Department of Environment and Resource Management

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

STATEWIDE ASSESSMENT: REPORT 2

- Hydrological assessment of stock and domestic farm dams in Queensland
- 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.

In Australia, stock and domestic water use is largely unlicensed and therefore little is known about the impact that stock and domestic farm dams have on streamflow.

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 hydrologic 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

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

The hydrologic modelling used a piece of software called STEDI, which stands for the Spatial Tool for Estimating Dam Impacts. The inputs to the modelling and the methods used to develop them are discussed in detail in the *Statewide Assessment: Report 1 – Methods and Inputs.*

This report presents the results of the hydrologic modelling, including a sensitivity analysis and regionalisation of outputs. The sensitivity analysis follows on from the assessment of potential options to improve the various input estimation methods, discussed in the *Statewide Assessment: Report 1 – Methods and Inputs.* This is used to develop the final recommendations to DERM for areas to consider for further investigation. This report also includes an assessment of the trends in stock and domestic farm dam development.

The STEDI modelling was undertaken for 55 catchments across Queensland, with the outputs from the modelling then regionalised across the whole of the state. (The results from the initial modelling are referred to as the baseline results, or Scenario 1.) The baseline modelling results demonstrate that there is considerable variation between the modelled catchments, both in terms of inputs and outputs.

In terms of volumetric impact as a percentage of mean annual flow, the highest percentage impact was seen in the south and south east of the state. The lowest percentage impact was seen in the north west of the state. The impact of farm dams per square kilometre was observed to be highest in the modelling catchments in the south east and in the north east, while the modelling catchments in the south west and west of the state have a lower modelled impact per square kilometre of catchment.

The majority of the modelled catchments showed the highest levels of impact in summer, with the second highest level of impact observed in autumn. Similar levels of impact are generally observed in winter and spring.

Regionalisation of results

The total volume of stock and domestic dams estimated for all of Queensland was 1,255 GL. The mean annual impact of those dams on the surface water resource across Queensland was 368 GL/year. This represents an average impact of 0.21 ML/km²/year. On average, for every 1 ML of storage volume of stock and domestic dams, the streamflow at the catchment outlet was reduced by 0.39 ML/year.

The level of impact varied across the state, with a minimum of 0.18 ML/year in Cooper Creek in the south west and the maximum 0.86 ML/year per ML of dams in the reporting area in Lake Frome, closely followed by the Maroochy River with 0.81 ML/year impact per ML of dams in the reporting area. The impact per ML of dams in each reporting area is highest along the eastern seaboard of the state, with the impact reducing to the south west of the state.

Annual impact per ML of predicted dam volume is highest in catchments with consistent streamflows and relatively low intra and inter-annual variability in flows. In these catchments, dams would be consistently filled each year by catchment runoff and the estimated demand and evaporation losses could be consistently taken each year from the dams, impacting upon the streamflow. By contrast, in a catchment with highly intermittent catchment runoff and large interannual variability the farm dams would often be empty within the STEDI model and during those periods they would not be having any impact. This study has adopted a consistent demand factor of 0.5 across Queensland and the same regression equation for estimating local catchment area in all catchments across the State, which may be producing some artefacts in the drier catchments with more intermittent flows. In those drier catchments, it may be that the actual demand factor is less than 0.5 and the local catchment area upstream of each stock and domestic dam is larger than in the rest of the state.

Key results of the regionalisation are presented in Figure 1 and Figure 2. Figure 1 presents the regionalised volumetric impact of dams per unit area (ML/km^2) in each reporting area, while Figure 2 presents the regionalised volumetric impact of dams per volume of dams in the reporting area (ML Impact/ML predicted dams).

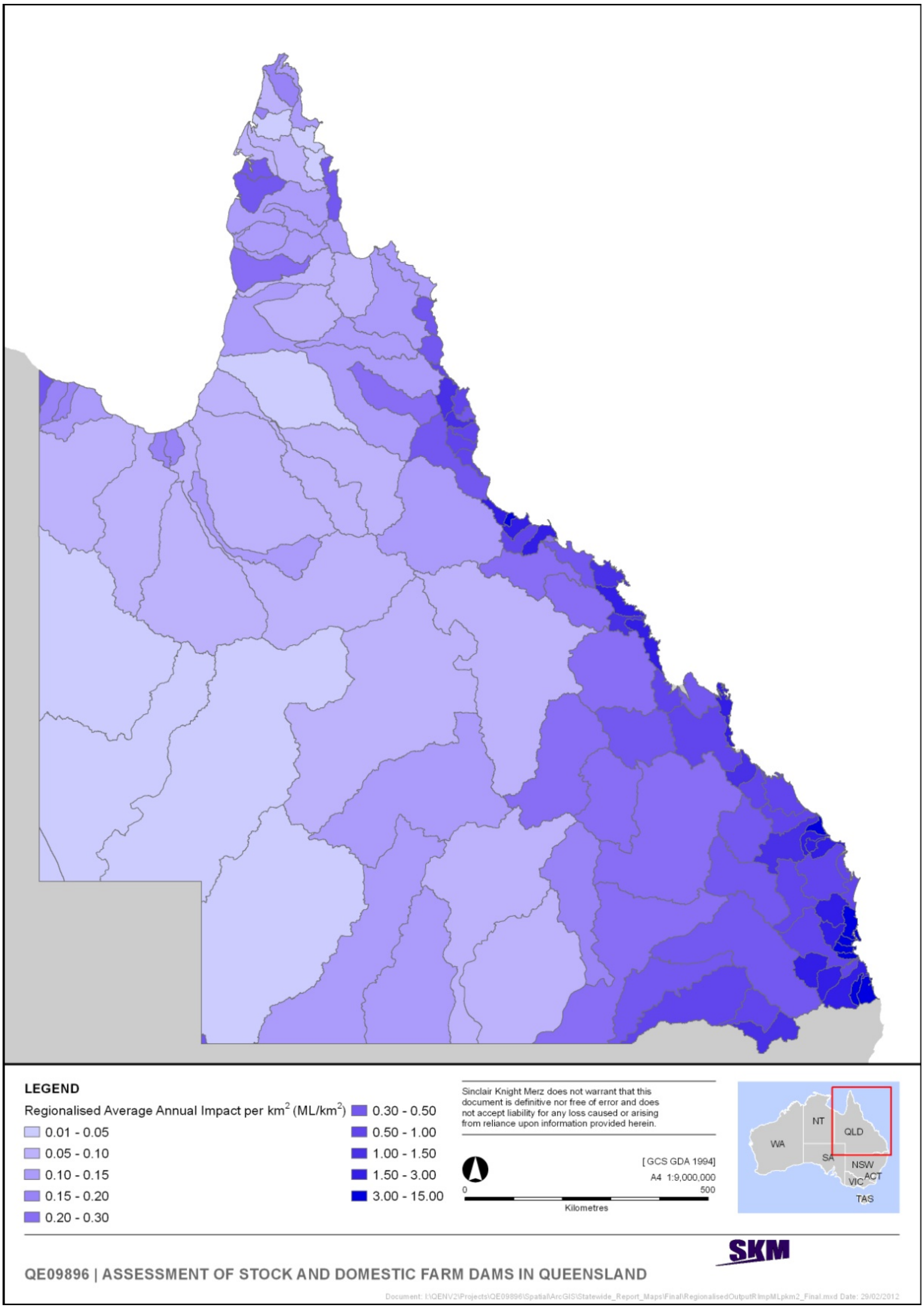

Figure 1 Map of the regionalised volumetric impact of dams per unit area (ML/km²) in each reporting area

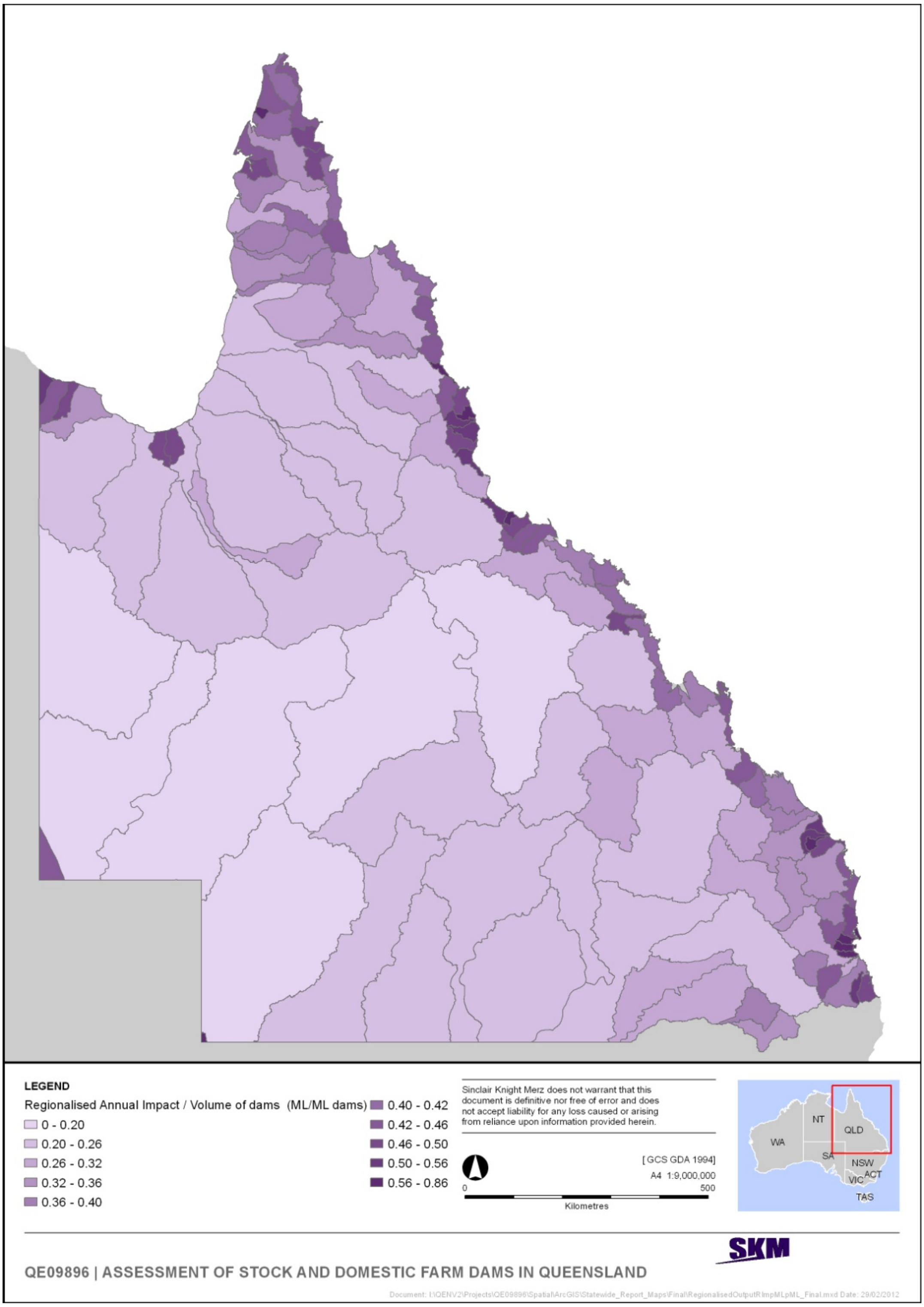

Figure 2 Map of the regionalised volumetric impact of dams per volume of dams in the reporting area (ML Impact/ML predicted dams)

Uncertainty and sensitivity

Overall uncertainty in estimates of impact on mean annual flow depends upon the method applied to come up with that estimate. In the MDB and south east Queensland, there is a readily available data set of digitised farm dams that captures the dams across this area. If a STEDI model were applied to flow data in a catchment where digitised data was available, the estimates of mean annual impact with 5% and 95% probabilities of exceedance would be from 18% lower to 22% higher than the best estimate of the mean annual impact established from the model. The dominant contributor to this overall uncertainty in a modelled catchment with digitised farm dams was from the surface area to volume relationship, which on its own results in a range from -15% to +17% of the best estimate value. The next largest contributors to the overall uncertainty in a catchment with digitised farm dams are in identifying stock and domestic dams from other dam types and in adopting a regional equation to estimate the total local catchment area upstream of the dams.

In areas where there is no digitised data set of farm dams, the impacts can still be modelled using STEDI but in that case a regional equation is required to estimate the total volume of stock and domestic farm dams and then a probability distribution is required to apportion that total volume into a number of farm dams by storage capacity. When this approach is used the overall uncertainty range (5% and 95% confidence limits) ranges from -60% to +160% of the best estimate value. The dominant contributor to this overall uncertainty is in the estimation of the total volume of dams using the regional regression equation, which results in a range in mean annual impacts (90% confidence interval) of -50% to +190% of the best estimate value. This demonstrates the value of digitising the extent of farm dams in an area, which very considerably reduces the uncertainty range in the estimate of mean annual impact in an area.

In areas where there is no digitised data set of farm dams and where a fast estimate of the impact of stock and domestic farm dams on mean annual flow is required, without running STEDI models, a rapid assessment regionalisation equation was adopted, as given in Equation 7.

Equation 1 Regionalisation equation for the impact of farm dams

$$\text{Annual volume of dam impact} = 2.85233 \times \frac{\text{predicted volume of dams}^{0.974585}}{\text{catchment area}^{0.21619}}$$

The confidence limits in mean annual impact associated with applying this equation with 5% and 95% probabilities of exceedance were -66% and +198% of the best estimate value. In other words, if the rapid estimate equation is applied without digitised farm dam data available then the 90% confidence limits cover a range between 1/3 and 3 times the true value. Applying a STEDI model to estimate the impact using an estimate of the total volume of stock and domestic dams will reduce this uncertainty somewhat but to achieve considerable reductions in this uncertainty, digitisation of farm dams in the area of interest would be required.

Priority areas for investment to reduce uncertainty flow from the results presented above. If an accurate estimate of the impact of farm dams is required for a particular area and there is not a comprehensive data set of digitised farm dams available then the most effective means of reducing this uncertainty is to digitise the extent of farm dams from aerial imagery of appropriate resolution. These digitised dams then should be run through a specific farm dam water balance model, such as STEDI, to estimate the impact on the water resource.

If digitisation and farm dam water balance modelling has already been performed in a particular area, as is the case in the 26 modelling catchments run in this study with digitised data available, then the most effective means of reducing the residual uncertainty would be by increasing the sample size of dam and regional coverage of dams used to estimate the surface area to volume relationship. Smaller reductions in overall uncertainty may also be delivered by further survey of landholders and/or metering a sample of stock and domestic farm dams to provide a more accurate estimate of usage from dams; or in re-estimating the local catchment area upstream of dams from a larger spatial data set.

Temporal trends in the volume of stock and domestic dams

A historical record of stock and domestic farm dam construction was developed based on an analysis of historical aerial imagery for 15 trial areas. Some areas were found to have a greater number of historical records available than others, and this provided more accurate estimates in those areas. This method is appropriate for identifying when dams are constructed, although the availability of data can vary between regions.

Overall, the results presented above show that population density can be a very good predictor of stock and domestic dam volume in areas of high population growth and also in areas of medium population growth. In areas of low population growth population density is not a good predictor of stock and domestic dam volume.

It is recommended that DERM investigate this relationship further, over a range of geographic areas and particularly where peri-urban development is known to be occurring.

Recommendations for improvement

Six methods were proposed to improve the existing input estimation methods. Three were considered to provide a moderate return for a low cost, reducing the uncertainty associated with these methods by approximately half. These were the surface area to volume relationship, the local catchment area and the demand factor, and they are recommended to DERM for further consideration.

Two of the methods were considered to be expensive to undertake, relative to their benefit. These were the identification method, the regional volume estimation. Improving the size distribution provides only a low return for a low cost and is not considered worth investigating further.

Trends in farm dam development

Trends in the development of stock and domestic farm dams were assessed through an analysis of historical aerial imagery for 15 trial areas. While this method is appropriate for identifying when dams are constructed, the availability of data can vary between regions. The analysis found a generally consistent trend of development, with low rates of development through the 1950s and 1960s, increasing rates of development through the 1970s and 1980s, with a dramatic increase seen through the 1990s. After 2000 the rate of development has slowed slightly, but is still quite high.

The historic trend in dam construction was then compared against population growth in the corresponding Local Government Areas (LGAs). This found that population density is a very good predictor of stock and domestic dam volume in areas of high population growth and also in areas of medium population growth. In areas of low population growth population density is not a good predictor of stock and domestic dam volume.

It is recommended that DERM investigate this relationship further, over a range of geographic areas and particularly where peri-urban development is known to be occurring, which is known to have an influence on stock and domestic dam development

.

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 the outcomes of the *Statewide Assessment* are presented in two reports: *Report 1 – Methods and Inputs* and this report, *Report 2 – Hydrological 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. The modelling was completed using 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 modelling results and sensitivity analysis of the Statewide Assessment. This report also presents a statewide regionalisation of the modelling results and a trends analysis of farm dam development over time.

1.2. Format of the report

The format of this report is as follows:

Section 2 Provides a summary of previous studies.
Section 3 Describes the study method.
Section 4 Provides a summary of the developed inputs to the modelling.
Section 5 Describes the baseline modelling results and regionalisation of outputs.
Section 6 Describes the sensitivity modelling conducted.
Section 7 Provides a summary of proposed improvements in future work.
Section 8 Discusses the assessment of the trends in farm dam development.
Section 9 Presents a description of the limitations of this study.
Section 10 Provides conclusions and recommendations.

2. Previous studies

Previously there have been a number of farm dam investigations completed at similarly large geographic scales covering the Murray Darling Basin (MDB), South Australia, Victoria and Western Australia. These have all had different aims, and have built on understanding gained in previous work. More relevant previous work has been summarised below.

There are also a number of projects currently underway in Victoria and Western Australia to better quantify the impacts of farm dams in those areas.

2.1. The farm dams component of the MDB Sustainable Yields Project

The MDB Sustainable Yields Project (MDBSYP) was completed in 2008 by CSIRO, and considered future water availability across eighteen different reporting regions of the MDB and for the MDB as a whole. The *future impact* of farm dams was considered as a part of the study.

To consider the impact of future farm dams, the MDBSYP produced:

An estimate of the existing (circa 2006) storage volume of catchment farm dams across the MDB. For this study farm dam volumes in the eastern parts of the Queensland MDB were estimated from an early release version of the Geoscience Australia man made water bodies spatial layer. This layer covered the upper Condamine basin and most of the Queensland part of the Border Rivers basin. For the rest of the Queensland MDB, the storage volume of farm dams was estimated by projecting rates of farm dam developments for similar landuses from the part of the state that was captured in the early Geoscience Australia farm dams layer;

A projection of the future growth in farm dam storage volume over the period to 2030. For Queensland, the assumption made in the project was that the growth in farm dam volume would be driven by stock and domestic dams and that the growth rate of those would be directly proportional to the projected growth in population in the Queensland MDB;

A projection of the additional impact of these future farm dams on the runoff from each of 450 subcatchments across the 18 reporting regions of the MDB, under three projected climate change scenarios (a wet, medium and dry future climate in 2030).

The focus of the MDBSYP was to estimate the impacts of *future farm dams*. To do this a number of simplifying assumptions were made (Chiew, et al., 2008).

Table 1 and Table 2 show the summary results for farm dam volumes and impacts across the reporting regions that are completely or partially within the Queensland MDB (note that for this study ‘farm dams’ refers to be stock and domestic dams as well as other purpose dams). The Border Rivers result is an aggregated total for the Queensland and New South Wales parts of that reporting region. For the Queensland MDB, the estimated existing volume of farm dams was 463 GL (including 79 GL of farm dams in the QLD part of the Border Rivers reporting region). The projected increase in the storage volume of farm dams for the four reporting regions that were completely within Queensland (excluding the Border Rivers) was 12 GL (or 3%) for the period to 2030. This additional 12 GL of dams was projected to cause a reduction of 7 GL, which represents 0.11% of the overall mean annual catchment runoff. Note that the Border Rivers results presented below are an aggregated total for the Queensland and New South Wales components, since separate results were not provided by SKM (2007).

Table 1 Existing and projected volume and density of farm dams*, by reporting region, from MDB Sustainable Yields Project (Sinclair Knight Merz, 2007).

Reporting Region	Area (km^2)	Estimated Existing Volume (GL)	Estimated Existing Density (ML/km^2)	Projected Volume increase by 2030 (GL)	Projected increase as % of existing dams	Projected density increase by 2030 (ML/km^2)
Paroo	35,587	0	0.00	0	0%	0.00
Warrego	76,615	75	0.98	0.05	0%	0.00
Condamine-Balonne	136,642	263	1.92	10	4%	0.08
Moonie	14,662	46	3.16	2	4%	0.13
Subtotal for 4 regions	263,506	384	1.46	12	3%	0.05
Border Rivers (includes NSW)	43,633	156	3.57	13	8%	0.29

*note that the MDBSY project refers to stock and domestic and other purpose dams as farm dams.

Table 2 Summary of modelled mean annual reductions in catchment runoff results for the scenario that includes medium case projected impacts of climate change to 2030, from MDB Sustainable Yields Project (Sinclair Knight Merz, 2007).

Reporting region	Existing volume of dams (GL)	Projected additional dams (GL)	Runoff for the $C_{+Plantations}$ scenario (mm)	Reduction in runoff over the reporting region (mm)	Reduction in runoff over the reporting region (GL)	Percentage of impact from $C_{+plantations}$ to Dmid
Paroo	0	0	14.56	0.00	0	0.00%
Warrego	75	0.05	29.20	0.00	0.1	0.00%
Condamine-Balonne	263	10	17.31	0.03	5	0.20%
Moonie	46	2	15.61	0.11	2	0.68%
Subtotal for 4 regions	384	12	20.30	0.02	7	0.11%
Border Rivers (includes NSW)	156	13	29.37	0.32	14	1.09%

2.2. Intercepting Activities Project

A recent study undertaken by SKM for the National Water Commission (NWC) provided a "Baseline Review of Surface Water Intercepting Activities" (Sinclair Knight Merz, CSIRO and Bureau of Rural Sciences, 2010),and part of that study estimated the impact of stock and domestic farm dams on streamflow across Australia. The aim of the intercepting activities project was to understand the impact of water intercepting activities outside the existing licensing frameworks across Australia (Sinclair Knight Merz, CSIRO and Bureau of Rural Sciences, 2010). With respect to farm dams, the study produced:

A broad estimate of the storage volume of existing (c 2007) farm dams across Australia (including the MDB);

A broad estimate of the impact on streamflows of existing farm dams across Australia;

A broad prediction of the storage volume of farm dams in 2030 across Australia; and

A broad prediction of the impact on streamflows of farm dams in 2030 across Australia.

The estimates and predictions produced from this study are appropriate to use as order of magnitude indications, but it was recognised during this study that more detailed estimates are possible using hydrological modelling techniques.

Sinclair Knight Merz, CSIRO and Bureau of Rural Sciences (2010) estimated that the total volume of stock and domestic farm dams in Queensland in 2008 was 351 GL and it predicted expansion in peri-urban development over the next 7 to 20 years would increase the total volume of farm dams across Queensland to 530 GL by 2030. It should be noted that the above estimates were based upon a coarse and rapid assessment, due to a lack of available data on farm dam volumes for that study. SKM (2009) explain the approach used to provide these estimates as, "Median dam volume densities (ML of dam storage volume per km² of area) for each landuse for northern NSW surface water management areas were used as a guide to determine farm dam volumes in Queensland."

The apparent inconsistencies between the estimated volume of 463 GL as the total volume of farm dams in the Queensland MDB from the *Murray Darling Sustainable Yields Project* (Sinclair Knight Merz, 2007) and the 351 GL estimate for the whole state in the *Intercepting Activities Report* (Sinclair Knight Merz, CSIRO and Bureau of Rural Sciences, 2010) can be explained by the 2007 study (for the MDB) including all farm dams, regardless of size, whilst the 2010 study only considered dams less than 5 ML in storage capacity. In both studies, the farm dam capacity estimates were largely based upon extrapolating densities of farm dam development for similar landuses from a relatively small sample area of Queensland or Northern NSW. Due to the methods applied, there is considerable uncertainty attached to the estimates of farm dam volumes provided by both studies.

