water balance for a farm dam (Sinclair Knight Merz, 2011c)**

STEDI uses the distribution of farm dam sizes in a catchment, the total volume of farm dams, and rainfall and evaporation inputs to simulate a water balance for each catchment. Different demand factors or timeseries can be specified for irrigation or stock and domestic dams. Depending on the amount of information in a catchment, either individual dams can be specified, or the total volume of dams can be used, and generic size distribution and impounded area relationships can be applied.

Bypass facilities can be modelled if required and additional water sources, e.g. groundwater, can be added to each dam, if the information is available.

A limitation of the model is that STEDI does not account for channel transmission losses within the catchment and it assumes that all parts of the catchment contribute equally to flow at all times. These assumptions have been made because there is a lack of sufficiently gauged catchments that would be widely representative of catchments containing farm dams to derive quantitative estimates of the impacts of spatial variability in flow generation and transmission losses. To the extent that both of these assumptions may result in an overestimation of the impact of farm dams within a given catchment, the STEDI model would produce a result that is conservative.

As the streamflow and climate data was available on a daily basis for all of the modelling catchments in the Statewide Assessment, a daily STEDI model has been developed and run for each of these catchments.

For the Statewide Assessment models, each dam was specified individually. No bypass facilities have been modelled and no additional sources of water have been included in this assessment. As described in Section 4.3.1, all of the identified stock and domestic dams have been included in the model. The dams that were not identified as stock and domestic dams have not been included.

STEDI outputs include a timeseries of flows that include the impact of farm dams (the input file from IQQM), the impact of farm dams, and the resultant unimpacted flows. This output provides the basis of the analysis of the impact of stock and domestic dams.

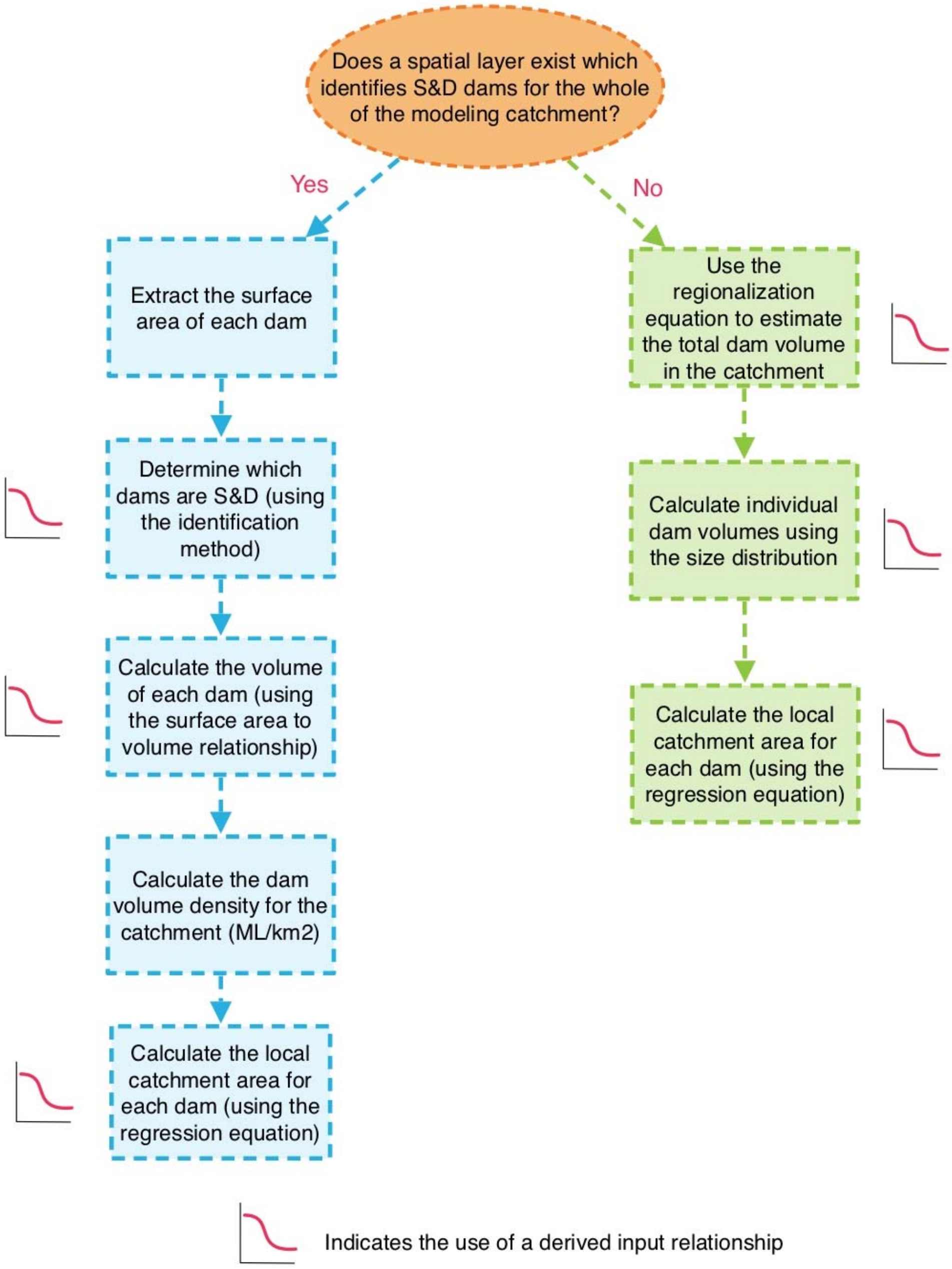
3.1. STEDI model inputs

For this study the STEDI models require the following inputs:

1. Climate inputs – rainfall, streamflow and evaporation;
2. Estimate of use or the demand factor for each dam – representing the annual volume taken extracted from the dam as a proportion of the storage capacity of the dam;
3. Catchment areas – total catchment area and the sum of the catchment areas that are upstream of all of the farm dams in the catchment; and
4. Estimate of the number and volume of farm dams in the catchment.

The methods used to prepare inputs 1-3 are the same for all of the modelled catchments. However, input 4 can be prepared in two different ways, depending on whether a suitable spatial layer is available for the catchment, identifying all of the likely stock and domestic dams. Figure 2 illustrates the two different approaches.

If a spatial layer is available it is preferable to use it, as this approach is considered to provide a more accurate estimate of the likely number and volume of stock and domestic dams. The relative accuracy of the two approaches will be assessed in Report 2.



▪ **Figure 2 Procedure for estimating the number and volume of stock and domestic dam for STEDI**

4. Inputs and methods

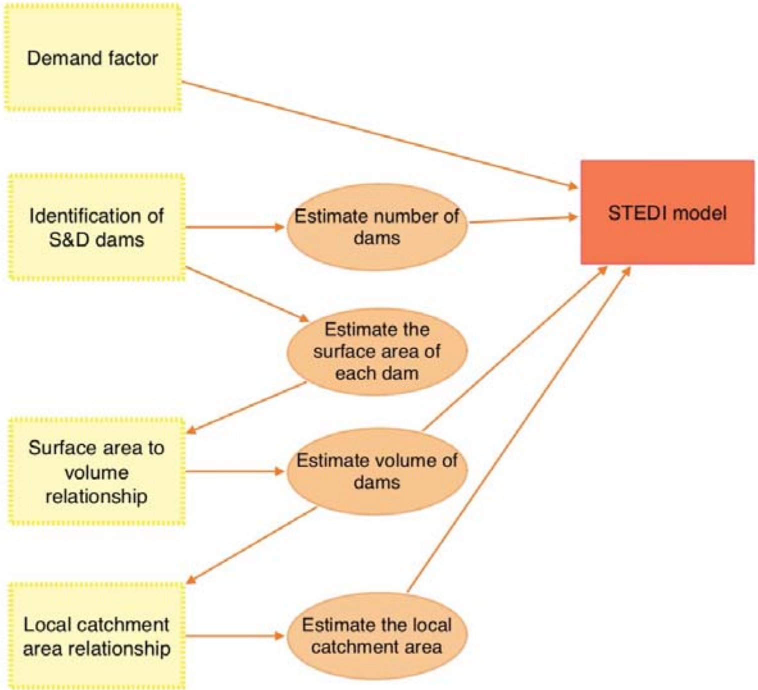
This section describes the methods used to prepare the input information required for the STEDI modelling. This included:

- Preparation of streamflow, climate and farm dams GIS layers;
- Identification of stock and domestic dams;
- Estimating the number of farm dams;
- Estimating the volume of farm dams;
- Estimating the size distribution of farm dams;
- Defining the local catchment area relationship; and
- Estimating demands.

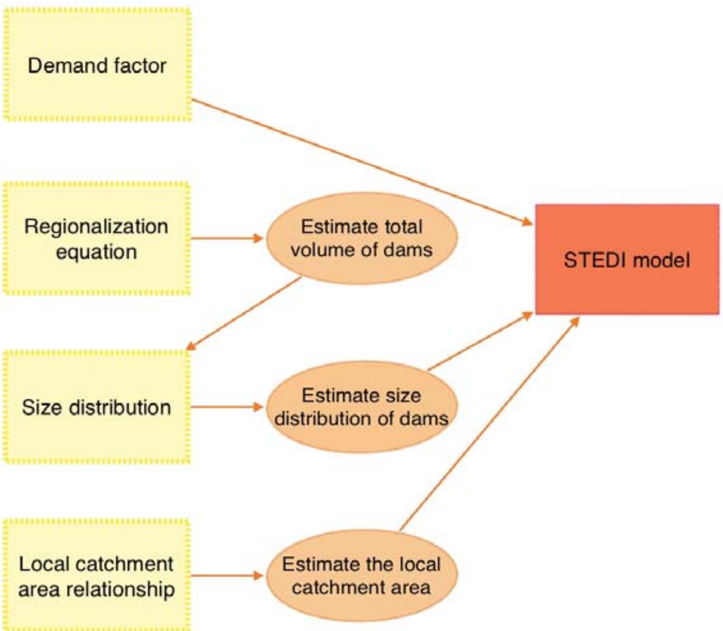
For the majority of these methods an alternative approach is also described.

Appendix A includes a summary description of all the datasets used in the analysis and collation of the farm dams project.

The following figures present the interaction of the input methods for catchments which have a spatial layer available (Figure 3) and where a spatial layer is not available (Figure 4).



▪ **Figure 3 Interaction of input estimation methods (when a spatial layer is available)**



▪ **Figure 4 Interaction of input estimation methods (when a spatial layer is not available)**

4.1. Streamflow and climate

The streamflow and climate data is considered to be of very good quality and suitable for further investigations. As the data is also already in a suitable format for use, readily available to DERM and regularly checked, updated and maintained by DERM, no alternative approach is suggested for these inputs.

4.1.1. Streamflow

Daily modelled streamflow for 55 catchments has been provided from water resource planning IQQM (Integrated Quality Quantity Models) models across Queensland. The inflow sequences used in the Statewide Assessment were sourced from the Queensland Hydrology Unit in the Department of Environment and Resource Management. The unit has developed models for many of the streams within Queensland. For information on the derivation of the flows used in the assessment the relevant model calibration report should be requested from the Department of Environment and Resource Management.

The modelling catchments were selected on the basis that they each have streamflow gauges at their outlet that were identified by DERM as having a sufficient length of record of reasonable quality flow data. They are also headwater gauges, unlikely to be impacted heavily by regulation or licensed diversions.

The length of modelled data at each gauge was between 82 and 121 years and varied between catchments according to the duration of the IQQM model that was established for that basin. Modelling periods of this length are likely to be sufficient to characterise the impact of stock and domestic dams on flow regimes across the typical range of climatic variability that is likely to be experienced in each catchment.

Modelling based on the historic streamflow record is not intended to reflect historic conditions as the level of farm dam development does not alter across the simulation period. Rather, the historic streamflow record provides a range of climatic conditions which test the catchment response.

4.1.2. Evapotranspiration and rainfall

Rainfall and evapotranspiration data have been sourced at the location of the streamflow gauges at the outlet of each modelling catchment from SILO. This data was supplied on a daily basis from 01/01/1890 to 30/06/2011.

The evapotranspiration data used is point potential evapotranspiration data from SILO calculated using Morton’s 1983 complementary areal relationship evapotranspiration model as described by

Wang *et al*. (2009). This "*point potential evapotranspiration may be taken as a rough preliminary estimate of evaporation from small water bodies such as farm dams and shallow water storages*" (Wang *et al*., 2009).

Therefore Morton's potential evapotranspiration as developed for SILO has been used as the evaporation input into STEDI.

4.1.3. Collation of streamflow, evapotranspiration and rainfall files

For each modelling gauge, two space delimited files were created, one for the streamflow and a second one for the rainfall and evapotranspiration data. The length of the files is specific to each modelling gauge, with duration defined by the maximum concurrent period of streamflow and climate data. The files did not require any infilling and the minimum period of record was 82 years for gauge 919005A (Rifle Creek at Fonthill).

4.2. Collation of farm dam GIS layers

There are a number of sources of spatial information about farm dams in Queensland. These include information in the Murray-Darling Basin from Geoscience Australia (A.1), a spatial layer of potentially referable dams from DERM (A.2), an extended project from DERM detailing dams in the Stradbroke, Brisbane, Logan-Albert, Pine and South Coast (A.3), and dams that have been digitised for this project (A.4). These layers are illustrated in Figure 5 and compared in Table 1. Table 1 illustrates the numbers of all dams identified in each data source, including town water supplies, irrigation and stock and domestic dams.

The DERM referable layer is a state-wide dataset showing farm dam locations and extents. The DERM data set was primarily created for monitoring the presence and location of potentially referable dams, under DERM's role as a regulator of dam safety in Queensland. This dataset has been created through remote sensing techniques using a method to capture areas where water with a surface area greater than 0.25 ha was present. This dataset was created using Landsat5 imagery from 1986-2005. It will be repeated using imagery from 1986-2009 and 2006-2010, although these layers are not yet available. There are 175,404 dams represented in the whole DERM referable dams layer.

The MDB waterbodies dataset from GA is a layer of points and polygons that have been digitised for the whole MDB. They were digitised by GA using imagery from 2005 and represent all waterbodies in the MDB. The dams have been attributed in a number of ways. Farm dams are considered to be a subset of those dams attributed with 'Town Rural Storage' in the feature type[1]. This layer is the layer that has been most widely used in previous studies of farm dam impacts. There are 68,297 dams detailed in the Queensland part of the MDB waterbodies dataset. Particularly for the Geoscience Australia dataset, Table 1 identifies all polygon dams that are specified as 'Town rural storages' and all point dams specified as 'Dams'.

The DERM extended layer is an extension of the GA project in the MDB, carried out by DERM in the south eastern part of Queensland. The data is comparable in quality to the GA waterbodies layer and represents 61,023 dams. It was completed in 2011 and there is a concurrent project being undertaken by GA in the catchments just to the north of the DERM extended layer.

There were 15 areas, totally about 8,840 km² selected to digitise as a part of this project. They were digitised using aerial photography captured in the last five years where possible. The digitisation specifications mean that the dams have similar characteristics in the layers digitised for the current project as the GA and DERM extended dams, however in the newly digitised areas all dams were represented as polygons and there are no "point" dam features. There are 12,058 dams in the nine digitised areas.

The four layers have variously been used as independent datasets, or compared against each other. To assist some of the assessment, the four layers were also correlated into a statewide layer, using the smallest geographical regions possible, down to modelling catchments, and using the best quality source of data available, e.g. the GA waterbodies layer in the MDB and the Extended DERM layer in south east Queensland. This layer was made up of reporting areas, and where a reporting area included one or more modelling catchments, it was split into the modelling catchment and the non-modelling catchment areas. This data was particularly useful in the regionalisation of the numbers of farm dams.

The most accurate representation of farm dams is considered to be in the digitised dam layer, followed by the GA and DERM extended layers, which are considered to be of equivalent quality. Given the method of capture, the referable dams layer is considered the least reliable (Sinclair Knight Merz, 2011d), for the purpose of this investigation.

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[1] Geoscience Australia specifies a number of feature types for man-made water bodies including: Aquaculture Area, Salt evaporator, settling pond, flood irrigation storage, town rural storage and water tank. Only features that are of the town rural storage type could possibly be stock and domestic farm dams. A town rural water storage is defined as: "A body of water collected and stored behind a constructed barrier for some specific use (with the exception of Flood Irrigation Storage)" (Geoscience Australia, 2007).

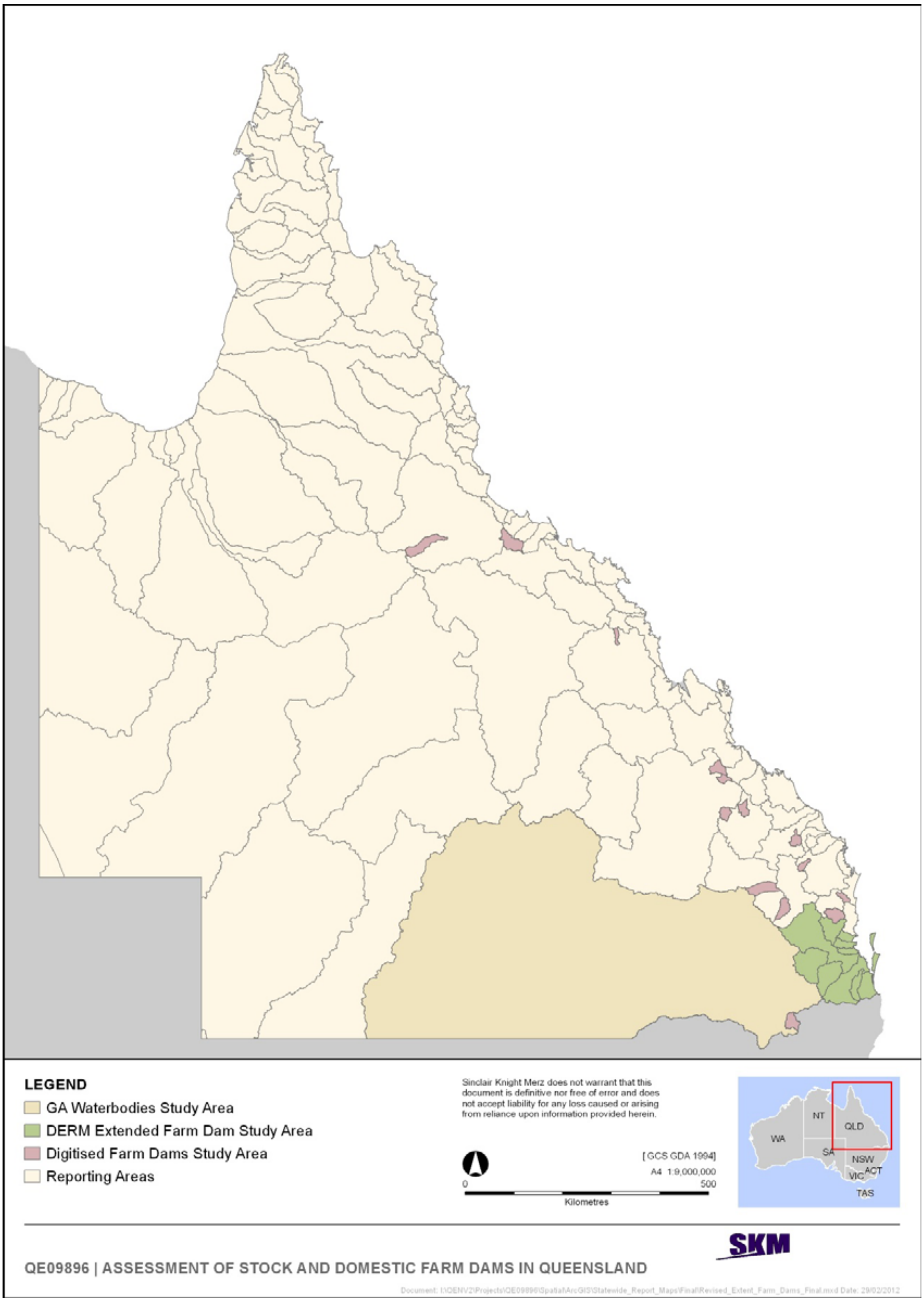
Table 1 provides a summary of the total number of identified dams in the various geographic extents. These numbers represent all dams, not only stock and domestic. Note that the number of dams observed in the Stanthorpe area has been included in the Murray-Darling Basin as well. The table illustrates only the dams that cover the entire digitised area. For instance, in Stanthorpe, there is a complete coverage of the referable dams layer, the MDB GA layer and the DERM digitised layer. Alternatively, for the MDB, the digitised dams only cover a portion of the area, and they are therefore not included for comparison. Note that the numbers presented in this table have changed significantly from those presented in the Pilot Study. A mistake was made in the Pilot Study and the numbers presented in Table 1 are considered to be correct.

Table 1 Total number of dams in various geographic extents**

Geographical area	Total number referable dams	Total number MDB GA dams	Total number DERM extended layer dams	Current project digitised layer dams	Area (km²)
Stanthorpe digitised area	273	4,408		4,249	669
Remainder of digitised areas *	457			7,809	8,165
Murray-Darling Basin	17,966	68,297			273,781
South East Queensland (Extent of extended DERM layer)	3,322		64,023		21,363

** note that this area has increased from the Pilot Study*

*** Note that the numbers presented in this table have changed significantly from those presented in the Pilot Study. A mistake was made in the Pilot Study and the numbers presented in Table 1 are considered to be correct.*



- **Figure 5 Extent of data used to estimate the number of farm dams**

4.3. Identification of stock and domestic dams

For a number of the methods used to prepare the STEDI inputs it was necessary to identify whether farm dams in the modelled catchments were used for stock and domestic or other purposes. An identification method was developed based on an intersection of dam location and landuse type. This identification method was applied to the GA waterbodies layer (A.1), the DERM referable dams layer (A.2), the DERM extended layer (A.3), and the digitised dam layers (A.4).

4.3.1. Adopted approach – Exclusion due to landuse type

There is no reliable way to identify if a dam is stock and domestic from any of the current farm dam spatial layers and therefore a method using a number of different inputs was developed to identify stock and domestic dams. The flowchart in Figure 6 illustrates the decision based approach that was adopted, and the steps taken are also described below.

For each of the layers the following steps and decisions were undertaken:

Step 1: The volume of each dam was calculated using the methods derived in Section 4.5.1. If the dam was bigger than 250 ML, it is unlikely to be used solely for stock and domestic purposes, so it was excluded.

Step 2: The feature type for each of the remaining dams was checked. If the dam had a feature type that is not considered to be a farm dam type (see Table 2), it was excluded.

Step 3: The remaining dams were checked to see if they were named. If it had a name, the dam is unlikely to be solely for stock and domestic purposes, so it was excluded.

Step 4: The landuse for each remaining dam was assessed using the BRS landuse layer. If it was located in a landuse type that is not considered to be stock and domestic (see Table 22 in Appendix C), it was excluded.

All of the remaining dams were considered to be stock and domestic dams, and were used in further analysis.

In previous studies the 5 ML has been assumed as the typical volume where the majority of dams transition between irrigation and stock and domestic use. The 5 ML transition is therefore a convenient means of applying an appropriate demand factor and pattern. However, in previous studies, all farm dams have been modelled, both irrigation and stock and domestic. In this study, the focus and therefore the modelling, was only on stock and domestic dams. In consultation with DERM Regional Officers, it was agreed that stock and domestic dams cover a large range of volumes, up to 250 ML in some cases. Therefore, in Step 1, 250 ML was used as an upper limit to exclude dams that were unlikely to be used solely for stock and domestic purposes.

There were a number of alternative options available to complete Step 4. The information available included the wetlands mapping layer from DERM, coal seam gas (CSG) bore maps, the DERM water licence database, mining lease parcels and the BRS 2005-06 landuse layer. These layers were assessed to see if they could be used in a consistent manner across the state to help identify dams that were not being used for stock and domestic purposes.

The complexity of assessing the proximity of a farm dam to a CSG bore, a water licence, a mining lease or a wetland was found to be significant. The main challenges were either locating the licences or parcels, and correlating with a farm dam, or using the layers in a consistent manner across the state. The only layer that was able to be applied in a consistent manner with some confidence was the landuse layer. Therefore the landuse designation was ultimately found to be the most pragmatic approach of inferring likely stock and domestic dams from non-stock and domestic dams that could be consistently applied across Queensland.

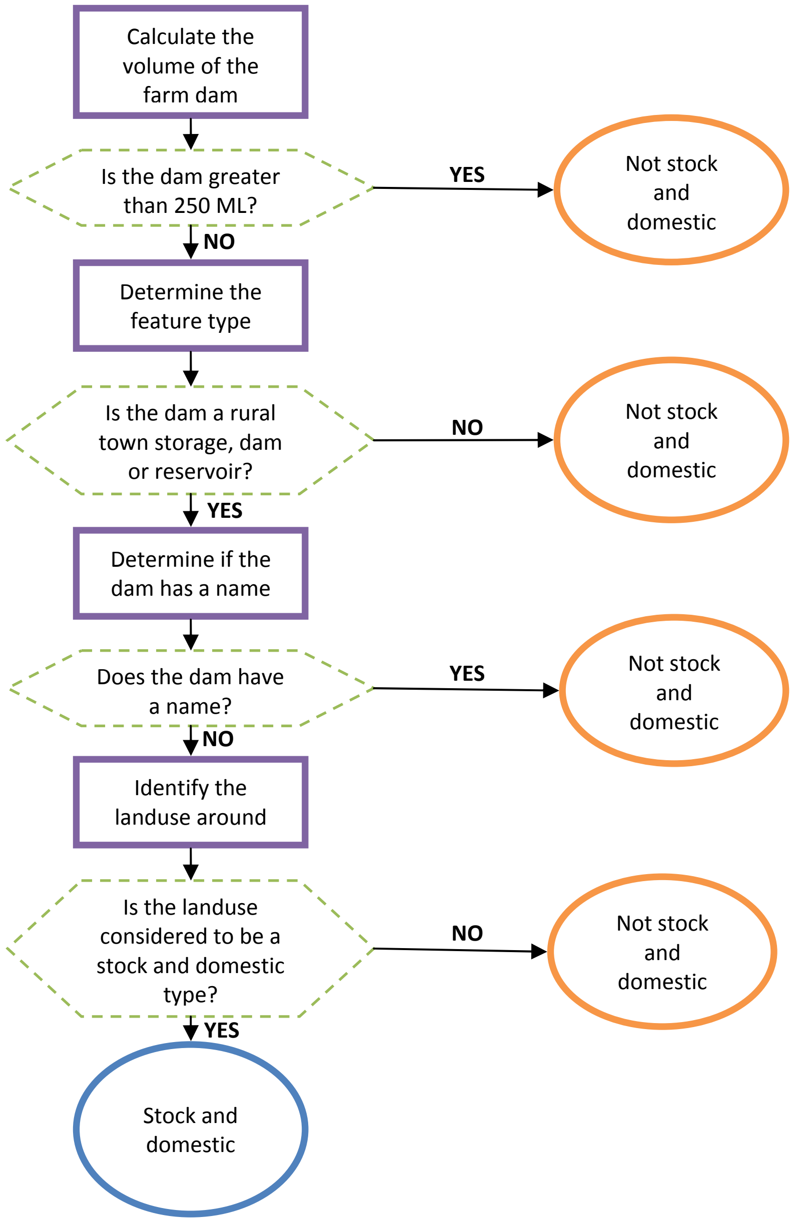
Using this approach, each dam was classified with an exclusion field, based on the numbered steps above, a stock and domestic field, based on the landuse and a modelling field which was a combination of the exclusion and stock and domestic fields, as illustrated in Figure 6 and Table 3. These classifications have been used in different ways for each analysis as detailed in the following sections.

- **Table 2 Feature types included in spatial analysis of farm dams**

Farm dam feature types	Feature types not considered to be farm dams	
Dam	Canal area	Swamp
Reservoir	Channel area	Watercourse area
Town Rural Storage	Flood Irrigation Storage	Watercourse bed
	Lake	Watercourse connector
	Subject to inundation	

- **Table 3 Summary of combinations of exclusion, stock and domestic and modelling fields**

Exclusion field	Stock and domestic field	Modelling field
Include	Stock and domestic	Model
Include	Not Stock and domestic	Do not model
Exclude	Stock and domestic	Do not model
Exclude	Not Stock and domestic	Do not model



- **Figure 6 Process diagram to determine if a dam is stock and domestic or not**

4.3.2. Alternative approach

The advantages of the method described above are that the required information is readily available and it is able to be applied across large areas in a consistent manner. However, the results of this method are very difficult to validate with existing information.

There are three suggested alternatives to the current approach (discussed in Section 4.3.2):

- Survey to validate the existing approach;
- Survey of individual areas as a direct modelling input; and
- Identification of dams through DERM spatial layers and ongoing data collection.

A survey of landholders and regional offices could be conducted in a number of discrete areas in order to validate the results of the existing identification process. A storage type would need to be assigned to each storage within the survey area. The survey would need to cover a large area in order that an extensive range of landuse types are assessed. An initial estimate of the required survey area is 5 distinct areas of at least 500 km^2 each. This would be time consuming to complete to a high level of accuracy and would rely heavily on the knowledge of the regional officers and community goodwill.

Outcomes of the survey could be used to either confirm the reliability of the existing method or to develop a new identification method, possibly based on a regionalisation regression. Alternatively, if STEDI modelling were required for a small catchment area (say less than 500 km^2) it may be possible to conduct a farmer survey of the storage types for the area.

Several of the additional spatial layers that DERM provided for this Project, but which were not used, contained some information about specific dam use. Unfortunately, this information was generally incomplete across catchments and inconsistently defined between the layers, and could not be used to develop an identification process. It is recommended that DERM reviews this information and collates it in a consistent and meaningful manner. Although this data is currently incomplete, if it continues to be updated over time this may provide an appropriate future data set for deriving a regional relationship to identify dam types.

4.4. Determining the number of farm dams

The number of stock and domestic farm dams in the modelling catchments in the MDB has been estimated using the GA waterbodies layer and the identification method described in Section 4.3. In the other modelling catchments, the number of dams has been estimated using the size distribution detailed in Section 4.7.1 and the volume estimate in Section 4.5.1.

The GA dataset has two types of features; there are polygons outlining dams that are generally greater than 625 m^2, and points representing smaller dams, note that this size classification is a somewhat arbitrary figure and is discussed further in Section 4.5.1. All points and polygons were assessed to ensure that they met the criteria for stock and domestic dams as per Section 4.3 and have been summarised in Table 4 and Figure 7.

Note that the number of point and polygon dams has only been calculated in the areas that had that information detailed by the digitisation, e.g. for the MDB areas and the extended DERM area. For the remaining modelling catchments the number of dams has been estimated using the size distribution detailed in Section 4.7.1 and the volume estimate in Section 4.5.2. Table 4 represents observed data only, and therefore only covers select modelling catchments, while Table 10 represents both the observed and predicted number of dams for the baseline assessment and covers all modelling catchments.

- **Table 4 Number of stock and domestic dams in modelling catchments with digitised information**

Modelling catchment		Data source	Number of point dams	Number of polygon dams	Total number of dams
119005A	Haughton River at Mount Piccaninny	Digitisation		141	141
120106A	Basalt River at Bluff Downs	Digitisation		76	76
130319A	Bell Creek at Craiglands	Digitisation		59	59
130349A	Don River at Kingsborough	Digitisation		148	148
130407A	Nebo Creek at Nebo	Digitisation		70	70
142202A	South Pine River at Drapers Crossing	Ext DERM	657	208	865
143110A	Bremer River at Adams Bridge	Ext DERM	93	126	219
143113A	Purga Creek at Loamside	Ext DERM	402	566	968
143211A	Buaraba Creek at 15.3 km	Ext DERM	178	297	475
143212A	Tenthill Creek at Tenthill	Ext DERM	1,180	1,229	2,409
143214A	Flagstone Creek at Windolfs	Ext DERM	167	160	327
143303A	Stanley River at Peachester	Ext DERM	94	44	138
143306A	Reedy Creek at Upstream Byron Creek	Ext DERM	27	19	46
145010A	Running Creek at 5.8km Deickmans Bridge	Ext DERM	31	25	56
145011A	Teviot Brook at Croftby	Ext DERM	54	70	124
145013A	Christmas Creek at Rudds Lane	Ext DERM	80	100	180
145101D	Albert River at Lumeah Number 2	Ext DERM	61	103	164
416204A	Weir River at Gunn Bridge	MDB	507	652	1159
416312A	Oaky Creek at Texas	MDB	152	159	311
416410A	Macintyre Brook at Barongarook	MDB	92	246	338
417201B	Moonie River at Nindigully	MDB	370	2,739	3,109

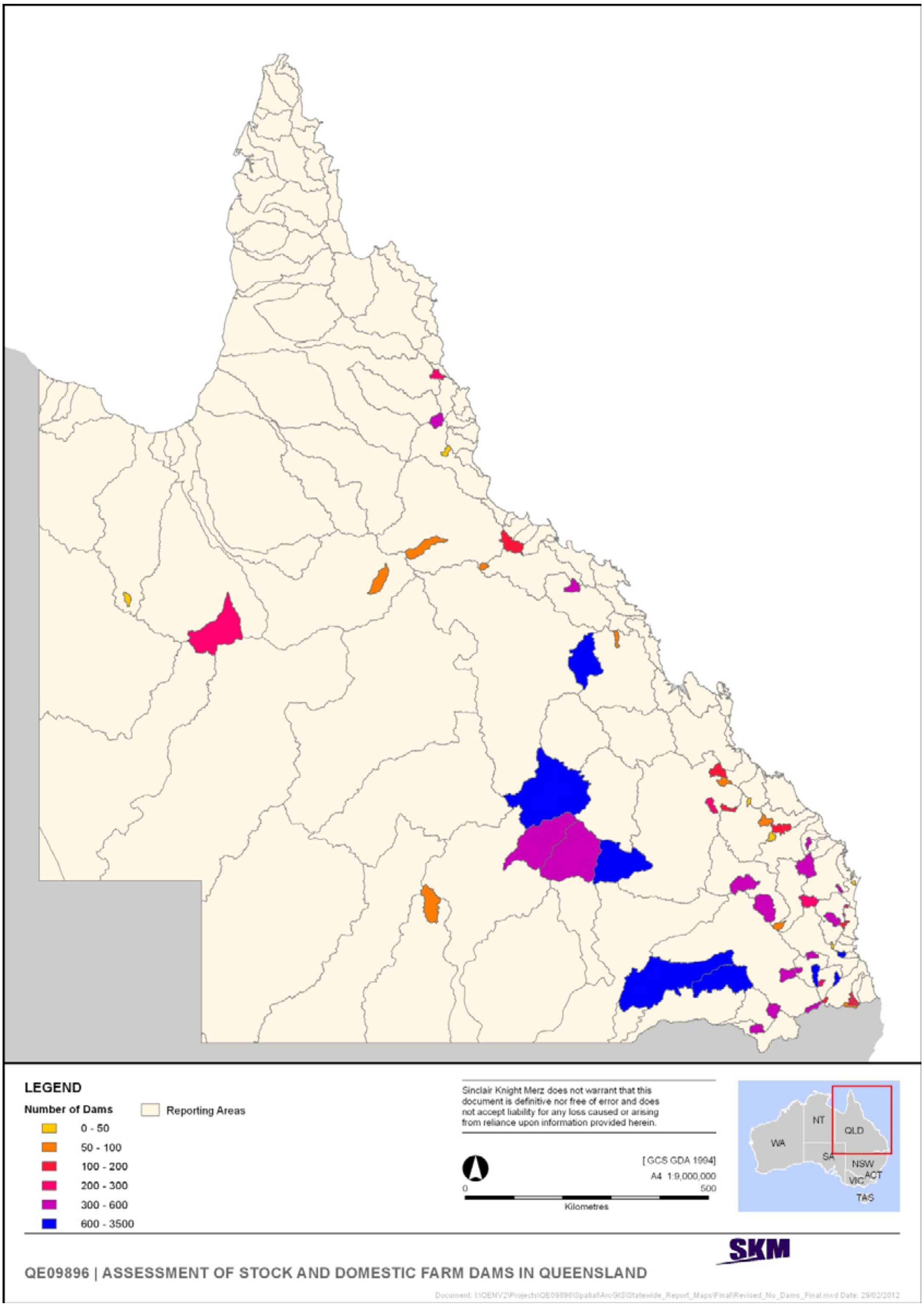


Figure 7 Number of dams estimated in each modelling area

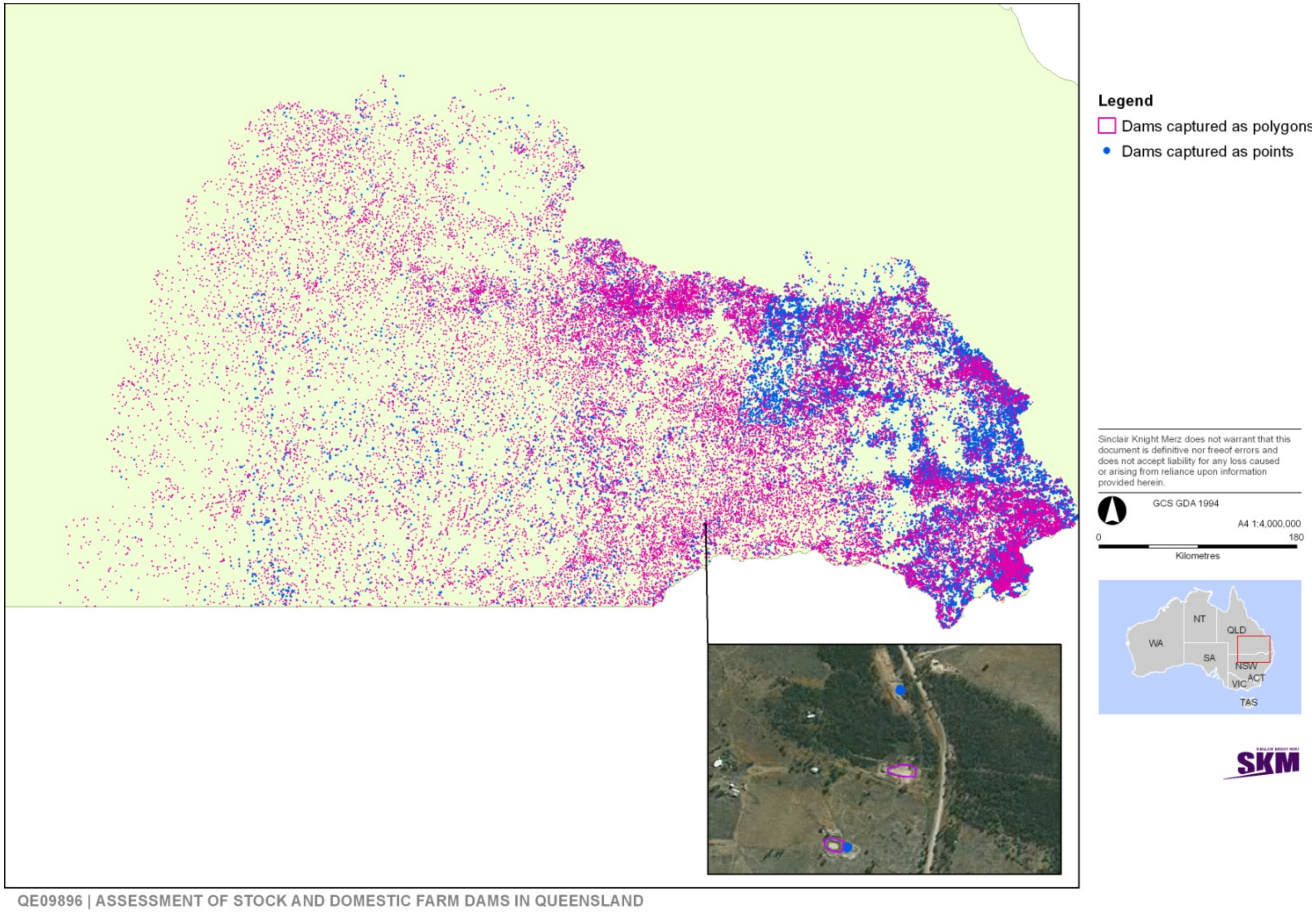
4.5. Determining the volume of stock and domestic farm dams

The volume of farm dams is a key hydrological factor in the assessment of the impact of farm dams. The ideal way to estimate the number and volume of farm dams would be to have a spatial layer across the state, detailing the boundaries of all farm dams at full supply level.