Sinclair Knight Merz (2011a) considered the hydrological impact of farm dams across the MDB by running the STEDI model in 162 gauged catchments across the MDB. The report only presents results for changes in the Sustainable Rivers Audit hydrology score (an index between 0 and 1) rather than more easily comparable numbers such as total farm dam volumes or mean annual impacts on stream flow.

2.3. Modelling of farm dams in South Australia using WaterCress

The South Australian Department for Water (SADFW) and its predecessor (Department of Water Land and Biodiversity Conservation) have used the WaterCress model (Clark, Pezzaniti, & Cresswell, 2002) extensively over the last eight years to estimate the hydrological impact of farm dams in the Mount Lofty Ranges region of South Australia (Alcorn M., Surface Water Assessment of the Bremer River Catchment, 2008; Alcorn M., 2010; Alcorn, Savadamuthu, & Murdoch, 2008; Alcorn M., 2006; Savadamuthu, 2003; Savadamuthu, 2004; Savadamuthu, 2006). The catchments of the Eastern Mount Lofty Ranges form part of the Murray Darling Basin. The WaterCress model is very similar in concept to STEDI in its representation of farm dams. The model represents each farm dam as a reservoir and then conducts a water balance computation for each individual farm dam, representing inflows to the dam, losses to evaporation, gains from rainfall directly on the storage, seepage losses and demands extracted from the dam. Demand factors and monthly patterns of demand can be applied to each of the dams in the catchment, in a very similar manner to the way that STEDI works. Although there is scope for inclusion of seepage losses from farm dams within WaterCress, in applying the model SADFW normally ignore seepage losses, which is the same approach that is used with STEDI (Alcorn M. R., 2011). Although Watercress allows for explicit inclusion of stream transmission losses, in the catchments modelled by Alcorn (2011) the large majority of these losses occur in the lower part of each of the modelled catchments, downstream of all of the farm dams.

One of the disadvantages of WaterCress (compared with STEDI) is that the each farm dam must be entered independently via the graphical user interface, which can make it cumbersome to enter a large number of small dams. Users of WaterCress (including Alcorn, 2011) typically work around this difficulty by "lumping" two or more (and often many) individual dams together. Such lumping of dams together can compromise the accuracy of the hydrological impact calculations from the model in some situations when compared to the approach in STEDI of independently modelling each farm dam in the catchment. Lumping of many dams together into one larger "notional" dam will normally result in more efficient capture of inflows to the dam and a lower occurrence of spills from the lumped storage than the STEDI approach of separately modelling the hydrological impacts of many dams.

Alcorn (2011) modelled the impact of 7103 dams with a total storage capacity of 18.4 GL in four catchments of the Eastern Mount Lofty Ranges area, which is within Murray Darling Basin.

About 90% (or 6545) of the modelled dams are not licensed and therefore only used for stock and domestic purposes, representing a total estimated storage capacity of 11.7 GL. The remaining 558 dams included in Alcorn (2011) were licensed for irrigation use (or combined irrigation and stock and domestic use). The total impact on end of system mean annual flows for the four catchments modelled by Alcorn (2011) was 11.5 GL/year, which represented 16% of the average mean annual flow at the end of the system.

2.4. Modelling Studies on impacts of farm dams in other Australian states

A number of other studies have been completed to assess the impacts of farm dams on water resources in other Australian states. Several of these studies have used the hydrological model STEDI that will be used in this current project, or its predecessor models TEDI and CHEAT. These projects include: the Moorabool River catchment in Victoria (Sinclair Knight Merz, 2003); the assessment of sustainable diversion limits for catchments across the whole of Victoria (Sinclair Knight Merz, 2004); Wilyabrup and Lefroy Brook catchments in South West Western Australia (Sinclair Knight Merz, 2008); several catchments in the MDB (Integrated Catchment Assessment and Management Centre (Australian National University) and Sinclair Knight Merz, 1999); and ongoing studies into the impacts of stock and domestic farm dams in Victoria and Western Australia.

3. Study method

3.1. Overall approach

The statewide assessment included five major steps as illustrated in Figure 3. The first step has been largely described in *Statewide Assessment: Report 1 – Methods and Inputs*, and included improving the surface area to volume relationship, regionalising the volume of farm dams, improving the understanding of local catchment area in Queensland and assessing stock and domestic farm dam demands. A short summary of the outcomes has been included in this report. Preparing the inputs to STEDI involved applying all the improved relationships to the modelling catchments chosen as a part of the *Pilot Study* and preparing all the streamflow and climate inputs.

A baseline STEDI model was then run for each of the 55 modelling catchments, representing the best available input data. A number of scenarios were also modelled (for 26 of the modelling catchments) to assess the sensitivity of the results to the input data. Once the STEDI modelling was completed, a regression analysis was undertaken to predict the impact of stock and domestic farm dams for all areas of Queensland, not just those 55 modelling catchments that were modelled. This regression equation was applied to all 121 reporting areas, resulting in a prediction of farm dam impact in each reporting area.

The results of the sensitivity modelling, the baseline scenario and the regression equation have been analysed, and the uncertainty in the predicted values has also been considered. There is a focus in the report on the improvements made to the relationships and the resulting impact on farm dams. However, the underlying purpose of the report is to provide a method that can be applied for the whole of Queensland to identify potentially significant areas of farm dam development and to provide recommendations for potential investments that can be made to improve the certainty of the predicted impacts.

Figure 3 Summary of main tasks for this phase of the project

3.2. What is a 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). In other words, catchment farm dams only harvest water directly from their own catchment and are not supplemented by any other water. Catchment farm dams can be used for irrigation, stock and domestic purposes, and any number of other water uses. For this project, only the impact of stock and domestic water use from farm dams has been considered.

3.3. What is STEDI?

STEDI is a piece of software that can be used to model the impact of farm dams on streamflow. STEDI Version 1.20 was used for this project and 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 4.

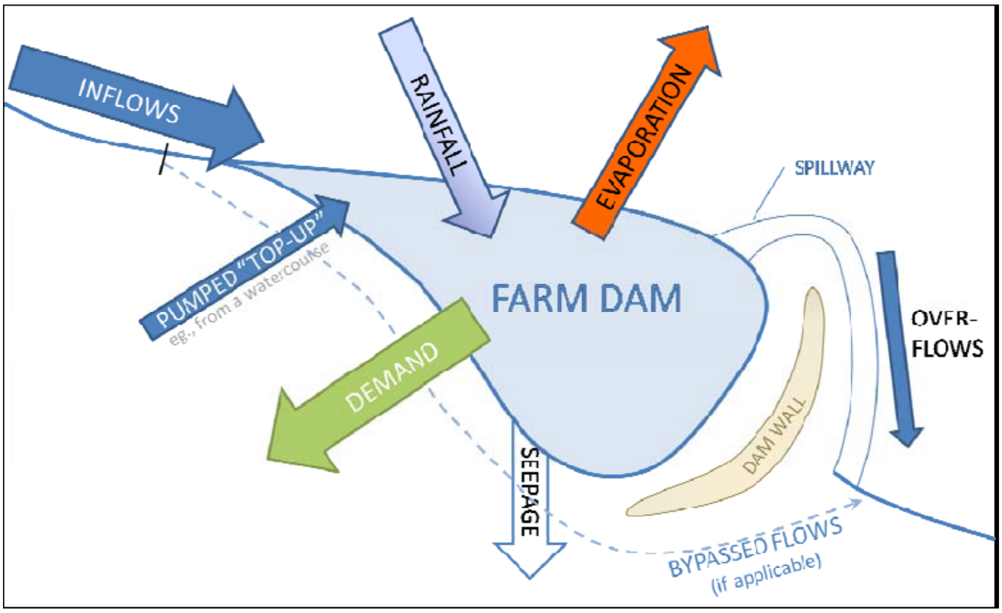

Figure 4 Simplified water balance for a farm dam (Sinclair Knight Merz, 2011c)

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. 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.

3.4. Inputs required for STEDI

For this study the STEDI models require the following inputs:

1. Streamflow, climate and farm dams GIS layers;
2. Identification of stock and domestic dams;
3. Estimated number and volume of farm dams;
4. The size distribution of farm dams;
5. The local catchment area relationship; and
6. Estimated demands.

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 5 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 number and volumes of stock and domestic dams.

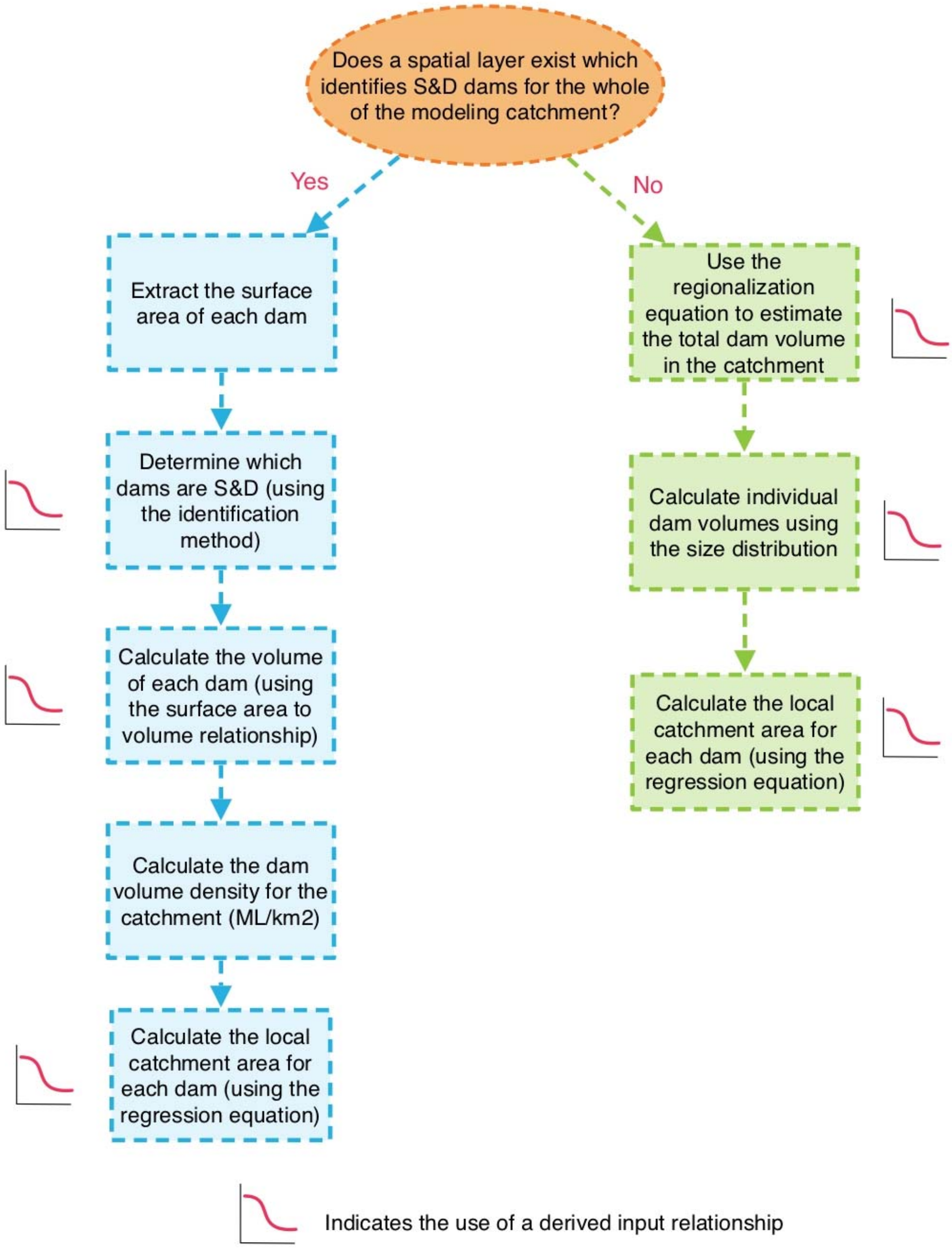

Figure 5 Procedure for estimating the number and volume of stock and domestic dam for STEDI

4. Summary of developed inputs

The following section summarises the input estimation methods developed for use in this study. Further detail is provided in the *Statewide Assessment: Report 1 – Methods and Inputs*.

4.1. Site selection

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.

DERM provided a list of possible streamflow gauges suitable for use in farm dam modelling. The final 55 modelling catchments were chosen from these to represent a wide variety of landuse characteristics, climatic and geographic areas as well as the areas with the most farm dam information was available. A map of the final modelling catchments is presented in Figure 6. As there was a specific focus on the south east of Queensland and upper parts of the Murray-Darling Basin, there is a higher density of modelling catchments in that area than in the rest of Queensland.

4.2. Streamflow inputs

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 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 which is likely to be experienced in each catchment.

4.3. Climate inputs

While the inflow from rainfall on the surface is clearly defined, there are a number of evaporation and evapotranspiration parameters that could be used to define the evaporative l from farm dams in the STEDI water balance model. As per Wang et al. (2009), the "*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*". Therefore point potential evapotranspiration (PPET) was considered the most appropriate evaporation type to use.

Rainfall and evapotranspiration data have been sourced at the location of the streamflow gauges (i.e. 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. It was supplied previous to the revision of the rainfall normalisation procedures in SILO on 26 January 2012. The PPET time series that was extracted from SILO was computed within SILO using Morton's 1983 complementary areal relationship evapotranspiration model as described by Wang et al. (2009).

4.4. 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, the DERM referable dams layer, the DERM extended layer, and the digitised dam layers.

There is no reliable way to identify if a dam is stock and domestic from any of the current farm dam spatial layers; therefore a method using a number of different inputs was developed to identify stock and domestic dams. For each of the layers the following steps and decisions were undertaken:

Step 1: The volume of each dam was calculated, if the dam was bigger than 250 ML it was considered 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 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 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, it was excluded.

4.5. Farm dam volumes

The volume of farm dams have been observed or estimated for all modelling catchments (Figure 6 and Figure 7) and reporting areas (Figure 8). The methods and assumptions that have been used to collate these numbers are described briefly in the following sections, and in more detail in the *Statewide Assessment: Report 1 – Methods and Inputs.*

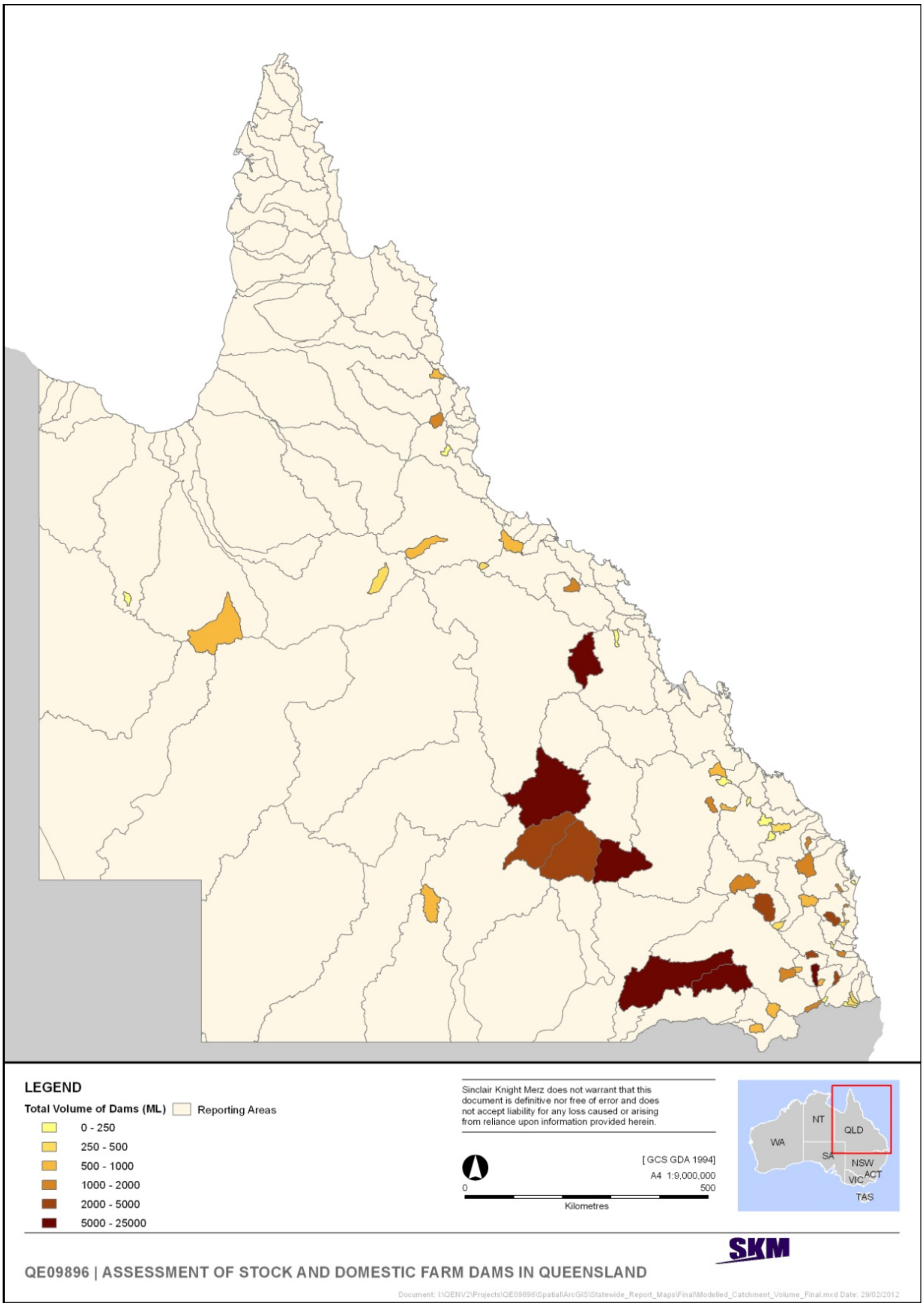

Figure 6 Volume of farm dams estimated in modelling catchments

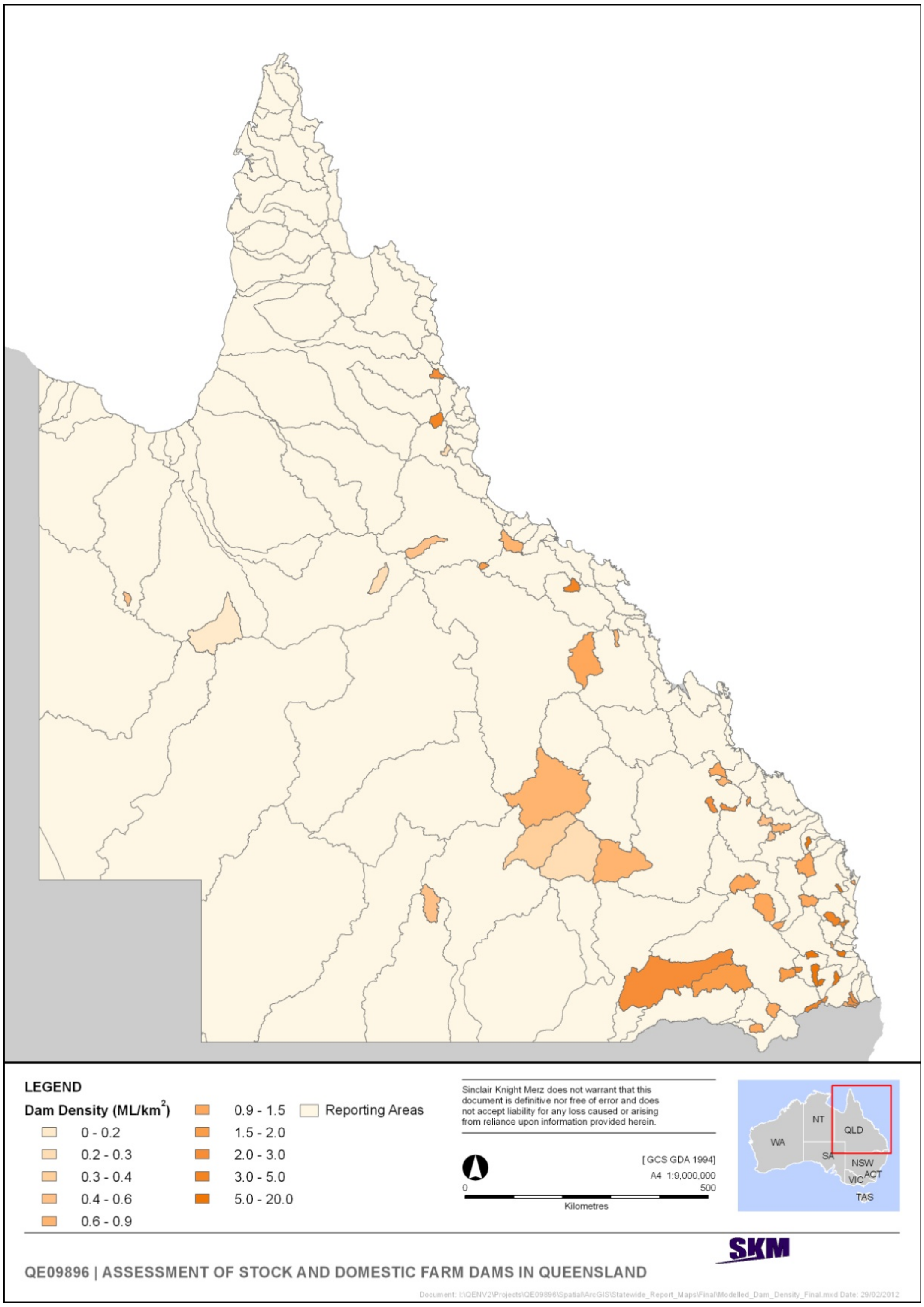

Figure 7 Volume density of farm dams estimated in modelling catchments

4.5.1. Dam surface area to volume relationship

A farm dam surface area to volume relationship was developed in order to estimate the volume of individual dams from a known surface area. 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 fitted regression relationship is provided as Equation 2. A more detailed description of method is provided in the *Statewide Assessment: Report 1 – Methods and Inputs.*

Equation 2 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 (m^2)*

4.5.2. Regionalisation of volumes

While there is reliable information on the number and surface area of farm dams in specific areas of Queensland, there are significant areas where very little is known about the volume of farm dams. In these areas a regionalisation equation was used to estimate the total dam volume.

To develop the regionalisation method, catchment characteristics were calculated for all the areas which had good farm dam information, using the DERM extended data, the MDB data and digitised area. This data represents 53 independent areas with a good estimate of farm dam numbers and volumes, and comprises a mixture of geographic scales including complete modelling catchments, complete reporting areas, the remnant part of reporting areas and some of the digitised areas. A more detailed description of method is provided in the *Statewide Assessment: Report 1 – Methods and Inputs*.

A regression relationship was developed based on the number of referable dams, the number of people in the area and the mean annual areal actual evapotranspiration, and is presented in Equation 3. This equation has been applied to the reporting areas and is illustrated in Figure 8.