While the DERM farm dam layer is a state-wide dataset, it does not reflect the number or volume of stock and domestic farm dams well across Queensland. It only represents dams that had more than 0.25 ha of standing water at the time of image capture, and does not identify smaller dams or dams with no water in them at the time of imagery capture. Additionally, given the resolution of the imagery and the capture method, the dam boundaries do not represent the surface area at full supply level. Both of these characteristics mean that the data layer will consistently underestimate the number and surface area of farm dams in Queensland.

Although the DERM data set may be used to indicate the presence of potentially referable dams, it is not considered appropriate to be directly used to estimate the number and volume of small farm dams (less than 0.25 ha surface area) across Queensland, which is of interest in this project. As this is the only statewide dataset, a regionalisation method was developed and applied as per Section 4.6 for catchments that did not have detailed information available, allowing the DERM dataset to be used indirectly. For areas where there was detailed farm dam information, the volume of individual farm dams has been estimated using the method described in this section.

The detailed information available in the GA waterbodies and DERM extended layers is represented by both polygons with a known surface area, and points that indicate the presence of a small dam (Figure 8). For the point dams, a surface area distribution was assigned, giving an estimated surface area for each point dam (Section 4.5.1). The volume of all points and polygons was then estimated using the surface area to volume relationship detailed in Section 4.5.2.



- **Figure 8 Example of the point and polygon dams captured by Geoscience Australia. Note that a surface area has been applied to the points as described in Section 4.5.1.**

4.5.1. Adopted Approach - Assignment of surface area for point dams

A large number of farm dams are represented in the spatial data sets as points only, without an estimate of their surface area. As a part of the GA specifications, these point dams were intended to represent smaller dams, specifically those dams with a surface area of less than 6400 m². In contrast with the specifications, there is also a general understanding that 625 m² has been the threshold surface area to use for identifying point or polygon dams (Pers. Comm. P Delaney, 10 January 2012). Neither of these specifications has been consistently applied in the MDB GA data as there are many point dams larger than 625 m² and polygon dams with surface area less than 6400 m².

Given these incongruities and the large variation in dam size, an analysis of point dams across the MDB was carried out in the Sustainable Rivers Audit (SRA) project in order to better understand the size of these point dams (Sinclair Knight Merz, 2011b). The SRA analysis produced a size distribution that has been used in this project to assign the Queensland point dams with a surface area and therefore a volume.

To assess the size distribution in the SRA project, the boundaries of 819 point dams were digitised across the MDB. The size of each dam was calculated, along with the volume using the previous Victorian surface area to volume relationship. Each of the dams were assigned to a class, and the size distribution was then assessed for five groups, the whole MDB, Victoria (including South Australia), NSW North, NSW South (including ACT) and Queensland. It was found that there were significant differences in the size distribution between different states and the whole MDB, and it was concluded that a state specific size distribution should be applied for each state. There were 75 dams assessed in Queensland, with a minimum surface area of 217 m², maximum of 9650 m² and mean surface area of 1470 m². The calculated size distribution for Queensland is presented in Table 5.

The size distribution was applied to the Queensland point dams by generating a random number for each dam, using the random number to assign each dam to a size class as detailed in Table 5. Each size class has been assigned a given dam surface area and the dam volumes were then estimated from the surface area, using Equation 1. The percentage of dams assigned in each class is also detailed in Table 5, illustrating that the overall percentage distribution between classes has been preserved.

- **Table 5 Size distribution of point dams from the SRA project (Sinclair Knight Merz, 2011b)**

Size class	Average surface area for dams in each class (m²)	Theoretical distribution of point dams in Queensland*		Applied distribution of point dams in the Queensland datasets (Percentage of all points in each class)
		Size class distribution (%)	(Percentage of all points in each class)	
1	291	0 - 17.8	17.8%	17.8%
2	672	17.8 – 37.1	19.3%	19.2%
3	1139	37.1 – 67.2	30.1%	30.1%
4	2171	67.2 – 93.2	26.0%	26.0%
5	3878	93.2 – 100	6.9%	6.8%

* Derived for the MDB SRA project

4.5.2. Adopted approach – Surface area to volume equation

A farm dam surface area to volume relationship was developed in order to estimate the volume of individual dams. A regression analysis was conducted on a sample of 73 dams in Queensland with the full dam area and volume approximated from Light Detection and Ranging (LiDAR) data (A.7) and a digital elevation model (DEM) (A.9). This analysis was based on a method used by SKM (2004) to estimate a farm dam volume-to-surface area relationship based on 149 dams in the MDB in Victoria.

The LiDAR survey used in this study is unable to penetrate the surface of any water that was in the water bodies at the time that the survey was flown. The initial estimate of the volume in each of the farm dams constructed from the LiDAR data therefore only constitutes the volume that is above the water surface and excludes the volume of water that was contained in the dam at the time of the LiDAR survey. The initial estimate then needs to be adjusted to account for the residual volume of water in the dam.

Figure 9 shows an example of a dam captured by the LiDAR survey. The full supply level of the dam is indicated by the blue line, while the surface area of the water held within the dam (residual volume) is indicated by the red line.

The regression analysis was therefore undertaken in three stages:

- Derive an initial regression equation based on the empty dams only;
- Estimate the unaccounted volume in dams with standing water (based on the residual water area); and
- Re-derive the regression equation based on the new volume estimate.

- **Figure 9 Example of the LiDAR capture of a dam in the Condamine River catchment. Note that the full supply level of the dam is indicated by the blue line, while the surface area of the water held within the dam (residual volume) is indicated by the red line.**

An initial regression equation was developed based on 13 dams in the sample which were completely empty at the time of survey. This provided an initial approximation of the surface area-to-volume relationship, which was used to estimate the unaccounted volume in dams with standing water. The estimated volume of water stored was then added to the volume above the water surface estimated from the LiDAR data for an extra 60 dams in the sample that had the unaccounted for contribution to the total volume representing less than 30% of the total estimated volume for the dam.

The choice of the 30% threshold represented a compromise between achieving a large sample of dams and avoiding a situation where the equation fitted by regression is itself populated with "data" that has largely been derived using the regression equation. By adopting 30% as the threshold, the size of the sample increases by five and half times. This means that for 60 dams, the unaccounted volume was estimated using the regression equation and included in the iterative development of the regression equation. In practise, the maximum residual volume represented only 23% of the total estimated volume.

The final area-to-volume regression relationship was developed based on 73 dams: the original 13 dams that were completely dry plus the 60 dams with an estimated below water surface volume of less than 23% of their total computed volume. The fitted regression relationship is provided as Equation 1.

- **Equation 1 Relationship between farm dam surface area and volume**

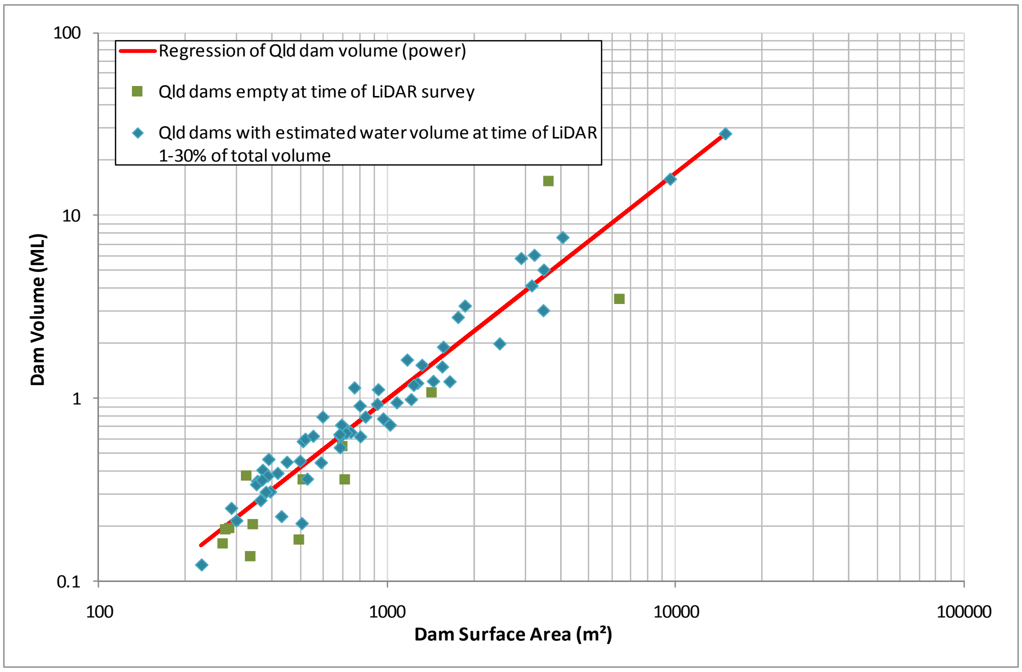
$$Volume = 1.9 \times 10^{-4} \times Surface\ Area^{1.23797}$$

Where:

***Volume** = Farm dam volume (ML)*
***Surface Area** = Farm dam surface area (m²)*

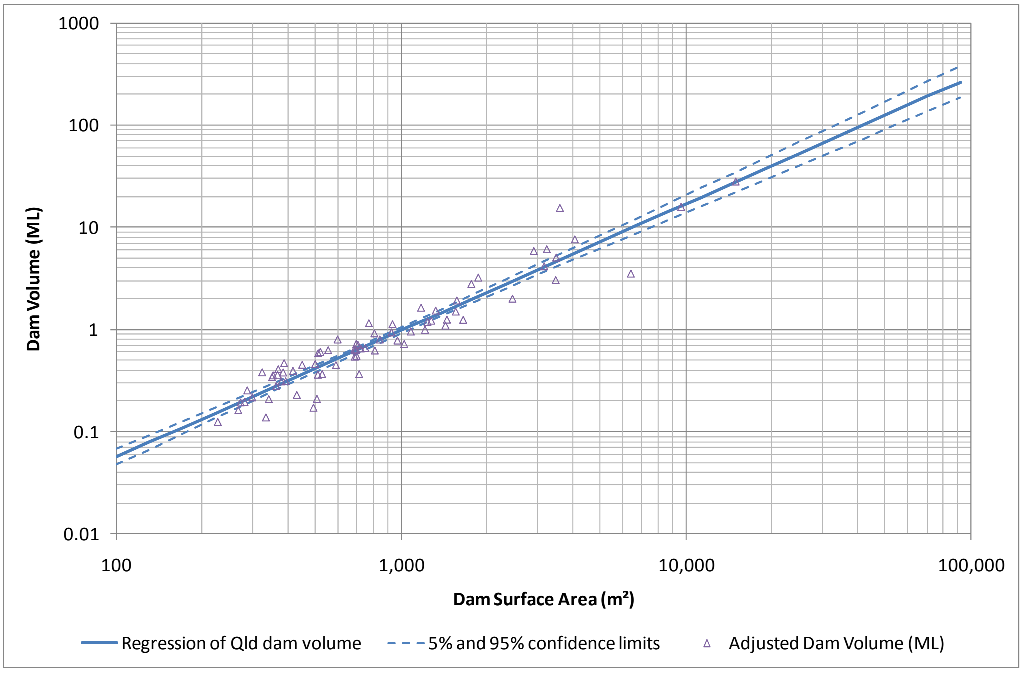
This equation provides a very good fit to the data, resulting in an adjusted coefficient of determination (r^2) of 0.9139 in the log-log domain. After removing the influence of using the regression equation to estimate a proportion (up to 23%) of the volume estimate for the dams that had some water in them at the time of the LiDAR survey adjusted r^2 value resulting from this relationship is 0.9024.

Figure 10 presents the farm dam volume-to-surface area relationship developed using the 73 dams in the sample of Queensland dams. The data set includes partly full dams (blue diamonds in Figure 10) that would otherwise be missed by only considering empty dams (green squares in Figure 10). A dam that was 23% full at the time of the survey would have 77% of its overall estimated volume contributed by real LiDAR data. Figure 10 demonstrates that there is little bias introduced by the estimation approach.



- **Figure 10 Relationship between farm dam Surface Area and Volume**

Figure 11 presents the adopted regression relationship with the 5% and 95% confidence limits. As demonstrated the confidence limits around the adopted relationship are very tight.



- **Figure 11 Relationship between farm dam Surface Area and Volume – with confidence limits**

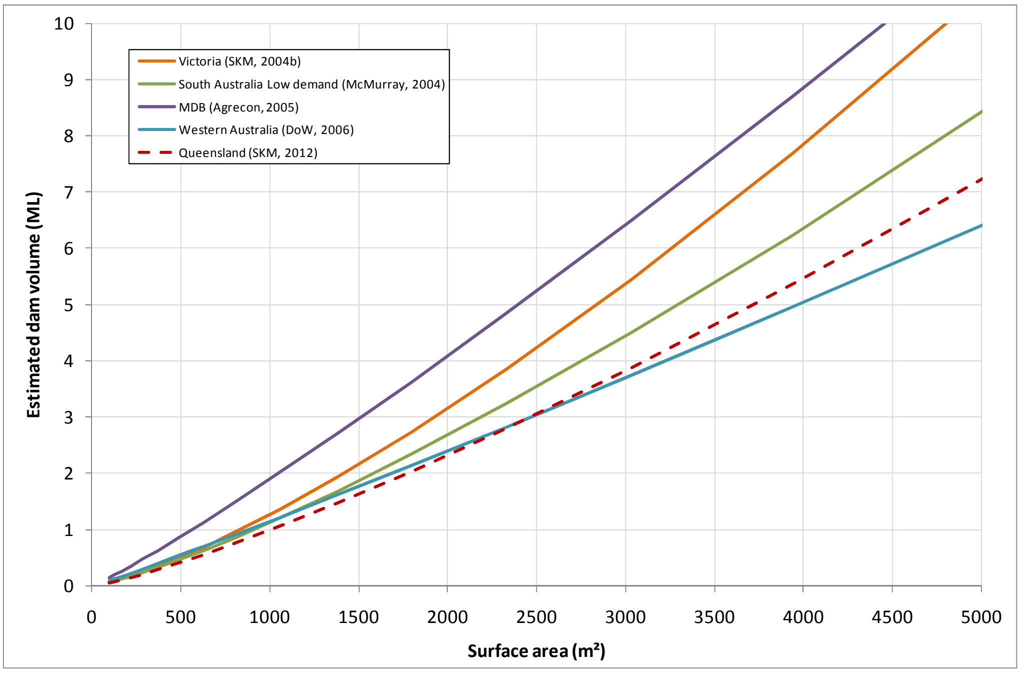
The sample of Queensland dams from the LiDAR survey used to derive the final relationship were located in the Lockyer, Southern Downs and Moreton Reporting Regions, as shown in Table 6. Use of the Queensland relationship for parts of the state outside the Lockyer, Southern Downs and Moreton reporting regions may introduce additional uncertainty.

- **Table 6 Number of dams used to calculate surface area versus volume relationship by catchment**

Reporting regions	Number of dams
Lockyer	33
Southern Downs	39
Moreton	1
Total	73

Figure 13 shows the spatial extent of the DEM and LiDAR data used in this assessment.

The degree of additional uncertainty introduced is difficult to quantify but the differences between the Queensland and other regional equations can provide some indication of the possible influence of regional variability. Figure 12 presents a relationship for Victoria (SKM, 2004b), MDB (Agrecon, 2005), Western Australia (DoW, 2006), and South Australia – low demand (McMurray, 2004)[2], compared to the adopted Queensland relationship. These relationships are all somewhat different, with the MDB relationship generating the largest volume for a given dam surface area and the Western Australian relationship generating the smallest volume for a given dam surface area. The Queensland relationship is shown to resemble the Western Australian relationship more closely than the other regional relationships.



- **Figure 12 Relationship between farm dam Surface Area and Volume – comparison of regional equations**

Figure 12 demonstrates that regional differences (e.g. terrain, rainfall, evaporation etc.) may create differences in the surface area to volume relationship for farm dams across different areas of Queensland. This is worth investigating at a later date, with more emphasis on a larger sample size, covering a wider geographic extent.

[2] McMurray (2004) developed separate equations for irrigation dams, which they called high demand dams, and stock and domestic dams, which they called low demand dams. Since the focus of the current project is on stock and domestic dams, only the low demand dams equation from McMurray (2004) is relevant.

- **Figure 13 Extent of data used to improve the relationship between surface area and farm dam volumes in Queensland**

4.5.3. Alternative approach

The adopted method for estimating the dam volume from its surface area is a robust method and the derived regression equation has a strong correlation and level of confidence. This method is considered suitable for developing input data for STEDI modelling and for future work by DERM.

It is not considered necessary to change this approach. However, if DERM are interested in validating this relationship through other means a ground survey could be carried out for a number of the dams which were used to develop the surface area to volume equation. This would provide an understanding of the accuracy of the LiDAR data, although ground survey also has limitations in terms of accuracy. While ground survey could be undertaken it is costly and time consuming in comparison to LiDAR analysis and is unlikely to provide an increase in the level of accuracy of data.

Alternatively, further LiDAR analysis could be undertaken to increase the number of data points used in the development of the surface area to volume equation. This would increase the confidence in the validity of the developed equation. An increase in the in the number of dams used in the analysis from 73 to 300 would reduce the uncertainty (standard deviation) associated with the developed equation to approximately half of the current level of uncertainty. The LiDAR analysis should also cover a range of geographic regions, in order to account for regional differences in terrain, rainfall, evaporation and landuse.

4.6. Regional volume estimate

As noted in Section 4.5, the volume of farm dams is a key hydrological factor in the assessment of the impact of farm dams. To enable an estimate of farm dams volume to be made where there is little or no good quality information, a regionalisation technique has been developed that uses catchment characteristics to estimate the volume of farm dams for any area across Queensland.

4.6.1. Adopted approach

To develop the regional volume method, catchment characteristics were calculated for all the areas that had good farm dam information, using the DERM extended data, the MDB data and digitised areas. These catchment characteristics and dam volumes represent 53 independent areas with a good estimate of farm dam numbers and volumes, and include complete modelling catchments, complete reporting areas, the remnant part of reporting areas and some of the digitised areas. Table 7 details the area of Queensland with farm dam volume data that was included in the regression analysis.

A regression relationship was developed to represent the dam volume in an area with the corresponding catchment characteristics. Catchment characteristics were calculated for the following statistics to explore their relevance in regionalising the volume of farm dams and included:

- The number and volume of referable dams from the DERM data, the DERM extended area, MDB GA waterbodies and digitised dams;
- The monthly and annual rainfall, areal potential, areal actual and point potential evapotranspiration from the BoM climate grids (A.6);
- Minimum, mean and maximum slope of each catchment ;
- Minimum, mean and maximum elevation of each catchment (Using the SRTM (m EGM96 vertical datum));
- Population from the ABS Census collection districts (2006), excluding districts with a population density greater than 300 people per square kilometre;
- Area of woody vegetation (Department of Climate Change and Energy Efficiency);
- Areas of various landuse as defined by the BRS 2005-06 landuse layer (A.12); and
- Area of expected stock and domestic landuse as defined by Appendix C.

A regression relationship was then developed in a step by step manner, including the most correlated catchment characteristics in order (Equation 2). The best relationship was found to include the number of referable dams, the number of people in the area and the mean annual areal actual evapotranspiration.

The t-statistics for each of the coefficients have been included in Table 8. Figure 14 and Figure 15 illustrate the comparison between the observed and estimated volume of stock and domestic farm dams on a linear and log scale respectively. Figure 16 and Figure 17 illustrate the same comparison, but for farm dam density. Figure 15 and Figure 17 illustrate that the derived relationship, with an R^2 of 0.93, represents the volume of farm dams well across the full range of observed volumes, with an even distribution of farm dams both above and below the one to one line.

While the p-Value for the mean annual areal actual evapotranspiration shows that the parameter is not statistically significant, it provides an important physical indicator of the volume of stock and domestic dams and an improved the visual fit of the relationship. It was therefore included in the final equation.

The prediction limits have been calculated for each of the catchment areas used in the regression analysis and are presented, along with the observed and estimated volume of dams in each catchment, in Table 23 in Appendix D. The prediction limits for each of the modelling catchments have also been estimated and used to test the sensitivity of the model to the regression in *Statewide Assessment: Report 2 – Hydrological assessment of stock and domestic farm dams in Queensland*.

- **Equation 2 Regionalisation equation for volume of farm dams**

$$\text{Volume of stock and domestic dams (ML)} = 99.05 \times e^{(-0.00068 \times \text{Mean annual ET})} \times \left(\max\left(\text{Number of referable dams}, 0.5\right)\right)^{0.51157} \times \text{Population}^{0.28092}$$

Where:

R^2 = 0.93

***Number of referable SD dams** = the number of dams in the DERM Referable dams layer, in SD landuses in a particular catchment. Note that where there are no dams in the DERM referable dams layer this should be set to a minimum value of 0.5.*

***Mean Annual AAET** = mean annual areal actual evapotranspiration (mm) from the BoM Grids in a particular catchment*

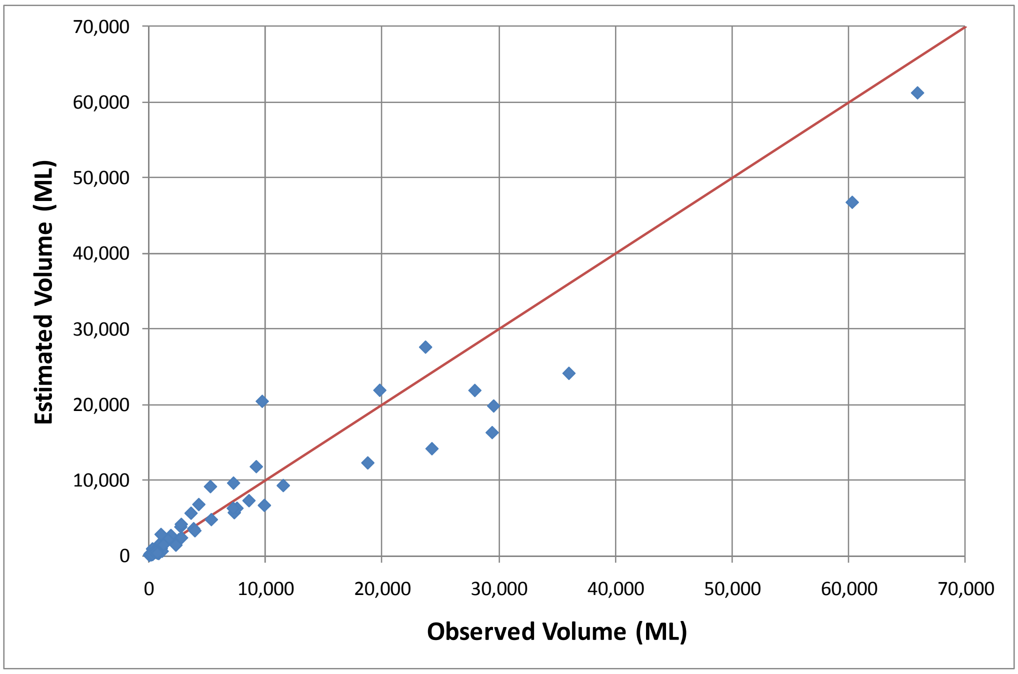
***Population** = number of people in the catchment sourced from ABS 2006 Census Collection District data. Note that the Collection Districts with population density greater than 300 people/km² have been excluded*

- **Table 7 Catchment areas of farm dam data used in regression analysis**

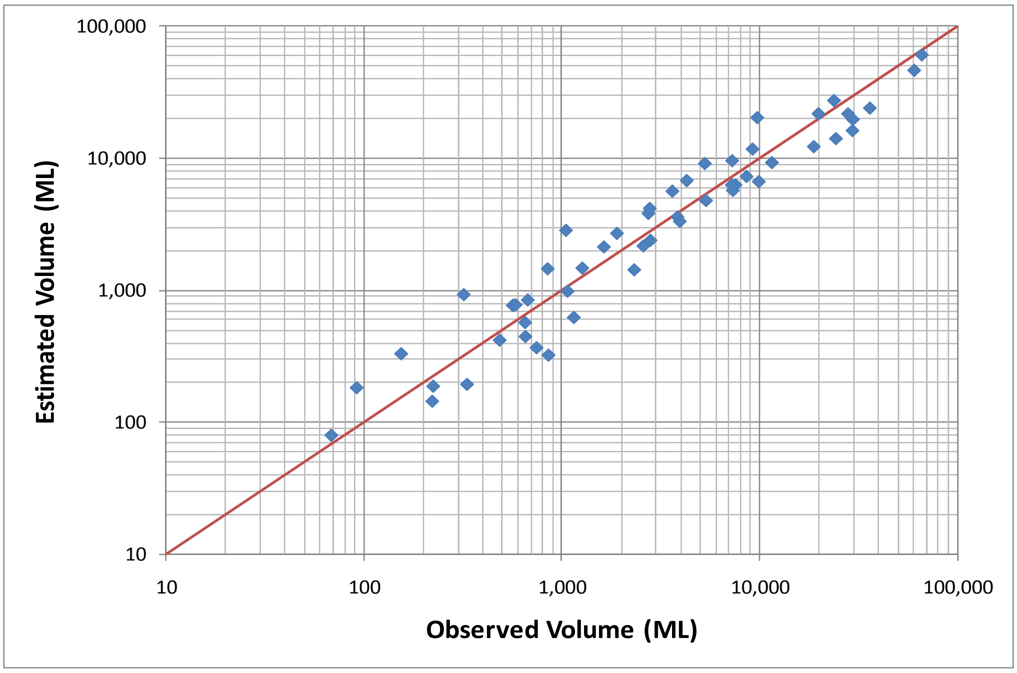
Area	Data source	Area covered (km²)
Digitisation areas	Digitised for this project	8,835
Modelling catchments	From DERM extended or MDB GA farm dam layers	39,105
Remnant areas		152,679
Reporting areas		98,944
Total area used to complete regression analysis		**299,563**

- **Table 8 t-Statistics and P-value for coefficients of Equation 2**

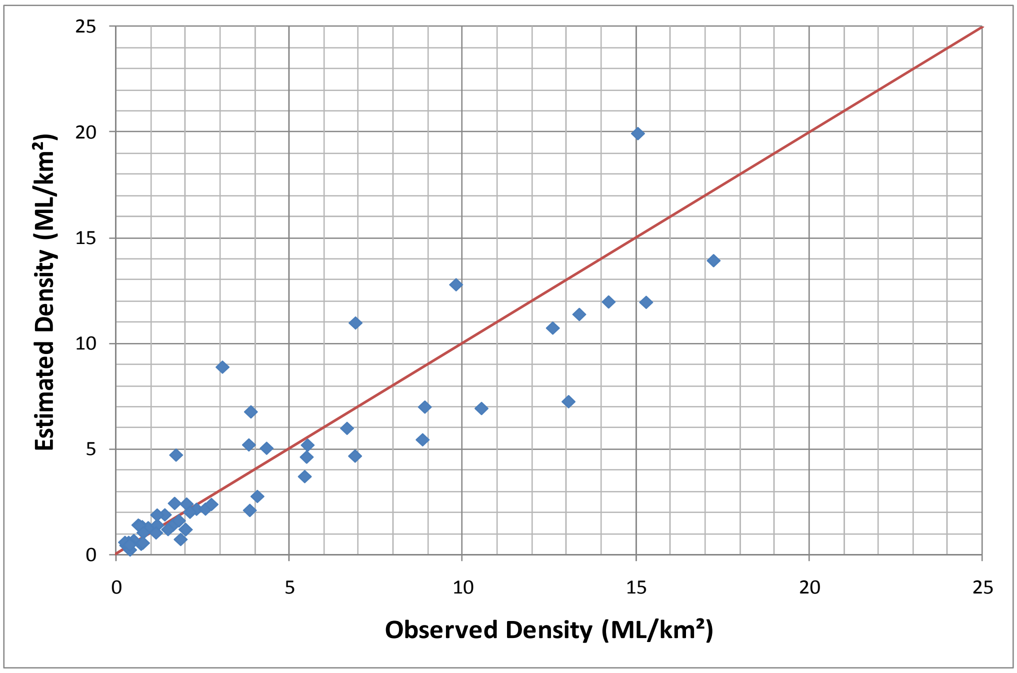
Coefficient	t Statistic	P-value
Log_n (Population)	5.87	3.76E-07
Log_n (Number of referable dams)	9.7	5.26E-13
Mean annual AAET	-0.96	0.34



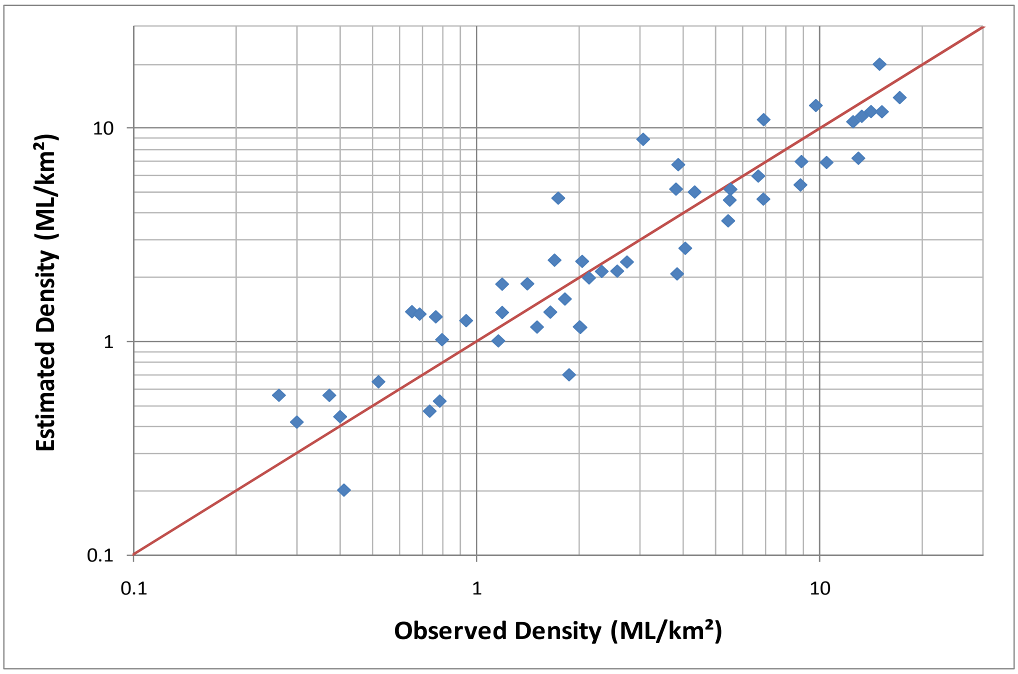
- **Figure 14 Observed stock and domestic farm dam volume compared to the volume estimated by Equation 2**



- **Figure 15 Observed stock and domestic farm dam volume compared to the volume estimated by Equation 2 on a log scale**



- **Figure 16 Observed stock and domestic farm dam density compared to the density estimated by Equation 2**



- **Figure 17 Observed stock and domestic farm dam density compared to the density estimated by Equation 2 on a log scale**

4.6.2. Alternative approach

The alternative approaches for estimating the volume of stock and domestic farm dams are:

- Reduce uncertainty in a particular area of interest by digitising the dams within it;
- Digitise a greater area of Queensland and repeat the regression analysis with more data to extrapolate to the whole state; or
- Digitise farm dams for all of Queensland.

For areas of particular interest, it may be worthwhile digitising those areas and reducing the uncertainty in the estimate for that area. Given the manual nature of digitisation, and the ongoing development in farm dams, completing the assessment for the whole State is a significant exercise, both in terms of time and money. An ideal outcome for DERM would be if this process were undertaken as part of another project, for example, an extension of the GA waterbodies layer.

4.7. Determining the size distribution of stock and domestic farm dams

4.7.1. Adopted approach - Size distribution of dams

Hydrological modelling of farm dams requires information about each individual farm dam within a catchment. However, it is recognised that such data is not always available, and therefore STEDI provides an alternative, simpler modelling approach which merely requires two pieces of information. The first of these two pieces of information is the total volume of dams within a catchment, and this was estimated using the equation given in Section 4.6. The second of these is the distribution of individual dam volumes within a catchment, and the derivation of this information is described below.

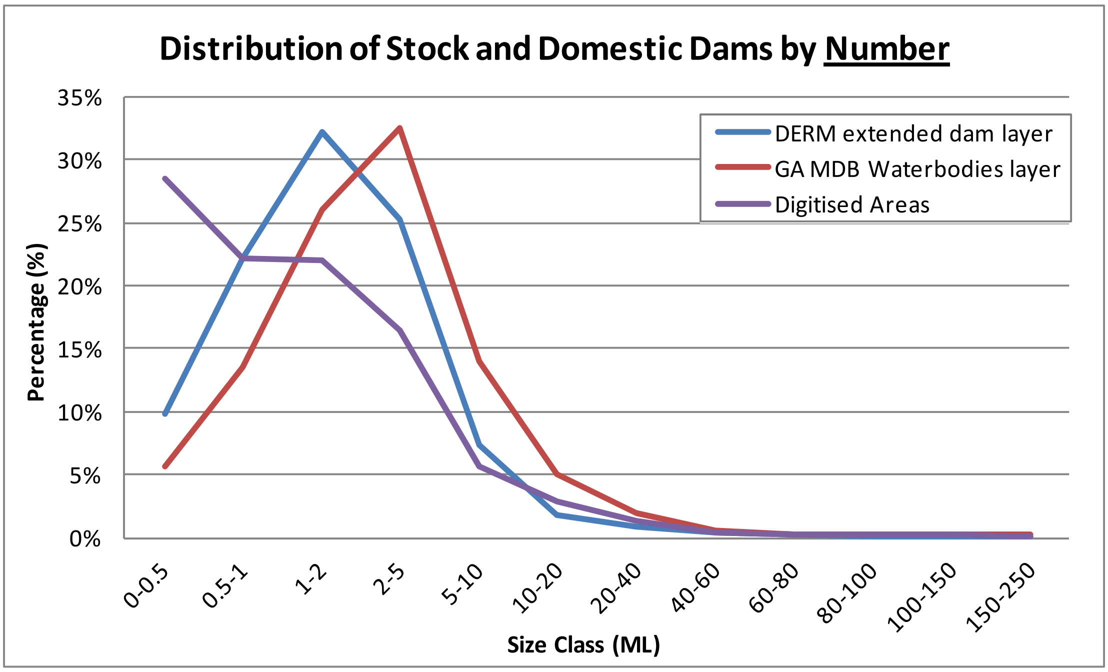
Four spatial layers were used to calculate the number and surface areas of farm dams in different regions of Queensland. These layers were the MDB GA waterbodies layer (A.1), the DERM referable dams layer (A.2), the DERM extended dam layer (A.3) and the digitised areas (A.4).

Farm dams were identified within these layers and the volume of each dam was then calculated based on the surface area to volume relationship developed for this project (Section 4.5.2). The dams identified from these spatial layers were grouped into size class categories and the data was also split into stock and domestic and non-stock and domestic, according to land use classification. Non-stock and domestic dams were removed from the analysis to provide a more accurate representation of modelled dams, as no non-stock and domestic dams were modelled.

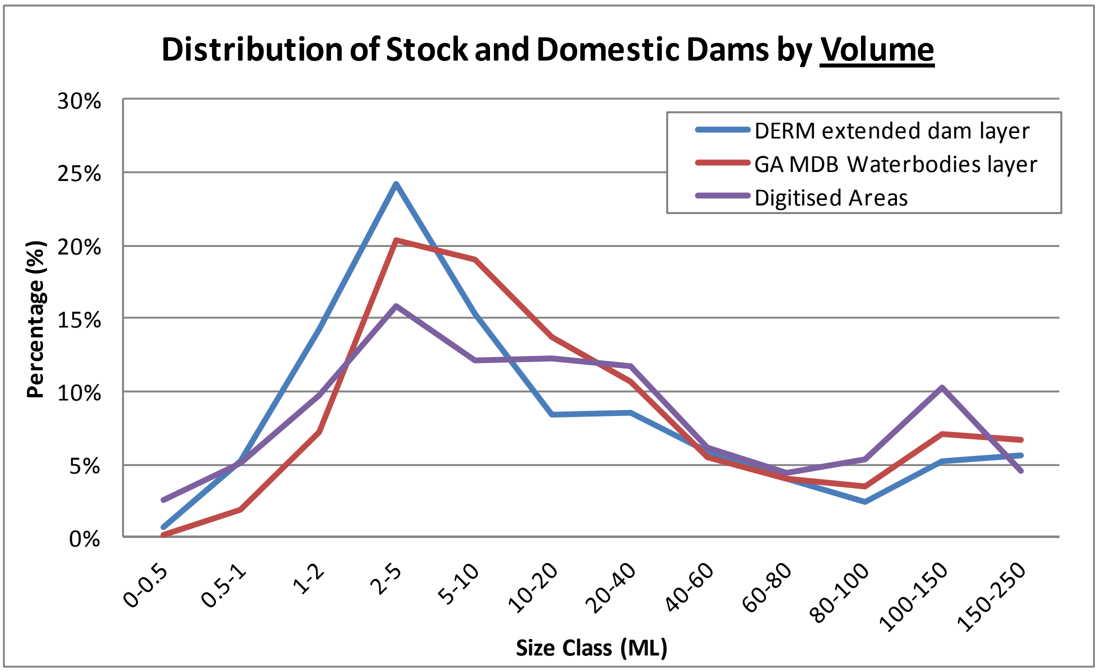
This showed that the DERM referable dams layer significantly under represents the number of small dams, as previously identified. Data from this layer was therefore excluded from the remainder of the analysis.

The following figures show the distribution of stock and domestic dams in the three spatial layers by volume (Figure 18) and by numbers (Figure 19). These figures show a similar pattern of distribution between the layers, with the majority of dams in the 0-10 ML range, with relatively few dams above 10 ML.

A final distribution was developed based on consolidating the data from the three remaining spatial layers, and based on stock and domestic dams only. This distribution is presented in Table 9 and Figure 20 and was used as a direct input to the STEDI modelling, in catchments where the number and volume of stock and domestic dams was not able to be determined directly from spatial data.



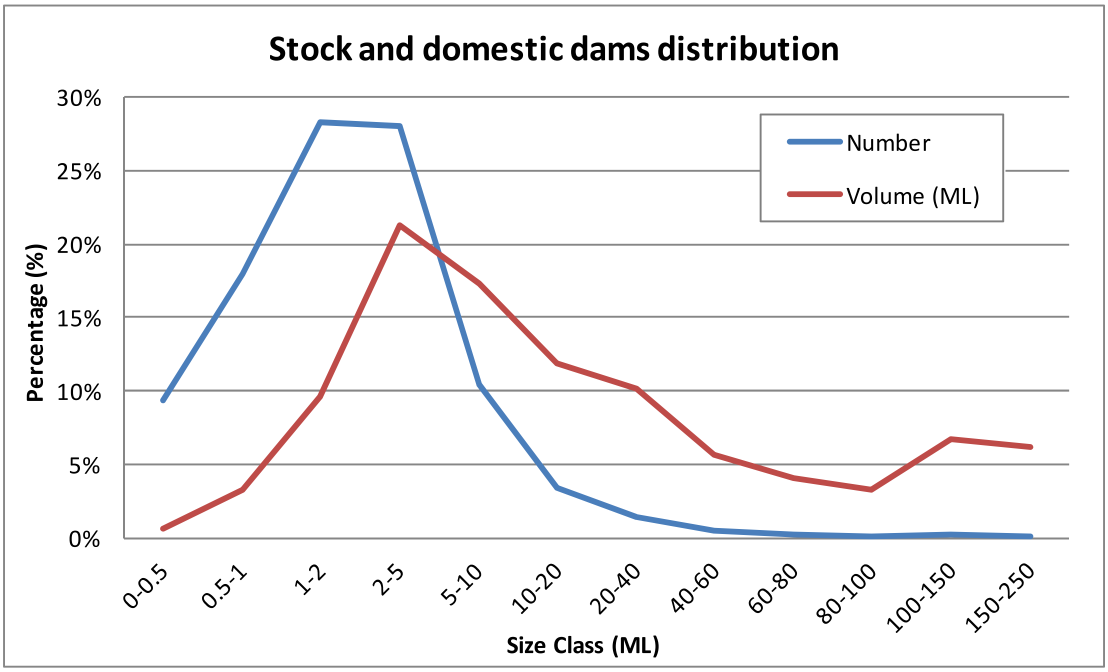
- **Figure 18 Distribution of stock and domestic dams by volume (and size class)**



- **Figure 19 Distribution of stock and domestic dams by numbers (and size class)**

- **Table 9 Queensland stock and domestic dam number and volume distribution**

Dam Size Class (ML)	Total Number and Volume of Dams		Percentage Distribution	
	Number	Volume (ML)	Number	Volume (ML)
0-0.5	11,803	2,854	9.4%	0.6%
0.5-1	22,579	15,874	18.0%	3.2%
1-2	35,576	47,287	28.3%	9.6%
2-5	35,121	104,486	28.0%	21.3%
5-10	13,013	84,931	10.4%	17.3%
10-20	4,268	58,407	3.4%	11.9%
20-40	1,796	49,489	1.4%	10.1%
40-60	566	27,822	0.5%	5.7%
60-80	285	19,699	0.2%	4.0%
80-100	184	16,373	0.1%	3.3%
100-150	269	32,783	0.2%	6.7%
150-250	163	30,464	0.1%	6.2%



- **Figure 20 Final Queensland stock and domestic dams distribution**

The final distribution is heavily affected by the GA layer, as this covers the most area of the spatial layers and has the largest number of dams; however given the level of accuracy of the GA layer this is considered appropriate.

The variation in the distribution for the three individual layers indicates that there may be a difference between the size distribution for dams in catchments inland compared to coastal, or in northern or southern catchments. However, there is currently insufficient information available to investigate this further with any confidence.

4.7.2. Alternative approach

The current approach is considered to provide an accurate estimate of the size distribution of stock and domestic dams on a regional basis. However, the majority of the data is from the MDB and may not adequately represent size distribution in more northern areas of the state. This could be investigated by digitising additional areas across the state, particularly in the north and west. Additional digitisation could also assist in reducing the uncertainty introduced by the point dams size distribution.

Alternatively, if the regional volume estimate was not required to estimate the total volume of stock and domestic farm dams in each modelled catchment, the size distribution method would also not be required. This would occur if there were spatial data available for all of the modelled catchments, identifying the individual dams in the catchment.

Also, it should be noted that the distributions shown in Figure 18 vary significantly for the smaller size classes. There could be significant regional differences in these smaller size classes because, for example, small dams may prove to be too unreliable in areas where rates of evaporation are high, and so there are fewer dams of this size. Such regional differences could be more clearly understood if further digitisation of dams were undertaken in areas with different levels of dam development and different physiographic characteristics.

4.8. Adopted number and volume of stock and domestic dams

Table 10 presents both the number and volume of dams adopted for the baseline assessment for all of the modelling catchments. The table also presents the dam density for the catchment, for ease of comparison. This data was determined either directly from spatial data and the surface area to volume relationship, or from the regional volume estimate and size distribution.

A comparison of the relative dam densities across the catchments shows a significant range, both for catchments using the regional volume estimate and direct estimate from spatial data. The highest estimated densities are in the North and South Maroochy River catchments (GS 141009A and GS 141002A). These catchments rely on the regional volume estimate, which is primarily driven by population, in these cases. However, these estimates are not unbelievable, considering the high level of peri-urban growth in the region (and associated development of small dams for stock and domestic purposes) and given the estimates from spatial data in the surrounding regions (e.g. GS 143113A, GS 143212A).

- **Table 10 Catchment area, number and volume of stock and domestic dams estimated or observed for each modelling catchment**

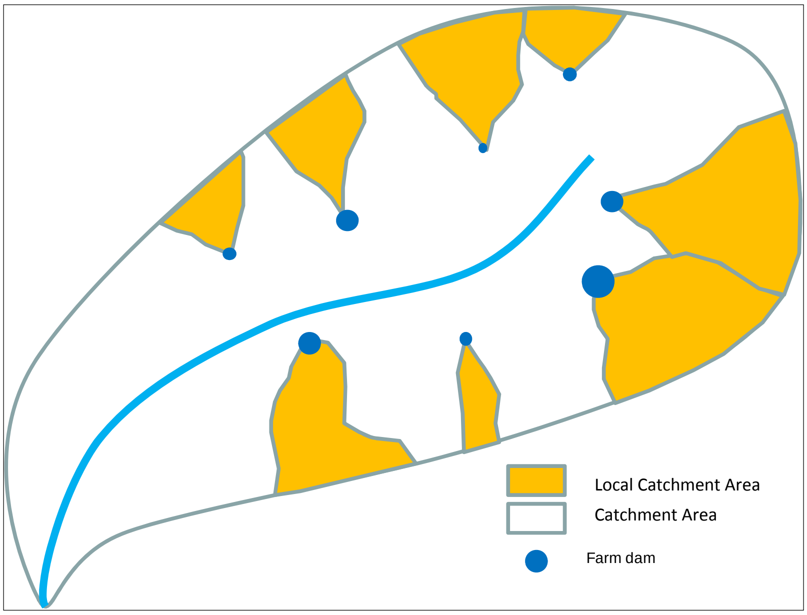
Gauge Number	Gauge Name	Modelled catchment area (km²)	Number of dams	Volume of dams (ML)	Dam density (ML/km^2)	Source of volume estimate
116009A	Cameron Creek at Glen Ruth	225	23	58	0.26	Regional eqn
116014A	Wild River at Silver Valley	572	400	1,749	3.06	Regional eqn
119005A	Haughton River at Mount Piccaninny	1,115	141	852	0.76	Spatial data
120014A	Broughton River at Oak Meadows	186	100	371	2.00	Regional eqn
120106A	Basalt River at Bluff Downs	1,300	76	676	0.52	Spatial data
120220A	Pelican Creek at Kerale	515	372	1,653	3.21	Regional eqn
130209A	Nogoa River at Craigmore	14,117	2,135	9,926	0.70	Regional eqn
130319A	Bell Creek at Craiglands	304	59	223	0.73	Spatial data
130324A	Dawson River at Utopia Downs	6,201	1,156	5,610	0.90	Regional eqn
130336A	Grevillea Creek at Folding Hills	245	169	544	2.22	Regional eqn
130348A	Prospect Creek at Red Hill	381	249	1,010	2.65	Regional eqn
130349A	Don River at Kingsborough	614	148	576	0.94	Spatial data
130407A	Nebo Creek at Nebo	239	70	155	0.65	Spatial data
130410A	Isaac River at Deverill	4,131	1,181	5,657	1.37	Regional eqn
135004A	Gin Gin Creek at Dam Site	556	126	457	0.82	Regional eqn
136006A	Reid Creek at Dam Site	213	28	92	0.43	Regional eqn
136108A	Monal Creek at Upper Monal	92	49	163	1.77	Regional eqn
136112A	Burnett River at Yarrol	413	71	245	0.59	Regional eqn
136202D	Barambah Creek at Litzows	664	218	779	1.17	Regional eqn
136203A	Barker Creek at Brooklands	255	78	285	1.12	Regional eqn
136306A	Cadarga Creek at Brovinia Station	1,329	344	1,390	1.05	Regional eqn
136315A	Boyne River at Carters	1,669	428	2,032	1.22	Regional eqn
137202A	Oaky Creek at Childers	174	306	1,230	7.06	Regional eqn
138004B	Munna Creek at Marodian	1,221	349	1,436	1.18	Regional eqn
138009A	Tinana Creek at Tagigan Road	107	349	1,469	13.80	Regional eqn
138110A	Mary River at Bellbird Creek	513	473	2,223	4.34	Regional eqn
140002A	Teewah Creek near Coops Corner	55	23	70	1.27	Regional eqn
141002A	South Maroochy River at Kureelpa	20	209	710	34.98	Regional eqn
141006A	Mooloolah River at Mooloolah	42	154	526	12.48	Regional eqn

Gauge Number	Gauge Name	Modelled catchment area (km²)	Number of dams	Volume of dams (ML)	Dam density (ML/km^2)	Source of volume estimate
141009A	North Maroochy River at Eumundi	43	272	1,097	25.33	Regional eqn
142202A	South Pine River at Drapers Crossing	167	865	1,639	9.81	Spatial data
143110A	Bremer River at Adams Bridge	121	219	659	5.45	Spatial data
143113A	Purga Creek at Loamside	223	968	2,815	12.60	Spatial data
143211A	Buaraba Creek at Atkinson Diversion Weir	264	475	2,331	8.85	Spatial data
143212A	Tenthill Creek at Tenthill	480	2,409	7,337	15.29	Spatial data
143214A	Flagstone Creek at Windolfs	148	332	577	3.90	Spatial data
143303A	Stanley River at Peachester	104	138	322	3.08	Spatial data
143306A	Reedy Creek at Upstream Byron Creek	58	46	69	1.19	Spatial data
145010A	Running Creek at 5.8km Deickmans Bridge	135	56	93	0.69	Spatial data
145011A	Teviot Brook at Croftby	87	124	225	2.59	Spatial data
145013A	Christmas Creek at Rudds Lane	165	180	334	2.02	Spatial data
145101D	Albert River at Lumeah Number 2	177	164	488	2.76	Spatial data
416204A	Weir River at Gunn Bridge	4,586	1,159	7,565	1.65	Spatial data
416312A	Oaky Creek at Texas	415	311	587	1.41	Spatial data
416410A	Macintyre Brook at Barongarook	564	338	656	1.16	Spatial data
417201B	Moonie River at Nindigully	12,091	3,109	24,282	2.01	Spatial data
422304A	Condamine River at Elbow Valley	293	434	1,275	4.35	Spatial data
422352A	Hodgson Creek at Balgownie	606	358	1,056	1.74	Spatial data
422407A	Maranoa River at Forestvale	9,135	593	2,746	0.30	Spatial data
423204A	Warrego River at Augathella	7,468	416	2,792	0.37	Spatial data
424202A	Paroo River at Yarronvale	1,816	62	749	0.41	Spatial data
913009A	Gorge Creek at Flinders Highway	251	35	123	0.49	Regional eqn
915007A	Betts Gorge Creek at Alstonvale	1,076	81	321	0.30	Regional eqn
915207A	Gilliat River at Gilliat	6,022	229	959	0.16	Regional eqn
919005A	Rifle Creek at Fonthill	355	210	763	2.15	Regional eqn

4.9. Determining the local catchment area of stock and domestic farm dams

4.9.1. Adopted approach – Regression equation

The local catchment area is the subarea of a catchment from which streamflow or runoff contributes directly to farm dams. The local catchment area directly affects how much water flows into the dams, and hence the level of impact on catchment streamflow. Figure 21 demonstrates the concept of the local catchment area reporting to farm dams.



▪ **Figure 21 Example of the relationship between catchment area and local catchment area (SKM, 2011b)**

The local catchment area for each dam could potentially be estimated directly from spatial data, such as the GA waterbodies layer and the DEM, however this method is extremely time consuming and inefficient to apply over a large scale. Hence, an equation is usually developed which relates a number of key factors within the catchment which may affect the proportion of the catchment regulated by farm dams. Potential factors include total catchment area, total dam volume, number of dams, mean annual rainfall, mean catchment slope and dam density.

A logical assumption would be that the local catchment area of a farm dam is directly related to the dam volume. This would be valid if the dam design were based on consideration of the optimal site within the catchment for the required dam yield. However, other considerations usually come into play, such as ease of access to the site and location relative to other farm infrastructure.

Farm dams are therefore usually sited wherever they are useful to a farmer and where it is practical to construct them. At an individual dam level this makes it difficult to estimate the local catchment area, although it is possible to develop a suitable method at a larger catchment level. Instead of trying to understand the local catchment area of individual dams, it is possible to focus on a larger catchment scale to estimate the sum of local catchment areas across an entire study catchment.

Previous studies

Previous studies have found that the proportion of the catchment which is impounded by farm dams is most dependent upon total catchment area, mean catchment slope and dam density. The relationship derived in the Sustainable Rivers Audit (Sinclair Knight Merz, 2011b) was able to show that impounded area could be estimated using Equation 3.

- **Equation 3 Existing relationship to calculate the local catchment area regulated by farm dams**

$$Proportion\ local\ catchment\ area^{0.5} = 0.0538Log_{10}(Area) - 0.057Slope + 0.1396Density^{0.5} + 0.34726$$

Where:

Proportion local catchment area *= the proportion of the modelled catchment that is regulated by farm dams (%)*
Area *= the area of the modelled catchment (km²)*
Slope *= slope of the modelled catchment is in degrees and is an average of the slope across the modelled catchment*
Density *= Farm dam density in the modelled catchment (ML/km²)*

This relationship is based on an analysis of 9129 dams in the Wimmera Catchment (SKM, 2011b). While the approach used to derive this relationship is valid, it would be inappropriate to apply this relationship derived from data in western Victoria to catchments in Queensland.

Queensland study

A new relationship was derived which is specific to Queensland, based on data in five gauge catchments. Individual farm dams were identified from the Geoscience Australia waterbodies layer (A.1) and the DERM extended farm dams layer (A.3), within the following gauge catchments:

- 143113 – Purga Creek at Loamside;
- 145013 – Christmas Creek at Rudds Lane;
- 416204 – Weir River at Gunn Bridge
- 422304 – Condamine River at Elbow Valley; and
- 422352 – Hodgson Creek at Balgownie.

The areas used in this analysis are presented in Figure 25.

The local catchment area for each dam was calculated using the 1 second DEM (A.9), which has a cell size of approximately 30 m x 30 m. The surface area of each dam was then calculated from the spatial layers and converted to a dam volume, using the relationship described in Section 4.5.2. For dams which were identified as points within the spatial layers the surface area of each dam was calculated using the size distribution described in Section 4.5.1.

Each of the gauge catchments was divided into a number of subcatchments, at the major confluences. The total dam volume and total local catchment area was reported for each subcatchment, along with the mean annual rainfall and the mean catchment slope.

These divisions created a number of nested subcatchments. For example, the division of the gauge catchment 145013 resulted in 17 subcatchments, nested within the overall catchment. This allowed an assessment of the local catchment area at a range of catchment sizes.

The analysis excluded subcatchments where the total catchment area was smaller than 10 km^2 or where the local catchment area was zero. This resulted in a total of 158 subcatchments accepted in the analysis. (While the excluded subcatchments were not included in the analysis at an individual level they were still picked up in the overall catchment analysis, as part of the larger catchments.)

A multiple regression analysis was then undertaken where a number of relationships were tested between local catchment area, total catchment area, dam density, number of dams, mean annual rainfall and mean catchment slope. In line with previous studies, this analysis found that the local catchment area is most dependent on the total catchment area, mean catchment slope and dam density. The final relationship derived for Queensland is presented in Equation 4.

- **Equation 4 Queensland relationship to calculate the local catchment area regulated by farm dams**

$$Proportion\ local\ catchment\ area^{0.5} = -0.048Log_{10}(Area) - 0.009Slope + 1.159Density^{0.1} - 0.759$$

Where:

***Proportion local catchment area** = the proportion of the modelled catchment that is regulated by farm dams*

***Area** = the area of the modelled catchment (km^2)*

***Slope** = slope of the modelled catchment is in degrees and is an average of the slope across the modelled catchment*

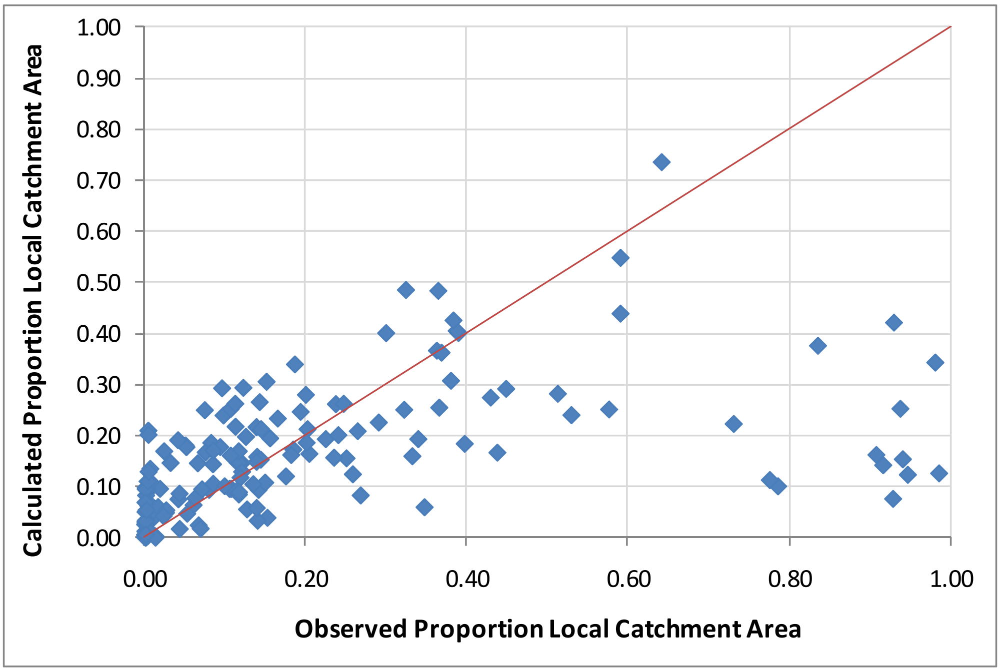
***Density** = Farm dam density in the modelled catchment (ML/km^2)*

This equation resulted in a reasonable correlation between the observed and calculated proportion local areas (grouped by subcatchment), as shown in Figure 22 (R^2 of 0.249, with a correlation of 0.499).

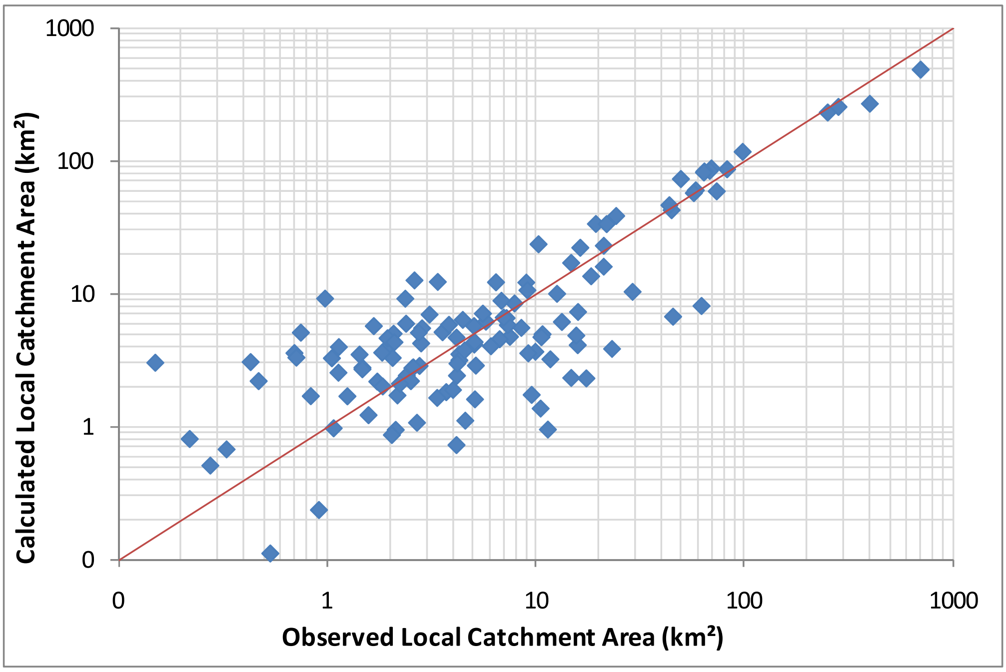
While this relationship does not give an initial impression of a particularly good fit to the data it actually results in a very good prediction of the local catchment area (km^2), particularly for the larger catchment areas as shown in Figure 23. The relationship between the observed and calculated local catchment area has an R^2 of 0.957, with a correlation of 0.978. When calculated in the log domain (as shown in Figure 23) the relationship between the observed and calculated local catchment area has an R^2 of 0.608, with a correlation of 0.780.

For this project we are primarily interested in catchments which are larger than 50 km^2 (52 of the 55 STEDI modelling catchments are larger than 50 km^2). If the local catchment area relationship is applied to catchments greater than 50 km^2 the relationship provides an R^2 of 0.958, with a correlation of 0.979. When calculated in the log domain (Figure 24) this relationship provides an R^2 of 0.640, with a correlation of 0.800.

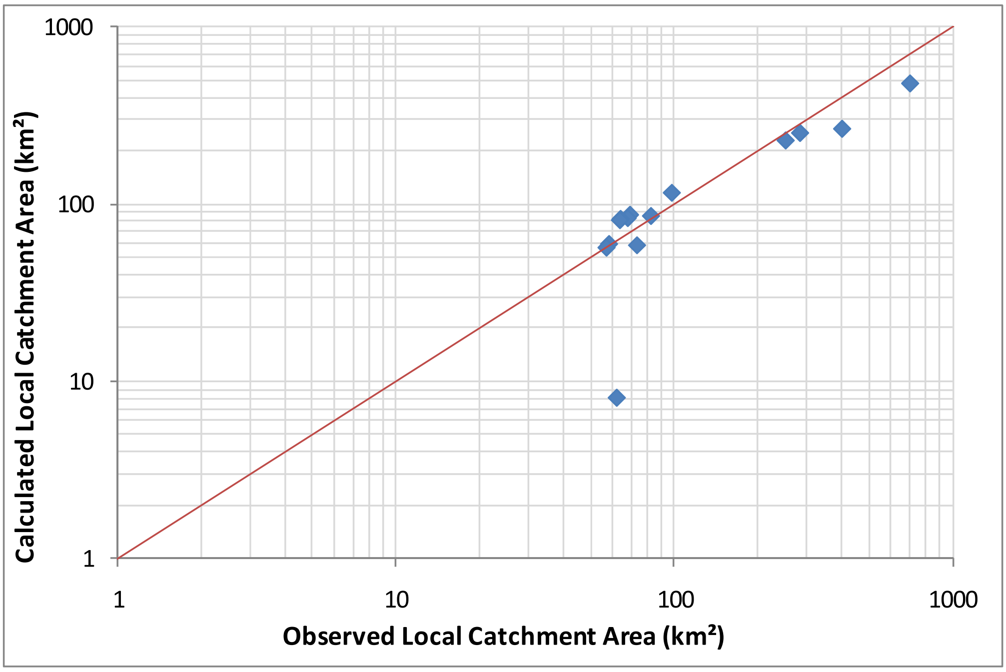
The local catchment area is often problematic to estimate as it is largely influenced by farmers' behaviour, rather than measurable physical characteristics of the catchment. Given this issue the derived equation is considered to show a very good correlation between observed and calculated values.



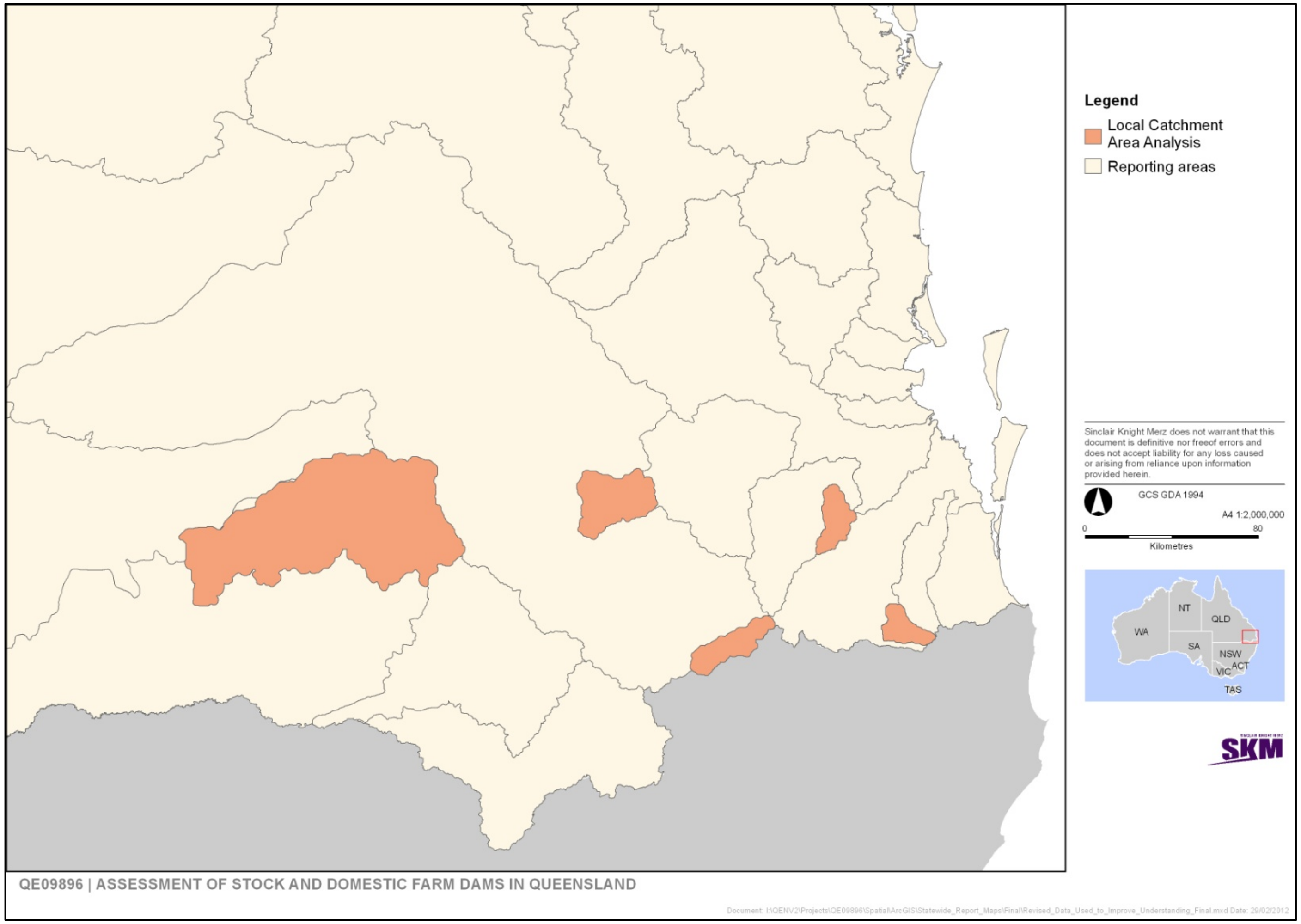
▪ **Figure 22 Comparison of observed and calculated proportion local catchment area**



▪ **Figure 23 Comparison of observed and calculated local catchment area (km^2)**



- **Figure 24 Comparison of observed and calculated local catchment area (CA > 50 km^2)**



■ **Figure 25 Extent of data used to improve the understanding of the local catchment area in Queensland**

4.9.2. Alternative approach

There are two alternatives to the approach adopted for this project:

- Direct derivation of local catchment areas for each modelled catchment; or
- Improvement of the developed local catchment area equation (Equation 4).

The ideal method for calculating the local catchment area is to directly derive the actual local catchment area for each modelled catchment from spatial data, such as the GA waterbodies layer and the DEM. This approach would currently be limited to the MDB (as the extent of the GA waterbodies layer) and existing digitised areas, unless further catchments were digitised. Whilst the accuracy of the derived results would be excellent (and only limited by the quality of the input data), this would be a resource intensive approach to take for a large scale investigation. It may however be a reasonable approach for projects focussed on small areas (e.g. less than 500 km^2) where a high level of accuracy is required and where spatial data already exists.

Alternatively, further work could be undertaken to improve the local catchment area equation developed for this project. This would require the same analysis as described in Section 4.9.1., which was based on data from five gauge catchments; one in the Brisbane catchment, one in the Logan-Albert catchment, one in the Border Rivers catchment and two in the Condamine-Balonne catchment. Any further work should expand on the geographic and climatic range of the data set and cover an area of at least 5000 km^2. Preferably, several catchments would be chosen representing a diverse range of climate, terrain, and dam development conditions.

4.10. Determining the usage from stock and domestic farm dams

STEDI requires an estimate of the demand placed on a dam for water consumption, separate from evaporation. This study has adopted the use of a demand factor, which defines the proportion of the dam volume which is used for stock and domestic purposes each year.

4.10.1. Adopted approach – Demand factor

The farm dam demands detailed in STEDI define the amount of water that is effectively taken from the stream at each timestep. The magnitude of mean annual demand for each dam is calculated by multiplying the demand factor and the volume of each dam. The demands are then extrapolated into a timeseries by using either a repeating monthly pattern of demand or a long term pattern timeseries on the same timestep as the model.

The demand factor is used to define the proportion of dam volume that is used each year, based on:

- **Equation 5 Demand factor as a function of annual average demand and dam volume**

$$Demand\ Factor = \frac{Average\ annual\ demand\ (ML)}{Volume\ of\ the\ dam\ (ML)}$$

For this study, two main methods were used to collect information about the water use from stock and domestic dams. In the first method, farm design sheets held by DERM were used to obtain information about stock and domestic farm dams. The second method used was a phone survey conducted among landholders who have stock and domestic dams on their property.

Based on the outcomes of this investigation a demand factor of 0.5 was adopted, with no seasonal pattern of demand.

Previous studies

Previous studies of farm dam impacts have assumed different demand factors for irrigation and stock and domestic use. A survey of dam owners conducted by SKM (2004) in Victoria as a part of the "Sustainable Diversion Limits" (SDL) project for the Department of Sustainability and Environment has provided the most commonly used demand factors. The study found that the demand factor for stock and domestic dams varied from 0.3 to 1.0 with both mean and median of 0.50 (SKM, 2004). The study also found that stock and domestic dams were generally less than 5ML in volume.

Since that study, there has been some analysis of the irrigation demand factor completed in the *Assessment of the hydrological impact of farm dams in the MDB* project (SKM, 2011). It was found that the irrigation demand factors previously derived in SKM (2004) were the most appropriate as no significant improvement could be made using the information available. There has been no recent investigation of the stock and domestic demand factor.

The demand from stock and domestic dams was assumed to be steady throughout the year (SKM, 2011). Some work has been completed on improving irrigation demand patterns but there has been little data available to improve the demand pattern for stock and domestic use.

McMurray (2003) used a remote sensing approach to estimate the total change in water stored in a farm dam over the period from December 2001 to April 2002, which represents the dry season in the Mount Lofty Ranges of South Australia, or the period of the year when most farm dams would typically experience a reduction in stored volume. He estimated net evaporation losses from each dam from pan evaporation and rainfall records in the region and estimated inflows to dams from streamflow records and rainfall runoff models, although these were relatively small for this dry season of the year. This enabled McMurray to estimate the remaining component, which represented the sum of usage from each of the dams and seepage losses. McMurray (2003) performed this analysis for 731 dams from five catchments in the Mount Lofty Ranges. McMurray (2003) separated his analysis on the basis of farm dam storage volume but did not attempt to categorise dams according to usage.

McMurray (2003) found that for all dams greater than 1 ML in estimated storage capacity, the sum of usage and seepage losses for the five month period (December 2001 to April 2002) represented on average 0.19 of the volume of water stored in the dam at the end of November 2001. The indicative uncertainty in the estimated demand factor estimated by McMurray (2003) was from 0.087 to 0.275. When the sample was constrained only to dams greater than 5 ML in estimated storage capacity, the demand factor was slightly smaller at 0.17 (with an indicative uncertainty range of 0.1 to 0.23).

McMurray (2003) did not attempt to estimate a representative mean annual demand factor. The demand factors computed represent usage over five months of one water year, which represent the driest and hottest months of that particular water year. If water usage were uniformly distributed across the water year, then the average demand factors from McMurray (2003) could be scaled up (by multiplying by 12 months / 5 months) to 0.46 for all dams greater than 1 ML and 0.41 for all dams greater than 5 ML. It is likely that usage from farm dams, even those for stock and domestic dams, could be higher in the hotter part of the year than the cooler part of the year, which would result in these values being overestimates of the total annual demand factor for that one particular water year (2001/02). A mitigating factor against these values being overestimates of the mean annual demand factor is that McMurray (2003) notes that for the region, "the 2001/02 summer was cooler with more cloud and rain periods than considered normal" and that total pan evaporation measured for the analysis period was between 79% and 89% of the mean value of pan evaporation for December to April periods at the evaporation gauge sites. Our interpretation of the data from McMurray (2003) would be that a mean annual demand factor of approximately 0.4 would be an appropriate estimate for the Mount Lofty Ranges. By contrast, Alcorn (2011) referenced the McMurray (2003) study and then assumed a mean annual demand factor of 0.3 for stock and domestic farm dams and 0.5 for irrigation dams in the Mt Lofty Ranges but it was not clear what Alcorns's justification was for distinguishing the demand factor on the basis of dam purpose.

Alcorn (2011) also assumed a monthly pattern of demand for stock and domestic dams that varies sinusoidally throughout the year and peaks with 15% of the mean annual demand in January and falls to 3% of the mean annual demand in June and July of each year. This pattern appears to be an assumed pattern for South Australia and does not appear to be supported by any other data or surveys.

Design Sheets

During the 1970s, 80s and 90s the Queensland Government provided a farm water supplies advisory service which aimed to assist farmers looking to develop their property for agricultural purposes. Under this program Queensland Government staff would, at the farmers' request, prepare a design for farm dams on the landholder's property. In most cases, landholders were asked by the designer about their water requirements, using calculations based on stocking numbers and guideline values of watering requirements for different stock types and estimates of domestic use.