Equation 3 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:

Number of referable SD dams *= the number of dams in the DERM Referable dams layer, in SD landuses in a particular catchment. Note that this has been capped at a minimum of 0.5 dams per catchment, or half of the minimum number.*

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*

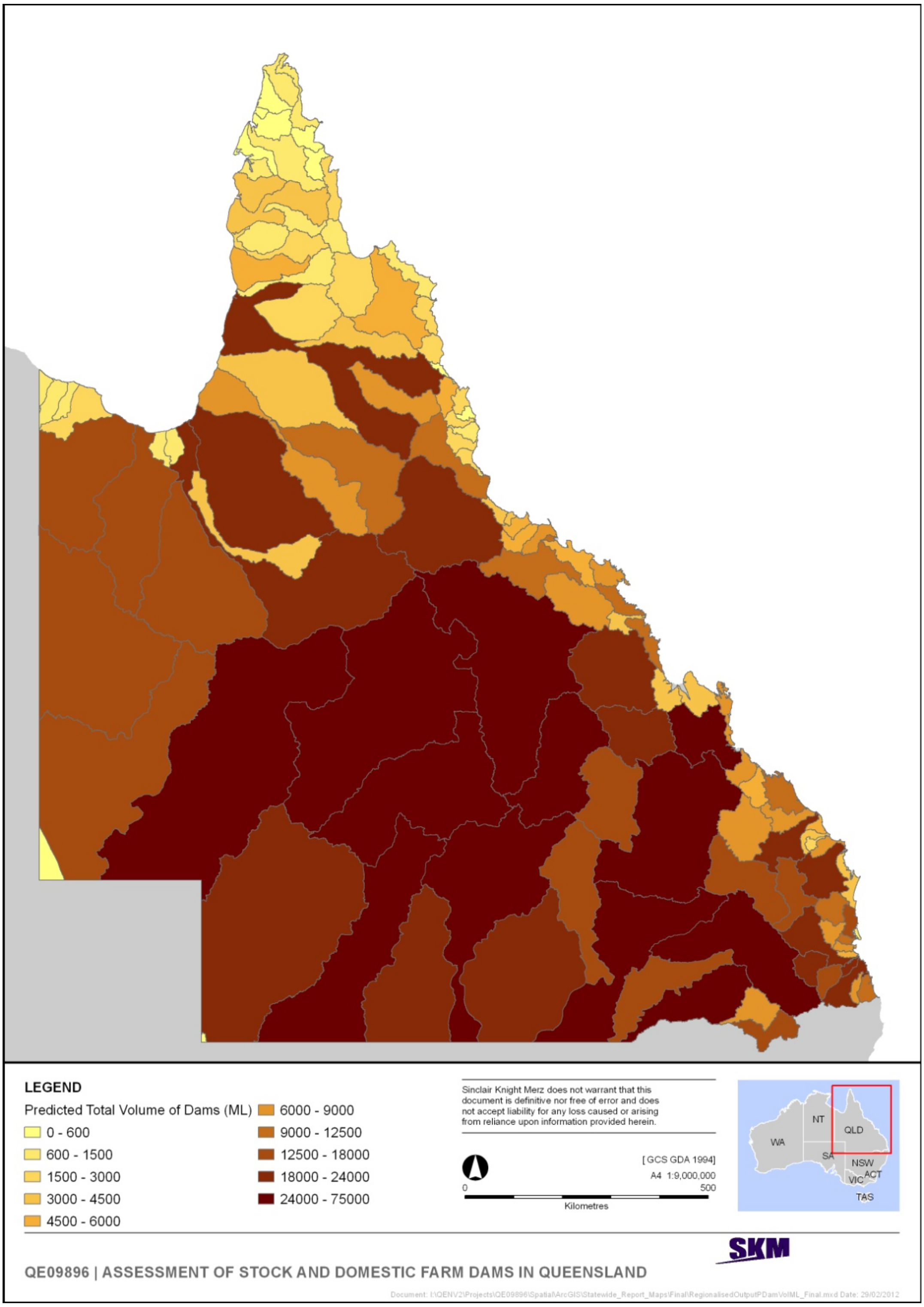

Figure 8 Volume of farm dams estimated in reporting areas

4.5.3. Size Distribution

For those modelling catchments with predicted farm dam volumes using Equation 3, a size distribution was used within STEDI to derive a representation of individual dams in the area for modelling purposes. A more detailed description of method is provided in the *Statewide Assessment: Report 1 – Methods and Inputs*.

Three 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, the DERM extended dam layer and the digitised areas. The adopted distribution is presented in Table 2.

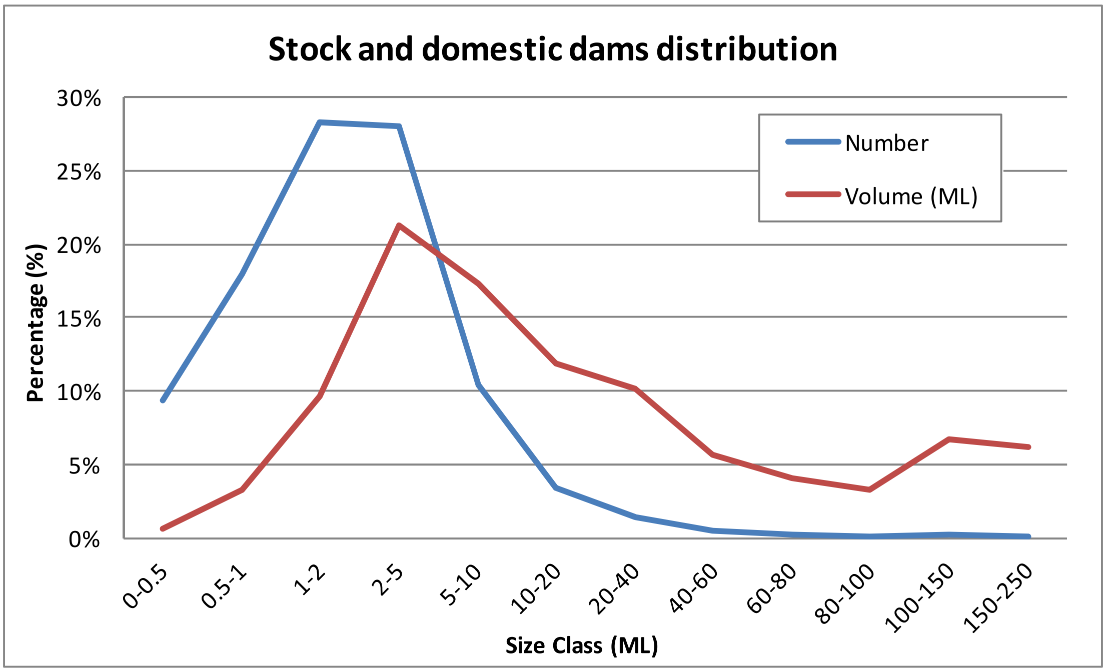

Figure 9 Final Queensland stock and domestic dams distribution

4.6. Farm dam catchment areas

In STEDI, the local catchment area is used to calculate the proportion of runoff from the whole catchment that flows through each dam. 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.

The local catchment area for each dam could potentially be estimated directly from spatial data, such as the GA waterbodies layer and a high resolution DEM, however this method is extremely time consuming and inefficient to apply over a large scale. Hence, for studies of farm dam impacts across large regions such as this one, aa regional equation is used to estimate the local catchment area upstream of dams. The regional equation estimates the total local catchment area on the basis of a number of key factors within the catchment, which may affect the proportion of the catchment regulated by farm dams.

A multiple regression analysis was 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. A more detailed description of method is provided in the *Statewide Assessment: Report 1 – Methods and Inputs*.

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 (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)*

4.7. Farm dam demands

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 nature of usage from stock and domestic dams is such that the average usage from a large number of dams would be relatively consistent from month to month within a year and from year to year and this conclusion was consistent with the results of a survey of farmers that was undertaken for this study. 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 F in *Statewide Assessment: Report 1 – Methods and Inputs*.

For this study, the repeating monthly pattern method was applied to estimate demands, with the demand on each day of the year represented in the STEDI model as 1/365 of the annual demand for the dam derived from the demand factor.

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.

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5. Modelling the impact of farm dams

In order to assess the hydrologic impacts of stock and domestic farm dams across Queensland modelling was undertaken in 55 catchments, the results of which were then regionalised across the state. Modelling was undertaken using a software package called STEDI, which stands for the Spatial Tool for Estimating Dam Impacts, and used the inputs described in Section 4.

5.1. Results of baseline modelling

Key outputs of the baseline modelling are presented in tables in 0, showing the average annual impact and seasonal impacts. However, these results are difficult to interpret from a table and a number of results have therefore been mapped instead.

Table 3 presents a summary of the range of modelling outputs, across the 55 modelled catchments. This shows that there is considerable variation between the catchments, both in terms of inputs and outputs.

Table 3 Summary of baseline modelling outputs

	Mean	Min	Max
No. of dams modelled	419	23	3109
Volume of dams (ML)	1891	58	24282
Average annual impact (ML)	1006	21	5738
Average annual impact (%)	2%	0%	17%

The volumetric impact on mean annual flow is illustrated in Figure 10. This shows that the highest impact on a total volume basis normally occurs in the catchments with the largest area.

The volumetric impact as a percentage of mean annual flow is demonstrated in Figure 11. This shows that as a percentage of mean annual flow, the highest percentage impact is in the south and south east of the state. With the modelling catchments of Tenthill Creek at Tenthill, Purga Creek at Loamside and the Moonie River at Nindigully having the highest percentage impact on mean annual flow. This is in contrast to the north west, for example the Gilliat River at Gilliat has the lowest percentage impact.

Figure 12 illustrates that the impact of farm dams per square kilometre is the highest in the modelling catchments near to the coast. The modelling catchments in the south west and west of the state have a lower modelled impact per square kilometre of catchment. This was because the catchments further from the coast typically have lower densities of stock and domestic farm dams than those in coastal catchments and because catchments that are further from the coast have more intermittent streamflow regimes, which reduces the efficiency that stock and domestic farm dams were found to have in removing runoff from the system.

The majority of the modelled catchments showed the highest levels of impact in summer, with the second highest level of impact observed in autumn. Similar levels of impact are generally observed in winter and spring (See 0 for maps showing percentage impact per calendar season).

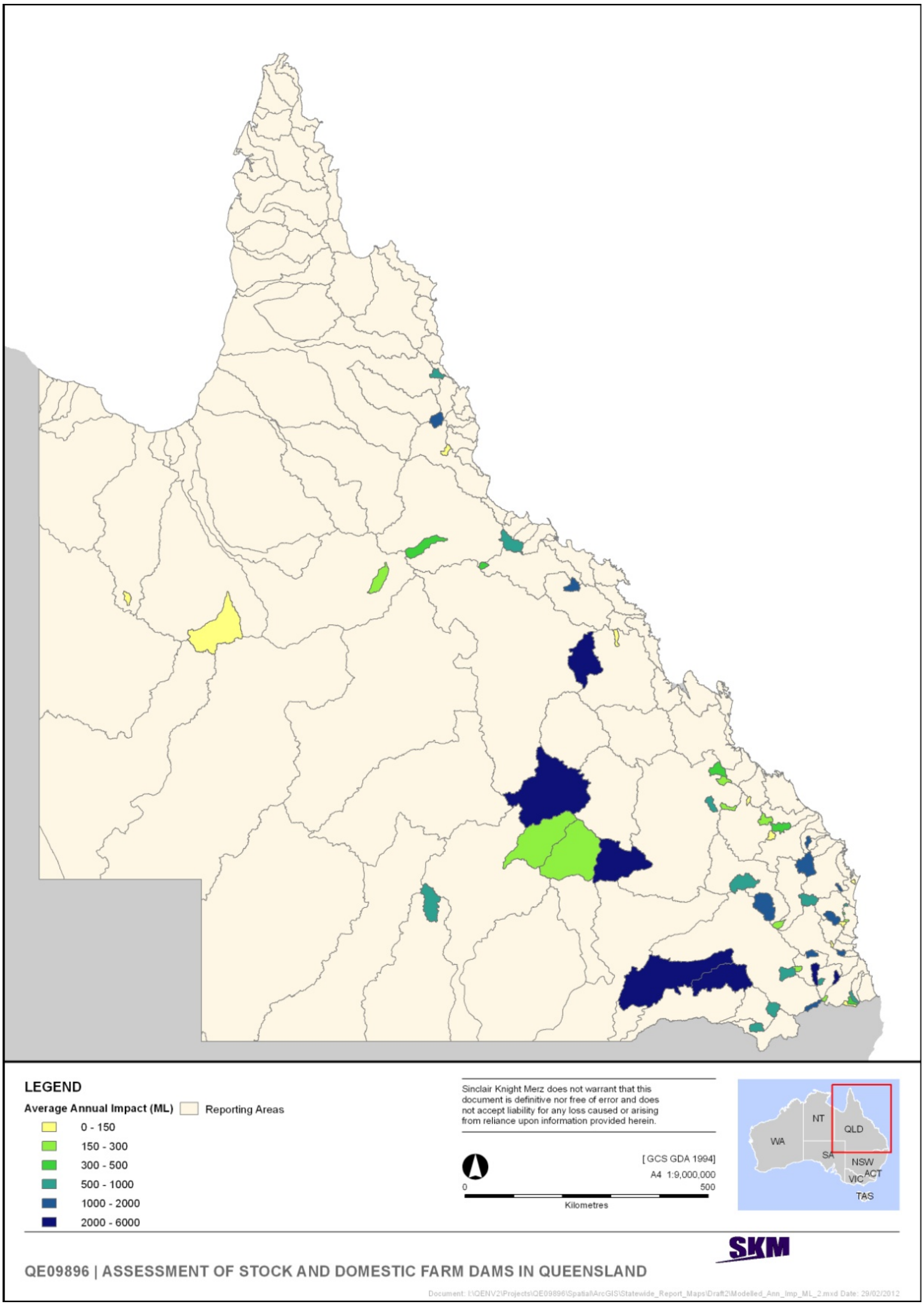

Figure 10 Map of the annual average farm dam impact in ML for each modelling catchment

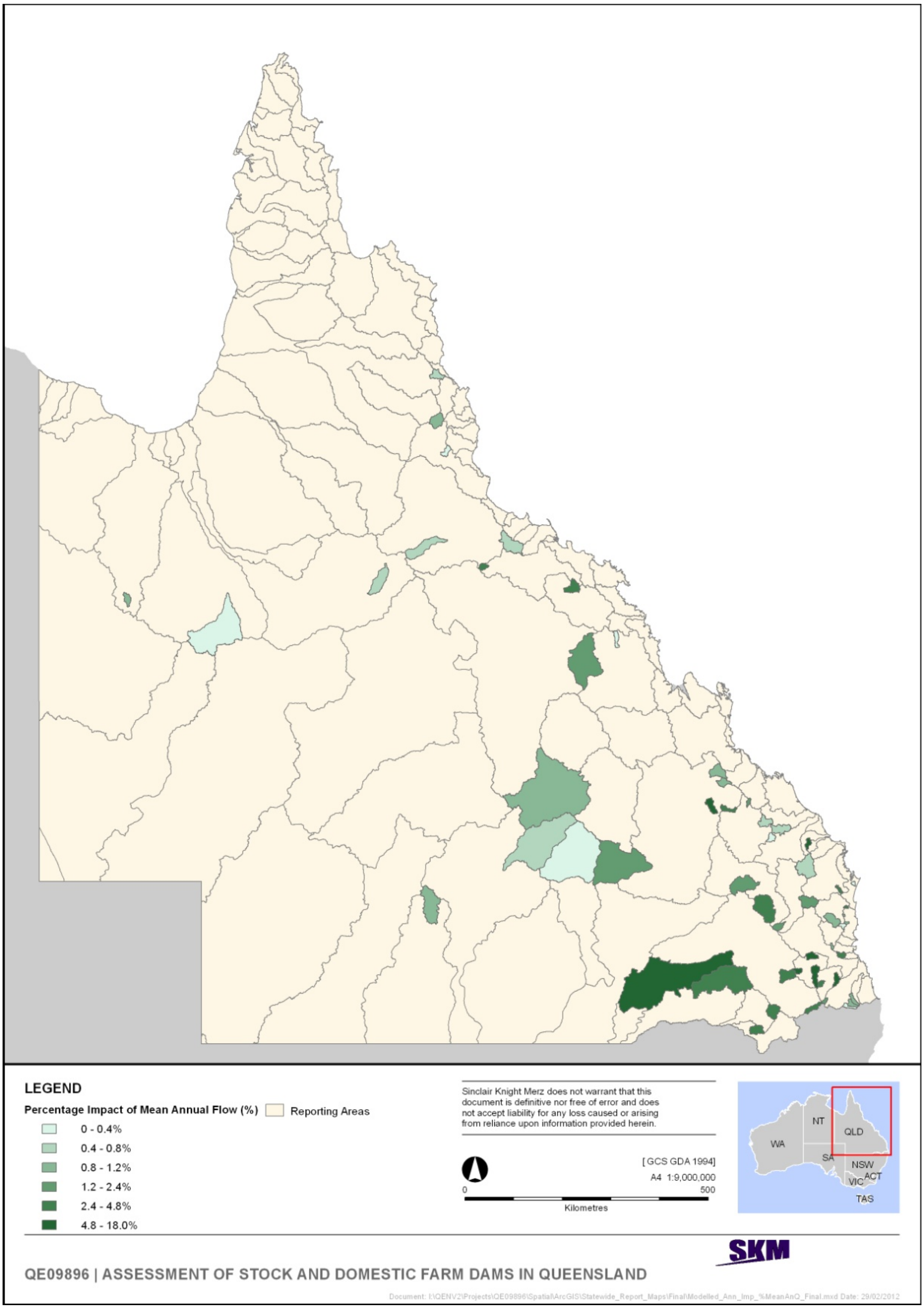

Figure 11 Map of the annual average farm dam impact as a percentage of mean annual flow for the modelling catchments

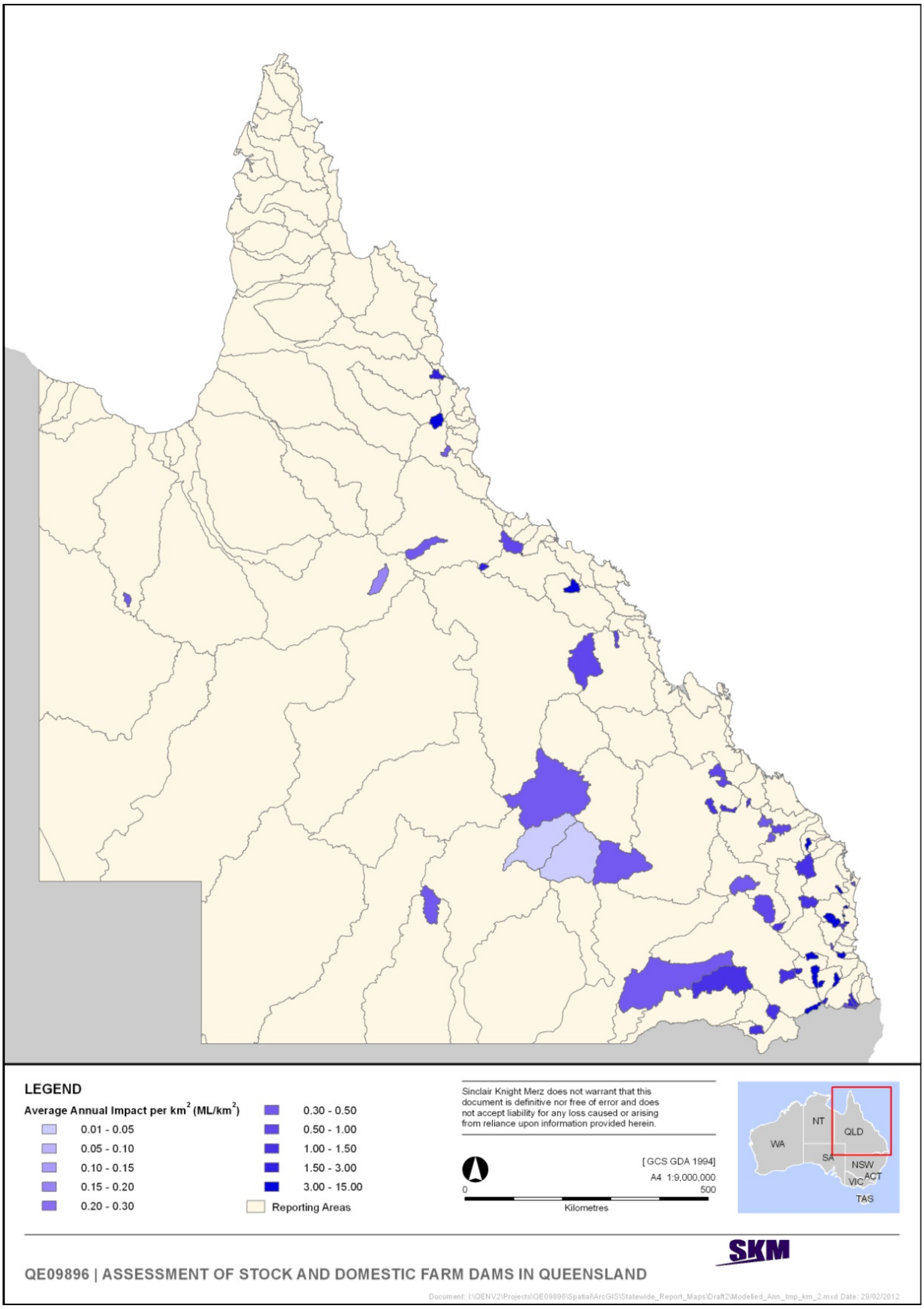

Figure 12 Map of the annual average farm dam impact per square kilometre of modelling catchment

5.2. Regionalisation of impacts on mean annual flow

5.2.1. Method of regionalisation

To estimate the impact of stock and domestic farm dams across Queensland, the impacts from the modelling catchments were used to develop a regression equation that could be applied to all 121 reporting areas.

The same parameters considered in the regionalisation of dam volumes (Section 4.5.2) were assessed as a part of the regression analysis. It was found that the volume of farm dams in each modelling catchment, along with the catchment area were the most relevant characteristics that could explain the impact of farm dams, with little influence from any of the other climatic variables. The resulting equation is presented in Equation 6, with the relevant t statistic and P-value for each of the variables presented in Table 4. These values demonstrate that both variables are statistically significant in the regression analysis.

Figure 13 - Figure 16 demonstrate the relationship between the modelled volumetric impact or impact per unit area in the modelling catchments and the predicted impact using the regression relationship. They show that, particularly in log space, the derived relationship represents the modelled impact well over the majority of the range. Where the modelled impact per unit area is at the upper or lower end of the range, the regionalised equation overestimates the impact per unit area (Figure 16).

Figure 17 and Figure 18 illustrate the volume and density of farm dams predicted using Equation 3 for all the reporting areas. Figure 17 shows that in absolute terms, the predicted volume of farm dams is highest in the reporting regions that are largest in area. When these volumes are normalised by the area of the reporting areas, Figure 18 shows that the dam density is predicted to be highest in the south east of the state reducing in density to the west and north of the state. These figures in turn influence the results of the regression equation discussed in Section 5.2.2.

The uncertainty in using this regression equation to predict the impact of farm dams across Queensland is discussed further in Section 5.2.3.