Some of the dam design documentation was available from the DERM archive and a total of 207 documentation files were accessed. These files were examined to collect information about S&D volumes and water requirements. Out of these files, only 8 files had information that could be used for S&D purposes, the remaining files contained information about ground water licensing and irrigation water requirements. The information collected from the design sheets was incorporated with the results of the phone survey.

The main limitations in using the design sheets are that they are dated from 1970 to 1995, with most of them sourced from the 1980s, and there were a limited sample from which to source information. While the documentation is historical and the sample size limits the significance of the conclusions drawn from this data, they are representative of a large number of dams built in the early development of farm dams in Queensland. Therefore it provides an important resource that should be utilised despite its limitations.

Phone Survey

A phone survey was also conducted among a number of property owners with stock and domestic dams. The phone survey was designed to collect a range of information about stock and domestic dams, including the number and volume of stock and domestic dams on the property and the amount of water used from those dams. Since the majority of property owners do not monitor the amount of water extracted from the dams they may be unable to directly estimate the volume of water extracted. Hence, additional questions were asked during the survey about the different purposes for which dam water is used.

Out of the 30 landholders who participated in the phone survey, only 10% of the participants were able to estimate the volume of a stock and domestic dam on the property and the amount of water extracted from that dam each year. A further 42 % of the participants were able to estimate the volume of a stock and domestic dam on their property but could not give the volume extracted from that dam. The remaining 48% of participants could not give the dam volume or the amount of water extracted. The high percentage of responses where the usage was unknown is consistent with the general management of S&D dams, which are not monitored.

Where the participants could not estimate the water usage a demand based approach was used to calculate the demand, where participants provided the specific purposes for which the dams were used. Table 11 presents the adopted average annual water requirements for stock and domestic purposes. These numbers were sourced from the Farm Dam advisory design sheets described in Section 4.10.1.

- **Table 11 Average annual water requirements**

Water Use	Average annual water requirement
Sheep	2 m^3/head/year
Beef cattle	16 m^3/head/year
Horse	18 m^3/head/year
Goat	3.6 m^3/head/year
Person	83 m^3/person/year
Garden	1500 m^3/year/0.1 ha

Out of the 30 response received from the phone survey only 17 contained sufficient information to determine the demand factor. The remaining responses were omitted as no reasonable estimate of volume or the demand from the dam could be made from the information received. The 17 phone surveys were then combined with the 8 farm dam design sheets.

A demand factor was calculated for each dam based on the information obtained. By analysing the data and comparing the results with the previous Victorian study the following conclusions were made:

- There was a linear relationship (albeit with substantial scatter) between the storage volume and demand from the dam, hence the use of a fixed demand factor was appropriate;
- The demand factor varied between 0.002 and 2.25, with a mean of 0.55 and a median of 0.48;
- Consistent results were found in terms of mean and median demand factor between the phone survey, design sheets and the Victorian study;
- Based upon the surveys and the design sheets, the 90% confidence interval for the mean demand factor (mean demand factor with 95% and 5% probabilities of exceedance) was 0.37 to 0.72;
- There was no obvious spatial trend in the demand factor; and
- The variability in demand factor increases when alternative sources of water are available. Farmers with an alternative water source will preferentially use water from the source that is

easiest to access, cheaper to obtain or provides highest quality water before switching to the alternative source, which increases the variability in the demand factor for the farm dam.

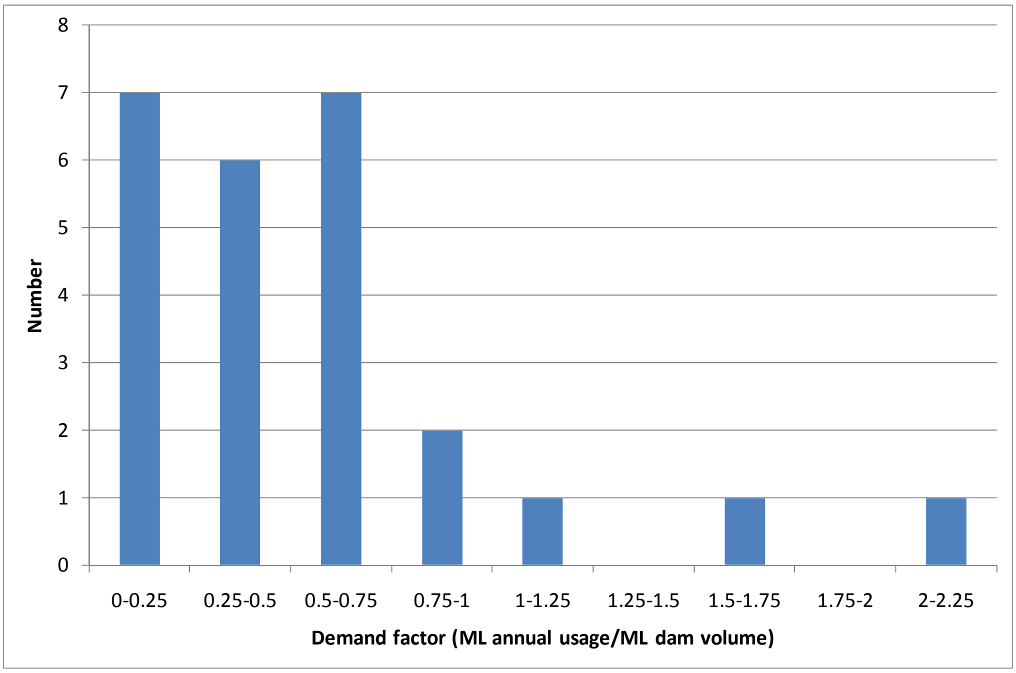
Further, a total of 61 S&D dams were identified on the surveyed properties and approximately 74% of these dams were less than 5 ML. This corresponds to the value of 75% of dams less than 5 ML reported in Victoria (Lowe et al., 2005).

The study found that the total storage capacity increases with the property size. The average density of stock and domestic dams (total volume of dams divided by total area of the properties from survey respondents) was 2.66 ML/km^2. However, the study found no relationship between the area of the property and the number of dams on that property.

Water use from 73% of the dams surveyed was not consistent throughout the year. Of these dams, 68% used more during summer months, 18% dams used more during winter and the remaining 14% of dams were used the most when stock was kept near to the dam location, with stock rotating between different dams on the property on a periodic basis. This apparent trend of seasonality is at odds with the previous studies which have reported that demand is consistent through the year. This may be worth investigating at a later date with a larger survey as the current information is insufficient to be conclusive regarding the effects of seasonality or to predict a seasonal pattern.

While the range of responses represents a significant range in the demand factor, there is insufficient information to exclude any data points as outliers. Each of the calculated demand factors reflects the information that was calculated either from the design sheets or the phone survey. Figure 26 illustrates the distribution of the calculated demand factors. While there are only 3 of 25 responses with a demand factor greater than 1, there is no reason to think that these responses do not represent very heavy users of farm dams.

This study is described in full in the report *Assessment of impact of stock and domestic dams in Queensland- Demand Factor* (Naseem, 2011), which is attached as Appendix E.



- **Figure 26 Distribution of farm dam demand factors**

4.10.2. Alternative approach

There are two alternatives to the approach adopted for this project:

- Direct metering of usage from stock and domestic dams; or
- Further phone surveys to improve the developed demand factor.

The current approach relies on anecdotal evidence and inference of stock and domestic water requirements from published data. More accurate data could be obtained by metering the direct use from individual stock and domestic dams. This would require installing meters for a minimum of 50 dams, with approval and co-operation from farmers. The dams would also need to be surveyed as part of the study. Metering would need to continue for a minimum of three years, in order to have a strong level of confidence in the results. There may also be a number of technical issues to overcome, such as accounting for evaporation and seepage from the dams.

Metering would be a long term project for DERM, or possibly an academic research project. This is unlikely to provide usable information for at least three years. It is also likely to be expensive and time consuming, although the outcomes would have a high level of reliability.

Spatial distribution is also a concern, metering would need to take place over a wide enough geographic area that any differences in usage due to climate, rainfall, etc. are captured within the results.

Alternatively, further phone surveys could be undertaken. The current mean demand factor and the estimated uncertainty in the mean demand factor was derived from 25 dams that had sufficient information in order to derive the demand factor (representing eight dams from the dam design sheets and 17 responses to the phone survey). If a further survey was conducted to obtain an additional 75 interpretable responses (increasing the sample size by a factor of four) then it would be expected that the range of uncertainty in the mean demand factor would be halved. Increasing the size of the survey by obtaining an additional 75 interpretable responses would be expected to decrease the 90% confidence interval range in the mean demand factor from a range of 0.35 to approximately 0.17. (In order to obtain 75 interpretable responses it would require between 100 and 150 farm dam owners to be willing to respond to the survey.)

It would be worth expanding the extent of the survey, in particular to address questions of seasonality, although the information provided by farmers from the survey was not particularly useful in quantifying seasonality of usage of farm dams.

It is not considered worth pursuing the analysis of the farm dam design sheets, as the proportion of design sheets applicable to stock and domestic dams only was found to be very low. This was a time consuming approach, given the lack of results.

5. Assessment of alternative methods

The following section provides an assessment of the relative advantages of the alternatives to the methods adopted for this study, as discussed in Section 4. These alternatives are assessed against concerns such as cost, usability, accuracy, ease of maintenance, improvement from adopted approach and applicability at different spatial scales.

The rankings used in the assessment of alternatives to the methods are provided in Table 12. For each of these criteria, a qualitative description is provided as well as a colour coding scale to allow each of the alternatives to be easily compared.

▪ **Table 12 Rating scale for assessment of options**

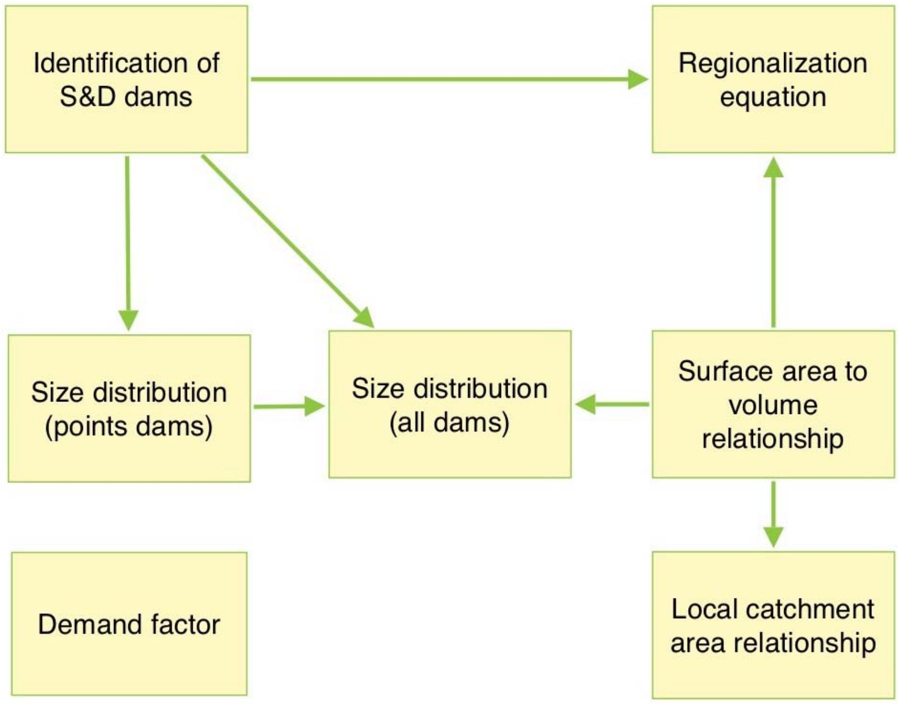
Criterion	Rating scale		
Cost and ability to acquire data	Low relative cost $0-$50,000	Medium relative cost $50,000-$200,000	High relative cost $200,000-$400,000
Cost of data processing	Low relative cost $0-$50,000	Medium relative cost $50,000-$200,000	High relative cost $200,000-$400,000
Usability by others	Suitable for a range of users	Limited usability for others	Not relevant for other users
Accuracy of estimate	High accuracy 70% - 100%	Medium accuracy 50% -70%	Low accuracy 0% - 50%
Ease of data maintenance and update	Easily updated and maintained	Able to update and maintain with some effort	Difficult to update and maintain
Improvement of accuracy of farm dam impact assessment	Significant improvement	Average improvement	Little improvement
Applicability at different scales	Applicable at all spatial scales	Applicable at some spatial scales	Applicable at limited spatial scales

The *Statewide Assessment: Report 2 – Hydrological assessment of stock and domestic farm dams in Queensland* also presents the outcomes of an assessment of the sensitivity of the model to changes in the input parameters. This has been used to further evaluate the benefit of improving the input estimation methods. Final recommendations with respect to improving these methods are provided in Report 2.

5.1. Interaction of STEDI input estimation methods

The direct use of the various input estimation methods into the STEDI modelling are described in Section 3.1. However, some of these methods are also used in the development of the other estimation techniques. For example, for the development of the size distribution the volume of each dam within a catchment area is estimated using the surface area to volume relationship. Figure 27 presents the interaction of the various methods, during their development.

Figure 27 shows that the identification of stock and domestic dams influences three other areas, as does the surface area to volume relationship. By contrast, development of the demand factor was not influenced by any other method, nor did it influence others. Without considering cost or other practicalities, it is recommended that consideration is given to improving the method to identify stock and domestic dams and the surface area to volume relationship above other areas, due to the extent of their influence.



- **Figure 27 Interaction of STEDI input estimation methods (during development of the methods)**

5.2. Identification of stock and domestic dams

For this study a dam identification method was developed based on an intersection of dam location and landuse type. The advantages of this approach are that the required information is readily available and it can be easily applied across large areas in a consistent manner. However, the results of this method are very difficult to validate with existing information.

There are three suggested alternatives to the current approach (discussed in Section 4.3.2):

- Survey to validate the existing approach;
- Survey of individual areas as a direct modelling input; and
- Identification of dams through DERM spatial layers and ongoing data collection.

Table 13 presents the outcomes of the assessment of various options to improve farm dam demand estimates, which are also summarised below:

- The current approach require the people who apply the method to have spatial analysis experience and would require some effort to update, although this won't be required for approximately ten years (when landuse types may have changed or improved spatial data becomes available).
- A survey of landholders and regional offices could be conducted in a number of discrete areas in order to validate the results of the existing identification process. The survey would need to cover a large area in order that an extensive range of landuse types are assessed. This would be time consuming to complete to a high level of accuracy and would rely heavily on the knowledge of the regional officers and community goodwill. Outcomes of the survey could be used to either confirm the reliability of the existing method or to develop a new identification method, possibly based on a regionalisation regression.
- If STEDI modelling were required for a small catchment area a survey could be conducted for that individual area. This would provide very accurate results for the surveyed catchment but would not be applicable to other areas.
- DERM currently hold some spatial and licensing information which identifies dam use type, however this information is currently managed inconsistently. This data could be consolidated and further information could be added to it as it becomes available, forming a database of stock and domestic dams across the state. In time this may provide an appropriate data set for deriving a regional relationship to identify dam types. DERM could manage this as a long term objective, collecting this information as part of other, ongoing work.

Table 13 Alternative approaches to identify stock and domestic dams

Criteria	Current approach	Survey to validate existing approach	Survey of individual areas as a direct modelling input	Identification through DERM spatial layers
Cost and ability to acquire data	No cost to utilise existing data	Cost depends on extent of survey area. (in the order of $150k)	Cost depends on size of survey area. (in the order of $30-50k)	Low cost, need to set up a data management system, then the majority of information would be gathered through regular business and other projects
Cost of data processing	No requirement to further process existing data	Moderate cost to process spatial data and update current identification method (depends on size of survey area).	Low cost to process spatial data - depends on size of survey area.	Some cost to manage and process data
Usability by others	Users should be experienced with spatial analysis and application.	Requires some understanding of databases and spatial analysis	Requires some understanding of databases and spatial analysis	Requires some understanding of databases and spatial analysis
Accuracy of estimate	Considered reasonable to provide an identification of S&D dams at a catchment scale.	Potentially very high – but depends upon the quality of the survey and the ability to identify the purpose of each dam	Potentially very high – but depends upon the quality of the survey and the ability to identify the purpose of each dam	Depends upon the quality of the input data – quality would tend to improve over time as more information is collected
Ease of data maintenance and update	Requires some effort to update and should be done by staff experienced with spatial analysis and application. (Update required in app. 10 years)	The survey results would not need to be updated for a number of years (app.5-10), although the whole survey would need to be done again to update it.	The survey results would not need to be updated for a number of years (app.5-10), although the whole survey would need to be done again to update it.	Requires long term management and maintenance
Improvement of accuracy of farm dam impact assessment	n/a	Very accurate within the survey area and improved accuracy of regional application	Very accurate within the survey area	Depends upon the quality of the input data – the accuracy would tend to improve over time as more information is collected
Applicability at different scales	Considered suitable for catchment scale analysis.	Considered suitable for catchment scale analysis.	Only applicable to the survey area	Depends on the quality and completeness of the collected data

5.3. Determining the volume of stock and domestic farm dams

A farm dam surface area to volume relationship was developed in order to estimate the volume of individual dams. A regression analysis was conducted on a sample of 73 dams in Queensland with the full dam area and volume approximated from Light Detection and Ranging (LiDAR) data and a digital elevation model (DEM).

The adopted method for estimating the dam volume from its surface area is a robust method and the derived regression equation has a strong correlation and level of confidence. This method is considered suitable for developing input data for STEDI modelling and for future work by DERM.

Whilst no alternatives are proposed for this method there are two ways that the level of confidence in the developed equation could be improved (as discussed in Section 4.5.3). They are:

- Ground survey of dams used to develop the surface area to volume equation; and
- Further LiDAR analysis.

The assessment of the options to improve the estimates of farm dam volumes is presented in Table 14 and summarised below:

- The current approach is a robust method and provides a high quality output. The method is easily applied and does not require any further maintenance or updating.
- A ground survey of the dams used to derive the surface area to volume relationship could be conducted in order to validate the data used to derived relationship. This is likely to be expensive to conduct, depending on the number of sites selected, and may not provide any improvement to the level of accuracy of the current approach.
- Further LiDAR analysis could be undertaken to increase the sample size used to derive the surface area to volume relationship. This could also be used to validate the equation at a wider scale and investigate potential regional differences. This approach is more likely to improve the current approach than the ground survey and is considered to provide better value for money.

▪ **Table 14 Alternative approaches to estimate stock and domestic dam volumes**

Criteria	Current approach	Ground survey of dams used in the development of the current approach	Further LiDAR analysis
Cost and ability to acquire data	No cost to utilise existing equation, spatial data used to derive the dam surface area is freely available	Expensive to conduct, depending on the number of dams chosen to be surveyed	Spatial data used to derive the dam surface area is freely available
Cost of data processing	No requirement to conduct further processing – volumes already assigned to each dam	Requires processing of survey data and comparison with LiDAR data – cost depends on the number of sites	Low cost but requires complex spatial processing - should be conducted by persons with considerable experience in spatial analysis
Usability by others	Easily used by others	Easily used by others	Easily used by others
Accuracy of estimate	Considered to provide an accurate estimate of dam volumes	Accurate information obtained	Accurate information obtained
Ease of data maintenance and update	Does not require further updating or maintenance	Would not require further updates or maintenance	Would not require further updates or maintenance
Improvement of accuracy of farm dam impact assessment	n/a	Potentially no improvement	Average improvement in equation (existing accuracy is already very high), although regional difference may be better accounted for
Applicability at different scales	Considered suitable for catchment scale analysis.	Considered suitable for catchment scale analysis.	Could improve the confidence in application on a regional basis

5.4. Determining the size distribution of stock and domestic farm dams

Four spatial layers were used to calculate the number and surface areas of farm dams in different regions of Queensland. Farm dams were identified within these layers and the volume of each dam was then calculated based on the surface area to volume relationship developed for this project.

The dams identified from these spatial layers were grouped into size class categories and the data was also split into stock and domestic and non-stock and domestic, according to land use classification. A size distribution was developed based on the stock and domestic dams only.

While this method is considered to provide a good estimate of the size distribution of stock and domestic dams it is influenced by two other methods; dam identification and the surface area to volume relationship. The size distribution may therefore benefit more from improvements to the two input methods than methods aimed at directly improving the distribution estimate.

The assessment of the options to improve the estimates of stock and domestic dam size distribution is presented in Table 15 and summarised below:

- The current approach suitable for regional application, although the majority of the data used to develop the distribution is from the south of the state. This creates some uncertainty when applied to northern areas.
- Additional digitisation could be conducted in targeted areas which would assist in reducing the uncertainty due to regional influences. The cost associated with this action depends on the size of the area digitised, with increasing benefit as the digitisation areas are increased.

Table 15 Alternative approaches to estimate stock and domestic dam size distribution

Criteria	Current approach	Additional Digitisation
Cost and ability to acquire data	Information is freely available	Cost depends on the area selected (app. $3000 per 1000 km^2). The minimum area recommended is 20,000 km^2, with increasing benefit as the digitisation area increases.
Cost of data processing	Further processing is not required	Relatively low cost but requires an experienced spatial analyst to process and QA the data (app. $10-20k)
Usability by others	Easily used by others	Easily used by others
Accuracy of estimate	Considered to provide an accurate estimate of dam volumes at a catchment scale	Accurate information obtained.
Ease of data maintenance and update	No maintenance or update required	Requires no maintenance or update
Improvement of accuracy of farm dam impact assessment	n/a	The accuracy of the current approach would increase, depending on the size of the additional digitisation areas.
Applicability at different scales	Considered suitable for catchment scale analysis. Higher confidence in Queensland MDB and south east Queensland than in areas to the north	Considered suitable for catchment scale analysis. Additional digitisation could improve the strength of regional representation in the distribution.

5.5. Determining the local catchment area of stock and domestic farm dams

The current approach to estimate the local catchment area is based on a regression relationship between the total catchment area, slope and dam density. The local catchment area is often problematic to estimate as it is largely influenced by farmers' behaviour, rather than measurable parameters. Given this difficulty the adopted regression equation is considered to show a very good correlation between observed and calculated values.

There are two alternatives to the approach adopted for this project (as discussed in Section 4.9.2):

- Direct derivation of local catchment areas for individual modelled catchments; or
- Improvement of the developed local catchment area equation.

Table 16 presents the outcomes of the assessment of the two options to improve local catchment area estimates, which are also summarised below:

- The current approach provides a moderate level of confidence and requires no further cost to maintain, update or implement;
- Direct derivation of local catchment areas for individual catchments would provide extremely accurate estimates (for that catchment);
- Further spatial analysis could be undertaken to expand the data set used to develop the local catchment area equation. This could reduce the uncertainty in the regression relationship and increase the confidence in using the equation across a wider geography.

Table 16 Alternative approaches to estimate the local catchment area

Criteria	Current approach	Direct derivation from spatial data	Further analysis for the LCA equation
Cost and ability to acquire data	No charge to utilise existing data	The required input data consists of a hydrologically imposed DEM and a spatial layer identifying individual dams. In the MDB, digitised areas and extended DERM areas this information is freely available, in other areas this would require additional digitisation (at an approximate cost of \$3,000 per 1000 km^2).	The required input data consists of a hydrologically imposed DEM and a spatial layer identifying individual dams. In the MDB, digitised areas and extended DERM areas this information is free, in other areas this would require additional digitisation (at an approximate cost of \$3,000 per 1000 km^2). Additional areas should be selected in a range of geographic locations, in order to ensure that different climatic regions are accounted for.
Cost of data processing	No requirement to process additional data	Relatively low cost but requires an experienced spatial analyst to process and QA the data (app. \$10-20k)	Relatively low cost but requires an experienced spatial analyst to process and QA the data (app. \$10-20k, depending on the extent of the study)
Usability by others	Easily used by others, although some spatial analysis experience is required	Easily used by others, although some spatial analysis experience is required	Easily used by others, although some spatial analysis experience is required
Accuracy of estimate	Developed equation is very accurate (R^2 of 0.958 for catchments > 50 km^2)	Very accurate estimate for individual catchments	Very accurate estimate for individual catchments
Ease of data maintenance and update	No requirement to update or maintain	No requirement to update or maintain	No requirement to update or maintain
Improvement of accuracy of farm dam impact assessment		This approach would create very accurate information for individual catchments although it may not improve significantly on the current approach	Some improvement to existing equation, but probably not significant. Could improve confidence in regional representativeness.
Applicability at different scales	Considered suitable for catchment scale analysis	Only applicable to the survey area	Suitable for catchment scale analysis at a regional scale

5.6. Determining the usage from stock and domestic farm dams

For this study, two main methods were used to collect information about the water use from stock and domestic dams. In the first method, farm design sheets held by DERM were used to obtain information about stock and domestic farm dams. The second method used was a phone survey conducted among landholders who have stock and domestic dams on their property. Based on the outcomes of this investigation a demand factor of 0.5 was adopted, with no seasonal pattern of demand.

There are two alternatives to the approach adopted for this project (as discussed in Section 4.10.2):

- Direct metering of usage from stock and domestic dams; or
- Further phone surveys to improve the developed demand factor.

Table 17 presents the outcomes of the assessment of various options to improve farm dam demand estimates, which are also summarised below:

- The adopted approach uses a demand factor which is applied to the dam storage volume; this is easy to apply and does not require any data processing. The approach is considered reasonable to provide an unbiased estimate of water demand for dams at the catchment scale. Consistent results were found in terms of mean and median demand factor between the phone survey, design sheets and the previous Victorian study (SKM, 2004);
- Direct metering of usage from stock and domestic dams would be costly and may be subject to resistance from farmers. However, if the technical difficulties (e.g. accounting for evaporation and seepage from the dams) could be overcome the results would provide significant improvements in the current understanding of farm dam demands. The information obtained from metering would be very detailed in relation to a small area of interest, although may be suitable for extrapolation across wider scales. This is a long term investigation and would take several years to complete; it is also likely to be more suitable to be carried out as a research project.
- Further phone surveys could also be undertaken to improve the confidence in the current approach. This would be much faster and cheaper to complete than a metering study. It would be also be worth exploring the question of seasonality of demand.

- **Table 17 Alternative approaches to estimate farm dam demands**

Criteria	Current approach	Metering	Further Phone Survey
Cost and ability to acquire data	No cost to utilise existing data	Expensive to establish and maintain, although this depends on the number of sites.	Cost depends on area of interest and number of responses required.
Cost of data processing	No cost to utilise existing data	Processing costs depends on number of sites	Data processing can be completed quickly (1-2 weeks) and easily
Usability by others	Easily used by others	Highly detailed data very useful to other users. Detailed information that can be applied for a range of applications.	Easily used by others
Accuracy of estimate	Considered reasonable to provide an unbiased estimate of water demand for many dams at the catchment scale.	Accurate information obtained.	Considered suitable to provide an unbiased estimate of water demand for many dams at the catchment scale. (depends on size of expanded survey)
Ease of data maintenance and update	Requires no effort to update.	Data can be collected over long term periods to further inform analysis.	Requires no effort to update.
Improvement of accuracy of farm dam impact assessment	n/a	Provides detailed information for metered sites, and can be used to inform estimates of water use in other regions.	Considered suitable to provide an unbiased estimate of water demand for many dams at the catchment scale. Confidence in current approach would increase, depending on the size of the expanded survey.
Applicability at different scales	Considered suitable for catchment scale analysis.	Provides detailed information for metered sites, and can be used to inform estimates of water use in other regions.	Considered suitable for catchment scale analysis – expanding the survey could improve confidence in the suitability of regionalisation

5.7. Regional volume estimate

For this project a regionalisation method was developed in order to estimate the total stock and domestic dam volume, for areas where spatial data identifying individual dams was not available. A regression relationship was developed based on the following catchment characteristics; number of referable dams, the number of people in the area and the mean annual areal actual evapotranspiration.

The alternative approaches for estimating the volume of stock and domestic farm dams are:

- Reduce uncertainty in a particular area of interest by digitising the dams within it;
- Digitise a greater area of Queensland and carry out the regression analysis with more data to extrapolate to the whole state; or
- Digitise farm dams for all of Queensland.

The assessment of the options to improve the regionalisation estimate of farm dam volumes is presented in Table 18 and summarised below:

- The current approach is easy to apply and requires no further updating or processing;
- Digitising individual modelling areas would increase the accuracy of the estimate for that area but would not improve the approach at a wider scale;
- Digitising a larger area and carrying out the regression analysis with more data would provide an increase in the confidence of this approach but would be quite costly to complete;
- Digitising the whole of Queensland would be very costly to complete but would provide the best outcome, in terms of accuracy. This would dispense with the need for the regionalisation approach altogether.

Table 18 Alternative approaches to the regional volume estimate

Criteria	Current approach	Digitise individual areas	Improve regression analysis through further digitisation	Digitise farm dams for all of Queensland
Cost and ability to acquire data	No charge to utilise existing data	Cost depends on the size of the area selected (app. $3000 per 1000 km^2)	Cost depends on the area selected (app. $2400 per 1000 km^2) – the area required to significantly improve the regression analysis would be in the order of 600,000 km^2	Very high cost (app. $2400 per 1000 km^2 – this cost is applicable for digitisation of areas larger than 15000 km^2)
Cost of data processing	No requirement to process additional data	Relatively low cost but requires an experienced spatial analyst to process and QA the data (app. $10-20k)	Moderate cost and requires experienced spatial analyst to process and QA the data	Moderate cost and requires experienced spatial analyst to process and QA the data
Usability by others	Easily used by others, although some spatial analysis experience is required	Easily used by others	Easily used by others, although some spatial analysis experience is required	Easily used by others, although some spatial analysis experience is required
Accuracy of estimate	Developed equation is considered accurate (R^2 of 0.93)	Accurate information obtained.	Very accurate estimate for individual catchments	Very accurate estimate for whole state
Ease of data maintenance and update	No requirement to update or maintain	Requires no maintenance or update	No requirement to update or maintain	No requirement to update or maintain
Improvement of accuracy of farm dam impact assessment		This approach would create very accurate information for individual catchments although it may not improve significantly on the current approach	Some improvement to existing equation and would improve confidence in regional representativeness.	High level of improvement in level of accuracy
Applicability at different scales	Considered suitable for catchment scale analysis	Only applicable to the digitised area	Suitable for catchment scale analysis at a regional scale	Suitable for catchment scale analysis at a regional scale

5.8. Summary of proposed alternatives

Table 19 presents one recommended alternative approach for each of the input estimation methods. These recommendations assume that the purpose of any further investigation is to estimate the hydrological impact of stock and domestic dams over a large area, for example, the Queensland Murray Darling Basin, or Statewide.

Table 19 Recommended approach to improve the current methods

Input Parameter	Current approach	Proposed alternative	Comment
Identification of S&D dams	Exclusion due to landuse type	Survey to validate existing approach	Reasonably costly, however this is an area where there is currently very little information.
Estimating the volume of dams	Surface area to volume relationship (regression analysis based on LiDAR and DEM)	Expand the existing analysis to include more sample points and a wider geographic distribution	
	Regional volume estimate	Digitise farm dams for all of Qld	Removes the need for the regional volume estimate and the size distribution. All volumes would be estimated using the surface area to volume relationship
	Size distribution	Additional digitisation	This method is only required if the regional volume estimate continues to be used
Local catchment area	Regression equation based on catchment characteristics	Expand the existing analysis to cover larger sample areas and a wider geographic distribution	This is a pragmatic approach, the alternative is to directly derive the local catchment area for each modelled catchment – which would be expensive and time consuming
Dam usage	Demand factor (as a proportion of the dam volume which is used each year)	Expand the existing analysis to include more sample points and a wider geographic distribution	This is a pragmatic approach as the alternative is to directly meter a number of dams for an extended time period (app. 50 dams 3 years) – which would be expensive and time consuming

These recommendations will be discussed further in the *Statewide Assessment: Report 2 – Hydrological assessment of stock and domestic farm dams in Queensland.*

If the purpose of a future study was to more accurately define the impact of stock and domestic farm dams across a smaller area (for example within one basin or catchment) then similar principles to those outlined in the table above would apply. If farm dams had not yet been digitised within that area, then the most effective means of reducing uncertainty in the estimate of impacts would be to digitise the surface area of farm dams within that area. The other means of reducing uncertainty that have been considered can still be applied to a smaller area (such as a single basin) but their cost effectiveness reduces (in terms of reduction in uncertainty per ML of total impact on the water resource) because in a larger regional study the results of these efforts can be spread across reducing the uncertainty for more catchments, more dams and more overall ML of impact.

For a smaller area, the broad recommendations would be:

1) Digitise farm dams in the area (to establish the number and surface area of dams, as well as the local catchment area)
2) Survey some of the dams to develop a more specific surface area to volume relationship
3) Survey local landholders using telephone or one-on-one interview techniques to understand the local demand factor and seasonal pattern better. This survey could also be used to identify stock and domestic dams on the properties, and to find out about the drivers for developing farm dams in the area.

6. Conclusions and further work

This report presents the final inputs and methods developed for this Project, in order to facilitate the estimation of the hydrologic impact of stock and domestic farm dams in Queensland. Where practical, alternative methods have been proposed and discussed with respect to their relative advantages and with a view to improving the adopted methods.

For this study the STEDI models require the following inputs:

1. Climate inputs – rainfall, streamflow and evaporation;
2. Estimate of use or the demand factor for each dam – representing the annual volume taken extracted from the dam as a proportion of the storage capacity of the dam;
3. Catchment areas – total catchment area and the sum of the catchment areas that are upstream of all of the farm dams in the catchment; and
4. Estimate of the number and volume of farm dams in the catchment.

The streamflow, rainfall and evaporation data adopted for this study is considered to be of very good quality and does not need to be updated or improved. This data is currently routinely developed and maintained as part of other ongoing work by DERM and further investigation is not required for these inputs.

The demand factor, used to estimate the direct usage from the dams has been derived from an analysis of phone survey responses and farm dam design sheets. The sample size of this analysis is quite small and it is therefore recommended to either revise the demand factor based on an expanded phone survey or based on a long term metering project.

The catchment area upstream of farm dams within each catchment was determined from detailed digital terrain model data for five small representative catchments and then was regionalised, for the purposes of modelling, using a regression relationship. The regression relationship relates the total catchment area upstream of the farm dams with the total catchment area, mean catchment slope and dam density. While the relationship shows a very good fit to the observed data there is some uncertainty associated with it due to the relatively small sample size and the limited geographic range represented in the digital terrain models that were used to derive the relationship. This relationship could be improved through further spatial analysis, over a wider geography.

A farm dam surface area to volume relationship was developed based on a sample of 73 dams in the Moreton, Lockyer and Sothern Downs reporting regions. The adopted relationship was also relatively consistent with similar relationships that were derived from samples of farm dams in Victoria, southern New South Wales, South Australia and south west Western Australia, which indicates that regional variations in the surface area to volume relationship are not too large. The adopted relationship has a strong correlation and level of confidence; however this could be improved through ground survey or additional LiDAR analysis. The LiDAR analysis is more likely to improve the current approach than the ground survey and is likely to provide better value for money.

Stock and domestic farm dams are currently identified through spatial analysis, using a landuse exclusion process. This method can be applied over large areas where little other information is available. There is a high level of uncertainty around this method, which is difficult to verify or quantify with currently available information. It would be worthwhile for DERM to investigate this area further and to consider testing the results from the landuse based analysis by investigation using field officers.

Overall, additional digitisation over a large area would seem to provide the most benefit to DERM. This could be used to directly identify individual dams for modelling (removing the need to use the regional volume estimate approach for the digitised areas) and as an input to improve the local catchment area regression relationship. Any additional digitisation should consider the need to incorporate geographic diversity, in order to account for the likely regional differences due to factors such as rainfall, evaporation, terrain and landuse.

Following on from this report, the STEDI modelling results and outcomes of the trends assessment are provided in the *Statewide Assessment: Report 2 – Hydrological assessment of stock and domestic farm dams in Queensland*. This report also presents the outcomes of an assessment of the sensitivity of the model to changes in the input parameters. This has been used to further evaluate the benefit of improving the input estimation methods. Final recommendations with respect to improving these methods are provided in Report 2.

7. Limitations of this study

This study has produced a method which can be used to estimate the hydrologic impact of stock and domestic farm dams across Queensland. The STEDI hydrologic model has been adopted for this study with model input estimation methods developed based on Queensland data and specifically suited to application within the Queensland context.

However, it is important that these methods are understood within the framework of the limitations of the study. These limitations include the following:

- STEDI works best when the input gauge streamflows are representative of the flows observed at each farm dam location. In other words, STEDI is not a water resource model, and does not take stream losses into account. On this basis, results for large catchments should be adopted with care, understanding that there may be significant uncertainty associated with estimated farm dam impacts depending on whether the flows at each dam location are under or over estimated.
- STEDI does not account for channel transmission losses within the catchment and it assumes that all parts of the catchment contribute equally to flow at all times. These assumptions have been made because there is a lack of sufficient data from catchments with multiple nested stream flow gauges and farm dams to be able to quantify these factors. These assumptions may result in an overestimation of the impact of farm dams within a given catchment, with the STEDI model producing a conservatively high estimate of the reduction in streamflow as a result of the dams.
- Farm dams have been modelled assuming that every dam is fully independent, and each dam has no effect on any other dam. In areas with very high levels of farm dam development (say >15ML/km^2) there is likely to be increasing incidence of dams "cascading" within a catchment. This effect has not been taken into account in the STEDI modelling and may result in overestimation of the impact of farm dams in catchments with high farm dam densities.
- The on-farm demand associated with each dam is based on a constant pattern of demand. This approach does not allow for seasonal or inter-annual variability, meaning that demands in a dry year will be identical to those in a wet year. It would be reasonable to assume however that usage from stock and domestic farm dams is much more consistent between years and seasons than the usage from irrigation dams.
- DERM has identified key areas of interest for this study as the Murray-Darling Basin and South East Queensland. These areas have been the primary source of data for the development of the input estimation methods. This is considered appropriate for the purpose of this study but does imply an increase in the uncertainty of results for other areas of the state.

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Appendix A Datasets available and/or utilised

A.1 Geoscience Australia Waterbodies

Characteristic	Description
Contents	Digitised dams and waterbodies for the Murray-Darling Basin
Currency	Data supplied 2008 using 2005 imagery (plus or minus 12 months)
Spatial extent	Murray-Darling Basin
Custodian	Geoscience Australia
Comments	Dams captured are either 'Flood Irrigation Storage' or 'Town Rural Storage'. All Flood Irrigation Storage dams were excluded as flood interception dams were not considered as a part of this project. This data set includes both points and polygons. According to the GA specifications (http://www.ga.gov.au/mapspecs/topographic/v5/appendixA_files/Waterbodies.jsp), the points are intended to represent dams that have a surface area smaller than 6400 m^2, while the polygons more accurately represent dams that are larger. In practice, the points and polygons have been captured across a range of sizes, with a general understanding that the points are smaller than 625 m^2 and the polygons larger. Again, many dams in the dataset have been found to break each rule, as discussed in Section 4.5.1.

A.2 Referable farm dams dataset from DERM

Characteristic	Description
Contents	Digitised dams that were investigated as a part of the assessment of potentially referable dams in Queensland
Currency	Landsat5 imagery from 1986-2005
Spatial extent	Queensland
Custodian	Department of Environment and Resource Management, QLD
Comments	This dataset has been created through remote sensing techniques using a method to capture areas where water with a surface area greater than 0.25ha was present. It was created using Landsat5 imagery from 1986-2005. ▪ Data represents only dams with water in them at time of capture ▪ All dams less than 0.25ha have not been included ▪ Dam boundaries do not represent full supply level ▪ Analysis of the MDB indicates that these dams represent only 10% of farm dams present in the GA waterbodies layer ▪ Given these characteristics, this dataset should not be used to directly define the characteristics of farm dams in Queensland

A.3 Extended farm dams dataset from DERM

Characteristic	Description
Contents	Digitised dams that were produced as an extension of the GA waterbodies layer
Currency	2011
Spatial extent	Logan-Albert, South Coast, Pine, Brisbane, Stradbroke Island
Custodian	DERM
Comments	Data is comparable to the GA Waterbodies layer

A.4 Dams digitised for this project

Characteristic	Description
Contents	Digitised dams that were produced as a part of this project by SKM
Currency	2011, with some indication of trends
Spatial extent	21 areas of south east Queensland totalling 13,158 km^2
Custodian	Project product
Comments	

A.5 Climate data from SILO

Characteristic	Description
Contents	Rainfall and evaporation data
Currency	Requested October 2011, data provided for the period 01/01/1890-30/06/2011
Spatial extent	Data available for all of Australia. For this project, data was requested at each modelling gauge
Custodian	Department of Environment and Resource Management, QLD
Comments	

A.6 Climate data from Bureau of Meteorology

Characteristic	Description
Contents	Rainfall and evapotranspiration data
Currency	1961 - 1990
Spatial extent	Australia
Custodian	Bureau of Meteorology
Comments	250m resolution dataset. Used to regionalise farm dam inputs and outputs

A.7 LIDAR Data from DERM

Characteristic	Description
Contents	Classified LiDAR strikes across five regions in South East Queensland representing elevation
Currency	2009 - 2010
Spatial extent	Sample areas around Southern Downs, Lockyer Valley, Gympie and Moreton Bay.
Custodian	DERM
Comments	This data was filtered by SKM to only use ground strikes (LAS class 2) in the analysis

A.8 Digital elevation model from DERM

Characteristic	Description
Contents	Elevation values representing the surface of the earth
Currency	Requested form IQ in May 2011
Spatial extent	MDBA extent, South East Queensland and Burnett areas.
Custodian	DERM
Comments	25m resolution DEM. The accuracy of this DEM depends on the accuracy of the source data and the error of ANUDEM`s interpolation. The average accuracy of AUSLIG's 1:100000 source data is + or - 25 metres in the horizontal position of well defined detail and + or - 5 metres in elevation for most mapsheets

A.9 Digital elevation model from Geoscience Australia

Characteristic	Description
Contents	Elevation values representing the surface of the earth
Currency	2011
Spatial extent	Australia
Custodian	Geoscience Australia
Comments	1" or about 30m. This data is still in draft form, the public release of the data is due later in 2011

A.10 Digital elevation model from Geoscience Australia

Characteristic	Description
Contents	Elevation values representing the surface of the earth
Currency	2008
Spatial extent	Australia, used on a state basis
Custodian	Geoscience Australia
Comments	9"

A.11 Aerial photography from DERM

Characteristic	Description
Contents	Digital and scanned aerial photography captured by various agencies on behalf of DERM
Currency	1951 - 2010
Spatial extent	Various study areas over SEQ
Custodian	DERM
Comments	This data varies in accuracy, detail, colour and quality

A.12 Bureau of Rural Statistics 2005-06 Landuse dataset

Characteristic	Description
Contents	A landuse map of Australia
Currency	2005-06
Spatial extent	Australia
Custodian	Bureau of Rural Statistics
Comments	50m resolution dataset

Appendix B Glossary and acronyms

Table 20 Glossary of terms

Term	Definition	Units
Adjusted farm dam volume	Estimated farm dam volume that includes a component of estimated volume and equation predicted volume.	
Area	Area of the reporting or modelling catchment, from the zonal statistics in	km²
AreaSD	Area of catchment that has a landuse that is considered to be stock and domestic as defined by the BRS 2005-06 landuse layer in Report 1	km²
Catchment farm dam	A farm dam is also called a catchment farm dam, and is a dam that "*predominantly harvests water from rainfall runoff events other than a defined waterway*" (EGIS, 2002).	
Density	Farm dam density in the modelled catchment	ML/km²
Estimated input data	Input data which has been estimated and/or calculated (e.g. storage volume from LiDAR and DEM information).	
Geographic units		
Digitised area	The digitised area refers to any one area or all areas that were digitised specifically for this project for either the current level of development, or the trend in dam development over time.	
Modelling catchment	The catchment area that has been modelled using STEDI. There are 55 modelling catchments that have been modelled and they each represent the area upstream of an IQQM streamflow gauge.	
Reporting area	Queensland is entirely covered by reporting areas that represent either entire drainage basins, or sub areas. They are defined by the IQ_ATLAS number. The reporting areas	
Impact	Represents the average annual impact of farm dams on the mean annual flow in an area. The impact has been presented in a number of ways, either as a modelled or regionalised impact, and as an absolute volume of impact (ML/year), a percentage of mean annual flow (%), an impact per unit area (ML/year/km²) or an impact per unit volume of farm dams in the area (ML/year/ML of dams) Impact = Q-nodams – Q-withdams	ML/day aggregated to ML/year
Local catchment area	Area of the modelled catchment that is regulated by farm dams	km²
Maximum elevation	Maximum SRTM elevation across the catchment area in a particular catchment area	m EGM96 vertical datum
Mean Annual AAET	Mean annual areal actual evapotranspiration (mm) from the BoM Grids in a particular catchment area	mm
Mean annual flow	Mean annual flow is the average annual outflow from each of the modelling catchments, with the impact of farm dams removed, or the aggregated Q-nodams variable.	ML/year
Measured or Observed data	Input data used in the analysis which has been sourced directly from recorded information (e.g. digitised surface area of dams).	
Number of referable SD dams	The number of dams in the DERM Referable dams layer, in stock and domestic landuses in a particular catchment area	Number of dams

Term	Definition	Units
Q-withdams	The current flow series used as an input to the STEDI modelling. This flow includes the impact of farm dams as it represents the current approved level of development. This has been sourced from the IQQM models for each modelling catchment. Impact = Q-nodams – Q-withdams	ML/day
Q-nodams	This represents the flow in the modelling catchments if the farm dams did not exist. It is an output from the STEDI modelling. Impact = Q-nodams – Q-withdams	ML/day
Percent Residual	The residual as a percentage of the observed value.	
Predicted values	Values obtained by applying a regression equation to measured or observed data, and/or estimated input data.	
Proportion local catchment area	The proportion of the modelled catchment that is regulated by farm dams	Percentage
Residual	The difference between an equation predicted value and the corresponding measured/estimated/adjusted value which the development of the equation is based on.	
Slope	Slope of the modelled catchment is calculated as the average slope across the catchment. Each point is assigned the maximum slope based on the elevation of all surrounding points. The average of all the maximum slopes for each point is then calculated.	degrees
Stock and domestic	Stock and domestic water is water that is used only for watering stock or for domestic (around the house or garden) purposes. In Queensland, under the Water Act 2000, Section 20(4), it is not required to have a water entitlement for using overland flow water collected in dams for stock or domestic purposes.	
Surface area (SA)	Surface area of individual dams	m^2
Volume (V)	Volume of individual dam	ML
Zonal statistics	Zonal statistics have been calculated for each of the geographic units detailed above. They represent a number of characteristics for each geographic unit and have been used in regionalisation. They include: ▪ The number and volume of referable dams from the DERM data, the DERM extended area, MDB GA waterbodies and digitised dams; ▪ The monthly and annual rainfall, areal potential, areal actual and point potential evapotranspiration from the BoM climate grids; ▪ Minimum, mean and maximum slope of each catchment ; ▪ Minimum, mean and maximum elevation of each catchment (Using the SRTM (m EGM96 vertical datum)); ▪ Population from the ABS Census collection districts (2006), excluding districts with a population density greater than 300 people per square kilometre; ▪ Area of woody vegetation (Department of Climate Change and Energy Efficiency); ▪ Areas of various landuse as defined by the BRS 2005-06 landuse layer; and ▪ Area of expected stock and domestic landuse	

- **Table 21 Acronyms used in this report**

Acronym	Meaning
BRS	Bureau of Rural Sciences
DEM	Digital Elevation Model
DERM	Department of Environment and Resource Management
EGM96	Earth Gravitational Model 1996
ET	Evapotranspiration
AAET	Areal actual evapotranspiration
APET	Areal potential evapotranspiration
PPET	Point potential evapotranspiration
GA	Geoscience Australia
IQQM	Integrated Quality and Quantity Model
LiDAR	Light distance and ranging – Airborne elevation modelling data
MDB	Murray-Darling Basin
ML	Megalitres
mm	Millimitres
SKM	Sinclair Knight Merz
SRA	Sustainable Rivers Audit
SRTM	Shuttle Radar Terrain Mission
STEDI	Spatial Tool for Estimating Dam Impacts

Appendix C Landuse based stock and domestic assessment

Table 22 Summary of landuses that are considered to be stock and domestic or not

Stock and domestic		
1.2.5 Traditional indigenous uses	1.3.2 Stock route	2.1.0 Grazing natural vegetation
3.2.0 Grazing modified pastures	3.2.1 Native/exotic pasture mosaic	3.3.1 Cereals
3.3.2 Beverage & spice crops	3.3.3 Hay & silage	3.3.4 Oil seeds
3.3.8 Legumes	5.2.0 Intensive animal production	5.2.1 Dairy
5.2.2 Cattle	5.2.4 Poultry	5.2.5 Pigs
5.4.0 Residential	5.4.2 Rural residential	6.2.2 Water storage - intensive use/farm dams
Not stock and domestic		
1.1.0 Nature conservation	4.1.0 Irrigated plantation forestry	5.6.0 Utilities
1.1.1 Strict nature reserves	4.1.3 Irrigated other forest production	5.6.1 Electricity generation/transmission
1.1.3 National park	4.2.0 Irrigated modified pastures	5.6.2 Gas treatment, storage and transmission
1.1.4 Natural feature protection	4.2.1 Irrigated woody fodder plants	5.7.0 Transport and communication
1.1.5 Habitat/species management area	4.3.0 Irrigated cropping	5.7.1 Airports/aerodromes
1.1.6 Protected landscape	4.3.1 Irrigated cereals	5.7.2 Roads
1.1.7 Other conserved area	4.3.2 Irrigated beverage & spice crops	5.7.3 Railways
1.2.0 Managed resource protection	4.3.3 Irrigated hay & silage	5.7.4 Ports and water transport
1.2.1 Biodiversity	4.3.4 Irrigated oil seeds	5.7.5 Navigation and communication
1.2.2 Surface water supply	4.3.5 Irrigated sugar	5.8.0 Mining
1.2.4 Landscape	4.3.6 Irrigated cotton	5.8.1 Mines
1.3.0 Other minimal use	4.3.7 Irrigated tobacco	5.8.2 Quarries
1.3.1 Defence	4.4.0 Irrigated perennial horticulture	5.8.3 Tailings
1.3.3 Residual native cover	4.4.1 Irrigated tree fruits	5.9.0 Waste treatment and disposal
1.3.4 Rehabilitation	4.4.2 Irrigated oleaginous fruits	5.9.2 Landfill
2.2.0 Production forestry	4.4.3 Irrigated tree nuts	5.9.3 Solid garbage
2.2.1 Wood production	4.4.4 Irrigated vine fruits	5.9.5 Sewage
3.0.0 Production from dryland agriculture and plantations	4.4.5 Irrigated shrub nuts fruits & berries	6.1.0 Lake
3.1.0 Plantation forestry	4.4.7 Irrigated vegetables & herbs	6.1.1 Lake - conservation

Not stock and domestic		
3.1.1 Hardwood production	4.5.0 Irrigated seasonal horticulture	6.1.2 Lake - production
3.1.2 Softwood production	4.5.1 Irrigated fruits	6.2.0 Reservoir/dam
3.1.3 Other forest production	4.5.3 Irrigated flowers & bulbs	6.2.1 Reservoir
3.1.4 Environmental	4.5.4 Irrigated vegetables & herbs	6.2.4 Effluent pond
3.3.0 Cropping	5.0.0 Intensive uses	6.3.0 River
3.3.5 Sugar	5.1.0 Intensive horticulture	6.3.1 River - conservation
3.3.6 Cotton	5.1.1 Shadehouses	6.3.2 River - production
3.4.0 Perennial horticulture	5.1.2 Glasshouses	6.3.3 River - intensive use
3.4.1 Tree fruits	5.1.3 Glasshouses (hydroponic)	6.4.0 Channel/aqueduct
3.4.2 Oleaginous fruits	5.2.6 Aquaculture	6.4.1 Supply channel/aqueduct
3.4.3 Tree nuts	5.3.0 Manufacturing and industrial	6.4.2 Drainage channel/aqueduct
3.4.4 Vine fruits	5.4.1 Urban residential	6.5.0 Marsh/wetland
3.4.5 Shrub nuts fruits & berries	5.5.0 Services	6.5.1 Marsh/wetland - conservation
3.5.0 Seasonal horticulture	5.5.1 Commercial services	6.5.2 Marsh/wetland - production
3.5.1 Fruits	5.5.2 Public services	6.6.0 Estuary/coastal waters
3.5.3 Flowers & bulbs	5.5.3 Recreation and culture	
3.5.4 Vegetables & herbs	5.5.4 Defence facilities	
	5.5.5 Research facilities	

Appendix D Estimated farm dam volume from regionalisation

- **Table 23 Measured and estimated volume of dams for catchments used in the regression analysis described in Section 4.6, with prediction limits**

Information source	Catchment ID or name	Measured volume (ML)	5% prediction limit (ML)	Estimated volume of farm dams (ML)	95% prediction limit (ML)
Digitisation areas	6	3,855	1,659	3,598	7,804
Digitisation areas	7	2,592	996	2,164	4,701
Digitisation areas	8	860	145	321	708
Digitisation areas	9	1,073	452	981	2,131
Digitisation areas	10	5,365	2,159	4,792	10,638
Digitisation areas	11	3,959	1,500	3,326	7,375
Digitisation areas	12	1,155	283	619	1,355
Digitisation areas	13	11,535	4,262	9,300	20,290
Digitisation areas	14	1,906	1,247	2,700	5,843
Digitisation areas	1	676	386	842	1,839
Digitisation areas	2	852	671	1,454	3,151
Digitisation areas	3	155	150	329	722
Digitisation areas	4	576	353	769	1,674
Digitisation areas	5	223	65	143	317
Modelling catchments	142202A	1,638	978	2,130	4,637
Modelling catchments	143110A	658	203	444	970
Modelling catchments	143113A	2,814	1,105	2,391	5,175
Modelling catchments	143211A	2,331	658	1,427	3,097
Modelling catchments	143212A	7,335	2,629	5,720	12,444
Modelling catchments	143214A	568	353	766	1,663
Modelling catchments	143303A	321	419	925	2,041
Modelling catchments	143306A	69	35	79	178
Modelling catchments	145010A	93	82	181	399
Modelling catchments	145011A	225	84	186	411
Modelling catchments	145013A	334	88	192	423
Modelling catchments	145101D	488	191	417	910
Modelling catchments	416312A	587	354	774	1,689
Modelling catchments	416410A	656	260	568	1,241
Modelling catchments	416800	7,565	2,898	6,298	13,683
Modelling catchments	417201B	24,282	6,470	14,169	31,028
Modelling catchments	422304A	1,274	679	1,470	3,183
Modelling catchments	422352A	1,054	1,315	2,845	6,153
Modelling catchments	422407A	2,746	1,760	3,830	8,334

Information source	Catchment ID or name	Measured volume (ML)	5% prediction limit (ML)	Estimated volume of farm dams (ML)	95% prediction limit (ML)
Modelling catchments	423204A	2,792	1,913	4,178	9,124
Modelling catchments	424202A	749	159	366	843
Remnant areas	Bremer River	18,784	5,623	12,292	26,873
Remnant areas	Stanley River	9,915	3,030	6,674	14,702
Remnant areas	Logan River	27,960	9,916	21,860	48,187
Remnant areas	Albert River	8,596	3,351	7,302	15,913
Remnant areas	Lockyer Creek	29,445	7,418	16,290	35,774
Remnant areas	Maranoa River	9,221	5,354	11,796	25,991
Remnant areas	Paroo River	9,729	8,981	20,436	46,503
Remnant areas	Warrego River	36,029	10,779	24,135	54,044
Remnant areas	Moonie River	3,630	2,571	5,646	12,399
Remnant areas	Macintyre & Weir Rivers	23,734	12,536	27,587	60,709
Remnant areas	Condamine River	65,917	27,444	61,173	136,354
Remnant areas	Macintyre Brook	7,243	2,900	6,296	13,667
Reporting areas	Caboolture River	7,270	4,337	9,616	21,321
Reporting areas	North Pine River	4,291	3,088	6,795	14,955
Reporting areas	Brisbane River	29,576	8,952	19,802	43,804
Reporting areas	Coomera & Nerang Rivers	5,293	4,185	9,153	20,015
Reporting areas	Wallam Creeks	19,811	9,773	21,896	49,056
Reporting areas	Balonne River	60,319	21,013	46,724	103,894

Appendix E Demand factor assessment

Griffih School of Engineering

Griffith University

7605ENG – Industrial Affiliates Program

Assessment of impact of stock and domestic dams in Queensland- Demand Factor

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4th November 2011

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Extended journal article

Abstract

Farm dam demand factor could be defined as the ratio of the annual demand for water (assuming farm dam does not empty) divided by the storage volume when the dam is full. It is one of the key inputs required to simulate the hydrological impacts of farm dams using the model called STEDI (Spatial Tool for Estimating Dam Impact). When using STEDI, farm dams are divided into stock and domestic (S&D) or irrigation dams depending on their sizes. As demand factor varies from dam to dam, this study was carried out to improve the understanding of the demand factor for S&D dams in selected catchments of Queensland. By conducting a phone survey among landholders and using the information from farm design sheets, it was found that the demand factor varied between 0.002 and 2.25 with a median of 0.48. The factors that largely influence demand are climate conditions and availability of alternative water sources.

Keyword: farm dams, demand factor, STEDI, stock and domestic, dam impact.

Introduction

Farm dams are used by landholders to meet their likely demand for water during the years with average annual rainfall. In most cases they are filled by capturing run-off from their own catchment during rainfall events. This decreases the volume of water that reaches waterways and reduces the flow in creeks and rivers. During the past few years, a number of studies have been conducted in different regions of Australia to estimate the hydrological impacts of farm dams. Most of these studies were focused on larger dams that are used for irrigation or commercial purposes. Limited information is available about the water use from smaller dams that are usually used for S&D purposes. Hence this project was carried out to investigate the demand from S&D farm dams selected catchments of Queensland.

Previous Studies in Australia

Farm dams play an important role in increasing the reliability of water supplies for Australian agricultural industry. Farm dams capture runoff and store it to supply the demand during insufficient rainfall (van Dijk et al., 2006). Size of farm dams varies depending on its primary use. Small dams up to 5 ML capacity are used for stock and domestic purposes and dams larger than 6 ML could be categorised as irrigation dams (Lowe, Nathan, & Morden, 2005).

Van Dijk el al (2006) found that the number and size of farm dam have increased over time and the largest increases were due to major droughts. In 2005, it was estimated that farm dam capacity in Queensland alone was 2.5 million ML(Gibbings & Raine, 2005). According van Dijk et al (2006) the cumulative impact of farm dams on streamflows could be significant even though an individual dam may not be a threat. In addition it was argued that a small number of larger dams will have a more significant impact on the streamflows compared to the effects from a large number of smaller dams with equivalent total volume (van Dijk, et al., 2006).

A study was conducted by Sinclair Knight Merz (SKM) in 2004 to estimate the demand factor by conducting a survey among landholders in Victoria. By using 15 responses, it was found that demand factor for S&D dams varied between 0.10 and 1.14. The median demand factor was 0.50 (SKM, 2004).

Materials and Methods

Two different methods were used to obtain information about the water use from S&D farm dams. A phone survey among landholders was conducted to find volume of S&D dams and the amount of water extracted from those dams each year. In cases were landholders could not give the volume of the dams, equation 1 developed by(Lowe, et al., 2005) (Lowe, et al., 2005) was used to estimate the volume. Surface areas of the dams were estimated using satellite images.

$$V = \frac{1}{6900} S^{1.314} \qquad \text{Equation 1}$$

Where V is the volume of the dam in ML and S is the surface area of the dam in m^2.

The farm design sheets held by Queensland Department of Environment and Resource Management had information about the water requirement and the capacity of some of the dams developed or proposed to be developed. Information obtained from both phone survey and the design sheets were used to estimate the demand factor by using the equation 2.

$$Demand\ Factor = \frac{Average\ annual\ demand\ (ML)}{Volume\ of\ the\ dam\ (ML)} \qquad \text{Equation 2}$$

Results

The mean demand factor obtained from phone survey was 0.59 and that of design sheets was 0.47. However the median from the both methods were 0.48. The median value is more accurate than the mean demand factor as it is not affected by large or extreme values. The range of values from the survey was 0.002 to 2.25. The box plot in figure 1 illustrates the variation in the demand factor from the two methods. The demand factor from the design sheets demonstrated much lower standard deviation (0.23) than the survey responses (0.59). An F-test found that the difference in standard was significant at the 1% level of significance

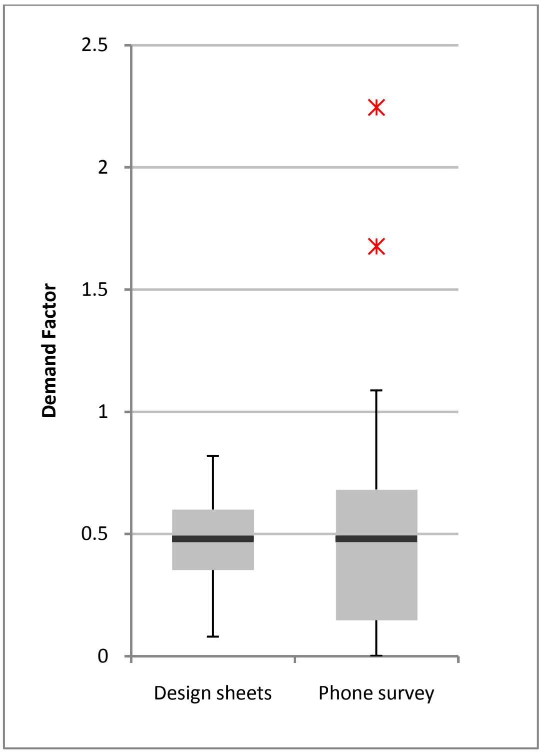

Figure 1. Box plot illustrating the variation in demand factor from two methods.

A number of factors could cause the variations in the demand factor. Some of these factors include the climate conditions, use of other water sources for S&D purposes, behaviour of livestock and other animals using the dams. The effect of having another water source for S&D purposes was examined in this study. Data from the phone survey was used in this case. Figure 2 shows a comparison of demand factor for properties with and without alternative S&D water sources.

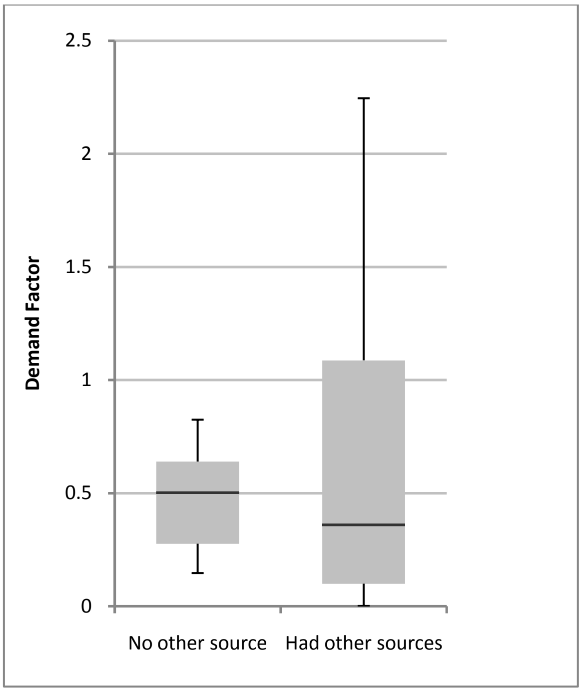

Figure 2. Box plot illustration the variation in demand factor when other water sources are used for S&D purposes.

Various analyses were carried out to determine the trends in volume and the demand from S&D dams. Following conclusions were made from the results:

- More than 74 % of the S&D dams are less than 5 ML,
- No trend was observed with the number of dams and area of the property,
- Total volume on the property increases with the area of the property,
- No trend obvious spatial trend in the demand factor,
- No trend observed between the demand factor and the volume of the dam.

Conclusions

The project carried out to estimate the demand factor for S&D dams in selected catchments of Queensland shows that demand factor varies between 0.002 to 2.25. The median demand factor was 0.48 and the mean was 0.59. There was no significant difference between the demand factor obtained in this study and the demand factor reported by SKM, 2004.

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Griffih School of Engineering

Griffith University

7605ENG – Industrial Affiliates Program

Assessment of impact of stock and domestic dams in Queensland- Demand Factor

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4th November 2011

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A report submitted in partial fulfilment of the degree of Master of Engineering with Advanced studies

EXECUTIVE SUMMARY

The demands from stock and domestic (S&D) farm dams in selected catchments of Queensland were investigated in this study. Average annual usage and their full storage capacity were estimated for a number of S&D dams to determine the demand factor.

A phone survey among landholders owning S&D dams, and farm dam design sheets held by Department of Environment and Resource Management (DERM) were used to collect information about the S&D. Landholders for the phone survey were selected by locating possible S&D dams on satellite imagery and by obtaining the names and addresses of the property owners from DERM. Farm designing sheets were obtained from DRERM archive.

A total of 30 landholders participated in the phone survey, and only 10 % of them were able to estimate the volume and demand from a S&D dam that they had. 42 % of the participants were able to estimate the volume of the dams but could not estimate the usage. A demand based approach was used to estimate the water extracted from those dams where the participants mentioned the different purposes for which the dams were used. For cases where landholders could not estimate the volume of the dam, surface area-volume relationship was used and the surface area of the dams were estimated using satellite images.

Out of 207 files obtained from DERM archive, only 8 files had sufficient information to estimate the S&D demands. The volume and water requirement from each of those dams were recorded and used in the analysis.

By using results from both the phone survey and dam design sheets, demand factor was calculated. Demand factor could be defined as the ratio of the annual demand for water (assuming farm dam does not empty) divided by the storage volume when the dam is full. The mean demand factor (0.59) and the median demand factor (0.48) were estimated for the dams studied. It was found that various factors could influence the demand factor including climate conditions, access alternative water sources and the rotation of livestock around the dams.

Analysis of volume of the dams showed that more than 74 % of the S&D dams were smaller than 5 ML and the average density of S&D dams on surveyed properties is 2.66 ML/km^2.

ACKNOWLEDGEMENTS

I would first like to thank Nicola Logan from Sinclair Knight Merz for giving me this opportunity to work on this project. I would also like to thank Chloe Wiesenfeld and Phillip Jordan from SKM for giving me continuous assistance throughout the project.

The completion of this project would not be possible without the data from Queensland Department of Environment and resource Management. I would like to thank Pushpa Onta from DERM for providing access to all the data that I required.

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ABBREVIATIONS

BOM	Bureau of Meteorology
DERM	Department of Environment and Resource Management
DSE	Department of Sustainability and Environment
GIS	Geographic Information System
MDB	Murray-Darling Basin
S&D	Stock and Domestic
SKM	Sinclair Knight Merz
STEDI	Spatial tool for Estimating Dam Impact
TEDI	Tool for Estimating Dam Impact

1 INTRODUCTION

1.1 Background

Farm dams are on-farm water storages that landholders have developed to meet their likely demand for water during the years with average annual rainfall. These water conservation structures are designed to store water using a constructed earth barrier or embankment. Depending on the agricultural landscape and source of supply, different structures have been used to optimise water and storage quality. The most common types of dams found in Australia are (Nelson, 1985):

- gully (embankment) dams;
- hillside dams;
- ring tanks;
- turkey's nest tanks;
- excavated tanks;
- off-creek storages; and
- spread-bank tanks

Farm dams are used for a broad range of purposes including long-term storage for live stock irrigation, domestic supply and fire fighting. In most cases they are used to store run-off from their own catchment during rainfall events. However, in some cases they are used as evaporation basins and storages for pumped groundwater (Stanton, 2005).

Australia being the driest inhabited continent with a highly variable rainfall, the availability of fresh water is limited. In large interior areas, the average annual rainfall is less than 300 mm while the average for the continent is 469 mm/year (Davis, 2007) . The ABS statistics 2006 Water Account 2004-2005 estimated that the rainfall volume across Australia was 2,789,424 GL and only 9% (242,779 GL) of it became runoff (ABS, 2006). Most of the rainfall was lost due to evaporation and transpiration.

Farm dams play an important role in increasing the reliability of water supplies for the Australian agricultural industry. Farm dams capture runoff and store it to supply the demand during insufficient rainfall (van Dijk, et al., 2006). Depending on the primary use, the size of the dams vary. Small dams up to 5 ML capacity are used for stock and domestic purposes and dams larger than 6 ML could be categorised as irrigation dams (Lowe, Nathan, & Morden, 2005).

Van Dijk el al (2006) found that the number and size of farm dam have increased over time and the largest increases were due to major droughts. In 2005, it was estimated that farm dam capacity in Queensland alone was 2.5 million ML(Gibbings & Raine, 2005). According van Dijk et al (2006) the cumulative impact of farm dams on streamflows could be significant even though an individual dam may not be a threat. In addition it was argued that a small number of larger dams will have a more significant impact on the streamflows compared to the effects from a large number of smaller dams with equivalent total volume (van Dijk, et al., 2006).

Even though there is evidence that farm dam have an impact on stream flows, there are very few studies conducted to investigate the magnitude of these impacts accurately. Neal et al (2002) suggested that the main reason for few published studies was due to lack of accurate streamflow data for different catchments (Neal, Nathan, Schreider, & Jakeman, 2002). However, due to the large number of spatial distribution of farm dams, it will be difficult to record the flow through each dam. Therefore it is important to develop methods and techniques that requires minimum input data

According to Beavis et al 1997, farm dams are used as "drought insurance" by farmers in areas with highly variable rain falls. Due to the changes in land use and management strategies, the numbers of farm dams have increased since the early 1970s. In addition to the State and Local legislations, a range of policies such as tax incentives and soil conservation programs controlled the development of farm dams (Beavis, Zhang, Evans, Jakeman, & Smith, 1997).

In Queensland, landowners do not require a water licence to use water for S&D purposes from dams filled by overland flow. According to Queensland Government Water Act 2000, water taken for **stock purposes** means:

> *"a) watering stock of a number that would normally be depastured on the land on which the water is, or is to be, used; or*
>
> *b) watering travelling stock on a stock route"*

and **"Domestic purposes** *include irrigating a garden, not exceeding 0.25 ha, being a garden cultivated for domestic use and not for the sale, barter or exchange of goods produced in the garden.*" (Queensland Government2000, pp. 661, 678 and 679)

1.2 Assessment of farm dams in Australia

During the past few years, a number of studies have being carried out to assess the impact of farm dams on stream flows in different region of Australia. In one of the earliest studies, Neil & Srikanthan (1986) used a simple storage water balance model coupled to runoff generation by a monthly runoff coefficient to investigate the effect of farm dams on stream flows (Neil & Srikanthan, 1986). The development of assessment techniques have advanced with increased computer power. In 2002, Neal et al developed a computer based water balance model known as TEDI (Tools for Estimation of Dam Impacts) that was used to determine the impact of farm dams on streamflow yield in individual catchments (Neal, et al., 2002). TEDI was developed by making a number of simplifying assumptions to run the model with minimum available information about the dam. These assumption were tested by Nathan et al (2005), by developing a more flexible model know as CHEAT (Complex Hydrological Evaluation of the Assumptions made in TEDI) that was capable of dealing with increased level of hydrological complexity. It was found that the assumption made in TEDI had a minimum impact on the results in most circumstances (Nathan, Jordan, & Morden, 2005).

By adding extra functionality, including the ability to model “top-up” pumping, more sophisticated representation of demand and extra reporting options; TEDI was upgraded to STEDI (Spatial Tool for Estimating Dam Impact). Input information such as catchment outflows, dam sizes, demand and climate information are required to simulate the impact of individual dams within a catchment. The name STEDI came from its ability to incorporate spatial data (eg. from a GIS) to represent the stream network (SKM, 2011b). This window based program is capable of simulating the impact of farm dams on streamflows at a catchment level. It has the ability to distinguish between irrigation and S&D dams and allows bypass facilities when needed (SKM, 2011a). Developing and testing of STEDI was carried out by Sinclair Knight Merz (SKM) in partnership with Department of Sustainability and Environment (DSE) (DSE, 2011).

An assessment of the future impact of farm dams on runoff in the Murray-Darling Basin (MDB) was conducted by Jordan et al (2008). This was the first of its kind which considered such a broader spatial scale. In this study, it was estimated the farm dam density in the region was 2.04 ML/km^2 with a total storage capacity of 2168 GL. It was also projected that, by

2030 additional 227 GL of farm dams will be developed across MDB. This would reduce the runoff by 180 GL across MDB (Jordan, Wiesenfeld, Hill, Morden, & Chiew, 2008).

Lowe et al (2005) used linear regression to develop a dam volume prediction equation. Aerial photography and topographic maps were used along with LIDAR (Light Detection And Ranging) data to develop a relationship between dam surface area and volume. It was estimated that around 340 000 farm dams, with total volume of 870 000 ML, were in the area studied in Victoria. However only 7 % of these dams were greater than 5 ML and stored around 60 % of the total volume (Lowe, et al., 2005). This indicates the presence of a large number of smaller dams on the region which usually appears as dot points on topographic maps.

Manual identification of number and size of dams from both aerial photography and high resolution satellite imagery could be time consuming. Dare & Duthie (2002) investigated the possibilities of automatic identification of dams from remotely sensed imagery (Dare & Duthie, 2002). It was found that automatic detection and classification of dams were possible by using certain image processing algorithms. Both manual and automatic methods were used and the results did not show a much difference. By comparing the cost-benefit analysis of both of the methods, it was suggested that automatic detection of dam is a suitable method for commercial purposes (Dare & Duthie, 2002).

Due to the lack of accurate data for larger areas, uncertainly lies when estimating the impact of farm dams on stream flows. A framework to consider the uncertainties when estimating the farm dam impact was developed by Lowe & Nathan in 2008. (Lowe & Nathan, 2008). In this framework, it was argued that the major errors in the estimations were due to the insufficient data on surrounding catchments areas. A ±11% variation in the volume of farm dams in the catchments and a ±29 % variation in the overall impact have been estimated. In addition it was found that regionalising the farm dam features posses a significant uncertainty. Therefore it was recommended to avoid regional estimates in future studies (Lowe & Nathan, 2008). Hence it is one of the areas in which more studies need to be conducted to collect more information in order to have a good understanding of the nature and magnitude of impacts.

1.3 Current project by SKM

Sinclair Knight Merz (SKM) has been contracted by the Queensland Department of Environment and Resource Management (DERM) to improve the assessment of hydraulic impact of S&D farm dams on stream flows across Queensland. As limited information is available about the S&D dams in Queensland, SKM's project is aimed to;

- develop and test methodologies for estimating stock and domestic farm dam development across Queensland,
- provide a baseline assessment using these methodologies,
- identify areas of predicted high future development,
- quantify the impact of that development on streamflow, and
- evaluate the accuracy of the farm dam impacts estimated using different methods.

A pilot study is planned to be carried out to improve the inputs to hydrological modelling. Three study area, Upper Condamine, Burnett and Warrego catchments were selected for the pilot study. The impact of S&D farm dams on selected pilot catchments will be modelled using STEDI.

Improving the input for STEDI model is one of the key parts of the project. Following key model inputs were considered to be improved during the project:

- the number of farm dams in the catchment,
- the volume of each farm dam,
- the catchment area of each farm dam,
- **demand factor and patterns of use**,
- trends in farm dam development.