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Equation 6 Regionalisation equation for the impact of farm dams

$$\text{Annual volume of dam impact} = 2.85233 \times \frac{\text{predicted volume of dams}^{0.974585}}{\text{catchment area}^{0.21619}}$$

Where:

R^2 = 0.77 in logarithmic-logarithmic transformed space
Annual volume of dam impact *= the volumetric impact of farm dams in the reporting area (ML/year)*
Predicted volume of dams *= the volume of dams in each reporting area predicted by* Equation 3 *(ML)*
Catchment area *= the area of the reporting area as calculated using the zonal statistics (km²)*

Table 4 t-Statistics and P-value for coefficients of Equation 6

Coefficient	t Statistic	P-value
Log_e(Predicted volume of dams (ML))	11.75	2.97E-16
Log_e (Catchment area (km²))	-3.003	0.004

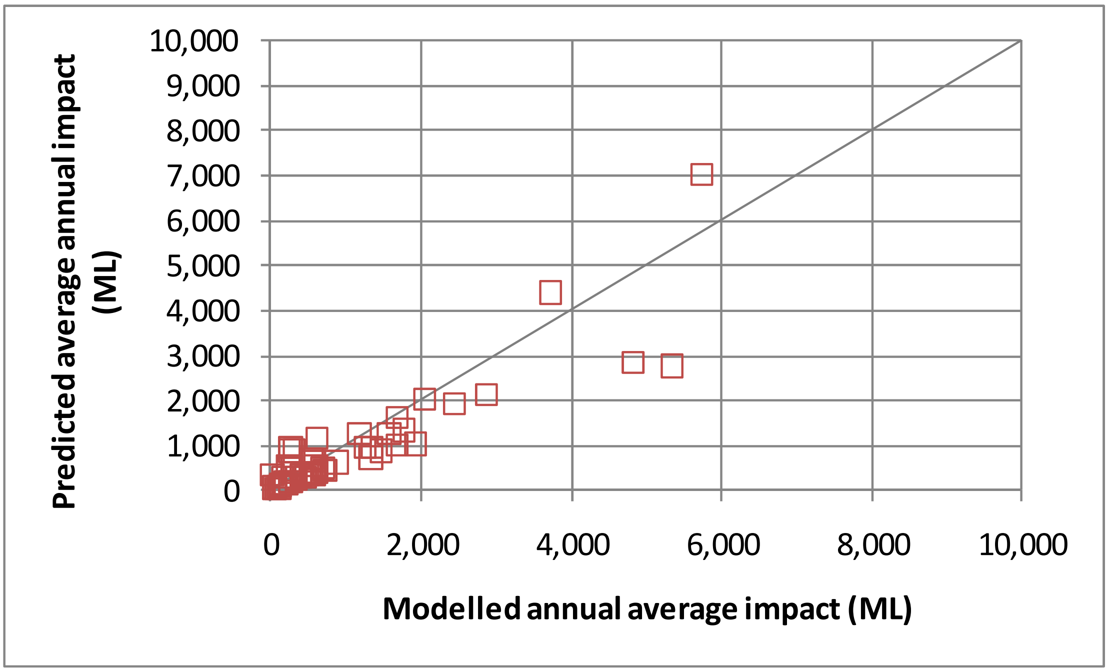


Figure 13 Modelled annual average impact (ML) compared to the predicted average impact from Equation 6 for the modelling areas on a linear scale

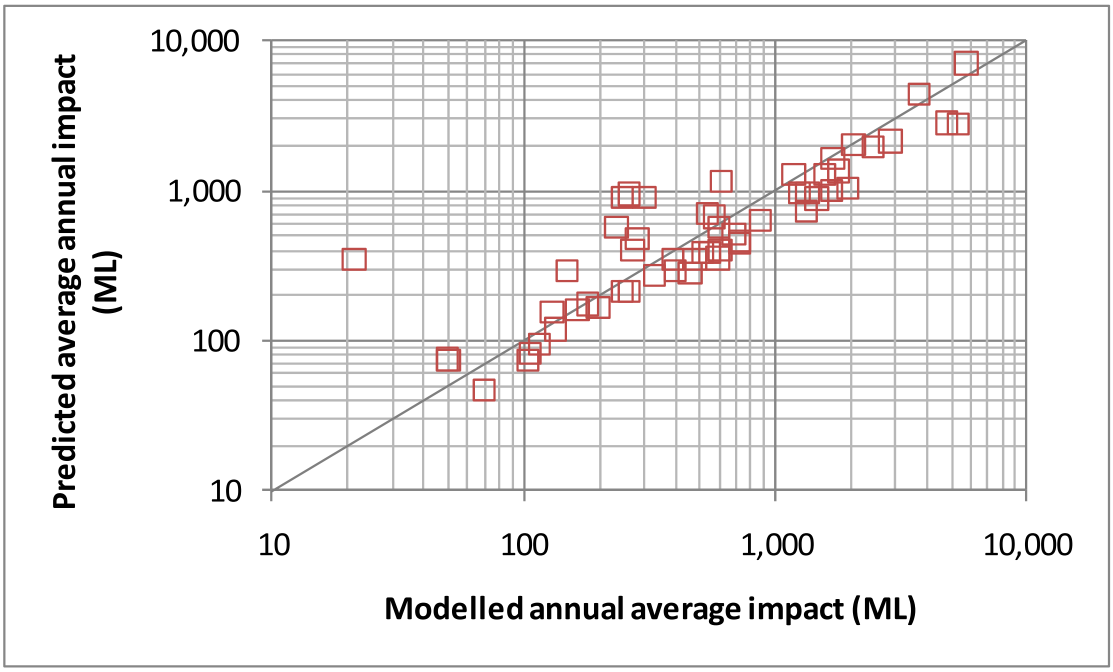


Figure 14 Modelled annual average impact (ML) compared to the predicted average impact from Equation 6 for the modelling areas on a log-log scale

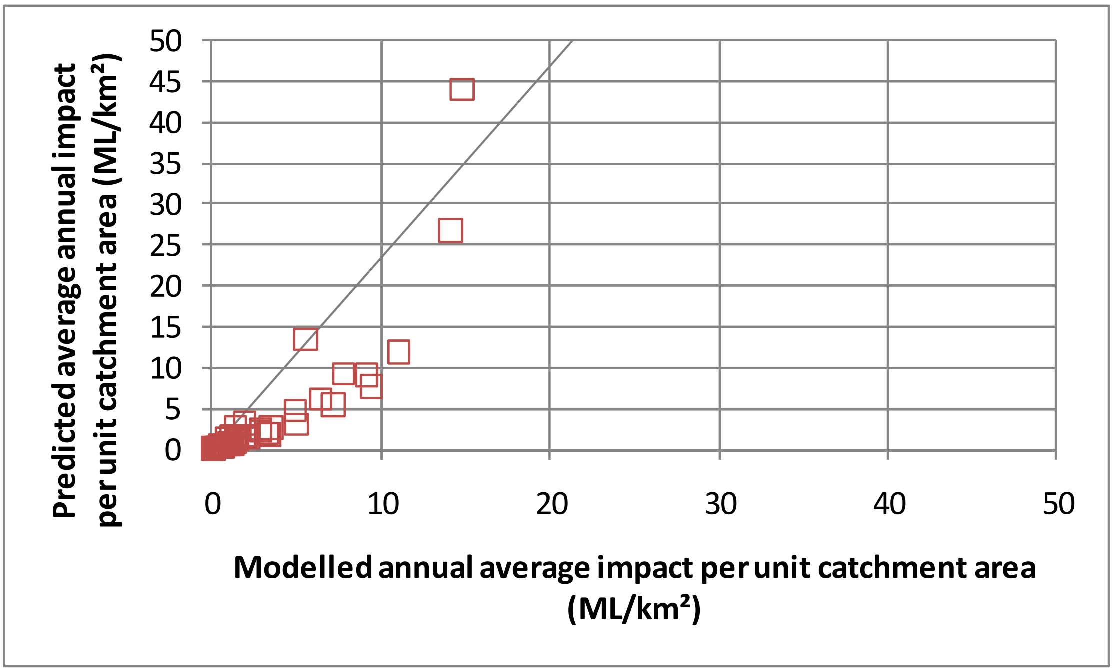


Figure 15 Modelled annual average impact per unit catchment area (ML/km²) compared to the predicted average impact per unit catchment area (ML/km²) from Equation 6 for the modelling areas on a linear scale

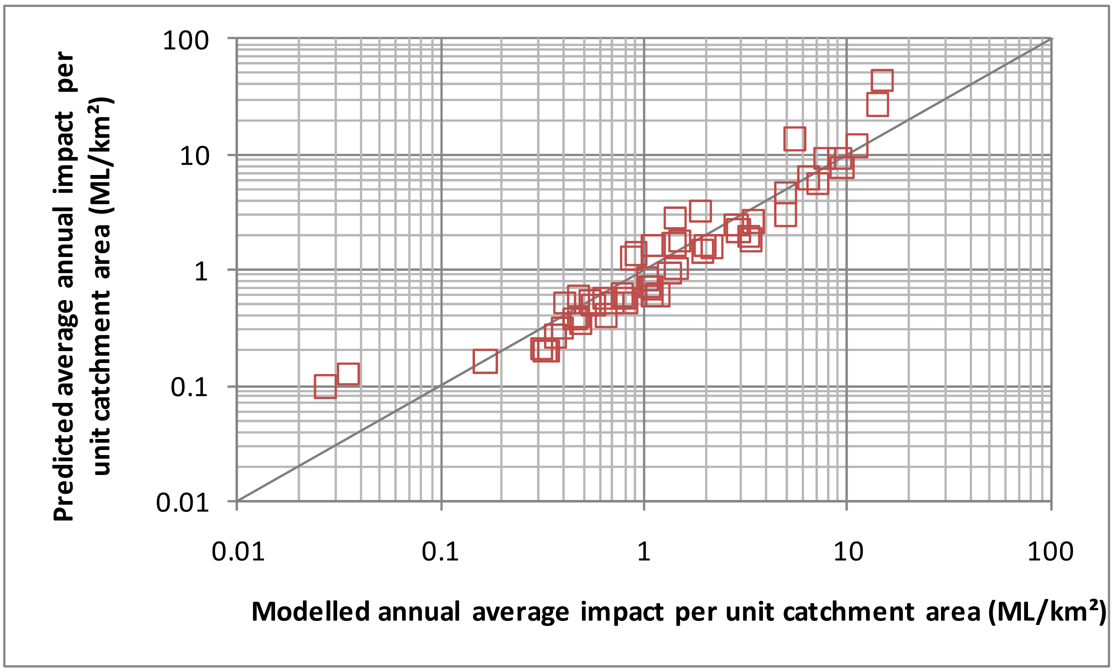


Figure 16 Modelled annual average impact per unit catchment area (ML/km²) compared to the predicted average impact per unit catchment area (ML/km²) from Equation 6 for the modelling areas on a log-log scale

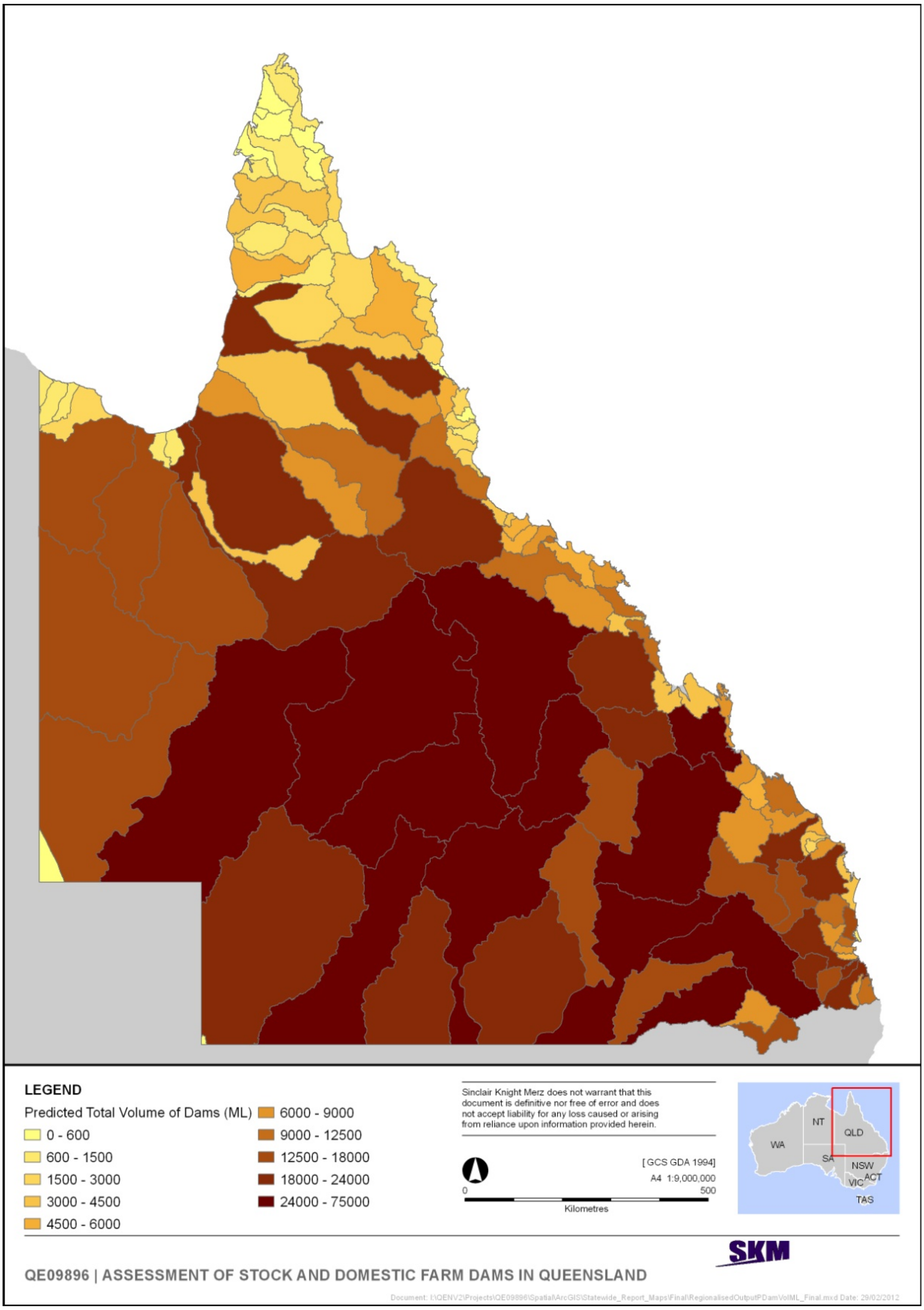


Figure 17 Map of the predicted farm dam volume in each of the reporting areas. (Note that this is the same figure as Figure 8, and is repeated to aid readability.)

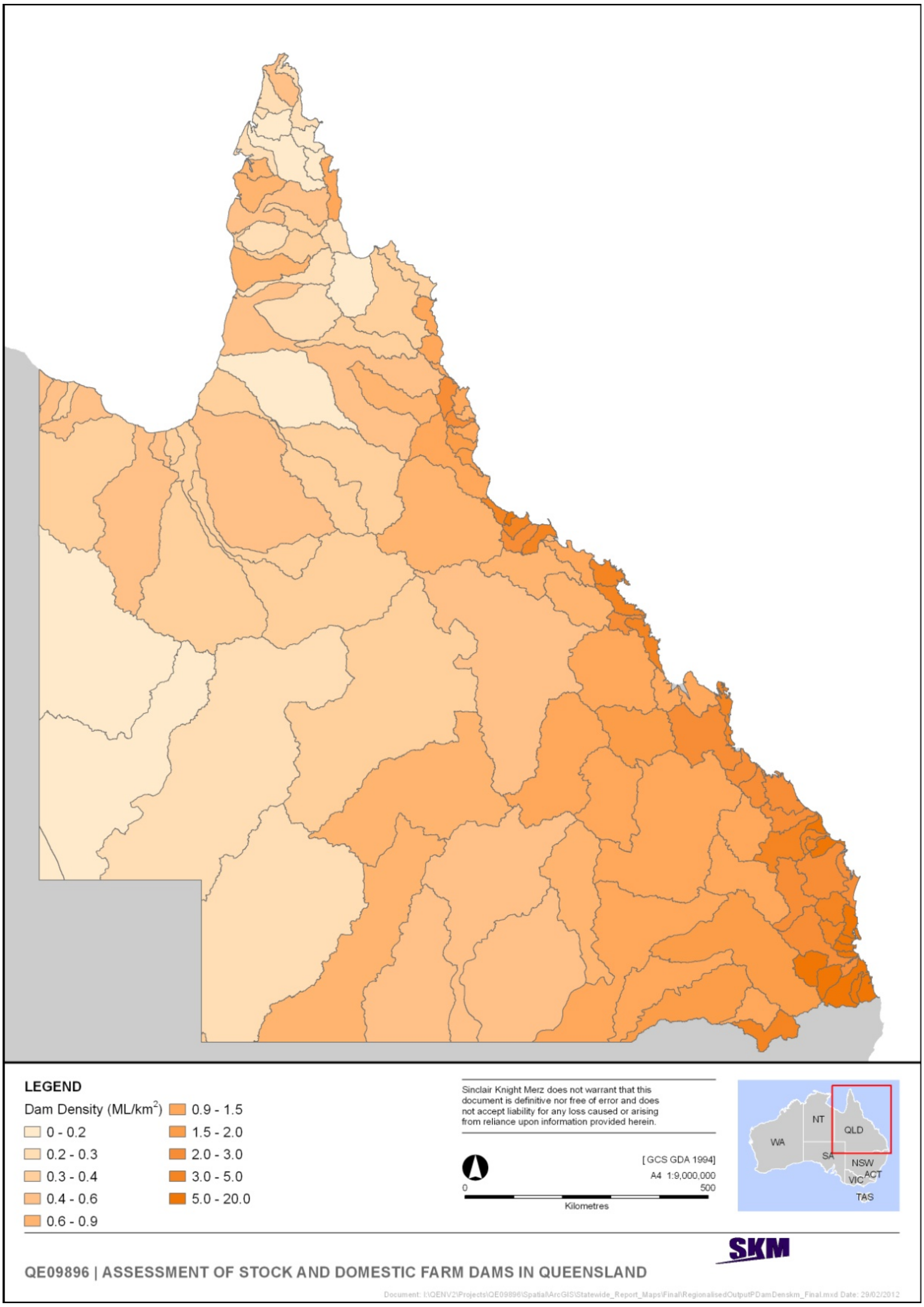


Figure 18 Map of the predicted farm dam volume density in each of the reporting areas

5.2.2. Statewide impacts

The regression equation described in Section 5.2.1 was applied to all the 121 reporting areas and the results of this regionalisation are presented in Figure 19, Figure 20 and Figure 21 with a summary of descriptive statistics in Table 5, and a table of all data in 0, Table 26. The volumetric impact as presented in Figure 19 shows that the absolute impact of dams is highest in the largest catchments. The highest volumetric impact is in the Condamine River, with approximately 14,500 ML of annual average impact. The smallest impact is in the Pascoe River basin in the far north of the state with only 26 ML of annual average impact. The Mitchell River in the Atherton Tablelands is showing a high volumetric impact of farm dams which is primarily driven by the high population in that reporting area. Similarly, the population in the Bulloo River catchment is significantly higher than that in the Paroo River, as are the number of referable dams.

The volumetric impact does not account for the size of the reporting areas, so the bigger catchments show a bigger impact based on their size. For this reason, the density of farm dam impact (the volumetric impact divided by the area of the reporting area) is a much more useful characteristic to compare the impact across Queensland (Figure 20). As can be seen in Figure 20, the impact per square kilometre is highest in the south east of the state, with the maximum in the Caboolture River with nearly 12 ML/km² of annual average impact per unit area. The minimum predicted impact densities occur in the Pascoe River, Olive River and Hay basins of around 0.01 ML/km². The impact per square kilometre is more consistent across the Tablelands area, and also between Georgina River and the Diamantina River and between Paroo and Bulloo than the volumetric impact was.

Another interesting characteristic is the annual average impact divided by the volume of predicted dams (Figure 21). This shows how the impact varies across Queensland normalised by the density of farm dam volumes. The average impact is 0.39 ML/year per ML of dams in the reporting area, the minimum is 0.18 in Cooper Creek in the south west and the maximum 0.86 ML/year per ML of dams in the reporting area in Lake Frome, closely followed by the Maroochy River with 0.81 ML/year impact per ML of dams in the reporting area. The impact per ML of dams in each reporting area is highest right along the eastern seaboard of the state, with the majority reducing to the south west of the state. Annual impact per ML of predicted dam volume are highest in catchments with consistent streamflows and relatively low intra- and inter-annual variability in flows. In these catchments, dams would be consistently filled each year by catchment runoff and the estimated demand and evaporation losses could be consistently taken each year from the dams, maximising the impact on stream flows over time. By contrast, in a catchment with highly intermittent catchment runoff and large interannual variability the farm dams would often be empty within the STEDI model and during those periods they would not be having any impact. This study has adopted a consistent demand factor of 0.5 across Queensland and the same regression equation for estimating local catchment area in all catchments across the State, which may be producing some artefacts in the drier catchments with more intermittent flows. In those drier catchments, it may be that the actual demand factor is less than 0.5 and the local catchment area upstream of each stock and domestic dam is larger than in catchments with more consistent flows, which could partially compensate for this effect.

Table 5 Descriptive statistics for the various statewide impact statistics

Statistic	Mean	Minimum	Maximum	Standard deviation
Annual volumetric impact (ML/year)	3,043	26	14,493	2,632
Annual impact per unit catchment area (ML/km^2)	0.98	0.01	11.82	1.72
Annual impact per mega litre of predicted dam volume (ML/year/ML dams)	0.39	0.18	0.86	0.13

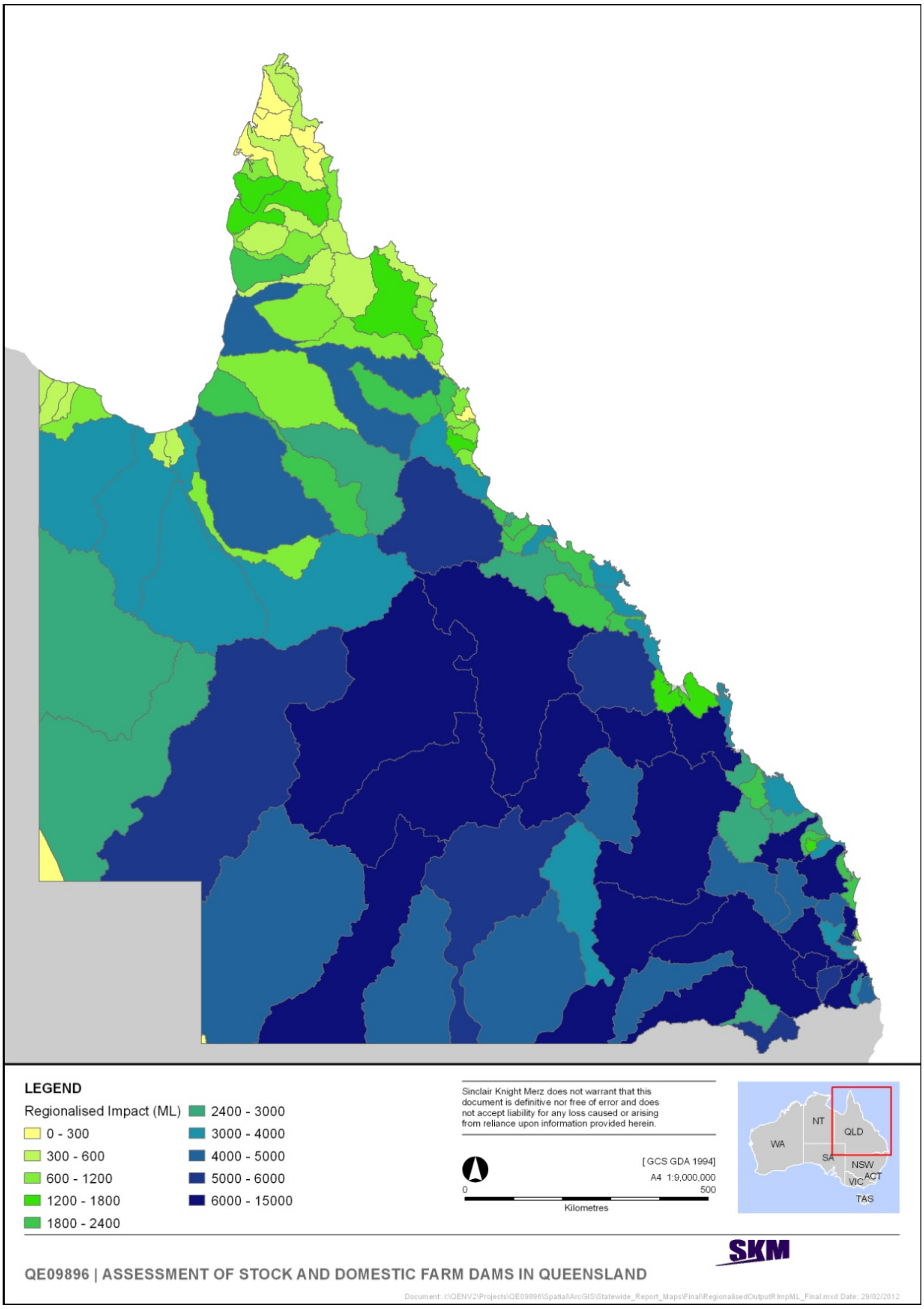


Figure 19 Map of the regionalised volumetric impact of dams (ML/year) in each reporting area