Rational to assume that demand for water would increase as the size of the dam increases. Larger dams provide a farmer with more capacity to supply their need for water, increasing demands. Often therefore, demand factor is defined as the ratio of the annual demand for water (assuming farm dam does not empty) divided by the storage volume when the dam is full (equation 1).

$$Demand\ Factor = \frac{Average\ annual\ demand\ (ML)}{Volume\ of\ the\ dam\ (ML)} \qquad \text{Equation 1}$$

A study conducted by SKM in Victoria as a part of the "Sustainable Diversion Limits" (SDL) project for the Department of Sustainability and Environment, found that the demand factor for S&D dams varied between 0.3 to 1.0 with a mean and median of 0.50 (SKM, 2004).

Demand could be defined as the water used from the farm dam by the landholders to supply their need for water. Evaporation and seepage losses are in addition to demands, as these are represented separately within models of farm dam like STEDI. Demand factor and pattern of use is one the least developed inputs. As there are very few studies conducted about the water use from S&D farm dams, information about the demand factor is limited.

1.4 Project Aims

As a part of SKM's study, the aim of this project was to understand the water use from farm dams for stock and domestic purposes in selected areas of Queensland. Information obtained during the study was used to derive the demand factor for S&D farm dam studied.
As limited information is currently available about the water use from S&D dams, particular aims of the project were to;

- Estimate the volume of water extracted from farm dams for S&D purposes
- Investigate the factors that influence the demand from S&D dams

2 DATA COLLECTION

During this project, two main methods were used to collect information about the water use from S&D dams. The first method used farm design sheets held by DERM to obtain information about S&D farm dams. The second method was a phone survey conducted among landholders who have S&D dams on their property. In addition to these two methods, an attempt was made to estimate the water use from S&D dam using the agricultural census data published by ABS.

Since phone survey requires ethical clearance from the Griffith School for Research, an Expedited Ethical Review Level 1 clearance has been obtained from the Human Research Ethics Committee (Appendix A).

2.1 Farm Design Sheets

During the 1970's, 80's and 90's, Queensland Government provided a farm water supplies advisory service that assisted farmers looking to develop their properties for agricultural purposes. Under this program, Queensland Government staff would, at the farmers' request, prepare designs for farm dams on the land holder's property. In some cases, landholders were asked by the designer about their water requirements.

The design documentations that were prepared for some of these farm dams were available from DERM archive. These dam design sheets were obtained from DERM archive and a total of 207 documentation files were received. These files were examined to collect information about S&D water requirements. Out of these files, only 8 files had information that could be used to estimate the S&D water use. Rest of the files had information about ground water licensing and irrigation water requirements. Table 1 gives the catchments on which those S&D dams were built or proposed to build.

Table 1. Catchments on which the dams were built or proposed to build.

Catchment	**Number of dams**
Burnett	1
Condamine-Balonne	7
Total	**8**

Since the design sheets (Appendix B) had information about the volume of the dam and the demand from those dams, these data were directly used to determine the demand factor.

2.2 Phone survey

To understand the stock and domestic water use from farm dams, a phone survey was conducted among a number of property owners. As DERM was unable to provide a list of landholders with S&D dam on their properties, various steps were completed to make a list of landholders who might have a S&D dam. Firstly, a number of farm dams with certain features were identified from satellite images. These features include the size and the surrounding areas of the dams. Once the dams were identified, Queensland cadastral data layer was used to locate the properties on which those dams were built. Names of landowners of those properties were then obtained from DERM. Finally, the contact details of the selected property owners were obtained by Macro match service provided by Sensis Data Solutions.

Phone survey was designed to collect various information about the S&D dams that participants have on their properties. These included the number and volume of S&D dams on the property, and the amount of water used from those dams. Since majority of the participants do not monitor the amount of water extracted from the dams, they were unable to give the exact amount of water extracted. Hence, extra information about different the purposes for which they used the dam water were asked during the survey. (The list of questions asked during the survey is attached at the Appendix C).

Phone survey was conducted from 26th September to 18th October 2011. Total of 30 landholders participated in the survey. Table 2 shows the distribution of participants to different catchments.

Table 2: Number of participants from different catchments

Catchment	**Number of participants**
Border river	4
Burnett	5
Condamine-Balonne	20
Logan Albert	1
Total	**30**

Information gathered from the phone survey was analyzed to estimate the demand factor. Depending on the amount of information that the participants have provided, responses were analyzed by dividing into three groups. Figure 1 shows the different types of responses received during the phone survey. As can been seen from the figure, only 10% of the participants were able to estimate the volume of a S&D dam on the property and the amount of water extracted from that dam each year. 42 % of the participants were able to estimate the volume of a S&D dam on their property but could not give the volume extracted from that dam. The rest 48% participants could not give the volume or the amount of water extracted from a S&D dam on the property. The high percentage of responses with unknown usage is consistent with water extracted from S&D domestic dams are not monitored.

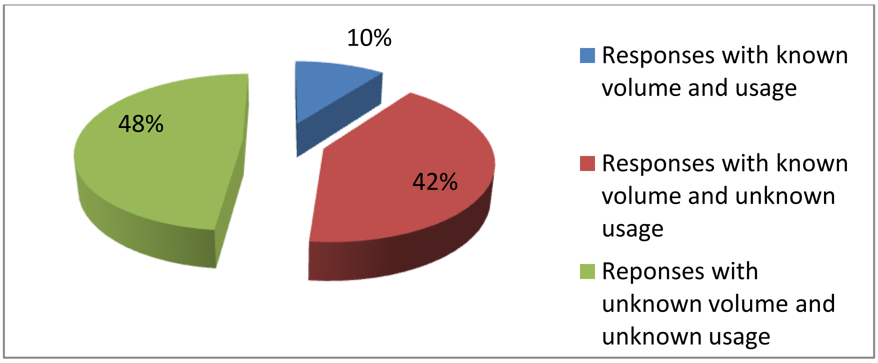

Figure 3. Types of responses received.

2.2.1 Estimating volume of the dams

Depending on the number of dams on a property, responses were divided into two groups; properties with single dam and properties with multiple dams.

a) Properties with single dam

When a landholder had a single dam and could not estimate the volume of that dam, the surface area volume relationship (equation 2) developed by (Lowe, et al., 2005) was used to calculate the volume of the dam.

$$V = \frac{1}{6900} S^{1.314} \qquad \text{Equation 2}$$

Where V is the volume of the dam in ML and S is the surface area of the dam in m^2.

For cases where landholders were unable to estimate the surface area, satellite images were used to identify the dams, and the surface areas were determined by drawing polygons on the dams. Figure 2 shows typical polygons drawn to determine the surface area of the dams.

Figure 4. Polygons drawn on S&D dams to determine the surface area.

The validity of equation 1 is tested by comparing the volume calculated with the volume estimated by participants. If more than one dam were on the property, the dam with closest volume to the participants' estimate was used in the comparison. As can be seen from figure 3, equation 1 gives a close estimate of the volume of the dams.

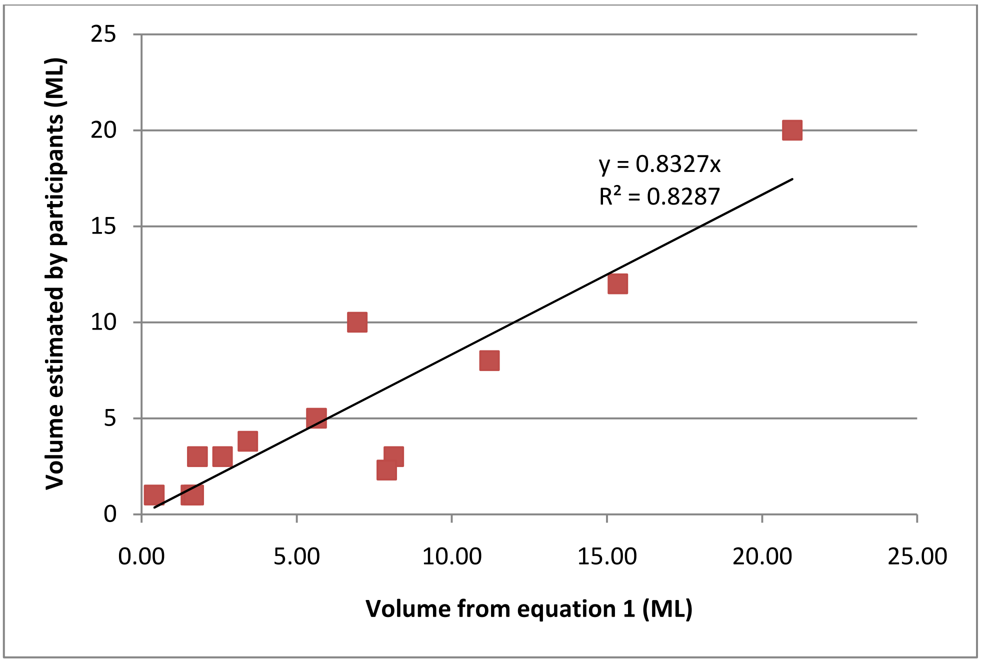

Figure 5. Comparison of volumes given by the participants and the volume estimated from equation 2.

b) Properties with multiple dams

More than 86 % of the participants used multiple dams to meet the stock and domestic requirements. If a participant has more than one S&D dam on the property and was unable to give the volume of one of the dams, equation 1 was used to estimate the volume of the dams on the property. For some properties the exact numbers of dams mentioned by the participants were not identified from the satellite images. This was expected as some of the participants could only give a rough estimate of the number of dams on their properties. In such cases the total volume of the dams on the property were calculated based on the number of dams identified. If the participants were able to give the volume of the dam and the demand from that specific dam, those numbers were used when determining the demand factor.

Out of the 29 responses received, 17 contained sufficient details to determine the demand factor. Rest of the response were omitted as no reasonable estimate of volume or the demand from the dam could be made from the information received. Responses within the following criteria were used to determine the demand factor;

- Participants gave the volume of the dam and demand from that specific dam
- Participants had a single dam and it was identified from the satellite images
- Participants stated a number of dams on their property that was within ± 30 % of the number of dams that are evident from the satellite imagery.

2.2.2 Estimating the water usage

The amount of water extracted from farm dams for stock or domestic purposes are usually not measured. Only 10 % of the participants were able to give an estimate of the annual usage from the dams. For the rest of participants, annual stock and domestic usages were calculated by identifying specific purposes the S&D dams are used. If the dam is used for domestic purposes, number of people living in the property as well as the size of garden was asked. If the dam is used for stock use, the type and number of animals were indentified.

Average annual water requirements for a person, garden and animals were obtained from existing literature. (A summary of the literature review undertaken is provided in Appendix D). Water requirement values used in the calculations are given in table 2 and 3.

Table 3. Average annual stock water intake values adopted.

Stock type	**Average annual water intake (m^3/head/year)**
Sheep	2
Beef cattle	16
Horse	18
Goat	3.6

Table 4. Average annual domestic water requirements.

Water use	**Average annual water requirement**
Person	83 m^3/person/year
Garden	1500 m^3/year/0.1 ha

2.2.3 Estimating the demand factor

Demand factor is used to estimate the number of time that a dam is emptied through extraction over a period of time. Equation 1 is used to determine the demand factor.

Since limited information was obtained about the volume of and the amount of water extracted from individual dams, demand factor was calculated by using the average volume of the dams on the property. The average annual demand from individual dams on a property was estimated by dividing the total stock and domestic water requirement by the number of dams on that property.

During the phone survey, landholders were asked whether the dam they were responding about in the survey had previously been emptied during the time that they could remember. In addition, they were also asked about whether they had alternative source of water for meeting their stock and domestic water needs.

2.3 ABS Census Data

Agricultural Census data published by ABS were studied to estimate the water use from S&D dams in Queensland. Data published by ABS had estimated surface water taken from dams, rivers and lakes for agricultural purposes in different Natural Resource Management areas of Queensland. However it does not give information about the proportion of water that was taken from dams for S&D purposes (ABS, 2011b). Other published data include livestock numbers for different Statistical Divisions (ABS, 2011a). Livestock use water from a range of sources including ground water bores, lakes, farm dams and water captured on melon holes. The percentage of water used from different sources by livestock could not be found from the literature. Hence the attempt made using the Census data could not provide sufficient information to estimate the demand from S&D farm dams.

3 RESULTS AND ANALYSIS

3.1 Analysis of Demand Factor

Data collected from both farm design sheets and phone survey was used to determine the demand factor. Total of 17 dams from phone survey and 8 dams from design sheets were used to estimate the demand factor. Table 5 and 6 gives the summary of results from the phone survey and the design sheets respectively.

Table 5. Summary of results from phone survey.

Dam number	Catchment	Mean volume of dam (ML)	Mean usage (ML)	Demand Factor	Access to other S&D water sources	Dam previously emptied
1	Condamine-Balonne	3.8	1.38	0.36	yes	no
2	Condamine-Balonne	2.7	4.48	1.68	yes	yes
3	Condamine-Balonne	5.1	1.60	0.31	no	no
4	Burnett	1.0	0.10	0.10	yes	yes
5	Border River	1.0	0.83	0.82	no	yes
6	Condamine-Balonne	2.6	1.63	0.63	no	no
7	Condamine-Balonne	2.8	1.47	0.52	no	no
8	Border River	4.2	2.03	0.48	no	no
9	Condamine-Balonne	3.1	2.08	0.68	no	yes
10	Condamine-Balonne	3.5	0.51	0.15	no	no
11	Condamine-Balonne	3.0	0.30	0.10	yes	no
12	Condamine-Balonne	3.3	1.74	0.53	yes	yes
13	Burnett	11.4	25.60	2.25	yes	yes
14	Condamine-Balonne	1.0	1.12	1.09	yes	yes
15	Border River	11.1	0.02	0.00	yes	yes
16	Condamine-Balonne	19.2	1.73	0.09	yes	yes
17	Condamine-Balonne	7.9	1.28	0.16	no	no
Mean				**0.59**		
Median				**0.48**		

Table 6. Summary of results from design sheets.

Dam number	**Catchment**	**Size of storage (ML)**	**Annual Requirement (ML)**	**Demand Factor**
1	Condamine-Balonne	5.50	3.20	0.58
2	Condamine-Balonne	18.00	4.80	0.27
3	Condamine-Balonne	4.12	2.72	0.66
4	Condamine-Balonne	0.79	0.65	0.82
5	Condamine-Balonne	63.70	24.00	0.38
6	Condamine-Balonne	24.00	10.83	0.45
7	Condamine-Balonne	7.65	3.87	0.51
8	Burnett	78.33	6.57	0.08
Mean				**0.47**
Median				**0.48**

The mean demand factor obtained from phone survey was 0.59 and that of design sheets was 0.47. However the median from the both methods were 0.48. The median value is more accurate than the mean demand factor as it is not affected by large or extreme values. The range of values from the survey was 0.002 to 2.25. The box plot in figure 4 illustrates the variation in the demand factor. Following information is given by the box plot;

- *Minimum* – the smallest farm dam demand factor.
- *First Quartile* – the demand factor which is greater than 25% of the sample.
- *Median* – the demand factor which is greater (and less than) 50% of the sample.
- *Third Quartile* – the demand factor which is greater than 75% of the sample.
- *Maximum* – the largest demand factor, not including outliers.
- *Inter Quartile Range* – the third quartile minus the first quartile
- *Outliers* – demand factors that are either greater than the third quartile or less than the first quartile by more than 1.5 times the inter quartile range.

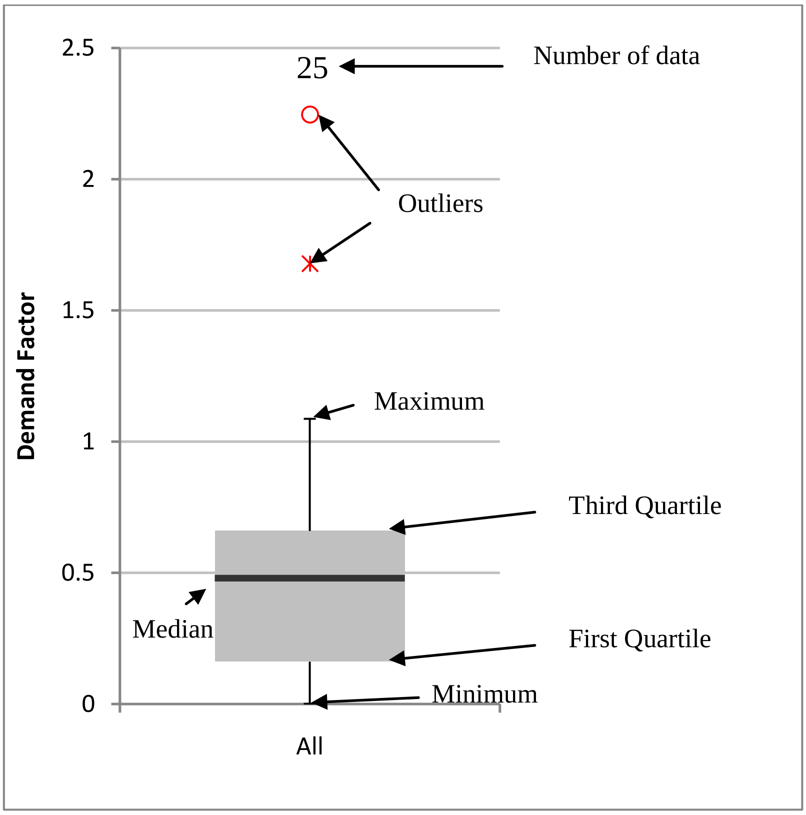

Figure 6. Box plot showing the variation of demand factor for all the dams from the phone survey and the dam design sheets.

The variation in the mean demand factors from both methods was statistically analyzed. Table 7 shows the result of the F-test. The demand factor from the design sheets demonstrated much lower standard deviation (0.23) than the survey responses (0.59). An F-test found that the difference in standard was significant at the 1% level of significance (see table 7).

Table 7. Summary of F-test for two methods.

	Phone survey	**Design sheets**
Mean	0.59	0.47
Variance	0.36	0.05
Standard deviation	0.60	0.23
P(F<=f) one-tail	0.0077	

The higher variance for the survey results may indicate that over many years since when a dam is designed, usage of the dam may evolve so that it is either much higher or lower than what may be considered an optimal design value.

The distribution of demand factor from the phone survey was analyzed by constructing a probability plot. The Cunnane (1978) formula (equation 3) was used to calculate the plotting position of each of the demand factor as it provides an unbiased means to calculate the exceedance probability (Cunnane, 1978).

$$Exceedance\ probability = \frac{r-0.40}{n+0.20} \qquad \text{(Equation 3)}$$

Where *r* is the rank and *n* is the total sample number.

Figure 5 shows the probability plot for the demand factors obtained from the phone survey. The plot shows a lognormal distribution with some heavy-tailed data.

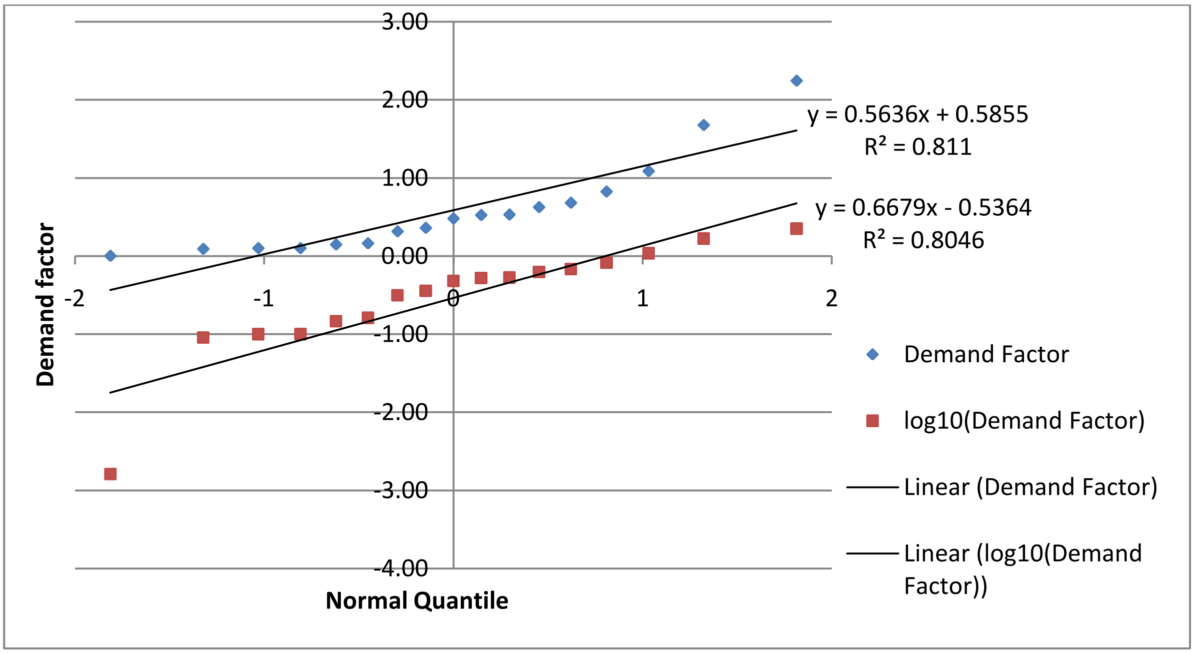

Figure 7. Probability plot of the demand factor from phone survey.

Box plot in Figure 6 is used illustrates the variation in demand factor from the two methods. In both cases the median demand factors was 0.48. A t-test was performed on the mean values of the demand factor from the survey and the design sheets, which demonstrated that there was no significant difference in the mean demand factor between two sources of data. Although the survey revealed that the usage from an individual dam may be much higher or lower than the average value from the sample, the mean demand factor of 0.59 remains a consistent estimate of the demand factor for S&D dams in Queensland.

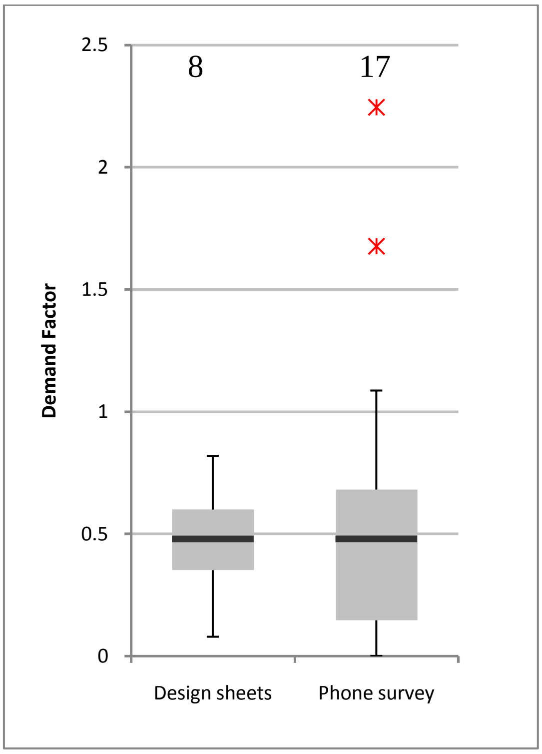

Figure 8. Box plot illustrating the variation in demand factor from two methods.

A number of factors could cause the variations in the demand factor. Some of these factors include the climate conditions, use of other water sources for S&D purposes, behavior of livestock and other animals using the dams. The effect of having another water source for S&D purposes was examined in this study. Data from the phone survey was used in this case. Figure 7 shows a comparison of demand factor for properties with and without alternative S&D water sources.

Access to alternative water sources increases the variance in the demand factor. Farmers with an alternative water source will preferentially use water from the source that is easiest to access, cheaper to obtain or provides highest quality water before switching to the alternative source. If the preferred source of water for a farmer is their farm dam, then they may have a higher than average demand factor, but if their preferred source is alternatives (such as bore) then they will have a lower than average demand factor. If a farmer has an alternative water source, then on average they will use less water from their farm dam because they are able to draw upon the alternative sources. They will use the water from the farm dam when their alternative water source fails.

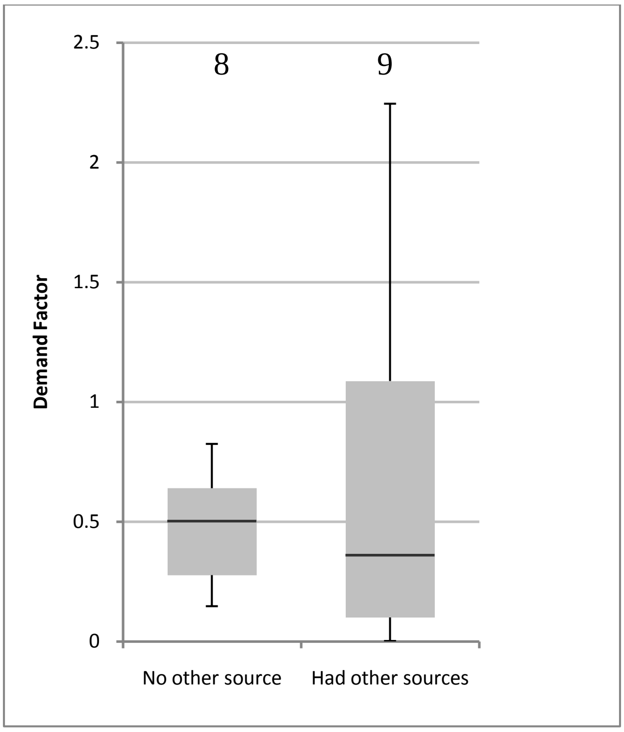

Figure 9. Box plot illustration the variation in demand factor when other water sources are used for S&D purposes.

Landholders that have farm dams as the only source water use water more consistently from the dam to supply their S&D demands but also not wanting to extract too much water and risk running their dams dry. It was found that all the dams surveyed were used at least once during the year and there was no dam with zero annual demand.

During the phone survey, participants were asked if the dam were emptied in the past. About 55% of the dams surveyed were emptied at least once in the past. The variation in demand factor for dams that were emptied and never emptied before is illustrated by the box plot on figure 8. It was found that the median demand factor for dams that were emptied was higher compared to dams that were never emptied. As would be expected higher demands increases the likelihood that a dam will be emptied

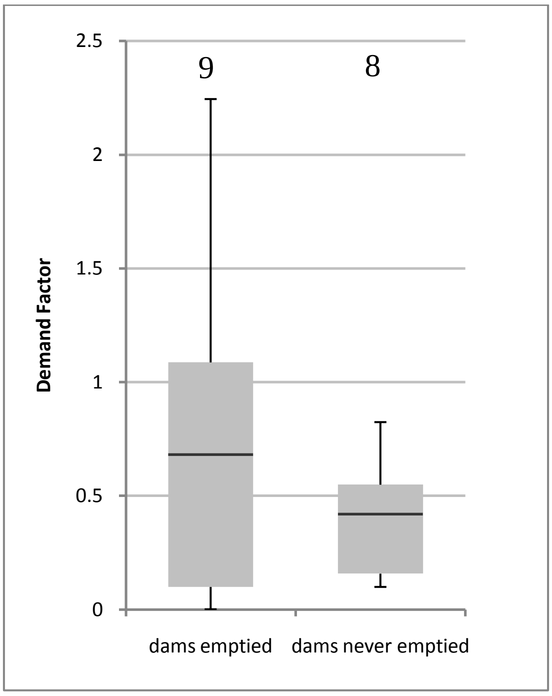

Figure 10. Box plot illustrating the variation in demand factor for dams that were emptied in the past and that had never emptied in the past.

Differences in demand factor based on the location of the dams are investigated. Dams that were used to estimate the demand factor are from Burnett, Balonne-Condamine and Border River catchment. Figure 9 illustrates the variation in demand factor for different catchments. The size of the circles represents the value of the demand factor. There is no obvious spatial trend in the demand factor.

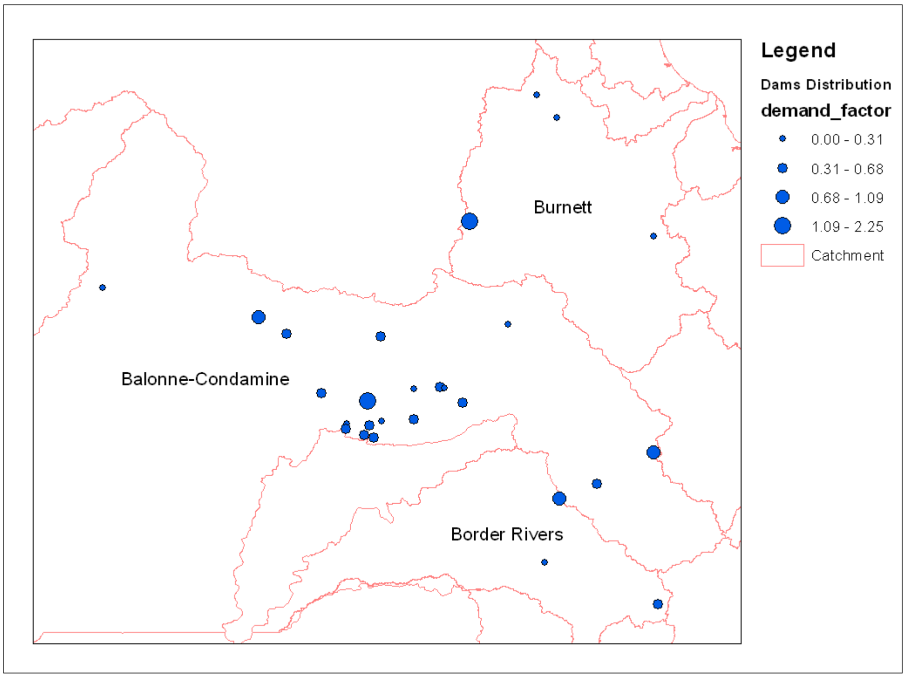

Figure 11. Variation in demand factor based on the location of the dam.

3.2 Analysis of Dams

The volume of the dams used for S&D purposes varies among landholders. The volume of dam is usually depends on the water requirement, type of use and the number of dams on the property. It was found that landholders usually use a single larger dam or many smaller dams. A total of 61 S&D dams were identified in the properties surveyed. Figure 10 shows the distribution of dams and sizes. More than 74 % of the dams are smaller than 5 ML which is in good agreement with Victorian value (75 %) reported by Lowe et al, 2005.

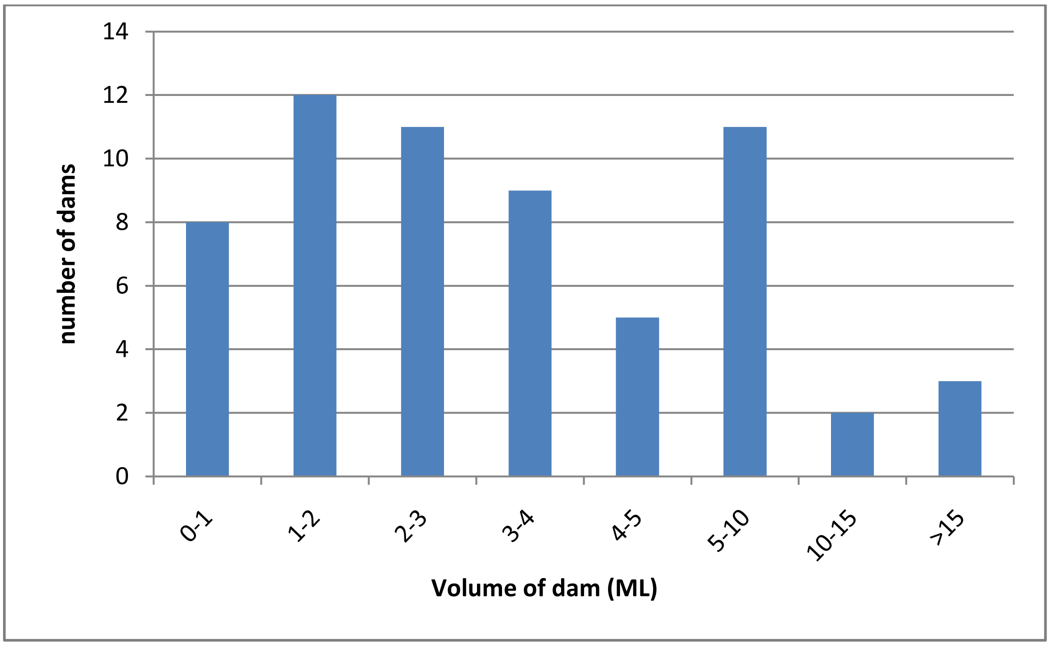

Figure 12. Distribution of dam sizes.

The relationship between the area of the property and the number of dams was investigated. During the phone survey, landholders were asked about the size of their property and the total number of S&D dams on their property. Figure 11 shows the number of dams built on properties of different sizes. Based on these results, it could be concluded there is no relationship between the area of the property and the number of dams on that property.

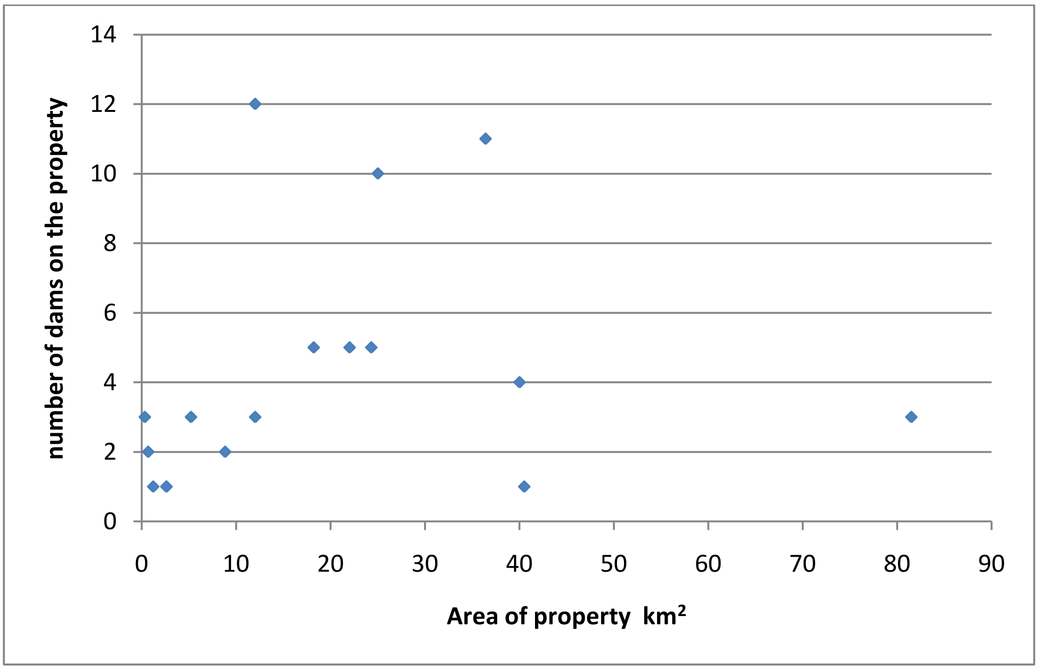

Figure 13. Variation in number of dams on properties with different size.

Another factor investigated is the relationship between the total volume of all dams and the size of the property. Figure 12 shows the relationship between the size of the property and the total volume of all dams on the property. It was found that total storage capacity on a property increases with the size of the property. By considering the total area of all the properties and total volume of S&D dams on those properties, the estimated density of S&D farm dam was 2.66 ML/km^2 which is 30 % higher than the farm dam density (2.04 ML/km^2) estimated by (Jordan, et al., 2008) for the whole MDB.

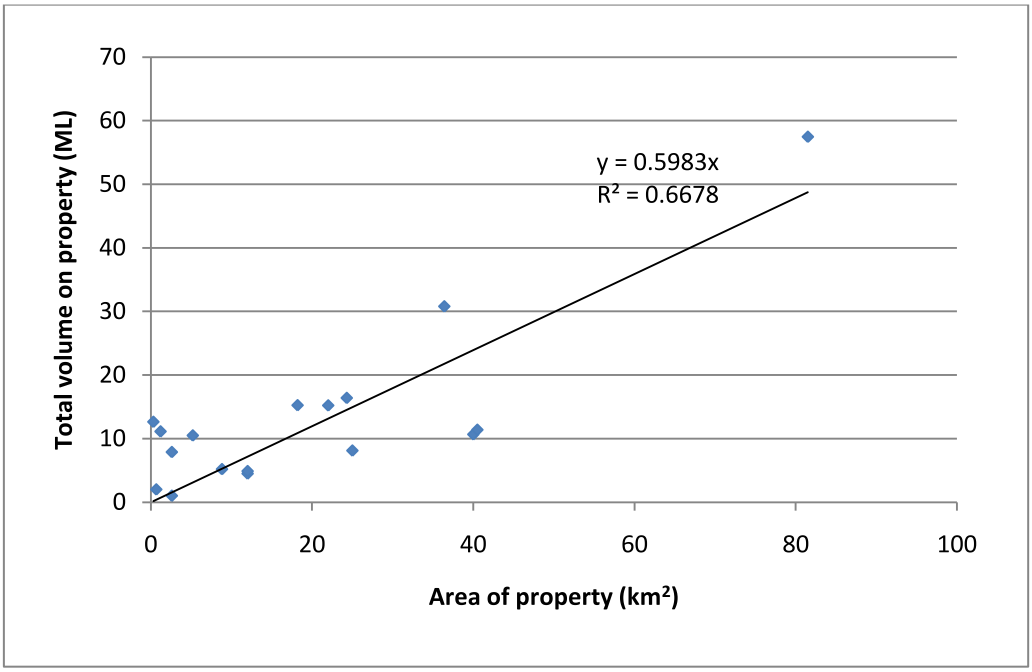

Figure 14. Relationship between the size of the property and the total volume on the property.

Results from both phone survey and farm design sheets were used to analyse the variation in demand from dams with different sizes. Figure 13 shows the demand from dams with different sizes. It can be seen that smaller dams were usually used when the demand is less. However, there were few larger dams with less demand and smaller dams with higher demand. These dams cause larger variation in the demand factor.