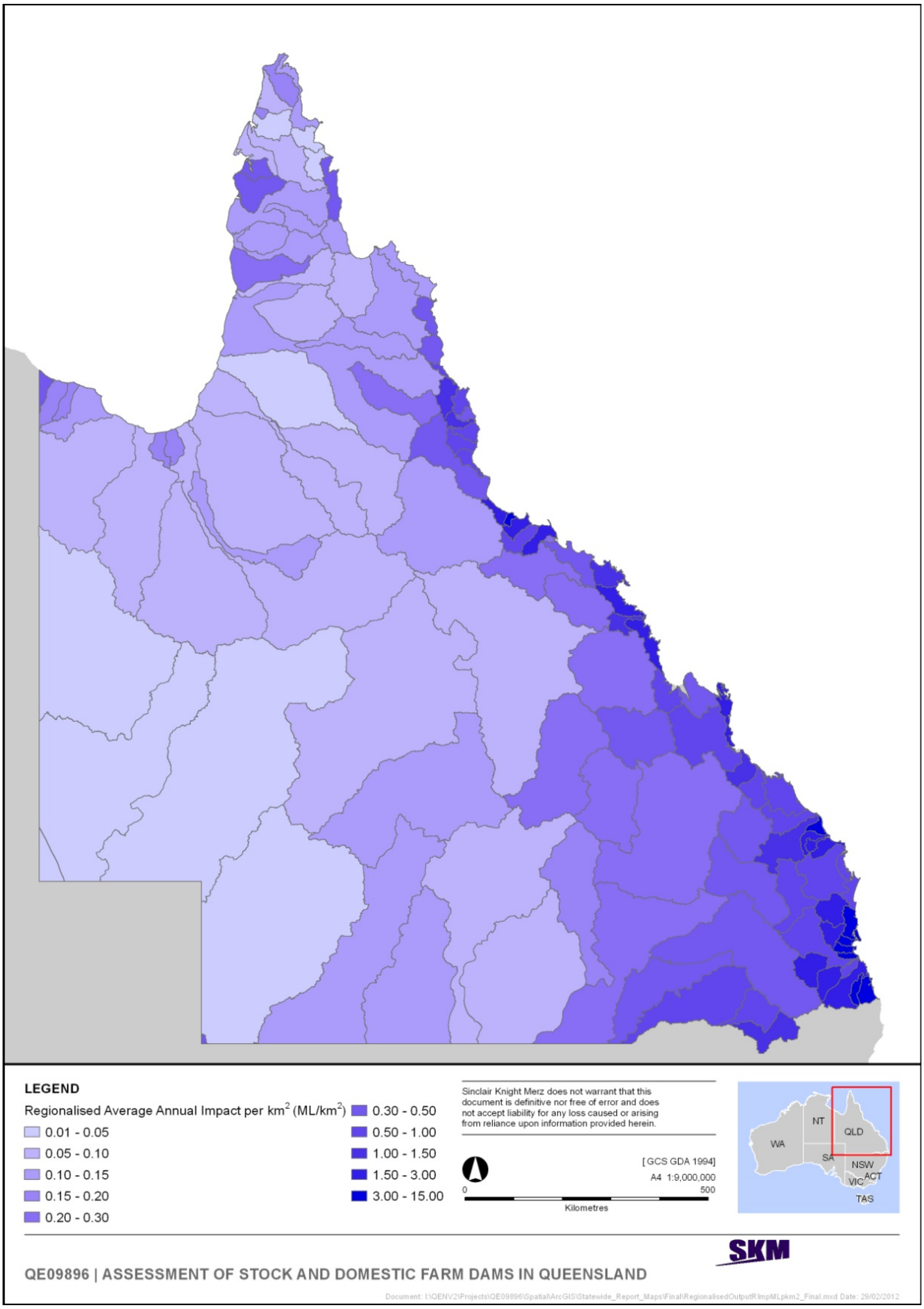


Figure 20 Map of the regionalised volumetric impact of dams per unit area (ML/km²) in each reporting area

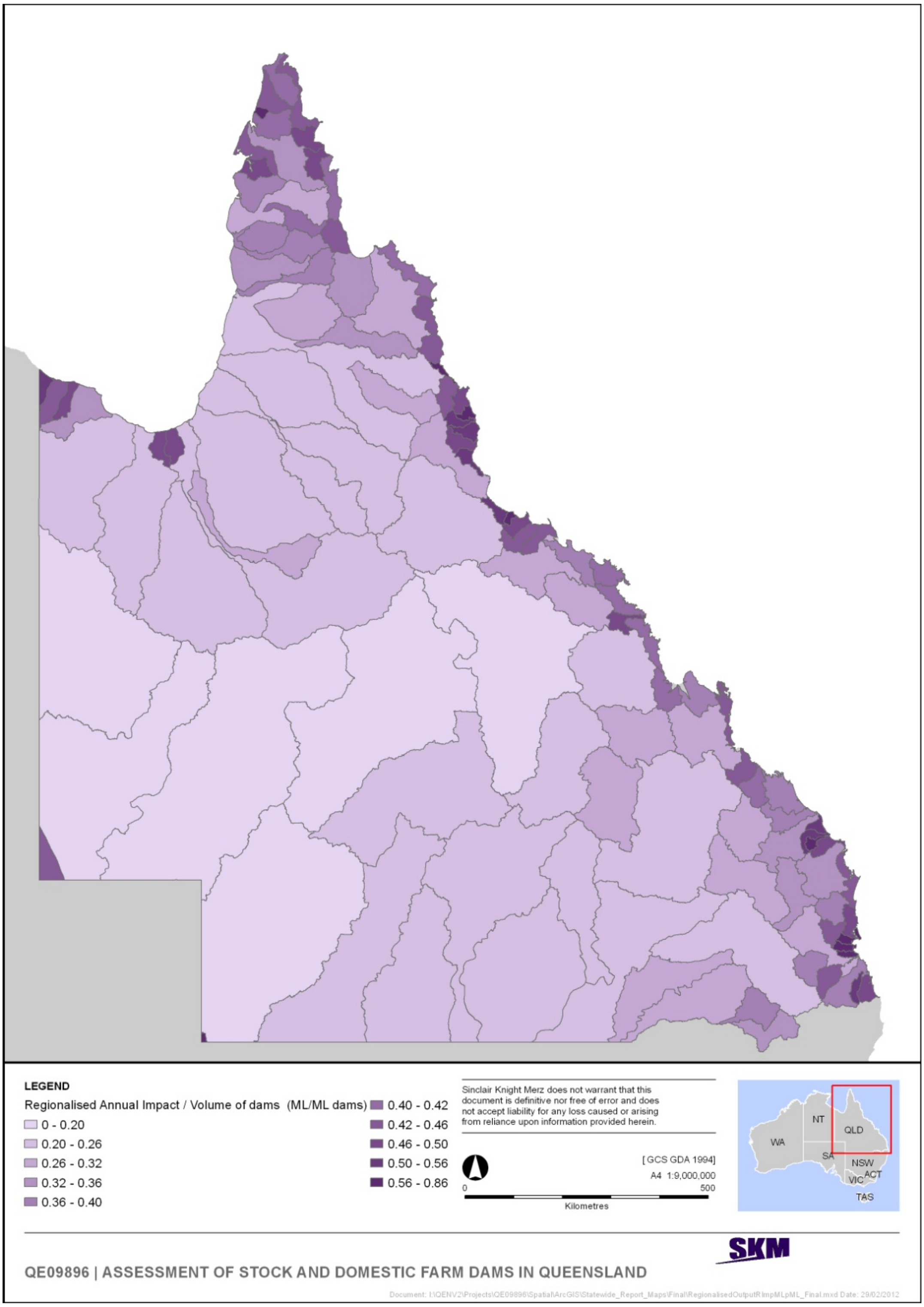


Figure 21 Map of the regionalised volumetric impact of dams per volume of dams in the reporting area (ML Impact/ML predicted dams)

5.2.3. Uncertainty in Mean Annual Impact

The uncertainty in this equation incorporates the uncertainty from all the preceding equations. The 90% prediction limits have been calculated for the regression of impacts for each reporting area and a statistical summary is provided in Table 6, with the full dataset supplied in 0, Table 27. The catchment with the minimum predicted annual average impact (Pascoe River with 26 ML predicted impact) also had the smallest range of predicted values, with 75 ML between the upper and lower prediction limits. The catchment with the highest predicted impact (Condamine River with 14,193 ML) had the largest range of 40,883 ML. The average range in the prediction limit for any basin was 8,129 ML.

The confidence limits in mean annual impact associated with applying this equation with 5% and 95% probabilities of exceedance were -66% and +198% of the best estimate value. In other words, if the rapid estimate equation is applied without digitised farm dam data available then the 90% confidence limits cover a range between 1/3 and 3 times the true value.

Table 6 Descriptive statistics for the prediction limits of the impact regression equation. See 0, Table 27 for full dataset.

Statistic	Mean	Minimum	Maximum	Standard deviation
Predicted annual average impact (ML)	3,043	26	14,493	2,632
5% prediction limit (ML)	1,014	8	4,617	853
95% prediction limit (ML)	9,143	83	45,500	8,142
Ratio between 5% prediction limit and the predicted annual impact	0.4	0.3	0.4	0.0
Ratio between 95% prediction limit and the predicted annual impact	3.0	2.8	3.2	0.1

6. Uncertainty and sensitivity to input parameters

There are a number of inputs and assumptions behind the STEDI modelling and the regionalisation of outputs. Some of these, such as the streamflow and climate data, are of very good quality and are used with a high level of confidence in the modelling. Other inputs, such as the demand factor, are based on limited data and are used with limited confidence. A number of sensitivity tests were undertaken in order to evaluate the relative impact that the uncertainty in the model inputs may create.

6.1. Summary of scenarios used to investigate sensitivity

Eleven scenarios were developed to assess the sensitivity of several relationships, factors and assumptions used in the study. These assessments used only those catchments where individual farm dam information was known or reasonably estimated based on spatial data. These scenarios are summarised in Table 7, where scenario 1 represents the base case.

Table 7 Sensitivity analysis scenarios

Scenario No.	Assessed parameter	(Scenario sub-no.) Change to base case model
2	Method of identifying stock and domestic dams	Assume all dams are stock and domestic to provide estimate of upper limit impact
3	Method of determining number and volume of farm dams	Where individual dam information is known, replace with a distribution of dam volumes and a total catchment volume
4	Surface area to volume relationship	(a) Lower confidence limit (95% probability of exceedance) (b) Upper confidence limit (5% probability of exceedance)
5	Impounded catchment area relationship	(a) Lower confidence limit (95% probability of exceedance) (b) Upper confidence limit (5% probability of exceedance)
6	Demand factor	(a) Lower confidence limit (95% probability of exceedance) (b) Upper confidence limit (5% probability of exceedance)
7	Stock and domestic farm dam volume regionalisation	(a) Apply equation where total dam volume already reasonably estimated (b) Lower confidence limit (95% probability of exceedance) (c) Upper confidence limit (5% probability of exceedance)

The following sections summarise the change to the modelled inputs and the key outcomes of the modelling, for ease of interpretation. Detailed results are presented in 0.

6.1.1. Estimation of stock and domestic dams (Scenario #2)

As detailed in Section 4.4, an approach was developed and applied to identify whether a catchment dam was used for stock and domestic purposes from the current farm dam spatial layers, based on a landuse exclusion process. This approach relies on various assumptions to derive a reasonable estimation of the number of farm dams used for stock and domestic purposes in each catchment.

To assess the greatest possible impact as a result of uncertainty in this method, a sensitivity analysis was undertaken assuming that all identified dams were used for stock and domestic purposes, thereby representing the maximum possible volume and impact. This analysis included an additional 868 dams which were previously disregarded for reasons outlined in Section 4.4.

The increase in dam volume ranged from 0 to 60.2% across the 26 modelled catchments, with a mean increase of 9.6% and a standard deviation of 13.4%. This resulted in an overall increase in the average annual impact of between 0 and 60.8%, with a mean change of +10.3% and a standard deviation of 13.6%. These results are summarised in Table 8, with detailed results presented in 0.

Table 8 Summary comparison of Scenarios 1 and 2 – Sensitivity of identification of stock and domestic dams

Parameter	Scenario 1	Scenario 2	Change from Scenario 1 to Scenario 2			
	(all catchments)	(all catchments)	Mean % change	Min % change	Max % change	Standard deviation
Total volume of dams modelled (ML)	61,079	64,980	**9.6%**	0.0%	60.2%	13.4%
Average annual impact (ML/year)	30,096	32,115	**10.3%**	0.0%	60.8%	13.6%

This scenario demonstrated a clear correlation between the modelled volume of dams and the average annual impact for each catchment, very close to a one to one relationship. This demonstrates that the ability to identify which dams are being used for stock and domestic purposes is a critical input into the STEDI modelling and impact assessment.

6.1.2. Farm dam distribution and individual volume (Scenario #3)

The farm dam size distribution and calculation of total catchment dam volumes is applied for modelling catchments where this information cannot be derived from more accurate data (e.g. spatial layers). More than half of the catchments in this study are assessed based on these estimation methods. The uncertainty associated with these methods can be assessed by applying them to catchments where individual farm dam details (number and volume) are already known.

The impacts in Scenario 1 were calculated using information known about individual farm dam volumes (from GA, Extended DERM and digitised data) in modelling catchments. Scenario 3 was based on the total aggregated volume of known farm dams in each modelling catchment, with the individual number and volume of dams estimated by applying the size distribution through STEDI. These two scenarios have been compared to assess the uncertainty in impacts based on the application of the size distribution.

The application of the size distribution resulted in a change in dam numbers ranging from -57.1% to +237.1% across the 26 modelled catchments, with a mean increase of 3.2% and a standard deviation of 71.2%. This resulted in an overall increase in the average annual impact ranging from -8.6% to 6.6%, with a mean change of -1.0% and a standard deviation of 4.0%. These results are summarised in Table 9, with detailed results presented in 0.

Table 9 Summary comparison of Scenarios 1 and 3 – Sensitivity of the use of the size distribution

Parameter	Scenario 1	Scenario 3	Change from Scenario 1 to Scenario 3			
	(all catchments)	(all catchments)	Mean % change	Min % change	Max % change	Standard deviation
Volume of dams modelled (ML)	61,079*	61,074*	0%	0%	0%	0%
Total no. of dams modelled	13,250	14,244	**3.2%**	-57.1%	237.1%	71.2%
Average annual impact (ML/year)	30,096	30,150	**-1.0%**	-8.6%	6.6%	4.0%

* Note that the volume of dams modelled is effectively the same in both scenarios, however is slightly different due to the application of the method.

This scenario demonstrates that the modelled impacts have a low sensitivity to either using the known individual farm dams, or an estimate of individual dams from the total volume using the size distribution. Compared with the results of Scenario 7, this scenario demonstrates that the size distribution is a much less critical factor as a model input than the volume estimate. It is more important to have an accurate estimate of the overall dam volume and that the distribution of dam sizes within the overall estimate of total volume contributes relatively little to the overall uncertainty.

6.1.3. Surface area to volume relationship (Scenario #4a & b)

The surface area to volume relationship was derived and used to estimate the individual dam volumes based on the surface areas observed in spatial surveying. A sensitivity analysis was undertaken to assess the statistical uncertainty associated with this equation.

This analysis involved two scenarios which applied the upper and lower confidence limits of the derived relationship to the known dam surface areas, in order to recalculate an upper and lower limit of dam volume.

Scenario 4a (application of the lower confidence limit) resulted in a change in total dam volumes ranging from -21.3% to -9.5% across the 26 modelled catchments, with a mean change of -14.6% and a standard deviation of 3.4%. In consequence, the change to annual average impact ranged from -49.7% to -5.3%, with a mean change of -14.5% and a standard deviation of 9.9%.

Scenario 4b (application of the upper confidence limit) resulted in a change in total dam volumes ranging from +10.7% to +28.0% across the 26 modelled catchments, with a mean change of +17.9% and a standard deviation of +5.0%. In consequence, the change to annual average impact ranged from +5.6% to +66.4%, with a mean change of +17.1% and a standard deviation of 13.1%.

These key results of these scenarios are summarised in Table 10 and Table 11, with detailed results presented in 0.

Table 10 Summary comparison of Scenarios 1 and 4a - Sensitivity of the surface area to volume relationship confidence limits (lower confidence limit, 95% probability of exceedance)

Parameter	Scenario 1	Scenario 4a	Change from Scenario 1 to Scenario 4a			
	(all catchments)	(all catchments)	Mean % change	Min % change	Max % change	Standard deviation
Total volume of dams modelled	61,079	50,641	**-14.6%**	-21.3%	-9.5%	3.4%
Average annual impact (ML)	30,096	25,810	**-14.5%**	-49.7%	-5.3%	9.9%

Table 11 Summary comparison of Scenarios 1 and 4b - Sensitivity of the surface area to volume relationship confidence limits (upper confidence limit, 5% probability of exceedance)

Parameter	Scenario 1	Scenario 4b	Change from Scenario 1 to Scenario 4b			
	(all catchments)	(all catchments)	Mean % change	Min % change	Max % change	Standard deviation
Total volume of dams modelled	61,079	74,190	**17.9%**	10.7%	28.0%	5.0%
Average annual impact (ML)	30,096	35,195	**17.1%**	5.6%	66.4%	13.1%

As shown in Scenario 2, the average annual impact is strongly affected by the modelled volume of dams, with the mean change in volume and impact for both scenarios a and b showing a close to one to one ratio. On average, the uncertainty introduced in the surface area to volume conversion relationship alone, results in the 90% confidence limits for mean annual impact being -14.5% to +17.1% of the best estimate of the mean annual impact. This level of uncertainty in mean annual impact assumes that the surface areas of all dams within the catchment are digitised and that uncertainty contributed from other sources (identification of stock and domestic dams, local catchment area for dams and demand factor) are ignored.

6.1.4. Local catchment area relationship (Scenario #5a & b)

The local catchment area relationship estimates the proportion of catchment area upstream of farm dams, in order to calculate the total impounded area of catchments for which individual dam details are known. A sensitivity analysis was undertaken to assess the statistical uncertainty associated with this equation.

This analysis involved two scenarios which applied the upper and lower confidence limits of the local catchment area relationship to each catchment, in order to derive an upper and lower estimate of the total catchment area upstream of the farm dams.

Scenario 5a (application of the lower confidence limit) resulted in a change in local catchment area ranging from -24.5% to -2.3% across the 26 modelled catchments, with a mean change of –6.5% and a standard deviation of 4.9%. In consequence, the change to annual average impact ranged from –22.7% to 0.0%, with a mean change of -2.9% and a standard deviation of 4.8%.

Scenario 5b (application of the upper confidence limit) resulted in a change in local catchment area ranging from +2.3% to +28.0% across the 26 modelled catchments, with a mean change of +6.8% and a standard deviation of +5.5%. In consequence, the change to annual average impact ranged from 0.0% to +25.3%, with a mean change of +3.0% and a standard deviation of 5.3%.

These results are summarised in Table 12 and Table 13, with detailed results presented in 0.

Table 12 Summary comparison of Scenarios 1 and 5a - Sensitivity of the local catchment area relationship confidence limits (lower confidence limit, 95% probability of exceedance

Parameter	Scenario 1	Scenario 5a	Change from Scenario 1 to Scenario 5a			
	(all catchments)	(all catchments)	Mean % change	Min % change	Max % change	Standard deviation
Local catchment area (km^2)	2,091	1,984	**-6.5%**	-24.5%	-2.3%	4.9%
Average annual impact (ML)	30,096	29,384	**-2.9%**	-22.7%	0.0%	4.8%

Table 13 Summary comparison of Scenarios 1 and 5b - Sensitivity of the local catchment area relationship confidence limits (upper confidence limit, 5% probability of exceedance)

Parameter	Scenario 1	Scenario 5b	Change from Scenario 1 to Scenario 5b			
	(all catchments)	(all catchments)	Mean % change	Min % change	Max % change	Standard deviation
Local catchment area (km^2)	2,091	2,202	**6.8%**	2.3%	28.0%	5.5%
Average annual impact (ML)	30,096	30,809	**3.0%**	0.0%	25.3%	5.3%

This scenario demonstrated a strong correlation between the modelled local catchment area and the average annual impact for each catchment, with the mean values for % change showing that a 1% change in local catchment area results in approximately a 0.5% change in mean annual impact. This demonstrates that the ability to identify the total catchment area upstream of the farm dams is an important input into the STEDI modelling and impact assessment.

6.1.5. Demand factor (Scenario #6a & b)

The demand factor (i.e., the proportion of a dam's total volume which would be used annually assuming the dam does not empty) has been estimated based on the approach detailed in Section 4.7. A sensitivity analysis was undertaken to assess the uncertainty associated with this factor.

This analysis involved two scenarios which applied upper and lower confidence limits (0.72 and 0.37) of the estimated demand factor, previously determined as part of this study. A more detailed description of this is provided in the *Statewide Assessment: Report 1 – Methods and Inputs*.

Scenario 6a (application of the lower confidence limit) reduced the total demand across each catchment by 26%. This resulted in a change to annual average impact ranged from -25.7% to -0.3%, with a mean change of -6.1% and a standard deviation of 5.4%.

Scenario 6b (application of the upper confidence limit) increased the total demand across each catchment by 44%. This resulted in a change to annual average impact ranged from +0.5% to +43.2%, with a mean change of +9.5% and a standard deviation of 9.0%.

These results are summarised in Table 14 and Table 15, with detailed results presented in 0.

Table 14 Summary comparison of Scenarios 1 and 6a - Sensitivity of mean annual impact to assumed demand factor of 0.37 (mean demand factor with 95% probability of exceedance) when compared to the baseline demand factor of 0.5

Parameter	Scenario 1	Scenario 6a	Change from Scenario 1 to Scenario 6a			
	(all catchments)	(all catchments)	Mean % change	Min % change	Max % change	Standard deviation
Total demand (ML/yr)	30,540	22,599	**-26.0%**			
Average annual impact (ML)	30,096	28,879	**-6.1%**	-25.7%	-0.3%	5.4%

Table 15 Summary comparison of Scenarios 1 and 6b - Sensitivity of mean annual impact to assumed demand factor of 0.72 (mean demand factor with 5% probability of exceedance) when compared to the baseline demand factor of 0.5

Parameter	Scenario 1	Scenario 6b	Change from Scenario 1 to Scenario 6b			
	(all catchments)	(all catchments)	Mean % change	Min % change	Max % change	Standard deviation
Total demand (ML/yr)	30,540	43,977	**44.0%**			
Average annual impact (ML)	30,096	31,921	**9.5%**	0.5%	43.2%	9.0%

These scenarios demonstrate that the outcomes of the modelling are not particularly sensitive to the assumed demand factor. On average, a 1% change in the estimated demand from farm dams within a catchment only results in approximately a 0.25% change in the estimated mean annual impact. This result may be related to the fact that for many dams, on-farm demand is less than evaporation. In such cases, uncertainty in the volume of water extracted is a smaller fraction of the total loss of water due to both extractions and evaporation from the dam surface. In catchments with consistent streamflows (little inter-annual variability), where extractive demand would form a larger component of the overall sum of demand and evaporation, the uncertainty in the demand factor may become more important.

6.1.6. Regionalised volume of dams (Scenario #7a, b & c)

For the model, a stock and domestic farm dam volume regionalisation equation has been developed to estimate the total volume of dams within a catchment where this information cannot be derived from more accurate data.

A sensitivity analysis was undertaken to assess the uncertainty associated with this equation by applying it to modelling catchments where the total volume of dams was already reasonably estimated from digitised data. In addition, two further scenarios assessed the upper and lower confidence limits of the equation. This analysis assessed the change in terms of total volume as well as impact to streamflow.

Scenario 7a (application of the regional volume estimate) resulted in a mean change to total dam volume of +21.7%, with a standard deviation of 63.0% (minimum -51.2%, maximum +187.6%). This resulted in a mean change to annual average impact of +25.5%, with a standard deviation of 69.4% (minimum -70.8%, maximum +189.1%).

Scenario 7b (application of the lower confidence limit) resulted in a mean change to total dam volume of -44.3%, with a standard deviation of 28.8% (minimum -78.8%, maximum +30.3%). This resulted in a mean change to annual average impact of -50.8%, with a standard deviation of 31.5% (minimum -98.2%, maximum +30.8%).

Scenario 7c (application of the upper confidence limit) resulted in a mean change to total dam volume of +166.3%, with a standard deviation of 137.5% (minimum +12.5%, maximum +534.8%). This resulted in a mean change to annual average impact of +188.1%, with a standard deviation of +188.9% (minimum +17.1%, maximum +775.0%).

These results are summarised in Table 16, Table 17 and Table 18, with detailed results presented in 0.

Table 16 Summary comparison of Scenarios 1 and 7a - Sensitivity of the regionalisation of dam volume

Parameter	Scenario 1	Scenario 7a	Change from Scenario 1 to Scenario 7a			
	(all catchments)	(all catchments)	Mean % change	Min % change	Max % change	Standard deviation
Total volume of dams modelled (ML)	61,079	52,891	**21.7%**	-51.2%	187.6%	63.0%
Average annual impact (ML)	30,096	27,938	**25.5%**	-70.8%	189.1%	69.4%

Table 17 Summary comparison of Scenarios 1 and 7b - Sensitivity of the regionalisation of dam volume and confidence limits (lower confidence limit, 95% probability of exceedance)

Parameter	Scenario 1	Scenario 7b	Change from Scenario 1 to Scenario 7b			
	(all catchments)	(all catchments)	Mean % change	Min % change	Max % change	Standard deviation
Total volume of dams modelled	61,079	24,257	**-44.3%**	-78.8%	30.3%	28.8%
Average annual impact (ML)	30,096	12,051	**-50.8%**	-98.2%	30.8%	31.5%

Table 18 Summary comparison of Scenarios 1 and 7c - Sensitivity of the regionalisation of dam volume and confidence limits (upper confidence limit, 5% probability of exceedance)

Parameter	Scenario 1	Scenario 7c	Change from Scenario 1 to Scenario 7c			
	(all catchments)	(all catchments)	Mean % change	Min % change	Max % change	Standard deviation
Total volume of dams modelled	61,079	115,328	**166.3%**	12.5%	534.8%	137.5%
Average annual impact (ML)	30,096	60,499	**188.1%**	17.1%	775.0%	188.9%

As seen with the other sensitivity modelling, any change to total dam volume generally resulted in an equivalent change to the average annual impact. These scenarios demonstrate that the outcomes of the modelling are very sensitive to the use of the regionalisation equation to estimate the total dam volume in a catchment. Use of the regionalisation equation increased the average annual impact by 25.5% (mean % change) with the upper and lower confidence limits changing by 188.1% and -50.8% respectively. This highlights a high level of uncertainty in the accuracy mean annual impacts resulting from application of the regional relationship for farm dam volumes.

6.2. Sensitivity analysis results summary

A summary of the results of the sensitivity analyses is presented in Table 19. This table summarises the sensitivity of the parameters in terms of the ratio of percentage change to the input parameter compared to the resulting percentage change to the average annual impact. For example, if a 5% increase in modelled dam volume caused a 5% increase in average annual impact the ratio would be expressed as 1:1. The table also provides an estimate of the likely variation in the range of impact due to the uncertainty associated with each parameter.

Where a parameter is sensitive it would require a small increase in the certainty of the parameter in order to reduce the potential impact range significantly. This is in contrast to a parameter which is not sensitive, which would require a large increase in the certainty of the parameter in order to provide a small reduction in the potential impact range.

Table 19 Summary of sensitivity analysis scenarios

Scenario no.	Assessed Parameter	Parameter sensitivity (ratio % change to % impact)	Impact range
2	Method of identifying stock and domestic dams	Sensitive (1:1)	+10% to -10%*
3	Method of determining number and volume of farm dams (size distribution)	Not sensitive (3:1)	-1%
4	Surface area to volume relationship	Sensitive (1:1)	-14% to +17%
5	Local catchment area relationship	Not Sensitive (2:1)	-3% to +3%
6	Demand factor	Not sensitive (4:1)	-6% to +10%
7	Stock and domestic farm dam volume regionalisation	Sensitive (1:1)	-50% to +190%

* for this parameter the lower range of impact is difficult to quantify with any certainty

Of the assessed input parameters three were found to be sensitive, with a 1% change to the input parameter generally resulting in a 1% change in average annual impact and all of these sensitive parameters related to dam volume (either through the identification of dams, the surface area to volume relationship or the regionalisation of dam volumes).

The two parameters which were not particularly sensitive to change were the size distribution and the demand factor. Although the demand factor is not a particularly sensitive input to the modelling, because there is significant unresolved uncertainty in the mean demand factor it can still contribute significantly to the overall uncertainty in estimated mean annual impact.

The largest range of potential impact due to uncertainty of the input estimation was seen in the regionalisation equation. The application of the upper and lower confidence limits of the equation resulted in a range in impact from -50% to +190%. This is by far the parameter of largest uncertainty and efforts should be made to dispense with using it altogether (i.e. only determine the volume of dams in a catchment from digitised data) in catchments where stock and domestic impacts could have an appreciable impact on the available surface water resources.

The second largest range of potential impact due to uncertainty of the input estimation was seen in the surface area to volume relationship. The application of the upper and lower confidence limits of the equation resulted in a range in impact from -14% to +17%. This parameter is considered to be the second ranked in importance of improving, with the third being the identification method and the fourth being the demand factor.

Final recommendations for improving the input estimation methods are provided in Section 7.

7. Recommendations for improvement of input parameters

The following section provides an assessment of the relative cost and resulting improvement which could be made to the methods adopted for this study by incorporating the alternative methods discussed in Section 5.8 of the *Statewide Assessment: Report 1 – Methods and Inputs*.

These alternatives are assessed against concerns such as existing sensitivity of each parameter, uncertainty range, cost to improve and the resulting uncertainty range after improvement. The rankings used in this assessment are provided in Table 20. 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 20 Rating scale for assessment of options

Criterion	Rating scale		
Parameter sensitivity	Not sensitive (3:1)	Moderately sensitive (2:1)	Sensitive (1:1)
Uncertainty range (average annual impact)	±5%	±10%	Greater than ±10%
Cost to improve	Low relative cost $0-$50,000	Medium relative cost $50,000-$200,000	High relative cost $200,000-$400,000
Resulting uncertainty range	±5%	±10%	Greater than ±10%
Benefit vs cost	High to moderate return for low cost	Moderate return for moderate cost	Low to moderate return for high cost

7.1. Assessment of alternative approaches

Table 21 provides a high level assessment of proposed alternatives to the input estimation methods adopted for this Project. This section should be reviewed in conjunction with Section 5 of the *Statewide Assessment: Report 1 – Methods and Inputs*. This will provide greater background into the suggested alternative approaches.

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 at a State scale.

Table 21 Assessment of alternative approaches to developing the STEDI inputs

Criteria	Identification of S&D dams	Estimating the volume of dams			Local catchment area	Dam usage
Current Approach	Exclusion due to landuse type	Surface area to volume relationship	Regional volume estimate	Size distribution	Regression equation	Demand factor
Proposed alternative	Survey to validate existing approach	Expand the existing analysis to include more sample points and a wider geographic distribution	Digitise farm dams for all of Qld	Additional digitisation	Expand the existing analysis to cover larger sample areas and a wider geographic distribution	Expand the existing analysis to include more sample points and a wider geographic distribution
Parameter sensitivity	Sensitive (1:1)	Sensitive (1:1)	Sensitive (1:1)	Not sensitive (3:1)	Sensitive (1:1)	Not sensitive (4:1)
Uncertainty range (average annual impact)	-10% to +10%[a]	-14% to +17%	-50% to +190%	-1%	-3% to +3%	-6% to +10%
Cost to improve	In the order of $150k	In the order of $50k	Very high cost (approx $2400 per 1000km^2)[b]	In the order of $50-100k	In the order of $50k	In the order of $30-50k
Projected uncertainty range after improvement set out above	-5% to +5%	-7% to +7%	-5% to +5%	Less than1%	-1% to +1%	-3% to +5%
Benefit vs cost	Moderate return for moderate cost	Moderate return for low cost	High return for high cost	Low return for moderate cost	Moderate return for low cost	Moderate return for low cost
Comment		The resulting uncertainty range depends on the sample size – this estimate is based on increasing the number of samples from 73 to 300.	This would dispense with using the regional volume estimate and size distribution - all volumes would be estimated using the surface area to volume relationship	This method is only required if the regional volume estimate continues to be used	The resulting uncertainty range depends on the sample size – this estimate is based on increasing the number of samples from 158 to 650	The resulting uncertainty range depends on the sample size – this estimate is based on increasing the number of samples from 17 to 80

[a] for this parameter the lower range of impact is difficult to quantify with any certainty

[b] note that this is a bulk digitisation cost and applies for areas of 15,000km2 or greater, smaller areas will cost more.

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.

7.2. Interaction of STEDI input estimation methods

The direct use of the various input estimation methods into the STEDI modelling is summarised in Section 4. However, some of these methods are also used in the development of the other estimation techniques. For example, during the development of the size distribution the volume of each dam within a catchment area is estimated using the surface area to volume relationship. Improving the accuracy of one method may therefore indirectly improve the accuracy of another method. Figure 22 presents the interaction of the various methods, during their development.

Figure 22 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.

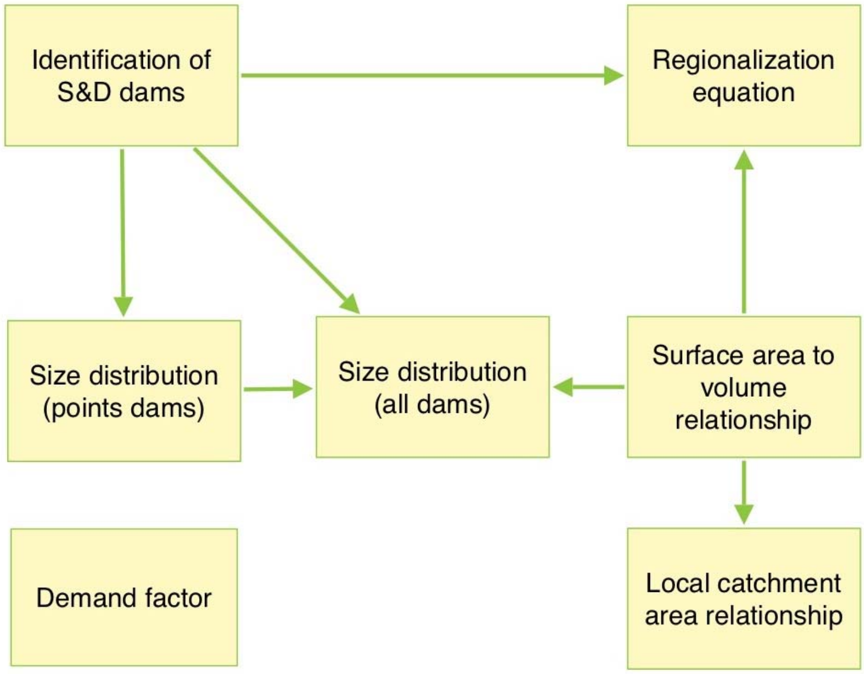


Figure 22 Interaction of STEDI input estimation methods (during development of the methods)

7.3. Summary

Six of the STEDI input estimation methods were considered for improvement, these were:

Identification of dams

Surface area to volume relationship

Regional volume estimate

Size distribution

Local catchment area

Dam usage

Of the six alternative methods discussed in Table 21 three are considered to provide a moderate return for a low cost, reducing the uncertainty associated with these methods by approximately half. These are the surface area to volume relationship, the local catchment area and the demand factor, and they are recommended to DERM for further consideration.

The largest area if uncertainty is associated with the regional volume estimate. However, it is difficult to eliminate this uncertainty without removing the method altogether by digitising all of the dams within the catchment or region of interest.

The surface area to volume relationship provided the second highest level of reduction in uncertainty at a very modest cost. Improvement of this relationship would also affect other input estimation methods, as illustrated in Figure 22.

Improvement of the identification method would also affect other input estimation methods, as illustrated in Figure 22. However, this would be at a higher cost for approximately the same level of improvement.

Improving the size distribution provides only a low return for a low cost and is not considered worth investigating further, at this stage.

The local catchment area relationship and the demand factor could both be improved with further investigation, both reducing the associated uncertainty by approximately half for a similar cost (approximately $50,000). Of these two it is recommended to improve the demand factor as this has a larger initial range of uncertainty than the catchment area relationship.

The costs discussed in this section are intended to provide high level guidance in comparison of the relative cost benefit of improving on the existing methods. These costs are indicative and will change depending factors such as the final extent of the study, timing etc. These costs are also for the individual tasks and do not account for any revision to other methods which may be affected by the investigation outcomes.

8. Temporal trends in farm dam development

The trends in farm dam development are important to understand as farm dam policies may be developed to not only manage current farm dams, but also the impact of future development.

8.1. Available data

While there is ongoing information collection of large dam construction in Queensland (primarily through license applications) construction of the smaller stock and domestic farm dams is unlicensed and generally not recorded. As such, it is difficult to establish when and where any development is taking place and what the trends in that development may be.

One way of identifying the time of farm dam construction is to review historical imagery. Aerial imagery is available over a number of years, sometimes back to the 1940s. The farm dams in an area are digitised over these years and a trend in development can be constructed. This trend could then be correlated with another factor, such as population, to provide a means to forecast future development of stock and domestic farm dams.

For this investigation historical imagery from DERM was collated in the areas shown in Figure 23. Historic population data was also sourced for these areas. While historical data does exist for other factors (e.g. agricultural production) the data is typically presented at the state level, which is too large a scale to be useful for this analysis

8.2. Assessment of historical imagery

The areas of historical imagery which were used in the assessment of stock and domestic farm dam development trends are shown in Figure 23. This shows that there was some geographic distribution of the areas used for the assessment, with the areas located in South East Queensland and the Murray Darling Basin. These areas also represent a range of coastal versus inland regions.

The historic aerial imagery was supplied as a series of photos with an associated flight diagram, showing the order and location of each photo. These photos were combined and ortho-rectified in order to provide a single layer of imagery for each area, for each date of capture. The quality of the historic aerial imagery was very good, however in several cases some of the older photos were missing and areas were adjusted in order to maintain a consistent analysis extent throughout the historic period.

Table 22 presents key information for each of the trends assessment areas.

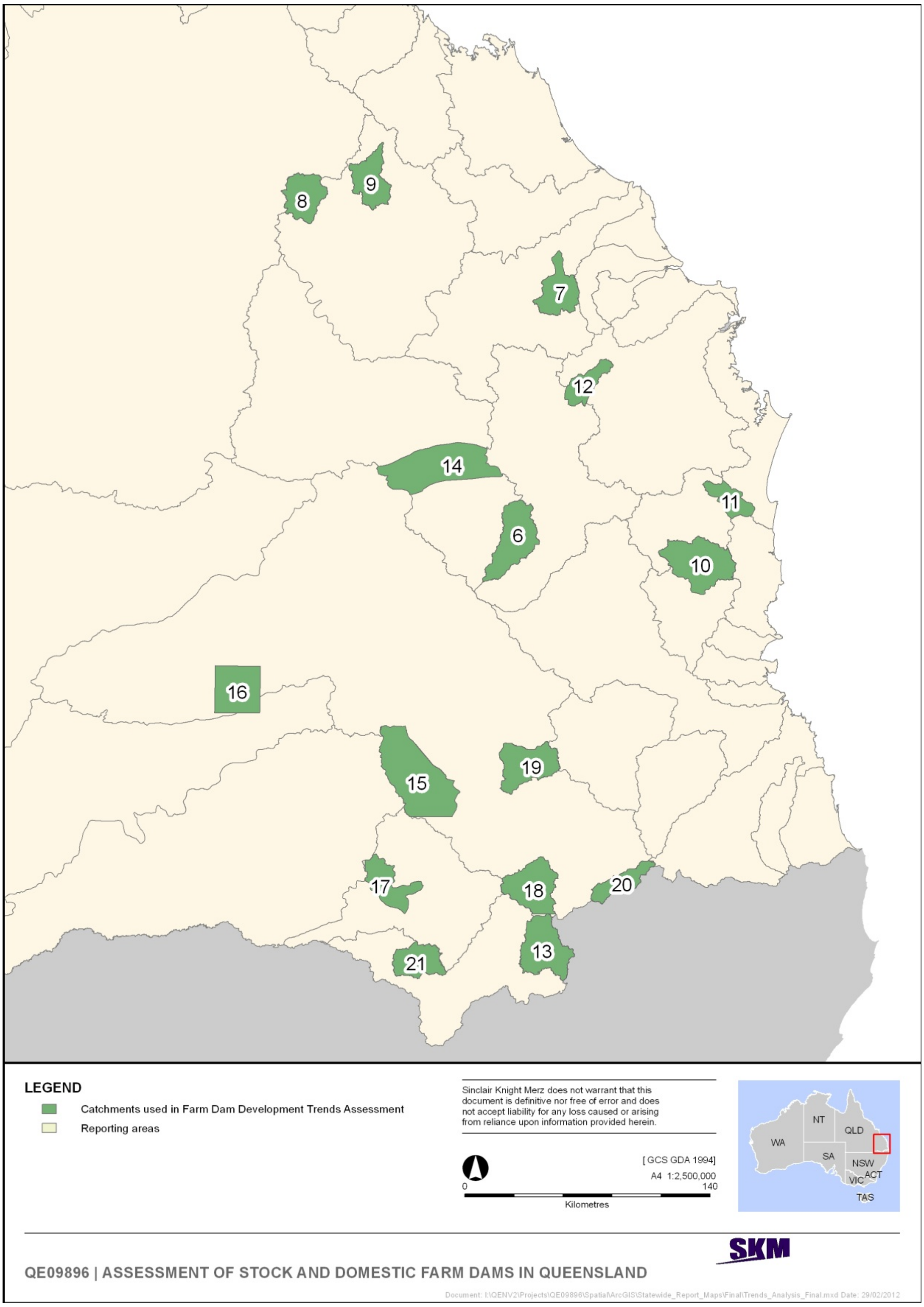


Figure 23 Areas used in the assessment of stock and domestic farm dam development trends

Table 22 Summary of historical imagery areas

Area no.	Catchment	Catchment Area (km^2)	LGA*	Years of imagery capture
6	Burnett Catchment (subarea)	666	Kingaroy Shire	1951, 1967, 1974,1993, 1996, 1999, 2006, 2009, 2010
7	Burnett Catchment (subarea)	459	Biggenden Shire	1953, 1954, 1969, 1973, 1979, 1995, 1996, 2002, 2010
8	Burnett Catchment (subarea)	437	Monto Shire	1958, 1971, 1996, 2004
9	Burnett Catchment (subarea)	451	Monto Shire	1955, 1958, 1967, 1971, 1996, 2004
10	Caloundra Catchment (subarea)	773	Caloundra City	1958, 1967, 1977, 1978, 1995, 2003, 2008, 2009, 2010
11	Noosa Catchment (subarea)	257	Noosa Shire	1958, 1967, 1968, 1979, 1994, 1996, 2002, 2008, 2010
12	Burnett Catchment (subarea)	278	Woocoo Shire	1996, 2010
13	Granite Belt Catchment (subarea)	627	Stanthorpe Shire	1955, 1975, 1998, 1999, 2007
14	Burnett Catchment (subarea)	1,079	Wondai Shire	1951, 1952, 1963, 1993, 1996, 2002, 2006
15	Condamine River at Cecil Weir	1,236	Millmerran Shire	1958, 1971, 1991, 2005
16	Created Area - not gauge station	613	Tara Shire	1955, 1956, 1971, 1989, 2006
17	MacIntyre Brook at Inglewood	426	Inglewood Shire	1949, 1959, 1971, 1990, 2006
18	Sandy Ck at Leslie Dam Wall	594	Warwick Shire	1959, 1968, 1989, 2006
19	Hodgson Creek at Balgownie	579	Cambooya Shire	1955, 1974, 1975, 1988, 2005
20	4223940	277	Warwick Shire	1951, 1970,1995
21	Oaky Creek at Texas	393	Inglewood Shire	1949, 1970, 1990, 2006

* This project has adopted the pre 2006 definition of the LGAs (as these areas are smaller than the current LGAs and provide more detail)

8.3. Factors influencing dam development

Figure 24 presents the trend in stock and domestic farm dam development over time for each of the trends areas and for the total area of analysis. The trend in development is presented as the cumulative proportion of total dam volume, where 100% represents the current level of development. This allows comparison between areas which may vary greatly in terms of total dam volumes.

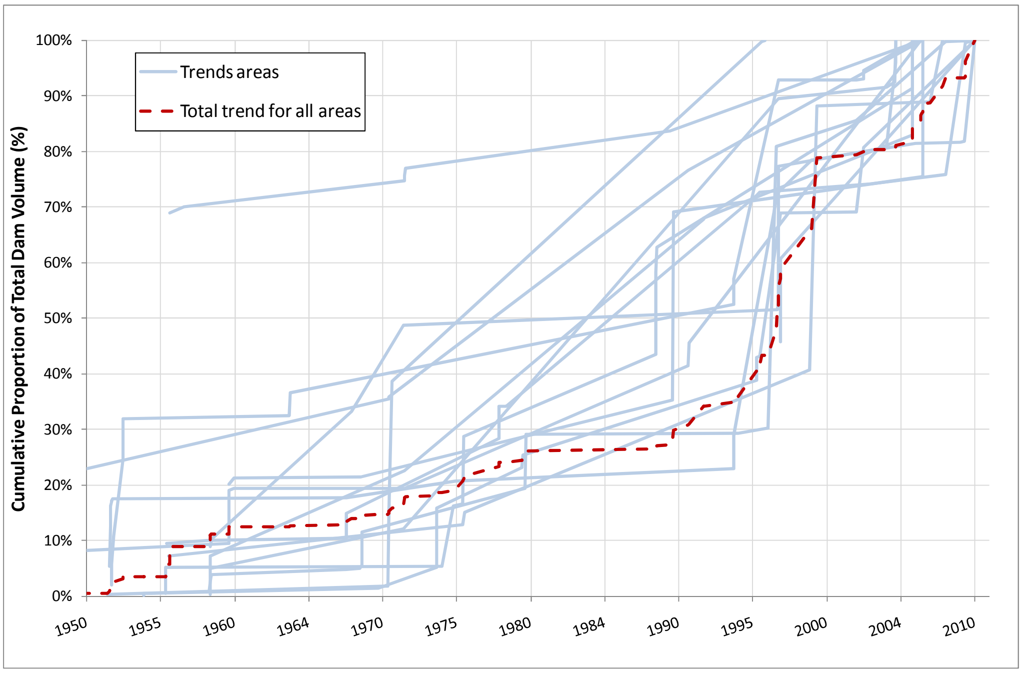


Figure 24 Trends in stock and domestic dam development – cumulative proportion of total dam volume

The trend lines in Figure 24 show a generally consistent pattern of development, with relatively few stock and domestic dams initially and low rates of development through the 1950s and 1960s. The rate of development increased slightly through the 1970s and 1980s, with a dramatic increase seen through the 1990s. After 2000 the rate of development has slowed slightly, but is still quite high.

The one area that does not follow this trend is area 16, located in Tara Shire. This area started with a relatively large number of stock and domestic dams in place in 1955 and development since then has been reasonably steady.

The sharp rise in dam development in the mid 1990s was seen in the majority of the assessed areas. This was initially thought to be a processing artefact, due to an improvement in the quality of the digital imagery during this period, however further investigation showed that this was not the case. The imagery prior to this period is of equivalent, if not better, resolution and would have picked up prior dam development.

A number of factors could potential influence stock and domestic farm dam development. Factors which were considered included:

- Change to cotton prices;

- Growth in peri-urban areas;
- Changes in water policy;
- Weather cycles; and
- Change to beef prices;

The early 1990s saw a considerable increase in the cotton price, which led to increased investment in cotton farming. While this may have caused an increase in the construction of large, water harvesting storages it is considered unlikely to have significantly affected the construction of small dams.

Several areas in Queensland have seen a large increase in population growth in peri-urban areas, particularly in the south east region and along the coast line. This is largely driven by the movement of young families who are attracted by cheaper housing and a semi rural lifestyle (Cavaye, 2007). Peri-urban development has been noted to lead to an increase in farm dam construction for stock and domestic purposes (LWA, 2008).

In addition, this was a period where new water management policy was being introduced in Queensland, such as the Environment Protection Act (1994) and the Condamine Balonne WAMP (1996). The Condamine Balonne WAMP imposed a moratorium on the construction of regulated water infrastructure. This may have created a feeling of uncertainty about the future of water rights amongst farmers, particularly in catchments in the MDB, and may have led to farmers pre-emptively constructing dams while they felt they still could.