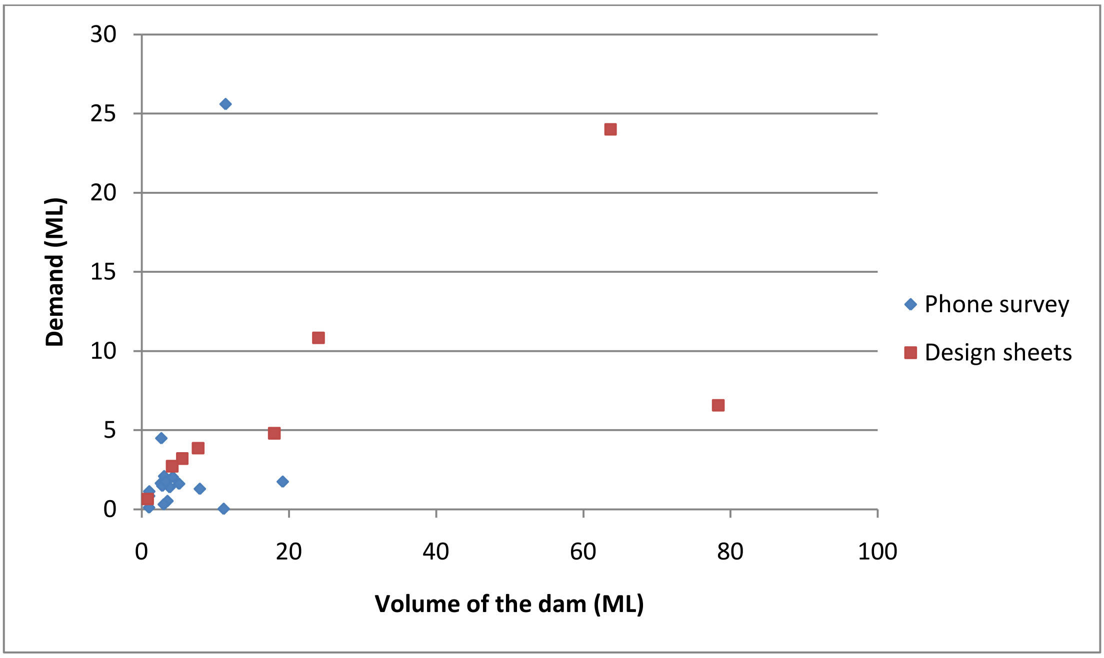

Figure 15. Variation in demand with dam volume.

Both phone survey and design sheet results were also used to analyse how the demand factor varies with dam size. Figure 14 shows the how the demand factor varies with volume of the dam. As can be seen from the figure, there is no relationship between the demand factor and the volume of the dam.

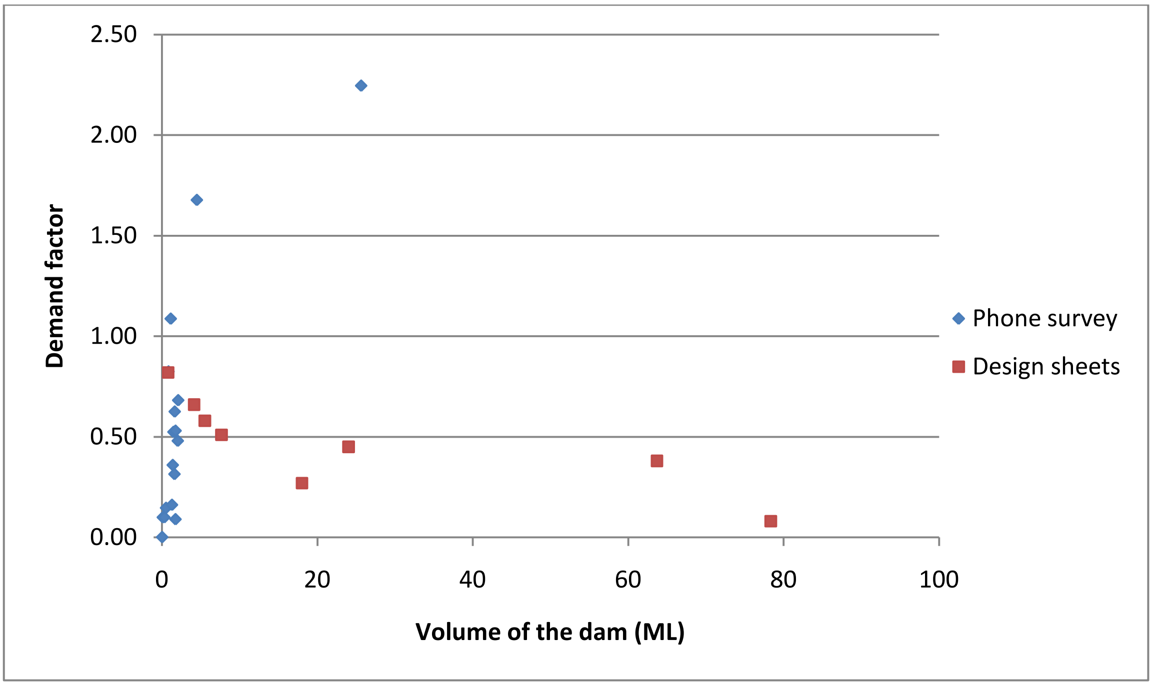

Figure 16. Variation in demand factor with volume of the dam.

3.3 Demand variation

Out of the 30 landholders that participated in the phone survey, 73 % believed that the amount of water used from the dams vary throughout the year. Based on the responses received, the three main factors that influence the demand variation are temperature, rainfall and the rotation of livestock around the dams. As can be seen from figure 15, 68 % stated that more water used from dams during summer. They estimate that during hot weather, anima drink more water from dams and also more water is available on dams due to summer rain. Those who said that more water is used from dams during dry winter months stated that they use other sources during summer. For example, some landholders use water from melon holes and spring or creeks during rainy season. Few participants believed that the demand from dams depend on how they rotate the stock around the dams. It was found that stocks are rotated around the dams usually in every 5 to 6 weeks depending on the number of dams on the property. Hence, some dams might be used only for few months in a year.

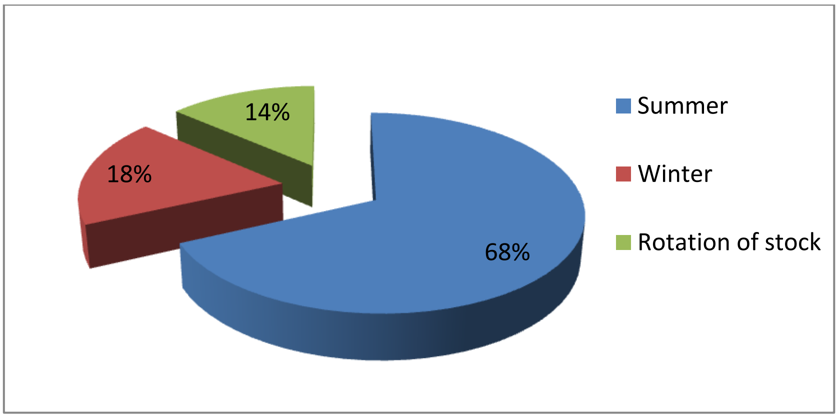

Figure 17. Illustration feedbacks about the demand variation.

The variation in temperature and rainfall could be used to identify months in which more water would be used from dams. Temperature and rainfall data obtained from the Bureau of Meteorology (BOM) website was used to illustrate (Figure 16) the climate variation in the Condamine-Balonne region. Rainfall data from Yarraman Upper station and temperature data from Gatton QDPI Research station were used as reasonably good quality data were available from these two stations.

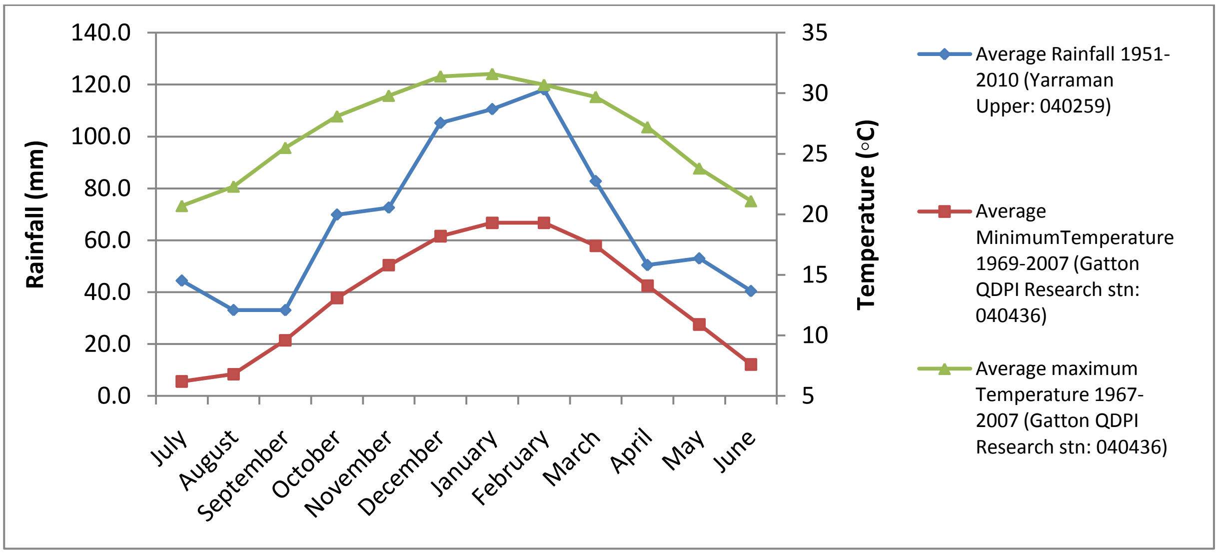

Figure 18. Long term average monthly rainfall and average maximum and minimum temperature, station names and numbers are given in the brackets. Source: (BOM, 2011).

As expected, higher rainfall and temperature was observed for the summer months. The higher rainfall could either decrease or increase the amount of water used from farm dams depending on the location of the dam. If a dam is located on a property with nearby creeks or melon holes, there is a great chance that less water will be used from that dam during wet seasons. However, if there is no such feature near the property, then more water will be used from the farm dam during the summer months as the animal drink more during hot weather and also more water is available from the dam.

4 CONCLUSIONS

Volume and water usage from S&D farm dams in a number of properties across different catchments in Queensland were studied in this project. A phone survey among the landholders and farm design sheet held by DERM were used to collected information about S&D farm dams. Out of 30 landholders who participated in the phone survey, only 10% of the participants were able to estimate the volume of a S&D dam on the property and the amount of water extracted from that dam each year. For rest of the participants, water requirement was estimated by demand based approach where participants provided the specific purposes for which the dams were used.

Demand factor for each dam was calculated based on the information obtained. By analyzing the data and comparing the results with a previous study in Victoria, following conclusions were made.

- The mean demand factor is 0.59,
- The median demand factor is 0.48,
- Consistent results were found in terms of mean and median demand factor between the phone survey, design sheets and the Victorian study,
- The variability in demand factor increases when alternative sources of water are available.

Furthermore, it was found that there was no spatial trend in the demand factor and the demand factor was influenced by the volume of the dam. About 74 % of the S&D dams studied were less 5 ML and the average density of S&D farm dam was 2.66 ML/km^2.

Water use from 73 % of the dams surveyed was not consistent throughout the year. 68 % of those dams were used more during summer months and 18 % dams were used more during winter. The rest 14 % dams were most used when the stocks were kept at the dams.

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6 APPENDICES

Appendix A. Ethical clearance Certificate

Griffith UNIVERSITY

HUMAN RESEARCH ETHICS COMMITTEE

<u>ETHICAL CLEARANCE CERTIFICATE</u>

This certificate generated on 26-10-2011.

This certificate comfirms that protocol 'Assessment of the impact of stock and domestic dams in Queensland- Demand Factor' (GU Protocol Number ENG/12/11/HREC) has ethical clearance from the Griffith University Human Research Ethics Commitee (HREC) and has been issued with authorisation to be commenced.

The ethical clearance for this protocol runs from 29-08-2011 to 28-10-2011.

The named members of the research team for this protocol are:
Prof IgorAgranovski
Mr Ahmed Naseem

The research team has been sent correspondence that lists the standard conditions of ethical clearance that apply to Griffith University protocols.

The HREC is established in accordance with the *National Statement on Ethical Conduct on Research Involving Humans.* The operation of this Committee is outlined in the HREC Standard Operating Procedure, which is available fromwww.gu.edu.au/or/ethics.
Please do not hesitate to contact me if you have any further queries about this matter.

Gary Allen
Manager, Research Ethics
Office for Research
G39 room 3.55 Gold Coast Campus
Griffith University
Phone: 3735 5585
Facsimile: 5552 9058
Email: g.allen@griffith.edu.au

Appendix B. Sample copy of farm dam design sheet

Affix this corner to file

WATER REQUIREMENT

(a) IRRIGATION

____ ha of ____________
____ ha of ____________
____ ha of ____________

Total irrg^n area = ____________
75% an'l Irr.Req.(Ir) = ____________
∴ Total an'l Irr.Req.= Area x (Ir) x 10
= ____ x ____ x 10
= ______ m³/yr

(b) STOCK & DOMESTIC

____ persons @ 83 m³/yr = ____ m³/yr
____ dairy cattle @ 33 m³/yr = ____ m³/yr
30 beef cattle @ 16 m³/yr = 480 m³/yr
____ pigs @ 8 m³/yr = ____ m³/yr
____ sheep @ 2 m³/yr = ____ m³/yr
____ poultry @ 2 m³/100 birds/yr = ____ m³/yr
____ ha garden x (Ir) x 10 = ____ m³/yr
∴ Total stock & domestic req = 480 m³/yr

Total nett water reqt. (Irrigation + Stock & Domestic) .... = ____ m³/yr
(c) LOSSES 35 % of nett requirements .... = 170 m³/yr
(d) GROSS ANNUAL REQUIREMENTS (total nett + losses) .... = 650 m³/yr
(e) TOTAL STORAGE REQUIREMENT = 650 m³/yr x ____ yrs. duration .... = 650 m³/yr

CATCHMENT ANALYSIS

(a) DESCRIPTION Area (A) = 32 ha Representative R'Fall Stn Toowoomba

Comment: Catchment consists of 30% native grasslands, KII 69, 40% crops and fallow KII 80, and 30% timbered areas (eucalypt stunted box). Catchment is in a fair hydrologic condition. Soil is a red brown deep loam. type B.

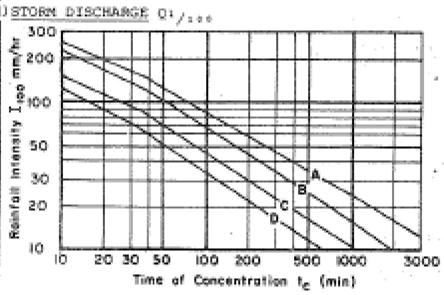
(b) YIELD ESTIMATE

LAND USE & COVER	Native Pastures & Grassland			Timbered Areas			Contoured Native Pastures			Imp. Perm Past	Rot^n Past	Crops	Fallow	H'stead Area	Roads
	P.	F	G	P	F	G	P	F	G						
SOIL A	68/	50/	39/	46/	36/	26/	47/	25/	6/	30/	58/	63/	77/	59/	73/
B	79/	69/ 30	61/	68/	60/ 30	52/	67/	59/	35/	58/	72/	74/	86/ 40	74/	81/
C	86/	79/	74/	78/	70/	62/	81/	75/	70/	71/	81/	82/	91/	82/	88/
D	89/	84/	80/	84/	76/	69/	85/	83/	79/	78/	85/	85/	94/	86/	90/

Nett K_{II} = 71 .... ∴ 75% ann. runoff (dr) .... = 26 mm
Est.ann.yield = (Area x dr x 10) m³/yr = 32 ha x 26 (mm) x 10 .... = 8 320 m³/yr

(c) DIVERTED CATCHMENT None

(d) STORM DISCHARGE $Q_{1/100}$



Slope S/S .... = 4 °
Length S/S (L) .... = 1.5 km
∴ Time of concentration (tc)=30.L .... = 45 min
Hence Intensity ($I_{1/100}$) .... = 78 mm/hr
Average slope of c'ment .... = 4 °
∴ Est. Coeff. of runoff (C) .... = 0.7

$Q_{1/100}$ = (C x $I_{1/100}$ x A)/360
= (0.7 x 45 x 32)/360
.... = 2.8 m³/s

(e) BYWASH SIZE ESTIMATES Inlet width for 0.5 m flow ≈ ($Q_{1/100}$ x 2) .... = 5.6 m

Outlet widths (i) L.B. ≈ 1.5 x $Q_{1/100}$ x $\sqrt{\text{Ret Slope}^\circ}$ = 1.5 x ____ x $\sqrt{\_\_\_^\circ}$ .... = ____ m

(ii) R.B. ≈ 1.5 x $Q_{1/100}$ x $\sqrt{\text{Ret Slope}^\circ}$ = 1.5 x 2.8 x $\sqrt{7}$ .... = 11.1 m

Other Bywash Facilities ____________

Measured Base Flow = ____ l/sec

Comment on Return Slope: Return slope is even sloping and well grassed with no drop off to the bed of the gully.

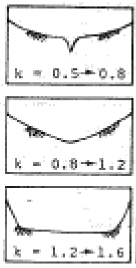
STORAGE AND EMBANKMENT VOLUMES

(a) CROSS SECT. COEFF 'k'

If different coefficients proposed for storage and embankment nominate

$k_{STORAGE}$ 1 $k_{EMBANKMENT}$ 1

Typical Range k Values



This Site Your Estimate k = 1

(b) NATURAL STORAGE ESTIMATE

Cap (m³) = 0.22 x k x W x D x L

Width (m)	x Depth (m)	x Length (m)	x 0.22k =	Cap (m³)
30	1.6	50	.22	528

(c) EMBANKMENT VOLUME Height (H) = 2.6 m Width (B) = 40 m

∴ Bank Vol. = 1.05 x B.H. (H + 1) = 1.05 x 1.0 x 40 x 2.6 x 3.6 = 390 m³ 390 − 130 bywash ex.

(d) TOTAL STORAGE = Bank Vol. 260/2 + Natural Storage 530 = 790 m³

@ an S/E ratio .... = ____ /1

MATERIALS

(a) CUTOFF TH's 1 show axis material with cutoff into ____

Length c'off 40 m Average depth 0.5 m

Estimated vol. of cutoff .... = 60 m³

Comments See logs and additional comments on back of form

(b) BORROW TH's ____ show borrow material. Comments ____

(c) BYWASH Comments ____

ESTIMATED COSTS

Embank'	390 m³ @ $1.00 /m³	$ 390	Carry F'wd		$
Cutoff	60 m³ @ $1.20 /m³	$ 72	Clearing	ha @ $ /ha	$
Stone Pt'g	5 m³ @ $10 /m³	$ 50	Fencing	km @ $ /km	$
Drop Inlet	m x mm	$			
Outlet	m x mm	$			512
		$	Conting'y	10%	$ 50
SUB-TOTAL (For 3%)		$		TOTAL	$ 562

SURVEY

BM.EL (St.datum/ass'med) ____ Location ____

Baseline Bearing ____° ____' Length ____ m. Comments

Preliminary Survey Only

WATER QUALITY

Sample Taken? – Why Not? Gully Dry

Conductivity Result? ____ Sample forwarded to H/O c/o Cl.Rec.R & S ____

Comments ____

FIN'CE

Required? – Applied For? – Forms Issued? –

Comments ____

LICENCE

Required? No Applied For? – Forms Issued? –

Maximum Bank Height ____ m Capacity ____ m³ ∴ Referable/Non Referable

Comments ____

Appendix C. Questionnaire used during the phone survey

Questions	**Response**
1. How big is your property in area?	
2. What is the primary use of your property? (e.g. cattle farming, cropping, dairy, irrigation)	
3. How many of your dams do you use just for stock and domestic purposes?	
4. Thinking about just one of those dams being used for stock and domestic purposes:	
a) What year was the dam built?	
b) What is the volume of the dam?	
c) What is the areal extent (surface area) of the dam?	
d) What is the depth of the dam?	
e) Where does the water in the dam come from? (please give estimated percentage figures if possible)? ▪ Catchment runoff ▪ Groundwater ▪ River/Flood water ▪ Multiple	
f) How much water do you think you use from your dam each year?	
g) How did you estimate that volume – meter, number and type of stock, other (specify)?	
▪ If used for the house – how many people live on the property?	
▪ If used for the garden – ▪ what is the approximate size of your garden?	
▪ If used for stock – ▪ What stock do you carry ▪ How many of each type use this dam, and ▪ What is your property's maximum safe carrying capacity?	
h) Is the dam used consistently throughout the year? If not, when do you mostly use it?	

Questions	Response
i) Do you use water for stock and domestic purposes from any other source – please indicate them if yes? ▪ groundwater bores ▪ springs ▪ creeks ▪ rainwater tanks ▪ dams/ring tanks ▪ pipelines	
j) Do you also use this stock and domestic dam for storage for other purposes – please indicate them if yes? ▪ Groundwater storage ▪ Landscape/amenity ▪ Other (please specify)	
5. Please answer the following questions if you were unable to provide an average annual volume used for stock and domestic purposes.	
a) Do you have a different pump for domestic use?	
b) What type of pump do you use for your stock watering? e.g. centrifugal pump	
c) Do you pump from the dam into tanks to then gravity feed? If so what size are your tanks?	
d) What is the brand of your pump? e.g. Southern Cross	
e) What is the model of your pump?	
f) What is the size of your pump? (e.g. 100 mm inlet and 100mm outlet delivery capacity)	
g) What is the size of the pump motor? (e.g. 12 kilowatts or 5 horsepower)	
h) On average, how many hours do you operate the pump per day/or how many days per week? (e.g. 12 hrs per day)	
6. Do you consent to us sharing your information with the Department as per the Privacy Statement below?	

Privacy Statement

SKM has been contracted by the Department of Environment and Resource Management, to collect some personal information from you for the purpose of better understanding the stock and domestic demands from farm dams. In participating in this project, we have collected information about your use of farm dams on your property.

This information will be provided to the Department to help them understand what kinds of households took part in the project, the demands from farm dams for those properties and for the Department's use when undertaking water resource planning in the future. The Department and contractors are bound by the Information Privacy Act 2009 and will ensure your information is kept confidential except for the purposes mentioned above.

Appendix D. Literature values of annual water requirements.

Table 8 and 9 gives the typical water consumption rates given by Nelson (1985)

Table 8. Typical stock water consumption rates.

Stock		**Average annual consumption (litres per head)**
Sheep:		
	Nursing ewes on dry feed	3300
	Fattening lambs on dry pasture	800
	Mature sheep on dry pasture	2500
	Fattening lamb on irrigated pasture	400
	Mature sheep on irrigated pasture	1300
Cattle:		
	Dairy cows, dry	16000
	Dairy cows in milk	25000
	Beef cattle	16000
	calves	8000
Horses:		
	Working	20000
	Grazing	13000

Table 9. Typical domestic water requirements.

	Average annual consumption (litres per head)
House with septic tank	65000
House without septic tank	50000

Table 10 and 11 gives the gives the typical water consumption rates given by (Mason, 1996).

Table 10. Stock water intake.

Animal	**Approximate water use (litres/day/head)**
Dry sheep	7
Ewes and lams	9
Dry cattle	45
Cows with calves	90
Milking cows	90
Horses	45

Table 11. Typical domestic water requirements.

Households with septic tank	65,000 L/head/annum
House hols without septic tank	50,000 L/head/annum
Household garden during summer	35,000 L/ha
Household garden during winter	17,500 L/ha

Note: The values adopted in this report are those values used in the design sheets.

Appendix H Example STEDI model output files

```
 SSS  TTTTT EEEEE DDD   I
S   S   T   E     D  D  I
S       T   E     D   D I
 SSS    T   EEE   D   D I
    S   T   E     D   D I
S   S   T   E     D   D I
 SSS    T   EEEEE DDDD  I
```

Spatial Tool for the Estimation of Dam Impacts
Version 1.20, September 2011
Sinclair Knight Merz, Melbourne

STEDI detailed calculation output
Created: 17/11/2011 at 17:52:20

Scenario File: D:\Projects\QE09896\ScenReRun\PS_422304A_Regionalis

Scenario Title: 422304A_PS_Regionalised_Eq._Vol_&_Dam_Distrib

Stream Name: Condamine River

Gauging Station Name: Condamine River at Elbow Valley

Gauge Number: 422304A

Output File: D:\Projects\QE09896\ScenReRun\PS_422304A_Scen_V2.o

Timestep: Daily

Total catchment area (km2): 278.000

Input streamflow corresponds to flow WITH dams present

Input Flow File : D:\Projects\QE09896\ScenReRun\Input_422304A.sf

Rainfall File: D:\Projects\QE09896\ScenReRun\Input_422304A.clm

Evaporation File: D:\Projects\QE09896\ScenReRun\Input_422304A.clm

Adopted probability distribution of dam volumes:

Proportion of Dams	Min Capac (ML)	Max Capac (ML)
0.18260	0.000	0.500
0.27350	0.500	1.000
0.27540	1.000	2.000
0.18750	2.000	5.000
0.04890	5.000	10.000
0.01810	10.000	20.000
0.00780	20.000	40.000

0.00280	40.000	60.000
0.00140	60.000	80.000
0.00060	80.000	100.000
0.00080	100.000	150.000
0.00060	150.000	250.000

Details of demand groups:

Demand group name	Stock&Domesti	Irrigation
Demand group ID	1	2
Upper vol threshold (ML)	250.00	99999.00
Demand factor	0.50	0.00
Demand in Jan	0.083	0.083
Demand in Feb	0.083	0.083
Demand in Mar	0.083	0.083
Demand in Apr	0.083	0.083
Demand in May	0.083	0.083
Demand in Jun	0.083	0.083
Demand in Jul	0.083	0.083
Demand in Aug	0.083	0.083
Demand in Sep	0.083	0.083
Demand in Oct	0.083	0.083
Demand in Nov	0.083	0.083
Demand in Dec	0.083	0.083

Surface Area (m²) = 3.36E-04 x Volume (ML) ^ 1.118

Estimate dam catchment areas from regression relationship with capacity

CatchArea (km²)	Capacity (ML)
0.000	0.000
0.231	5.000
0.923	100.000

Exponent of relationship between natural flow and area: 1.000

Number of Dams in Network: 317

Node	Type	Next Node Downstrea	Surface Area (m²)	Farm Dam Capacity (ML)	Area (km²)	Free Area (km²)	Impounded Area (km²)	Total Inflow (%)	% Total Present? (T or F?)	Bypass Capacity (ML/d)	By Ra (ML/d)
1	Outlet	0		252.43	25.57	278.00	90.801				
2	Dam	1	127.6	0.076	0.00	0.00	0.00	0.001	T	0.0000	0.0000 Sto
3	Dam	1	6476.2	6.129	0.24	0.00	0.24	0.086	T	0.0000	0.0000 Sto
4	Dam	1	288.7	0.189	0.01	0.00	0.01	0.003	T	0.0000	0.0000 Sto
5	Dam	1	834.5	0.620	0.03	0.00	0.03	0.010	T	0.0000	0.0000 Sto
6	Dam	1	1284.6	1.004	0.05	0.00	0.05	0.017	T	0.0000	0.0000 Sto
7	Dam	1	318.6	0.211	0.01	0.00	0.01	0.004	T	0.0000	0.0000 Sto
8	Dam	1	1379.0	1.087	0.05	0.00	0.05	0.018	T	0.0000	0.0000 Sto
9	Dam	1	550.9	0.390	0.02	0.00	0.02	0.006	T	0.0000	0.0000 Sto
10	Dam	1	1216.7	0.945	0.04	0.00	0.04	0.016	T	0.0000	0.0000 St

11	Dam	1	1437.4	1.139	0.05	0.00	0.05	0.019	T	0.0000	0.0000	St
12	Dam	1	1468.4	1.166	0.05	0.00	0.05	0.019	T	0.0000	0.0000	St
13	Dam	1	1546.8	1.236	0.06	0.00	0.06	0.021	T	0.0000	0.0000	St
14	Dam	1	1343.0	1.056	0.05	0.00	0.05	0.018	T	0.0000	0.0000	St
15	Dam	1	28.8	0.014	0.00	0.00	0.00	0.000	T	0.0000	0.0000	Sto
16	Dam	1	1220.1	0.948	0.04	0.00	0.04	0.016	T	0.0000	0.0000	St
17	Dam	1	1273.6	0.995	0.05	0.00	0.05	0.017	T	0.0000	0.0000	St
18	Dam	1	2961.7	2.556	0.12	0.00	0.12	0.043	T	0.0000	0.0000	St
19	Dam	1	6889.2	6.568	0.24	0.00	0.24	0.087	T	0.0000	0.0000	St
20	Dam	1	561.0	0.398	0.02	0.00	0.02	0.007	T	0.0000	0.0000	Sto
21	Dam	1	3490.2	3.071	0.14	0.00	0.14	0.051	T	0.0000	0.0000	St
22	Dam	1	1959.6	1.611	0.07	0.00	0.07	0.027	T	0.0000	0.0000	St
23	Dam	1	2635.9	2.244	0.10	0.00	0.10	0.037	T	0.0000	0.0000	St
24	Dam	1	15931.9	16.768	0.32	0.00	0.32	0.114	T	0.0000	0.0000	S
25	Dam	1	3522.8	3.103	0.14	0.00	0.14	0.052	T	0.0000	0.0000	St
26	Dam	1	1433.0	1.135	0.05	0.00	0.05	0.019	T	0.0000	0.0000	St
27	Dam	1	1590.1	1.275	0.06	0.00	0.06	0.021	T	0.0000	0.0000	St
28	Dam	1	850.9	0.634	0.03	0.00	0.03	0.011	T	0.0000	0.0000	Sto
29	Dam	1	2797.6	2.398	0.11	0.00	0.11	0.040	T	0.0000	0.0000	St
30	Dam	1	201.3	0.126	0.01	0.00	0.01	0.002	T	0.0000	0.0000	Sto
31	Dam	1	3971.9	3.548	0.16	0.00	0.16	0.059	T	0.0000	0.0000	St
32	Dam	1	1000.5	0.760	0.04	0.00	0.04	0.013	T	0.0000	0.0000	St
33	Dam	1	2144.9	1.782	0.08	0.00	0.08	0.030	T	0.0000	0.0000	St
34	Dam	1	2004.4	1.652	0.08	0.00	0.08	0.027	T	0.0000	0.0000	St
35	Dam	1	1114.4	0.857	0.04	0.00	0.04	0.014	T	0.0000	0.0000	St
36	Dam	1	9335.7	9.225	0.26	0.00	0.26	0.094	T	0.0000	0.0000	St
37	Dam	1	1840.1	1.501	0.07	0.00	0.07	0.025	T	0.0000	0.0000	St
38	Dam	1	1162.5	0.898	0.04	0.00	0.04	0.015	T	0.0000	0.0000	St
39	Dam	1	1992.7	1.641	0.08	0.00	0.08	0.027	T	0.0000	0.0000	St
40	Dam	1	139.4	0.084	0.00	0.00	0.00	0.001	T	0.0000	0.0000	Sto
41	Dam	1	1620.3	1.302	0.06	0.00	0.06	0.022	T	0.0000	0.0000	St
42	Dam	1	416.1	0.285	0.01	0.00	0.01	0.005	T	0.0000	0.0000	Sto
43	Dam	1	1178.9	0.913	0.04	0.00	0.04	0.015	T	0.0000	0.0000	St
44	Dam	1	4220.7	3.798	0.18	0.00	0.18	0.063	T	0.0000	0.0000	St
45	Dam	1	2023.5	1.669	0.08	0.00	0.08	0.028	T	0.0000	0.0000	St
46	Dam	1	1861.2	1.520	0.07	0.00	0.07	0.025	T	0.0000	0.0000	St
47	Dam	1	2227.4	1.859	0.09	0.00	0.09	0.031	T	0.0000	0.0000	St
48	Dam	1	1226.4	0.954	0.04	0.00	0.04	0.016	T	0.0000	0.0000	St
49	Dam	1	2757.1	2.359	0.11	0.00	0.11	0.039	T	0.0000	0.0000	St
50	Dam	1	6687.8	6.353	0.24	0.00	0.24	0.087	T	0.0000	0.0000	St
51	Dam	1	12327.9	12.588	0.29	0.00	0.29	0.103	T	0.0000	0.0000	S
52	Dam	1	1925.1	1.579	0.07	0.00	0.07	0.026	T	0.0000	0.0000	St
53	Dam	1	3147.6	2.736	0.13	0.00	0.13	0.046	T	0.0000	0.0000	St
54	Dam	1	22.8	0.011	0.00	0.00	0.00	0.000	T	0.0000	0.0000	Sto
55	Dam	1	2102.7	1.743	0.08	0.00	0.08	0.029	T	0.0000	0.0000	St
56	Dam	1	970.3	0.734	0.03	0.00	0.03	0.012	T	0.0000	0.0000	Sto
57	Dam	1	2014.6	1.661	0.08	0.00	0.08	0.028	T	0.0000	0.0000	St
58	Dam	1	1594.0	1.279	0.06	0.00	0.06	0.021	T	0.0000	0.0000	St
59	Dam	1	1138.1	0.877	0.04	0.00	0.04	0.015	T	0.0000	0.0000	St
60	Dam	1	1741.0	1.411	0.07	0.00	0.07	0.023	T	0.0000	0.0000	St
61	Dam	1	1480.7	1.177	0.05	0.00	0.05	0.020	T	0.0000	0.0000	St
62	Dam	1	363.7	0.245	0.01	0.00	0.01	0.004	T	0.0000	0.0000	Sto
63	Dam	1	904.4	0.679	0.03	0.00	0.03	0.011	T	0.0000	0.0000	Sto
64	Dam	1	13787.8	14.266	0.30	0.00	0.30	0.108	T	0.0000	0.0000	S
65	Dam	1	733.2	0.537	0.02	0.00	0.02	0.009	T	0.0000	0.0000	Sto

66	Dam	1	1236.5	0.962	0.04	0.00	0.04	0.016	T	0.0000	0.0000 St
67	Dam	1	228.6	0.146	0.01	0.00	0.01	0.002	T	0.0000	0.0000 Sto
68	Dam	1	7036.5	6.725	0.24	0.00	0.24	0.088	T	0.0000	0.0000 St
69	Dam	1	1081.7	0.829	0.04	0.00	0.04	0.014	T	0.0000	0.0000 St
70	Dam	1	588.7	0.420	0.02	0.00	0.02	0.007	T	0.0000	0.0000 Sto
71	Dam	1	129.0	0.077	0.00	0.00	0.00	0.001	T	0.0000	0.0000 Sto
72	Dam	1	534.2	0.377	0.02	0.00	0.02	0.006	T	0.0000	0.0000 Sto
73	Dam	1	3350.3	2.933	0.14	0.00	0.14	0.049	T	0.0000	0.0000 St
74	Dam	1	1483.2	1.180	0.05	0.00	0.05	0.020	T	0.0000	0.0000 St
75	Dam	1	4398.4	3.977	0.18	0.00	0.18	0.066	T	0.0000	0.0000 St
76	Dam	1	881.6	0.659	0.03	0.00	0.03	0.011	T	0.0000	0.0000 Sto
77	Dam	1	972.9	0.736	0.03	0.00	0.03	0.012	T	0.0000	0.0000 Sto
78	Dam	1	1683.8	1.359	0.06	0.00	0.06	0.023	T	0.0000	0.0000 St
79	Dam	1	30265.5	34.359	0.45	0.00	0.45	0.160	T	0.0000	0.0000 S
80	Dam	1	1563.9	1.252	0.06	0.00	0.06	0.021	T	0.0000	0.0000 St
81	Dam	1	408.6	0.279	0.01	0.00	0.01	0.005	T	0.0000	0.0000 Sto
82	Dam	1	4257.9	3.835	0.18	0.00	0.18	0.064	T	0.0000	0.0000 St
83	Dam	1	2070.8	1.713	0.08	0.00	0.08	0.029	T	0.0000	0.0000 St
84	Dam	1	537.7	0.379	0.02	0.00	0.02	0.006	T	0.0000	0.0000 Sto
85	Dam	1	1095.0	0.840	0.04	0.00	0.04	0.014	T	0.0000	0.0000 St
86	Dam	1	4438.6	4.018	0.19	0.00	0.19	0.067	T	0.0000	0.0000 St
87	Dam	1	228.9	0.146	0.01	0.00	0.01	0.002	T	0.0000	0.0000 Sto
88	Dam	1	2388.3	2.009	0.09	0.00	0.09	0.033	T	0.0000	0.0000 St
89	Dam	1	792.0	0.585	0.03	0.00	0.03	0.010	T	0.0000	0.0000 Sto
90	Dam	1	760.2	0.559	0.03	0.00	0.03	0.009	T	0.0000	0.0000 Sto
91	Dam	1	2208.7	1.841	0.09	0.00	0.09	0.031	T	0.0000	0.0000 St
92	Dam	1	4962.4	4.551	0.21	0.00	0.21	0.076	T	0.0000	0.0000 St
93	Dam	1	3808.3	3.385	0.16	0.00	0.16	0.056	T	0.0000	0.0000 St
94	Dam	1	1329.4	1.044	0.05	0.00	0.05	0.017	T	0.0000	0.0000 St
95	Dam	1	952.8	0.719	0.03	0.00	0.03	0.012	T	0.0000	0.0000 Sto
96	Dam	1	884.2	0.662	0.03	0.00	0.03	0.011	T	0.0000	0.0000 Sto
97	Dam	1	3086.2	2.676	0.12	0.00	0.12	0.045	T	0.0000	0.0000 St
98	Dam	1	467.6	0.325	0.02	0.00	0.02	0.005	T	0.0000	0.0000 Sto
99	Dam	1	1114.6	0.857	0.04	0.00	0.04	0.014	T	0.0000	0.0000 St
100	Dam	1	2435.9	2.054	0.10	0.00	0.10	0.034	T	0.0000	0.0000 S
101	Dam	1	1761.7	1.430	0.07	0.00	0.07	0.024	T	0.0000	0.0000 S
102	Dam	1	1075.0	0.823	0.04	0.00	0.04	0.014	T	0.0000	0.0000 S
103	Dam	1	2141.9	1.779	0.08	0.00	0.08	0.030	T	0.0000	0.0000 S
104	Dam	1	2032.3	1.678	0.08	0.00	0.08	0.028	T	0.0000	0.0000 S
105	Dam	1	5045.8	4.637	0.21	0.00	0.21	0.077	T	0.0000	0.0000 S
106	Dam	1	559.6	0.397	0.02	0.00	0.02	0.007	T	0.0000	0.0000 St
107	Dam	1	1758.4	1.427	0.07	0.00	0.07	0.024	T	0.0000	0.0000 S
108	Dam	1	2125.3	1.764	0.08	0.00	0.08	0.029	T	0.0000	0.0000 S
109	Dam	1	401.4	0.274	0.01	0.00	0.01	0.005	T	0.0000	0.0000 St
110	Dam	1	6314.5	5.958	0.24	0.00	0.24	0.086	T	0.0000	0.0000 S
111	Dam	1	1210.7	0.940	0.04	0.00	0.04	0.016	T	0.0000	0.0000 S
112	Dam	1	8663.6	8.486	0.26	0.00	0.26	0.092	T	0.0000	0.0000 S
113	Dam	1	1918.2	1.573	0.07	0.00	0.07	0.026	T	0.0000	0.0000 S
114	Dam	1	1219.6	0.948	0.04	0.00	0.04	0.016	T	0.0000	0.0000 S
115	Dam	1	753.1	0.553	0.03	0.00	0.03	0.009	T	0.0000	0.0000 St
116	Dam	1	5618.3	5.229	0.23	0.00	0.23	0.084	T	0.0000	0.0000 S
117	Dam	1	171.7	0.106	0.00	0.00	0.00	0.002	T	0.0000	0.0000 St
118	Dam	1	8321.8	8.112	0.25	0.00	0.25	0.091	T	0.0000	0.0000 S
119	Dam	1	1021.2	0.777	0.04	0.00	0.04	0.013	T	0.0000	0.0000 S
120	Dam	1	526.7	0.371	0.02	0.00	0.02	0.006	T	0.0000	0.0000 St