In 1997 the Murray Darling Basin Cap was implemented, capping the extraction of surface water at 1993 development levels. This led to the development of alternative water sources, particularly groundwater and overland flow capture. The cap may have contributed to the rise in construction of stock and domestic farm dams in the MDB.

El Nino periods may have also led to dam construction, where farmers will put in infrastructure during or just after dry periods, in order to capture as much water as possible when it does eventually rain. Relevant El Nino periods occurred in 1977, 1982-83, 1991-92, 1994, 1997-98 and 2002-03.

The 1980s and 1990s also saw a consistent growth in beef cattle numbers, particularly in Queensland (MLA, 2004). This may have contributed to a requirement for more water storages.

Trends in population growth were also assessed in the same areas, as shown in Figure 23. Figure 25 show the trends in population growth over time for each of the trends areas and for the total area of analysis. Population is expressed as density (number of people per square kilometre) in order to facilitate a comparison between areas of different sizes. The trends in population density shown in Figure 25 are generally very flat, indicating low growth rates, except for areas 10 and 11 which are located in Caloundra City and Noosa Shire respectively. These regions have seen substantial growth since the 1980s, particularly in peri-urban farm development.

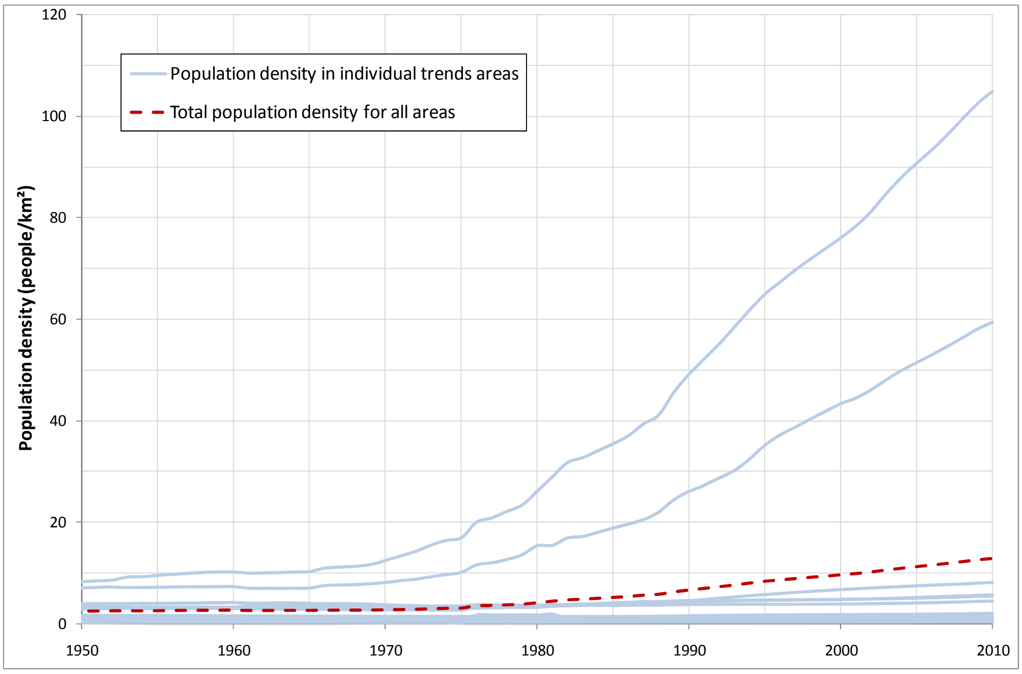


Figure 25 Trends in population growth – population density

A closer look at the change in population density over time shows three distinct trends; high growth in Caloundra and Noosa (see Figure 26), medium growth (Figure 27) and low growth (Figure 28).

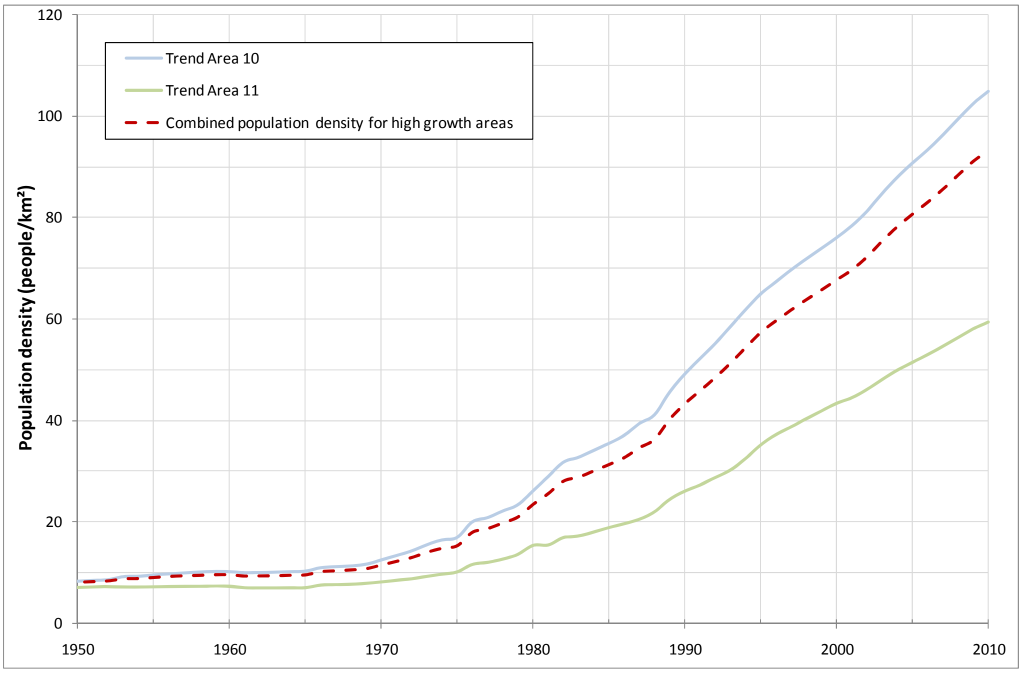


Figure 26 Trends in population growth in areas with high growth – population density (areas 10 & 11)

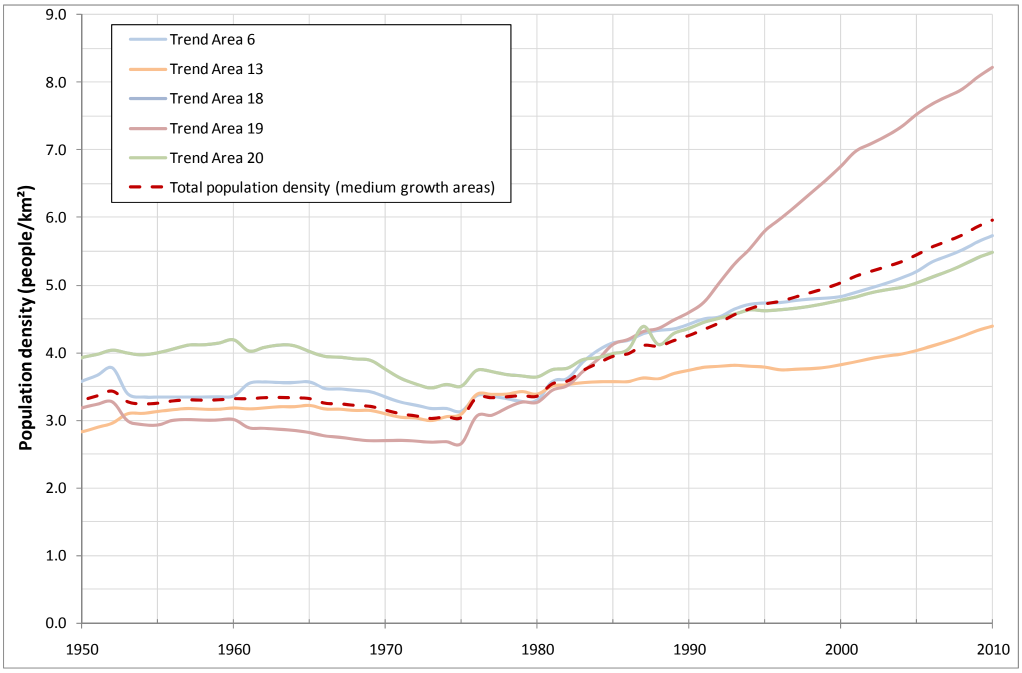


Figure 27 Trends in population growth in areas with medium growth – population density

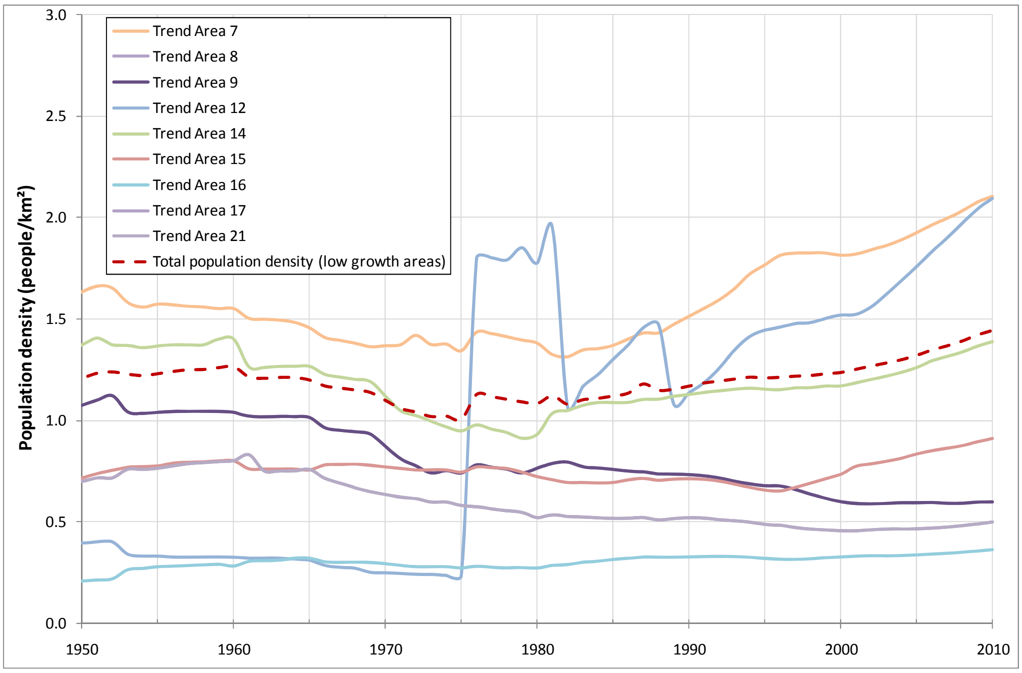
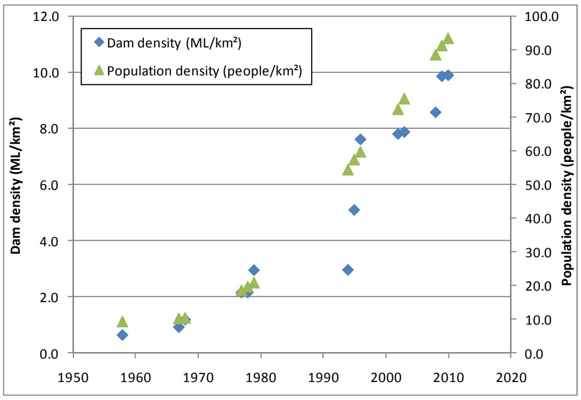


Figure 28 Trends in population growth in areas with low growth – population density

When population density is plotted against the total volume of dams for each of these three regions a strong correlation is demonstrated between these factors in the high growth areas and in the medium growth areas. However, the low growth areas show a very low correlation between population and total volume of dams.

Figure 29 presents the change to population density and density of stock and domestic dams over time, as well as the correlation between these two factors in the two high growth areas (Caloundra City and Noosa Shire). These figures demonstrate that population can be a very good indicator for stock and domestic dams in areas of high growth in population density, where significant peri-urban development is occurring. It is recommended that DERM investigate this correlation further, over a range of geographic areas where peri-urban farm development is known to be occurring.

a)



b)

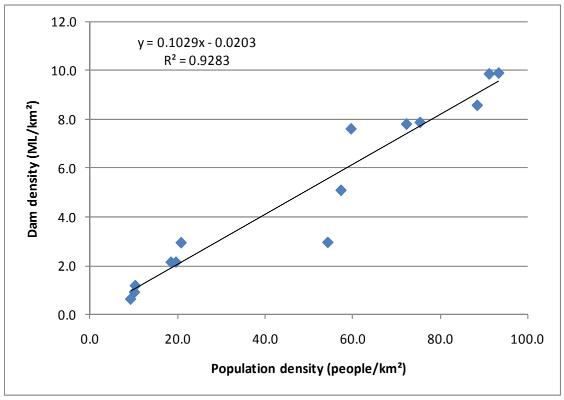
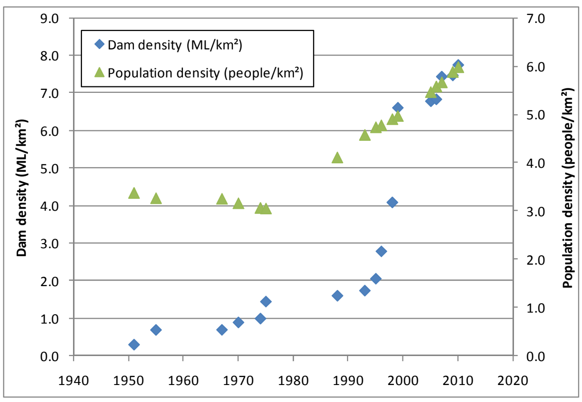


Figure 29 High growth areas - a) Change to population density and density of stock and domestic dams over time, b) Correlation of population density and density of stock and domestic dams

Figure 30 presents the change to population density and density of stock and domestic dams over time, as well as the correlation between the two factors in the medium growth areas. These figures demonstrate that population can also be a good indicator for stock and domestic dams in areas of medium growth in population density. However, the correlation between population and volume of dams is less likely to be causal, than in peri-urban farm areas. It is recommended that DERM investigate this correlation further, over a range of geographic areas and considering other potential factors for dam growth.

a)



b)

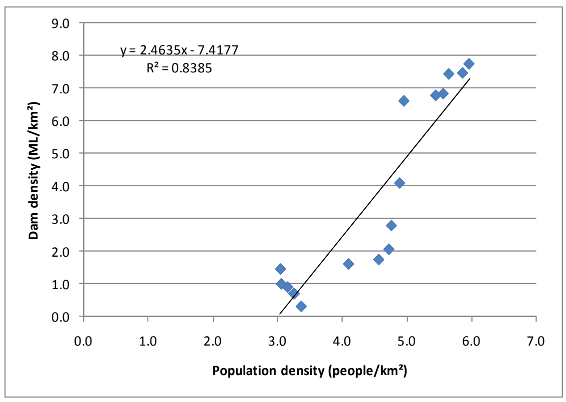


Figure 30 Medium growth areas – a) Change to population density and density of stock and domestic dams over time, b) Correlation of population density and density of stock and domestic dams

Figure 31 presents the change to population density and density of stock and domestic dams over time, as well as the correlation between the two factors in the low growth areas. The two factors show a very low correlation in these areas and it is not recommended to use population as a predictor of dam volume in regions of very low population growth.

a) b)

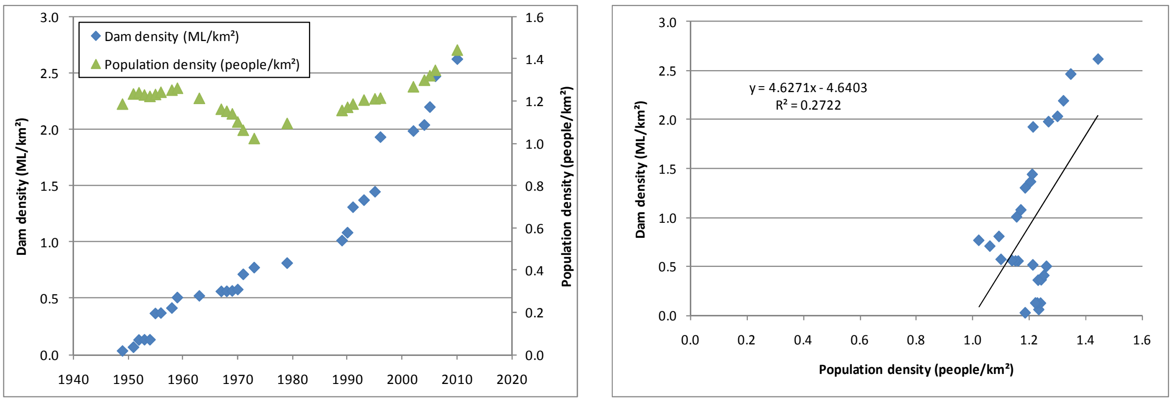


Figure 31 Low growth areas – a) Change to population density and density of stock and domestic dams over time, b) Correlation of population density and density of stock and domestic dams

8.4. Summary

Trends in the development of stock and domestic farm dams were assessed through an analysis of historical aerial imagery for 15 trial areas. While this method is appropriate for identifying when dams are constructed, the availability of data can vary between regions. The analysis found a generally consistent trend of dam development, with low rates of development through the 1950s and 1960s, increasing rates of development through the 1970s and 1980s, with a dramatic increase seen through the 1990s. After 2000 the rate of development has slowed slightly, but is still quite high.

The historic trend in dam construction was then compared against population growth in the corresponding Local Government Areas. This found that population density is a very good predictor of stock and domestic dam volume in areas of high population density (greater than 10 people/km²) and also in areas of medium population density (3 to 5 people/km²). In areas of low population growth population density is not a good predictor of stock and domestic dam volume.

A very strong correlation was found between population density and total volume of stock and domestic dams in areas with high population growth (R^2 of 0.93). This is of particular interest in areas of high peri-urban development, such as the Sunshine Coast region. Population density could be used as an indicator of total stock and domestic dam volume in these areas. However, it is recommended that this correlation is investigated further, due to the small sample size of peri-urban areas available for this analysis.

A strong correlation was also found between population density and total volume of stock and domestic dams in areas with medium population growth (R^2 of 0.84). Population density could also be used as an indicator of total stock and domestic dam volume in these areas, although population is less likely to be a primary consideration in dam construction in these areas.

The correlation equations developed for the high growth areas and the medium growth areas are different, reflecting different influences on development in the areas. The development of stock and domestic dams is much less influenced by peri-urban development in areas of medium growth.

It is recommended that DERM investigate this relationship further, over a range of geographic areas and particularly where peri-urban development is recognised to be occurring, as this is known to have an influence on stock and domestic dam development

9. 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 inflows to each dam 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 to be able to quantify these factors. STEDI is not intended to be used as a water resource model, rather it is intended to estimate the impact of farm dams on runoff. These assumptions may result in an overestimation of the impact of farm dams within a given catchment, with the STEDI model producing a conservative result.
- 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.
- 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.
- 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.
- Recommendations have been made for potential options to improve the input estimation methods used to develop the inputs to the STEDI modelling. 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 at a State scale. These recommendations may not be suitable if smaller areas are being considered, and smaller site specific studies are recommended for such cases.

- There were two issues which were difficult to answer with a degree of certainty; these were the source and ultimate purpose of farm dams. It is difficult to establish where water is sourced from, for example is the dam catching overland flow only, or being supplied with water pumped from a river? The purpose of the storage is also difficult to establish, with many dams potentially being used for more than one purpose, e.g. irrigation and stock watering.

10. Conclusions and recommendations

This project performed an assessment of the impact on the surface water resource of stock and domestic farm dams across the whole of Queensland. This *Statewide Assessment Report 2* addressed three main areas:

Provision of maps and tables of the estimated impact on the water resource of stock and domestic dams for 121 reporting regions across Queensland.

Providing insight into the uncertainties in estimation of farm dam impacts at catchment and regional scale and assessing the relative contributions from those individual sources of uncertainty, given that there is considerable variability in the data available in different parts of Queensland to estimate farm dam impacts. This will also inform possible future investment in data collection and modelling activities to reduce uncertainty in estimates.

Deriving the temporal trend in the volume of farm dams across Queensland over the last 60 years and the relationship between temporal trends and factors that may have influenced those trends, to provide insight on how the total storage volume and impact of stock and domestic dams on the water resource may change in future years.

10.1. Method

STEDI models were established and run using daily flow and climate data for 55 modelling catchments, which were distributed across Queensland, although there were higher concentrations of modelling catchments in south east Queensland and in the eastern part of the Queensland Murray Darling Basin (MDB). The results from these modelling catchments were then analysed to assess the inter-annual variability in farm dam impacts, assess seasonal variability in impacts, assess contributions to overall uncertainty from different types of uncertainty in the modelling process and regionalised to produce estimates of mean annual impact for reporting regions across the State.

10.2. Overall impact on the water resource

The total volume of stock and domestic dams estimated for all of Queensland was 1,255 GL. The mean annual impact of those dams on the surface water resource across Queensland was 368 GL/year. This represents an average impact of 0.21 ML/km^2/year. On average, for every 1 ML of storage volume of stock and domestic dams, the streamflow at the catchment outlet was reduced by 0.39 ML/year. The overall volume of stock and domestic dams in Queensland was considerably larger than the volumes estimated in previous studies (Sinclair Knight Merz, CSIRO and Bureau of Rural Sciences, 2010) because the current study relaxed the assumed maximum volume applicable for a stock and domestic dam of 5 ML and the current study used more extensive spatial data and a more robust approach for regionalisation of farm dam impacts than the coarse approach adopted in the 2010 study. The total volume of stock and domestic dams estimated for the Queensland Murray Darling Basin was similar in the current study to the estimate from Sinclair Knight Merz (2007) but the impact on mean annual flow was found to be less in the current study because lower demand factors were adopted in the current study.

There is considerable spatial variability in the storage volume and mean annual impact of farm dams across Queensland. The highest density of farm dams (ML of dams per km² of catchment area) occur in coastal catchments, particularly in south east Queensland. Therefore, the highest mean annual impacts per unit catchment area are also observed in these same catchments. Coastal catchments also have more consistent streamflow patterns (less inter-annual variability) and these catchments therefore have a higher annual impact per ML of total storage volume than catchments with more intermittent streamflow patterns.

10.3. Uncertainty in estimated mean annual impacts and contributions from uncertainty in different data inputs

Overall uncertainty in estimates of impact on mean annual flow depends upon the method applied to come up with that estimate. In the MDB and south east Queensland, there is a readily available data set of digitised farm dams that captures the dams across this area. If a STEDI model were applied to flow data in a catchment where digitised data was available, the estimates of mean annual impact with 5% and 95% probabilities of exceedance would be from 18% lower to 22% higher than the best estimate of the mean annual impact established from the model. The dominant contributor to this overall uncertainty in a modelled catchment with digitised farm dams was from the surface area to volume relationship, which on its own results in a range from -15% to +17% of the best estimate value. The next largest contributors to the overall uncertainty in a catchment with digitised farm dams are in identifying stock and domestic dams from other dam types and in adopting a regional equation to estimate the total local catchment area upstream of the dams.

In areas where there is no digitised data set of farm dams, the impacts can still be modelled using STEDI but in that case a regional equation is required to estimate the total volume of stock and domestic farm dams and then a probability distribution is required to apportion that total volume into a number of farm dams by storage capacity. When this approach is used the overall uncertainty range (5% and 95% confidence limits) ranges from -60% to +160% of the best estimate value. The dominant contributor to this overall uncertainty is in the estimation of the total volume of dams using the regional regression equation, which results in a range in mean annual impacts (90% confidence interval) of -50% to +190% of the best estimate value. This demonstrates the value of digitising the extent of farm dams in an area, which very considerably reduces the uncertainty range in the estimate of mean annual impact in an area.

In areas where there is no digitised data set of farm dams and where a fast estimate of the impact of stock and domestic farm dams on mean annual flow is required, without running STEDI models, a rapid assessment regionalisation equation was adopted, as given in Equation 7.