121	Dam	1	776.6	0.572	0.03	0.00	0.03	0.010	T	0.0000	0.0000 St
122	Dam	1	137.6	0.083	0.00	0.00	0.00	0.001	T	0.0000	0.0000 St
123	Dam	1	918.7	0.691	0.03	0.00	0.03	0.011	T	0.0000	0.0000 St
124	Dam	1	1275.0	0.996	0.05	0.00	0.05	0.017	T	0.0000	0.0000 S
125	Dam	1	1042.8	0.796	0.04	0.00	0.04	0.013	T	0.0000	0.0000 S
126	Dam	1	1225.5	0.953	0.04	0.00	0.04	0.016	T	0.0000	0.0000 S
127	Dam	1	8135.0	7.909	0.25	0.00	0.25	0.091	T	0.0000	0.0000 S
128	Dam	1	1022.0	0.778	0.04	0.00	0.04	0.013	T	0.0000	0.0000 S
129	Dam	1	991.3	0.752	0.03	0.00	0.03	0.013	T	0.0000	0.0000 St
130	Dam	1	2115.6	1.755	0.08	0.00	0.08	0.029	T	0.0000	0.0000 S
131	Dam	1	2282.9	1.910	0.09	0.00	0.09	0.032	T	0.0000	0.0000 S
132	Dam	1	931.2	0.701	0.03	0.00	0.03	0.012	T	0.0000	0.0000 St
133	Dam	1	639.6	0.461	0.02	0.00	0.02	0.008	T	0.0000	0.0000 St
134	Dam	1	117.6	0.069	0.00	0.00	0.00	0.001	T	0.0000	0.0000 St
135	Dam	1	335.6	0.224	0.01	0.00	0.01	0.004	T	0.0000	0.0000 St
136	Dam	1	959.5	0.725	0.03	0.00	0.03	0.012	T	0.0000	0.0000 St
137	Dam	1	412.8	0.282	0.01	0.00	0.01	0.005	T	0.0000	0.0000 St
138	Dam	1	953.4	0.720	0.03	0.00	0.03	0.012	T	0.0000	0.0000 St
139	Dam	1	266.6	0.173	0.01	0.00	0.01	0.003	T	0.0000	0.0000 St
140	Dam	1	24.0	0.012	0.00	0.00	0.00	0.000	T	0.0000	0.0000 Sto
141	Dam	1	874.0	0.653	0.03	0.00	0.03	0.011	T	0.0000	0.0000 St
142	Dam	1	5950.2	5.575	0.24	0.00	0.24	0.085	T	0.0000	0.0000 S
143	Dam	1	1903.0	1.559	0.07	0.00	0.07	0.026	T	0.0000	0.0000 S
144	Dam	1	2260.1	1.889	0.09	0.00	0.09	0.031	T	0.0000	0.0000 S
145	Dam	1	1172.5	0.907	0.04	0.00	0.04	0.015	T	0.0000	0.0000 S
146	Dam	1	1232.2	0.959	0.04	0.00	0.04	0.016	T	0.0000	0.0000 S
147	Dam	1	2900.9	2.497	0.12	0.00	0.12	0.042	T	0.0000	0.0000 S
148	Dam	1	701.5	0.511	0.02	0.00	0.02	0.009	T	0.0000	0.0000 St
149	Dam	1	7427.8	7.144	0.25	0.00	0.25	0.089	T	0.0000	0.0000 S
150	Dam	1	1056.2	0.807	0.04	0.00	0.04	0.013	T	0.0000	0.0000 S
151	Dam	1	573.4	0.408	0.02	0.00	0.02	0.007	T	0.0000	0.0000 St
152	Dam	1	2341.0	1.965	0.09	0.00	0.09	0.033	T	0.0000	0.0000 S
153	Dam	1	1703.8	1.377	0.06	0.00	0.06	0.023	T	0.0000	0.0000 S
154	Dam	1	584.2	0.416	0.02	0.00	0.02	0.007	T	0.0000	0.0000 St
155	Dam	1	1469.9	1.168	0.05	0.00	0.05	0.019	T	0.0000	0.0000 S
156	Dam	1	1589.5	1.275	0.06	0.00	0.06	0.021	T	0.0000	0.0000 S
157	Dam	1	535.3	0.377	0.02	0.00	0.02	0.006	T	0.0000	0.0000 St
158	Dam	1	751.8	0.552	0.03	0.00	0.03	0.009	T	0.0000	0.0000 St
159	Dam	1	1572.4	1.259	0.06	0.00	0.06	0.021	T	0.0000	0.0000 S
160	Dam	1	1199.6	0.930	0.04	0.00	0.04	0.015	T	0.0000	0.0000 S
161	Dam	1	1607.3	1.290	0.06	0.00	0.06	0.021	T	0.0000	0.0000 S
162	Dam	1	504.0	0.353	0.02	0.00	0.02	0.006	T	0.0000	0.0000 St
163	Dam	1	1078.9	0.826	0.04	0.00	0.04	0.014	T	0.0000	0.0000 S
164	Dam	1	828.6	0.615	0.03	0.00	0.03	0.010	T	0.0000	0.0000 St
165	Dam	1	1736.4	1.407	0.07	0.00	0.07	0.023	T	0.0000	0.0000 S
166	Dam	1	1275.5	0.997	0.05	0.00	0.05	0.017	T	0.0000	0.0000 S
167	Dam	1	114.7	0.067	0.00	0.00	0.00	0.001	T	0.0000	0.0000 St
168	Dam	1	1239.8	0.965	0.04	0.00	0.04	0.016	T	0.0000	0.0000 S
169	Dam	1	56.8	0.031	0.00	0.00	0.00	0.001	T	0.0000	0.0000 Sto
170	Dam	1	1638.2	1.318	0.06	0.00	0.06	0.022	T	0.0000	0.0000 S
171	Dam	1	5374.1	4.975	0.23	0.00	0.23	0.083	T	0.0000	0.0000 S
172	Dam	1	1410.7	1.115	0.05	0.00	0.05	0.019	T	0.0000	0.0000 S
173	Dam	1	725.5	0.530	0.02	0.00	0.02	0.009	T	0.0000	0.0000 St
174	Dam	1	670.6	0.486	0.02	0.00	0.02	0.008	T	0.0000	0.0000 St
175	Dam	1	7365.2	7.077	0.25	0.00	0.25	0.089	T	0.0000	0.0000 S

176	Dam	1	1883.8	1.541	0.07	0.00	0.07	0.026	T	0.0000	0.0000 S
177	Dam	1	1195.6	0.927	0.04	0.00	0.04	0.015	T	0.0000	0.0000 S
178	Dam	1	2048.4	1.692	0.08	0.00	0.08	0.028	T	0.0000	0.0000 S
179	Dam	1	715.5	0.522	0.02	0.00	0.02	0.009	T	0.0000	0.0000 St
180	Dam	1	364.8	0.246	0.01	0.00	0.01	0.004	T	0.0000	0.0000 St
181	Dam	1	9802.5	9.742	0.27	0.00	0.27	0.096	T	0.0000	0.0000 S
182	Dam	1	3190.1	2.777	0.13	0.00	0.13	0.046	T	0.0000	0.0000 S
183	Dam	1	2167.8	1.803	0.08	0.00	0.08	0.030	T	0.0000	0.0000 S
184	Dam	1	2154.4	1.791	0.08	0.00	0.08	0.030	T	0.0000	0.0000 S
185	Dam	1	390.1	0.265	0.01	0.00	0.01	0.004	T	0.0000	0.0000 St
186	Dam	1	2371.7	1.994	0.09	0.00	0.09	0.033	T	0.0000	0.0000 S
187	Dam	1	2909.2	2.505	0.12	0.00	0.12	0.042	T	0.0000	0.0000 S
188	Dam	1	743.9	0.545	0.03	0.00	0.03	0.009	T	0.0000	0.0000 St
189	Dam	1	191.8	0.120	0.01	0.00	0.01	0.002	T	0.0000	0.0000 St
190	Dam	1	1410.3	1.115	0.05	0.00	0.05	0.019	T	0.0000	0.0000 S
191	Dam	1	1509.0	1.203	0.06	0.00	0.06	0.020	T	0.0000	0.0000 S
192	Dam	1	1585.8	1.271	0.06	0.00	0.06	0.021	T	0.0000	0.0000 S
193	Dam	1	340.9	0.228	0.01	0.00	0.01	0.004	T	0.0000	0.0000 St
194	Dam	1	2212.5	1.845	0.09	0.00	0.09	0.031	T	0.0000	0.0000 S
195	Dam	1	1661.7	1.339	0.06	0.00	0.06	0.022	T	0.0000	0.0000 S
196	Dam	1	86.9	0.049	0.00	0.00	0.00	0.001	T	0.0000	0.0000 Sto
197	Dam	1	982.0	0.744	0.03	0.00	0.03	0.012	T	0.0000	0.0000 St
198	Dam	1	719.8	0.526	0.02	0.00	0.02	0.009	T	0.0000	0.0000 St
199	Dam	1	2133.6	1.771	0.08	0.00	0.08	0.029	T	0.0000	0.0000 S
200	Dam	1	1925.3	1.579	0.07	0.00	0.07	0.026	T	0.0000	0.0000 S
201	Dam	1	1295.5	1.014	0.05	0.00	0.05	0.017	T	0.0000	0.0000 S
202	Dam	1	2189.7	1.823	0.08	0.00	0.08	0.030	T	0.0000	0.0000 S
203	Dam	1	5151.9	4.746	0.22	0.00	0.22	0.079	T	0.0000	0.0000 S
204	Dam	1	1192.5	0.924	0.04	0.00	0.04	0.015	T	0.0000	0.0000 S
205	Dam	1	481.6	0.335	0.02	0.00	0.02	0.006	T	0.0000	0.0000 St
206	Dam	1	3714.0	3.292	0.15	0.00	0.15	0.055	T	0.0000	0.0000 S
207	Dam	1	1010.9	0.768	0.04	0.00	0.04	0.013	T	0.0000	0.0000 S
208	Dam	1	1448.9	1.149	0.05	0.00	0.05	0.019	T	0.0000	0.0000 S
209	Dam	1	142.6	0.086	0.00	0.00	0.00	0.001	T	0.0000	0.0000 St
210	Dam	1	49287.4	59.268	0.63	0.00	0.63	0.225	T	0.0000	0.0000
211	Dam	1	6550.4	6.208	0.24	0.00	0.24	0.086	T	0.0000	0.0000 S
212	Dam	1	617.6	0.443	0.02	0.00	0.02	0.007	T	0.0000	0.0000 St
213	Dam	1	384.5	0.261	0.01	0.00	0.01	0.004	T	0.0000	0.0000 St
214	Dam	1	1458.7	1.158	0.05	0.00	0.05	0.019	T	0.0000	0.0000 S
215	Dam	1	660.5	0.477	0.02	0.00	0.02	0.008	T	0.0000	0.0000 St
216	Dam	1	1944.5	1.597	0.07	0.00	0.07	0.027	T	0.0000	0.0000 S
217	Dam	1	1182.6	0.916	0.04	0.00	0.04	0.015	T	0.0000	0.0000 S
218	Dam	1	797.9	0.590	0.03	0.00	0.03	0.010	T	0.0000	0.0000 St
219	Dam	1	14151.3	14.687	0.30	0.00	0.30	0.109	T	0.0000	0.0000
220	Dam	1	65668.1	81.685	0.79	0.00	0.79	0.284	T	0.0000	0.0000
221	Dam	1	5079.1	4.671	0.22	0.00	0.22	0.078	T	0.0000	0.0000 S
222	Dam	1	1182.6	0.916	0.04	0.00	0.04	0.015	T	0.0000	0.0000 S
223	Dam	1	853.9	0.636	0.03	0.00	0.03	0.011	T	0.0000	0.0000 St
224	Dam	1	781.9	0.577	0.03	0.00	0.03	0.010	T	0.0000	0.0000 St
225	Dam	1	588.1	0.419	0.02	0.00	0.02	0.007	T	0.0000	0.0000 St
226	Dam	1	965.3	0.730	0.03	0.00	0.03	0.012	T	0.0000	0.0000 St
227	Dam	1	2768.5	2.370	0.11	0.00	0.11	0.039	T	0.0000	0.0000 S
228	Dam	1	4755.5	4.340	0.20	0.00	0.20	0.072	T	0.0000	0.0000 S
229	Dam	1	1198.8	0.930	0.04	0.00	0.04	0.015	T	0.0000	0.0000 S
230	Dam	1	2269.8	1.898	0.09	0.00	0.09	0.032	T	0.0000	0.0000 S

231	Dam	1	1401.7	1.107	0.05	0.00	0.05	0.018	T	0.0000	0.0000 S
232	Dam	1	915.4	0.688	0.03	0.00	0.03	0.011	T	0.0000	0.0000 St
233	Dam	1	1065.9	0.815	0.04	0.00	0.04	0.014	T	0.0000	0.0000 S
234	Dam	1	1829.9	1.492	0.07	0.00	0.07	0.025	T	0.0000	0.0000 S
235	Dam	1	11365.8	11.495	0.28	0.00	0.28	0.100	T	0.0000	0.0000
236	Dam	1	417.1	0.286	0.01	0.00	0.01	0.005	T	0.0000	0.0000 St
237	Dam	1	1305.9	1.023	0.05	0.00	0.05	0.017	T	0.0000	0.0000 S
238	Dam	1	152.7	0.093	0.00	0.00	0.00	0.002	T	0.0000	0.0000 St
239	Dam	1	1109.4	0.853	0.04	0.00	0.04	0.014	T	0.0000	0.0000 S
240	Dam	1	365.0	0.246	0.01	0.00	0.01	0.004	T	0.0000	0.0000 St
241	Dam	1	2558.8	2.170	0.10	0.00	0.10	0.036	T	0.0000	0.0000 S
242	Dam	1	378.6	0.256	0.01	0.00	0.01	0.004	T	0.0000	0.0000 St
243	Dam	1	1738.4	1.409	0.07	0.00	0.07	0.023	T	0.0000	0.0000 S
244	Dam	1	364.6	0.246	0.01	0.00	0.01	0.004	T	0.0000	0.0000 St
245	Dam	1	1737.8	1.408	0.07	0.00	0.07	0.023	T	0.0000	0.0000 S
246	Dam	1	2164.3	1.800	0.08	0.00	0.08	0.030	T	0.0000	0.0000 S
247	Dam	1	885.5	0.663	0.03	0.00	0.03	0.011	T	0.0000	0.0000 St
248	Dam	1	1114.0	0.857	0.04	0.00	0.04	0.014	T	0.0000	0.0000 S
249	Dam	1	1986.6	1.635	0.08	0.00	0.08	0.027	T	0.0000	0.0000 S
250	Dam	1	3701.4	3.279	0.15	0.00	0.15	0.055	T	0.0000	0.0000 S
251	Dam	1	1929.0	1.583	0.07	0.00	0.07	0.026	T	0.0000	0.0000 S
252	Dam	1	678.9	0.492	0.02	0.00	0.02	0.008	T	0.0000	0.0000 St
253	Dam	1	2116.1	1.755	0.08	0.00	0.08	0.029	T	0.0000	0.0000 S
254	Dam	1	4886.7	4.474	0.21	0.00	0.21	0.074	T	0.0000	0.0000 S
255	Dam	1	227.4	0.145	0.01	0.00	0.01	0.002	T	0.0000	0.0000 St
256	Dam	1	1171.7	0.906	0.04	0.00	0.04	0.015	T	0.0000	0.0000 S
257	Dam	1	1590.1	1.275	0.06	0.00	0.06	0.021	T	0.0000	0.0000 S
258	Dam	1	14011.0	14.524	0.30	0.00	0.30	0.108	T	0.0000	0.0000
259	Dam	1	3232.4	2.818	0.13	0.00	0.13	0.047	T	0.0000	0.0000 S
260	Dam	1	82.7	0.047	0.00	0.00	0.00	0.001	T	0.0000	0.0000 Sto
261	Dam	1	1163.0	0.899	0.04	0.00	0.04	0.015	T	0.0000	0.0000 S
262	Dam	1	94.2	0.054	0.00	0.00	0.00	0.001	T	0.0000	0.0000 Sto
263	Dam	1	1668.5	1.346	0.06	0.00	0.06	0.022	T	0.0000	0.0000 S
264	Dam	1	961.2	0.726	0.03	0.00	0.03	0.012	T	0.0000	0.0000 St
265	Dam	1	1071.0	0.820	0.04	0.00	0.04	0.014	T	0.0000	0.0000 S
266	Dam	1	4819.6	4.405	0.20	0.00	0.20	0.073	T	0.0000	0.0000 S
267	Dam	1	3713.3	3.291	0.15	0.00	0.15	0.055	T	0.0000	0.0000 S
268	Dam	1	831.9	0.618	0.03	0.00	0.03	0.010	T	0.0000	0.0000 St
269	Dam	1	862.7	0.644	0.03	0.00	0.03	0.011	T	0.0000	0.0000 St
270	Dam	1	6353.6	6.000	0.24	0.00	0.24	0.086	T	0.0000	0.0000 S
271	Dam	1	5274.3	4.872	0.23	0.00	0.23	0.081	T	0.0000	0.0000 S
272	Dam	1	1267.7	0.990	0.05	0.00	0.05	0.016	T	0.0000	0.0000 S
273	Dam	1	2181.1	1.815	0.08	0.00	0.08	0.030	T	0.0000	0.0000 S
274	Dam	1	2938.6	2.534	0.12	0.00	0.12	0.042	T	0.0000	0.0000 S
275	Dam	1	3491.7	3.072	0.14	0.00	0.14	0.051	T	0.0000	0.0000 S
276	Dam	1	303.2	0.200	0.01	0.00	0.01	0.003	T	0.0000	0.0000 St
277	Dam	1	451.5	0.312	0.01	0.00	0.01	0.005	T	0.0000	0.0000 St
278	Dam	1	4849.7	4.436	0.21	0.00	0.21	0.074	T	0.0000	0.0000 S
279	Dam	1	3992.5	3.569	0.17	0.00	0.17	0.059	T	0.0000	0.0000 S
280	Dam	1	1123.2	0.864	0.04	0.00	0.04	0.014	T	0.0000	0.0000 S
281	Dam	1	1081.6	0.829	0.04	0.00	0.04	0.014	T	0.0000	0.0000 S
282	Dam	1	2357.0	1.980	0.09	0.00	0.09	0.033	T	0.0000	0.0000 S
283	Dam	1	1124.4	0.866	0.04	0.00	0.04	0.014	T	0.0000	0.0000 S
284	Dam	1	2044.3	1.689	0.08	0.00	0.08	0.028	T	0.0000	0.0000 S
285	Dam	1	1792.3	1.458	0.07	0.00	0.07	0.024	T	0.0000	0.0000 S

286	Dam	1	1056.2	0.807	0.04	0.00	0.04	0.013	T	0.0000	0.0000 S
287	Dam	1	1086.8	0.833	0.04	0.00	0.04	0.014	T	0.0000	0.0000 S
288	Dam	1	3352.6	2.936	0.14	0.00	0.14	0.049	T	0.0000	0.0000 S
289	Dam	1	1121.5	0.863	0.04	0.00	0.04	0.014	T	0.0000	0.0000 S
290	Dam	1	2702.0	2.307	0.11	0.00	0.11	0.038	T	0.0000	0.0000 S
291	Dam	1	743.9	0.545	0.03	0.00	0.03	0.009	T	0.0000	0.0000 St
292	Dam	1	585.8	0.417	0.02	0.00	0.02	0.007	T	0.0000	0.0000 St
293	Dam	1	3207.1	2.794	0.13	0.00	0.13	0.047	T	0.0000	0.0000 S
294	Dam	1	2172.2	1.807	0.08	0.00	0.08	0.030	T	0.0000	0.0000 S
295	Dam	1	1077.4	0.825	0.04	0.00	0.04	0.014	T	0.0000	0.0000 S
296	Dam	1	2270.9	1.899	0.09	0.00	0.09	0.032	T	0.0000	0.0000 S
297	Dam	1	437.0	0.301	0.01	0.00	0.01	0.005	T	0.0000	0.0000 St
298	Dam	1	2365.6	1.988	0.09	0.00	0.09	0.033	T	0.0000	0.0000 S
299	Dam	1	703.7	0.513	0.02	0.00	0.02	0.009	T	0.0000	0.0000 St
300	Dam	1	1706.7	1.380	0.06	0.00	0.06	0.023	T	0.0000	0.0000 S
301	Dam	1	1247.6	0.972	0.04	0.00	0.04	0.016	T	0.0000	0.0000 S
302	Dam	1	5530.7	5.138	0.23	0.00	0.23	0.084	T	0.0000	0.0000 S
303	Dam	1	153.6	0.093	0.00	0.00	0.00	0.002	T	0.0000	0.0000 St
304	Dam	1	4918.3	4.506	0.21	0.00	0.21	0.075	T	0.0000	0.0000 S
305	Dam	1	2622.7	2.231	0.10	0.00	0.10	0.037	T	0.0000	0.0000 S
306	Dam	1	540.7	0.382	0.02	0.00	0.02	0.006	T	0.0000	0.0000 St
307	Dam	1	24045.8	26.567	0.39	0.00	0.39	0.140	T	0.0000	0.0000
308	Dam	1	4079.7	3.656	0.17	0.00	0.17	0.061	T	0.0000	0.0000 S
309	Dam	1	2332.9	1.957	0.09	0.00	0.09	0.033	T	0.0000	0.0000 S
310	Dam	1	1790.8	1.456	0.07	0.00	0.07	0.024	T	0.0000	0.0000 S
311	Dam	1	1210.9	0.940	0.04	0.00	0.04	0.016	T	0.0000	0.0000 S
312	Dam	1	1012.7	0.770	0.04	0.00	0.04	0.013	T	0.0000	0.0000 S
313	Dam	1	792.0	0.585	0.03	0.00	0.03	0.010	T	0.0000	0.0000 St
314	Dam	1	209.9	0.133	0.01	0.00	0.01	0.002	T	0.0000	0.0000 St
315	Dam	1	1280.1	1.001	0.05	0.00	0.05	0.017	T	0.0000	0.0000 S
316	Dam	1	1286.2	1.006	0.05	0.00	0.05	0.017	T	0.0000	0.0000 S
317	Dam	1	3332.2	2.916	0.13	0.00	0.13	0.049	T	0.0000	0.0000 S
318	Dam	1	6498.0	6.152	0.24	0.00	0.24	0.086	T	0.0000	0.0000 S
TOTALS			827335.4	780.000	278.00			100.000			

Day YYYYMMDD	Rainfall (mm/d)	Potential Evaporatn (mm/d)	|-------Flow WITH Dams------| In-stream (ML/d)	Dam Rain (ML/d)	Total (ML/d)	Flow WITH NO Dams (ML/d)	Total Storage (ML/d)	Total Storage (ML)	Num. Dams Full (% Full) (of 317)	Overf From Dam % Natu
18900101	0.00	5.30	0.00	0.00	0.00	0.00	0.00	0.000	0	0.000
18900102	0.00	5.50	0.00	0.00	0.00	0.00	0.00	0.000	0	0.000
18900103	0.00	6.30	0.00	0.00	0.00	0.00	0.00	0.000	0	0.000
18900104	0.00	6.70	0.00	0.00	0.00	0.00	0.00	0.000	0	0.000
18900105	0.00	7.00	0.00	0.00	0.00	0.00	0.00	0.000	0	0.000
18900106	0.30	6.50	0.00	0.00	0.00	0.00	0.00	0.000	0	0.000
18900107	0.00	6.70	0.00	0.00	0.00	0.00	0.00	0.000	0	0.000
18900108	0.00	5.80	0.00	0.00	0.00	0.00	0.00	0.000	0	0.000
18900109	0.00	5.40	0.00	0.00	0.00	0.00	0.00	0.000	0	0.000
18900110	0.00	6.10	0.00	0.00	0.00	0.00	0.00	0.000	0	0.000
18900111	7.10	5.90	4.00	0.00	4.00	4.41	0.39	0.049	0	0.000
18900112	21.50	4.90	10.00	0.00	10.00	11.01	14.09	1.806	0	0.000
18900113	32.90	5.30	84.00	0.00	84.00	92.51	44.39	5.691	0	0.000
18900114	29.80	5.40	37.00	0.00	37.00	40.75	67.28	8.625	0	0.000
18900115	11.00	3.90	37.00	0.00	37.00	40.75	75.86	9.725	0	0.000
18900116	4.40	3.50	22.00	0.00	22.00	24.23	77.79	9.973	0	0.000

18900117	5.40	5.50	25.00	0.00	25.00	27.53	79.19	10.153	0	0.000
18900118	3.20	3.30	15.00	0.00	15.00	16.52	79.58	10.203	0	0.000
18900119	2.10	5.50	16.00	0.00	16.00	17.62	77.35	9.916	0	0.000
18900120	0.30	5.60	12.00	0.00	12.00	13.22	73.13	9.376	0	0.000
18900121	0.00	4.90	11.00	0.00	11.00	12.11	69.15	8.866	0	0.000
18900122	2.90	5.60	19.00	0.00	19.00	20.92	67.80	8.692	0	0.000
18900123	8.90	5.80	22.00	0.00	22.00	24.23	71.55	9.173	0	0.000
18900124	0.40	5.70	11.00	0.00	11.00	12.11	67.23	8.620	0	0.000
18900125	0.00	5.20	9.00	0.00	9.00	9.91	62.80	8.051	0	0.000
18900126	0.00	5.20	8.00	0.00	8.00	8.81	58.26	7.469	0	0.000
18900127	1.00	5.00	10.00	0.00	10.00	11.01	54.92	7.041	0	0.000
18900128	0.00	3.60	7.00	0.00	7.00	7.71	51.61	6.616	0	0.000
18900129	3.00	5.20	15.00	0.00	15.00	16.52	50.26	6.444	0	0.000
18900130	0.30	5.40	7.00	0.00	7.00	7.71	45.71	5.860	0	0.000
18900131	15.20	5.90	53.00	0.00	53.00	58.37	57.73	7.401	0	0.000
18900201	6.90	5.00	23.00	0.00	23.00	25.33	60.47	7.753	0	0.000
18900202	1.40	5.50	16.00	0.00	16.00	17.62	57.55	7.378	0	0.000
18900203	13.90	5.00	6.00	0.00	6.00	6.61	64.36	8.251	0	0.000
18900204	4.20	5.40	13.00	0.00	13.00	14.32	63.53	8.145	0	0.000
18900205	0.80	6.30	10.00	0.00	10.00	11.01	58.84	7.543	0	0.000
18900206	1.50	6.00	11.00	0.00	11.00	12.11	55.07	7.060	0	0.000
18900207	0.10	4.90	4.00	0.00	4.00	4.41	50.35	6.455	0	0.000
18900208	0.10	5.10	3.00	0.00	3.00	3.30	45.36	5.815	0	0.000
18900209	0.40	3.30	6.00	0.00	6.00	6.61	42.43	5.440	0	0.000
18900210	0.40	5.00	3.00	0.00	3.00	3.30	38.36	4.918	0	0.000
18900211	0.70	5.30	3.00	0.00	3.00	3.30	34.50	4.424	0	0.000
18900212	1.30	5.30	9.00	0.00	9.00	9.91	31.81	4.078	0	0.000
18900213	24.40	5.30	89.00	0.00	89.00	98.02	55.47	7.111	0	0.000
18900214	1.80	5.20	39.00	0.00	39.00	42.95	55.45	7.109	0	0.000
18900215	0.00	5.00	28.00	0.00	28.00	30.84	52.99	6.794	0	0.000
18900216	7.90	5.10	31.00	0.00	31.00	34.14	57.29	7.345	0	0.000
18900217	5.50	4.70	23.00	0.00	23.00	25.33	59.13	7.581	0	0.000
18900218	2.10	4.80	25.00	0.00	25.00	27.53	58.27	7.471	0	0.000
18900219	3.10	3.40	37.00	0.00	37.00	40.75	60.62	7.771	0	0.000
18900220	12.20	3.00	79.00	0.00	79.00	87.00	75.07	9.625	0	0.000
18900221	9.00	3.10	65.00	0.00	65.00	71.58	85.38	10.947	0	0.000
18900222	11.30	4.70	163.00	0.00	163.00	179.51	106.20	13.616	0	0.000
18900223	0.60	2.90	84.00	0.00	84.00	92.51	111.65	14.314	0	0.000
18900224	3.50	5.10	91.00	0.00	91.00	100.22	118.39	15.178	0	0.000
18900225	0.40	4.80	65.00	0.00	65.00	71.58	120.18	15.408	0	0.000
18900226	12.50	5.00	230.00	0.00	230.00	253.30	148.53	19.042	0	0.000
18900227	1.80	2.90	119.00	0.00	119.00	131.06	158.52	20.323	0	0.000
18900228	0.90	5.10	103.00	0.00	103.00	113.43	164.32	21.067	0	0.000
18900301	1.50	5.00	84.00	0.00	84.00	92.51	168.89	21.653	0	0.000
18900302	0.00	4.90	77.00	0.00	77.00	84.80	171.59	21.999	0	0.000
18900303	0.20	4.50	71.00	0.00	71.00	78.19	174.18	22.331	0	0.000
18900304	0.10	4.50	66.00	0.00	66.00	72.69	176.19	22.588	0	0.000
18900305	0.80	4.50	62.00	0.00	62.00	68.28	178.36	22.867	0	0.000
18900306	0.50	4.50	57.00	0.00	57.00	62.77	179.78	23.049	0	0.000
18900307	5.80	4.50	53.00	0.00	53.00	58.37	185.18	23.741	0	0.000
18900308	16.30	4.50	472.00	0.00	472.00	519.82	241.72	30.989	0	0.000
18900309	17.80	5.00	1116.00	0.00	1116.00	1229.06	364.32	46.707	0	0.000
18900310	59.30	4.40	3043.79	14.21	3058.00	3245.93	596.63	76.490	299	31.287
18900311	4.60	4.80	1804.00	0.00	1804.00	1839.13	630.55	80.840	305	76.750
18900312	2.20	4.80	728.00	0.00	728.00	741.90	641.25	82.211	306	77.142

18900313	1.20	5.00	410.00	0.00	410.00	418.95	646.01	82.822	307	74.377
18900314	2.00	4.50	341.00	0.00	341.00	348.15	650.05	83.340	307	75.226
18900315	0.70	4.30	309.00	0.00	309.00	316.33	653.36	83.764	307	72.473
18900316	2.00	4.10	292.00	0.00	292.00	298.20	656.77	84.202	307	74.976
18900317	1.10	4.30	267.00	0.00	267.00	273.37	659.46	84.546	308	72.314
18900318	0.70	4.00	252.00	0.00	252.00	258.10	661.78	84.844	308	71.960
18900319	0.00	4.30	229.00	0.00	229.00	235.38	663.57	85.073	308	68.304
18900320	0.10	4.20	212.00	0.00	212.00	218.03	665.16	85.277	308	67.731
18900321	0.00	4.50	197.00	0.00	197.00	203.06	666.46	85.444	308	65.417
18900322	15.10	4.80	211.35	6.65	218.00	215.20	671.14	86.044	309	78.015
18900323	31.20	4.00	1066.45	18.55	1085.00	1081.30	688.90	88.320	312	82.413
18900324	5.80	2.30	492.54	2.46	495.00	498.10	693.85	88.956	312	85.095
18900325	7.90	4.00	269.31	2.69	272.00	272.77	696.80	89.334	312	83.508
18900326	3.30	4.20	209.00	0.00	209.00	212.09	698.10	89.500	313	81.537
18900327	78.70	4.60	8077.42	54.58	8132.00	8137.98	764.34	97.993	315	89.029
18900328	3.60	4.20	4576.00	0.00	4576.00	4593.20	780.00	100.000	317	92.924
18900329	0.00	3.90	2306.00	0.00	2306.00	2310.27	780.00	100.000	317	94.920
18900330	0.40	4.00	1113.00	0.00	1113.00	1117.02	780.00	100.000	317	93.074
18900331	0.10	3.50	614.00	0.00	614.00	617.86	780.00	100.000	317	90.292
18900401	7.50	2.20	1116.79	4.21	1121.00	1117.69	780.00	100.000	317	96.014
18900402	1.50	3.80	755.00	0.00	755.00	757.98	780.00	100.000	317	92.725
18900403	0.30	3.70	494.00	0.00	494.00	497.89	780.00	100.000	317	88.635
18900404	1.60	3.60	378.00	0.00	378.00	380.73	780.00	100.000	317	89.307
18900405	0.60	3.70	317.00	0.00	317.00	320.64	780.00	100.000	317	84.900
18900406	0.20	3.80	278.00	0.00	278.00	282.06	780.00	100.000	317	81.720
18900407	0.00	3.80	254.00	0.00	254.00	258.22	780.00	100.000	317	79.645
18900408	0.20	4.00	235.00	0.00	235.00	239.22	780.00	100.000	317	78.278
18900409	0.00	3.60	219.00	0.00	219.00	223.06	780.00	100.000	317	77.710
18900410	17.40	2.20	645.93	12.07	658.00	646.50	780.00	100.000	317	95.941
18900411	1.70	3.50	385.00	0.00	385.00	387.57	780.00	100.000	317	89.886
18900412	0.10	3.60	270.00	0.00	270.00	273.97	780.00	100.000	317	81.592
18900413	0.00	3.20	210.00	0.00	210.00	213.73	780.00	100.000	317	78.503
18900414	0.00	3.10	178.00	0.00	178.00	181.64	780.00	100.000	317	75.745
18900415	0.80	4.40	168.00	0.00	168.00	172.06	780.00	100.000	317	72.034
18900416	0.00	3.20	153.00	0.00	153.00	156.73	780.00	100.000	317	71.826
18900417	0.10	3.60	144.00	0.00	144.00	147.97	780.00	100.000	317	68.579
18900418	1.30	2.90	143.00	0.00	143.00	145.40	780.00	100.000	317	79.468
18900419	0.30	3.00	128.00	0.00	128.00	131.31	780.00	100.000	317	70.300
18900420	0.20	3.20	120.00	0.00	120.00	123.56	780.00	100.000	317	66.516
18900421	0.10	3.00	112.00	0.00	112.00	115.48	780.00	100.000	317	65.149
18900422	0.20	2.90	104.00	0.00	104.00	107.31	780.00	100.000	317	64.355
18900423	2.30	2.90	109.00	0.00	109.00	110.58	780.00	100.000	317	81.860
18900424	3.40	2.90	104.64	0.36	105.00	105.66	780.00	100.000	317	86.670
18900425	0.90	2.90	94.00	0.00	94.00	96.73	780.00	100.000	317	67.114
18900426	0.10	2.90	84.00	0.00	84.00	87.32	779.93	99.991	315	56.787
18900427	0.70	2.90	84.00	0.00	84.00	86.89	779.92	99.990	315	61.792
18900428	1.10	2.90	81.00	0.00	81.00	83.59	779.95	99.993	316	64.209
18900429	0.50	2.80	75.00	0.00	75.00	77.92	779.88	99.985	315	57.422
18900430	2.40	3.20	86.00	0.00	86.00	87.84	779.99	99.999	316	74.756
18900501	1.30	3.80	72.00	0.00	72.00	75.02	779.89	99.986	314	54.517
18900502	0.90	2.90	66.00	0.00	66.00	68.63	779.83	99.978	315	56.494
18900503	7.10	2.00	902.96	4.04	907.00	904.00	780.00	100.000	317	95.660
18900504	2.90	1.70	956.05	0.95	957.00	957.05	780.00	100.000	317	95.764
18900505	0.20	2.50	501.00	0.00	501.00	503.95	780.00	100.000	317	90.707
18900506	0.20	2.80	237.00	0.00	237.00	240.19	780.00	100.000	317	82.861