Equation 7 Regionalisation equation for the impact of farm dams

$$\text{Annual volume of dam impact} = 2.85233 \times \frac{\text{predicted volume of dams}^{0.974585}}{\text{catchment area}^{0.21619}}$$

The confidence limits in mean annual impact associated with applying this equation with 5% and 95% probabilities of exceedance were -66% and +198% of the best estimate value. In other words, if the rapid estimate equation is applied without digitised farm dam data available then the 90% confidence limits cover a range between 1/3 and 3 times the true value. Applying a STEDI model to estimate the impact using an estimate of the total volume of stock and domestic dams will reduce this uncertainty somewhat but to achieve considerable reductions in this uncertainty, digitisation of farm dams in the area of interest would be required.

Priority areas for investment to reduce uncertainty flow from the results presented above. If an accurate estimate of the impact of farm dams is required for a particular area and there is not a comprehensive data set of digitised farm dams available then the most effective means of reducing this uncertainty is to digitise the extent of farm dams from aerial imagery of appropriate resolution. These digitised dams then should be run through a specific farm dam water balance model, such as STEDI, to estimate the impact on the water resource.

If digitisation and farm dam water balance modelling has already been performed in a particular area, as is the case in the 26 modelling catchments run in this study with digitised data available, then the most effective means of reducing the residual uncertainty would be by increasing the sample size of dam and regional coverage of dams used to estimate the surface area to volume relationship. Smaller reductions in overall uncertainty may also be delivered by further survey of landholders and/or metering a sample of stock and domestic farm dams to provide a more accurate estimate of usage from dams; or in re-estimating the local catchment area upstream of dams from a larger spatial data set.

10.4. Temporal trends in the volume of stock and domestic dams

Trends in the development of stock and domestic farm dams were assessed through an analysis of historical aerial imagery for 15 trial areas. The analysis found a generally consistent trend of dam development, with low rates of development through the 1950s and 1960s, increasing rates of development through the 1970s and 1980s, with a dramatic increase seen through the 1990s. After 2000 the rate of development has slowed slightly, but is still quite high.

The development of stock and domestic dams is influenced by a number of factors, such as agricultural trends in commodity pricing, changes to water management policy, weather cycles and growth in peri-urban development. Several factors may be based on individual farmers decision making and is therefore difficult to predict, or tease out of the picture of temporal development patterns.

When the historic trend data was compared against population growth this demonstrated that population density is a very good indicator of stock and domestic dam volume in areas of high population density (greater than 10 people/km²) and also in areas of medium population density (3 to 5 people/km²). In areas of low population growth population density is not a good indicator of stock and domestic dam volume.

A very strong correlation was found between population density and total volume of stock and domestic dams in areas with high population growth (R^2 of 0.93). This is of particular interest in areas of high peri-urban development, such as the Sunshine Coast region. Population density could be used as an indicator of total stock and domestic dam volume in these areas. However, it is recommended that this correlation is investigated further, due to the small sample size of peri-urban areas available for this analysis.

A strong correlation was also found between population density and total volume of stock and domestic dams in areas with medium population growth (R^2 of 0.84), and population density could also be used as an indicator of total stock and domestic dam volume in these areas. The correlation equations developed for the high growth areas and the medium growth areas are different, reflecting different influences on development in the areas.

10.5. Recommendations

The results presented in this study represent an initial Statewide estimate of the overall impact of stock and domestic dams on the surface water resource across Queensland. It is recommended that these results are used as an initial estimate of the impact and, given the considerable uncertainty in the estimates that were produced from the regionalisation equation in particular, they should not be used in themselves for setting policies on volumetric impacts and surface water entitlements.

Where stock and domestic farm dams are to be accounted for explicitly in policy for a particular catchment, the estimated impact should be based upon a modelling study. In future studies, a model that appropriately reflects the water balance from many individual farm dams, such as STEDI, should be adopted and the input data on the farm dams used in the model should be obtained by digitising farm dams from aerial imagery.

In catchments with digitised data on farm dams and STEDI models established, the next largest reductions in overall uncertainty are likely to be achieved by increasing the size of the sample of dams that were used to derive the surface area to volume conversion relationship. Since digitised dams are available across the entire Queensland MDB and south east Queensland, if the focus of stock and domestic dam policy is in these areas the largest improvements could be achieved by DERM investing in further work to reduce the uncertainty contributed from the surface area to volume conversion equation. Appreciable improvements are also likely to be achieved by gaining a more accurate estimate of the demand from farm dams, either by metering a sample of stock and domestic dams or further farmer surveys on the issue. Appreciable improvements may also be achieved by further spatial analysis to establish the local catchment area upstream of farm dams. DERM should also consider investing further resources into these activities.

Strong relationships between increases in stock and domestic farm dam volumes and population growth rate were established in two peri-urban areas that have experienced rapid population growth over the last few decades. For catchments in peri-urban areas, particularly in south east Queensland and the eastern part of the MDB, this rapid population growth, apparently driving rapid growth in stock and domestic farm dam volumes, may be having significant local affects on the surface water resource. Given that this is the case, DERM should consider examining farm dam development trends in other peri-urban areas to provide greater confidence about the nature of this trend, to inform water resources planning processes in these catchments.

In areas of Queensland that are not seeing peri-urban development and associated high population growth rates, the relationship between growth in stock and domestic farm dam volumes and population was considerably weaker than in peri-urban areas. Growth rates in farm dam volumes observed in non-peri-urban areas are more likely to have been influenced by other factors, such as changes in water resources policy, weather patterns (particularly drought) and change in activity of particular agricultural sectors. If stock and domestic farm dams become a policy focus in a particular non-peri-urban area of Queensland, then further work should be conducted to establish the driving factors for current and projected future growth rates in stock and domestic dams.

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Summary of baseline results for modelling catchments

Table 23 Summary of mean annual impact in the modelling catchments

Modelling catchment		Annual average flow (with dams) (ML)	Annual average flow (with no dams) (ML)	Annual average farm dam impact (ML)	Annual percentage impact of dams (on flow with no dams)
116009A	Cameron Creek at Glen Ruth	155,591	155,661	70	0.04%
116014A	Wild River at Silver Valley	180,851	182,783	1,932	1.06%
119005A	Haughton River at Mount Piccaninny	169,056	169,774	719	0.42%
120014A	Broughton River at Oak Meadows	8,206	8,608	402	4.67%
120106A	Basalt River at Bluff Downs	60,079	60,557	478	0.79%
120220A	Pelican Creek at Kerale	62,618	64,293	1,676	2.61%
130209A	Nogoa River at Craigmore	508,360	513,174	4,813	0.94%
130319A	Bell Creek at Craiglands	18,375	18,539	163	0.88%
130324A	Dawson River at Utopia Downs	134,685	137,136	2,452	1.79%
130336A	Grevillea Creek at Folding Hills	5,759	6,030	271	4.49%
130348A	Prospect Creek at Red Hill	8,071	8,639	568	6.57%
130349A	Don River at Kingsborough	45,816	46,210	394	0.85%
130407A	Nebo Creek at Nebo	59,483	59,616	134	0.22%
130410A	Isaac River at Deverill	152,493	155,358	2,865	1.84%
135004A	Gin Gin Creek at Dam Site	79,708	80,167	459	0.57%
136006A	Reid Creek at Dam Site	37,789	37,893	104	0.28%
136108A	Monal Creek at Upper Monal	8,616	8,745	130	1.48%
136112A	Burnett River at Yarrol	36,493	36,690	197	0.54%
136202D	Barambah Creek at Litzows	49,782	50,504	723	1.43%
136203A	Barker Creek at Brooklands	14,573	14,836	262	1.77%
136306A	Cadarga Creek at Brovinia Station	23,196	23,736	540	2.27%
136315A	Boyne River at Carters	47,442	48,780	1,338	2.74%
137202A	Oaky Creek at Childers	24,621	25,870	1,249	4.83%
138004B	Munna Creek at Marodian	191,178	192,504	1,326	0.69%
138009A	Tinana Creek at Tagigan Road	34,588	35,767	1,179	3.30%
138110A	Mary River at Bellbird Creek	167,242	169,018	1,776	1.05%
140002A	Teewah Creek near Coops Corner	33,313	33,363	50	0.15%

Modelling catchment		Annual average flow (with dams) (ML)	Annual average flow (with no dams) (ML)	Annual average farm dam impact (ML)	Annual percentage impact of dams (on flow with no dams)
141002A	South Maroochy River at Kureelpa	25,479	25,779	300	1.17%
141006A	Mooloolah River at Mooloolah	26,171	26,404	233	0.88%
141009A	North Maroochy River at Eumundi	24,520	25,132	611	2.43%
142202A	South Pine River at Drapers Crossing	45,281	46,854	1,573	3.36%
143110A	Bremer River at Adams Bridge	18,049	18,646	597	3.20%
143113A	Purga Creek at Loamside	12,221	14,266	2,045	14.34%
143211A	Buaraba Creek at Atkinson Diversion Weir	25,050	26,735	1,685	6.30%
143212A	Tenthill Creek at Tenthill	18,610	22,334	3,724	16.68%
143214A	Flagstone Creek at Windolfs	5,133	5,415	282	5.20%
143303A	Stanley River at Peachester	71,964	72,111	147	0.20%
143306A	Reedy Creek at Upstream Byron Creek	6,061	6,111	50	0.82%
145010A	Running Creek at 5.8km Deickmans Bridge	43,400	43,505	105	0.24%
145011A	Teviot Brook at Croftby	12,865	13,112	247	1.89%
145013A	Christmas Creek at Rudds Lane	39,644	39,974	329	0.82%
145101D	Albert River at Lumeah Number 2	49,541	50,056	515	1.03%
416204A	Weir River at Gunn Bridge	126,345	131,676	5,331	4.05%
416312A	Oaky Creek at Texas	14,652	15,203	551	3.63%
416410A	Macintyre Brook at Barongarook	20,438	21,039	601	2.86%
417201B	Moonie River at Nindigully	76,196	81,934	5,738	7.00%
422304A	Condamine River at Elbow Valley	39,779	41,235	1,457	3.53%
422352A	Hodgson Creek at Balgownie	19,829	20,698	870	4.20%
422407A	Maranoa River at Forestvale	92,755	93,002	247	0.27%
423204A	Warrego River at Augathella	48,796	49,057	261	0.53%
424202A	Paroo River at Yarronvale	53,249	53,839	590	1.10%
913009A	Gorge Creek at Flinders Highway	10,047	10,162	115	1.13%
915007A	Betts Gorge Creek at Alstonvale	28,846	29,025	178	0.61%
915207A	Gilliat River at Gilliat	106,014	106,035	21	0.02%
919005A	Rifle Creek at Fonthill	134,879	135,563	684	0.50%

Table 24 Summary of seasonal impact in the modelling catchments (% impact)

Modelling catchment		Average percentage impact in Summer (ML)	Average percentage impact in Autumn (ML)	Average percentage impact in Winter (ML)	Average percentage impact in Spring (ML)
116009A	Cameron Creek at Glen Ruth	0.03%	0.02%	0.16%	0.46%
116014A	Wild River at Silver Valley	1.08%	0.59%	6.18%	8.82%
119005A	Haughton River at Mount Piccaninny	0.45%	0.25%	1.56%	1.98%
120014A	Broughton River at Oak Meadows	4.83%	2.38%	8.06%	10.83%
120106A	Basalt River at Bluff Downs	0.73%	0.76%	2.39%	1.80%
120220A	Pelican Creek at Kerale	2.66%	1.54%	4.79%	8.80%
130209A	Nogoa River at Craigmore	1.02%	0.75%	0.93%	1.18%
130319A	Bell Creek at Craiglands	0.70%	0.92%	1.46%	2.27%
130324A	Dawson River at Utopia Downs	1.84%	1.52%	1.79%	2.45%
130336A	Grevillea Creek at Folding Hills	4.06%	4.14%	4.55%	11.48%
130348A	Prospect Creek at Red Hill	6.43%	5.31%	7.18%	11.42%
130349A	Don River at Kingsborough	0.69%	0.82%	1.59%	2.84%
130407A	Nebo Creek at Nebo	0.25%	0.13%	0.64%	1.37%
130410A	Isaac River at Deverill	2.07%	1.12%	3.34%	3.77%
135004A	Gin Gin Creek at Dam Site	0.48%	0.43%	0.91%	1.44%
136006A	Reid Creek at Dam Site	0.24%	0.20%	0.38%	0.72%
136108A	Monal Creek at Upper Monal	1.33%	1.09%	2.03%	5.24%
136112A	Burnett River at Yarrol	0.48%	0.43%	0.62%	1.77%
136202D	Barambah Creek at Litzows	1.35%	1.06%	1.50%	3.05%
136203A	Barker Creek at Brooklands	1.58%	1.51%	1.87%	2.88%
136306A	Cadarga Creek at Brovinia Station	2.04%	2.52%	1.49%	4.39%
136315A	Boyne River at Carters	2.49%	2.76%	2.43%	4.15%
137202A	Oaky Creek at Childers	4.02%	3.08%	8.83%	15.95%
138004B	Munna Creek at Marodian	0.62%	0.48%	0.80%	2.47%
138009A	Tinana Creek at Tagigan Road	2.50%	1.90%	4.14%	17.27%
138110A	Mary River at Bellbird Creek	0.71%	0.62%	1.60%	5.13%
140002A	Teewah Creek near Coops Corner	0.10%	0.04%	0.15%	0.51%
141002A	South Maroochy River at Kureelpa	0.16%	0.04%	2.92%	8.03%
141006A	Mooloolah River at Mooloolah	0.62%	0.12%	1.52%	6.91%
141009A	North Maroochy River at Eumundi	1.77%	0.71%	3.93%	11.36%

Modelling catchment		Average percentage impact in Summer (ML)	Average percentage impact in Autumn (ML)	Average percentage impact in Winter (ML)	Average percentage impact in Spring (ML)
142202A	South Pine River at Drapers Crossing	2.89%	2.19%	4.20%	10.45%
143110A	Bremer River at Adams Bridge	2.59%	2.78%	3.82%	6.08%
143113A	Purga Creek at Loamside	13.71%	11.68%	13.54%	25.37%
143211A	Buaraba Creek at Atkinson Diversion Weir	6.48%	4.99%	6.20%	11.88%
143212A	Tenthill Creek at Tenthill	15.98%	16.45%	15.72%	20.20%
143214A	Flagstone Creek at Windolfs	5.01%	4.61%	5.27%	8.98%
143303A	Stanley River at Peachester	0.10%	0.04%	0.43%	1.42%
143306A	Reedy Creek at Upstream Byron Creek	0.64%	0.58%	0.92%	2.43%
145010A	Running Creek at 5.8km Deickmans Bridge	0.20%	0.17%	0.23%	0.64%
145011A	Teviot Brook at Croftby	1.35%	1.85%	2.29%	3.76%
145013A	Christmas Creek at Rudds Lane	0.68%	0.53%	0.73%	2.37%
145101D	Albert River at Lumeah Number 2	0.82%	0.71%	1.08%	2.94%
416204A	Weir River at Gunn Bridge	4.32%	3.41%	3.67%	4.75%
416312A	Oaky Creek at Texas	3.30%	3.69%	3.39%	4.03%
416410A	Macintyre Brook at Barongarook	2.76%	2.48%	2.69%	3.43%
417201B	Moonie River at Nindigully	7.30%	6.62%	6.37%	7.54%
422304A	Condamine River at Elbow Valley	3.31%	3.20%	3.04%	5.94%
422352A	Hodgson Creek at Balgownie	3.88%	3.30%	4.19%	6.45%
422407A	Maranoa River at Forestvale	0.26%	0.28%	0.28%	0.24%
423204A	Warrego River at Augathella	0.65%	0.41%	0.68%	0.68%
424202A	Paroo River at Yarronvale	1.10%	0.91%	1.11%	1.64%
913009A	Gorge Creek at Flinders Highway	1.11%	0.87%	2.41%	2.45%
915007A	Betts Gorge Creek at Alstonvale	0.62%	0.55%	0.67%	1.20%
915207A	Gilliat River at Gilliat	0.02%	0.02%	0.02%	0.02%
919005A	Rifle Creek at Fonthill	0.22%	0.25%	2.34%	4.59%

Table 25 Summary of seasonal impact in the modelling catchments (ML/km²)

Modelling catchment		Annual average farm dam impact (ML/km²)	Average impact in Summer (ML/km²)	Average impact in Autumn (ML/km²)	Average impact in Winter (ML/km²)	Average impact in Spring (ML/km²)
116009A	Cameron Creek at Glen Ruth	0.31	0.08	0.07	0.08	0.08
116014A	Wild River at Silver Valley	3.38	1.84	0.81	0.52	0.21
119005A	Haughton River at Mount Piccaninny	0.64	0.43	0.14	0.04	0.03
120014A	Broughton River at Oak Meadows	2.17	1.45	0.31	0.18	0.23
120106A	Basalt River at Bluff Downs	0.37	0.24	0.09	0.02	0.02
120220A	Pelican Creek at Kerale	3.26	2.04	0.60	0.25	0.35
130209A	Nogoa River at Craigmore	0.34	0.19	0.08	0.04	0.03
130319A	Bell Creek at Craiglands	0.54	0.29	0.13	0.07	0.05
130324A	Dawson River at Utopia Downs	0.40	0.20	0.10	0.04	0.05
130336A	Grevillea Creek at Folding Hills	1.10	0.59	0.28	0.09	0.14
130348A	Prospect Creek at Red Hill	1.49	0.82	0.34	0.15	0.19
130349A	Don River at Kingsborough	0.64	0.35	0.16	0.07	0.06
130407A	Nebo Creek at Nebo	0.56	0.34	0.14	0.05	0.03
130410A	Isaac River at Deverill	0.69	0.48	0.14	0.05	0.03
135004A	Gin Gin Creek at Dam Site	0.83	0.38	0.19	0.13	0.12
136006A	Reid Creek at Dam Site	0.49	0.22	0.11	0.07	0.09
136108A	Monal Creek at Upper Monal	1.40	0.69	0.33	0.21	0.17
136112A	Burnett River at Yarrol	0.48	0.24	0.11	0.06	0.06
136202D	Barambah Creek at Litzows	1.09	0.47	0.25	0.17	0.19
136203A	Barker Creek at Brooklands	1.03	0.47	0.20	0.17	0.19
136306A	Cadarga Creek at Brovinia Station	0.41	0.21	0.09	0.04	0.07
136315A	Boyne River at Carters	0.80	0.39	0.18	0.10	0.13
137202A	Oaky Creek at Childers	7.17	3.51	1.34	0.98	1.32
138004B	Munna Creek at Marodian	1.09	0.50	0.25	0.14	0.19
138009A	Tinana Creek at Tagigan Road	11.07	3.06	2.68	2.47	2.77
138110A	Mary River at Bellbird Creek	3.46	0.94	0.85	0.78	0.88
140002A	Teewah Creek near Coops Corner	0.91	0.18	0.08	0.22	0.41
141002A	South Maroochy River at Kureelpa	14.80	0.82	0.17	5.20	8.34
141006A	Mooloolah River at Mooloolah	5.52	1.53	0.31	1.31	2.28
141009A	North Maroochy River at	14.11	4.19	1.57	3.18	5.01

Modelling catchment		Annual average farm dam impact (ML/km²)	Average impact in Summer (ML/km²)	Average impact in Autumn (ML/km²)	Average impact in Winter (ML/km²)	Average impact in Spring (ML/km²)
	Eumundi					
142202A	South Pine River at Drapers Crossing	9.42	3.59	2.36	1.39	2.01
143110A	Bremer River at Adams Bridge	4.94	2.03	1.14	0.75	0.99
143113A	Purga Creek at Loamside	9.16	4.26	2.48	1.28	1.10
143211A	Buaraba Creek at Atkinson Diversion Weir	6.39	2.75	1.92	1.01	0.69
143212A	Tenthill Creek at Tenthill	7.76	3.28	2.47	1.35	0.73
143214A	Flagstone Creek at Windolfs	1.90	0.83	0.60	0.35	0.15
143303A	Stanley River at Peachester	1.41	0.27	0.10	0.40	0.61
143306A	Reedy Creek at Upstream Byron Creek	0.87	0.25	0.24	0.18	0.18
145010A	Running Creek at 5.8km Deickmans Bridge	0.78	0.22	0.20	0.15	0.20
145011A	Teviot Brook at Croftby	2.83	1.02	0.72	0.50	0.57
145013A	Christmas Creek at Rudds Lane	1.99	0.52	0.48	0.41	0.57
145101D	Albert River at Lumeah Number 2	2.91	0.83	0.75	0.58	0.73
416204A	Weir River at Gunn Bridge	1.16	0.47	0.27	0.25	0.18
416312A	Oaky Creek at Texas	1.33	0.51	0.30	0.27	0.25
416410A	Macintyre Brook at Barongarook	1.07	0.44	0.19	0.20	0.24
417201B	Moonie River at Nindigully	0.47	0.20	0.13	0.09	0.05
422304A	Condamine River at Elbow Valley	4.97	1.57	1.39	1.02	1.02
422352A	Hodgson Creek at Balgownie	1.43	0.66	0.28	0.23	0.27
422407A	Maranoa River at Forestvale	0.03	0.01	0.01	0.00	0.00
423204A	Warrego River at Augathella	0.03	0.01	0.01	0.00	0.00
424202A	Paroo River at Yarronvale	0.32	0.15	0.09	0.04	0.04
913009A	Gorge Creek at Flinders Highway	0.46	0.28	0.10	0.03	0.04
915007A	Betts Gorge Creek at Alstonvale	0.17	0.13	0.03	0.00	0.00
915207A	Gilliat River at Gilliat	0.00	0.00	0.00	0.00	0.00
919005A	Rifle Creek at Fonthill	1.92	0.42	0.39	0.54	0.56

Summary of baseline results for reporting areas

Table 26 Summary of data for reporting areas used in Figure 17 - Figure 21

Reporting area		Estimated volume of dams (ML)	Estimated density of dams (ML/km²)	Regionalised volumetric impact of dams (ML/year)	Regionalised volumetric impact of dams per km² (ML impact/km²)	Regionalised volumetric impact of dams per volume of dams (ML Impact/ML predicted dams)
IQ Atlas Num	Reporting area name	Figure 15	Figure 16	Figure 17	Figure 18	Figure 19
80	Albert River	7,452	9.08	3,973	4.84	0.53
590	Alice River	2,878	0.23	873	0.07	0.30
51	Archer River	4,245	0.42	1,333	0.13	0.31
2035	Baffle Creek	9,449	2.28	3,527	0.85	0.37
81	Balonne River	46,724	1.17	10,261	0.26	0.22
14	Barcoo River	37,091	0.68	7,672	0.14	0.21
102	Barker & Barambah Creeks	13,128	2.14	4,466	0.73	0.34
30	Barratta Creek	7,995	4.44	3,590	1.99	0.45
1626	Barron River	5,304	2.50	2,322	1.09	0.44
29	Black River	3,755	3.62	1,936	1.87	0.52
96	Bohle River	3,744	10.36	2,425	6.71	0.65
27	Bowen River	7,141	0.76	2,250	0.24	0.32
103	Boyne & Auburn Rivers	15,480	1.16	4,428	0.33	0.29
2028	Boyne River	5,540	2.18	2,331	0.92	0.42
32	Bremer River	13,824	6.50	5,905	2.78	0.43
36	Brisbane River	19,802	2.73	6,430	0.89	0.32
16	Bulloo River	32,548	0.60	6,757	0.12	0.21
61	Burrum River	6,268	5.05	3,069	2.47	0.49
22	Caboolture River	9,616	19.91	5,711	11.82	0.59
2036	Calliope River	6,446	2.84	2,768	1.22	0.43
48	Cliffdale Creek	2,583	0.43	919	0.15	0.36
20	Cloncurry River	16,909	0.36	3,681	0.08	0.22
68	Coen River	1,050	0.34	442	0.14	0.42
591	Coleman River	1,113	0.22	419	0.08	0.38
101	Comet River	16,814	0.95	4,524	0.26	0.27

Reporting area		Estimated volume of dams (ML)	Estimated density of dams (ML/km²)	Regionalised volumetric impact of dams (ML/year)	Regionalised volumetric impact of dams per km² (ML impact/km²)	Regionalised volumetric impact of dams per volume of dams (ML Impact/ML predicted dams)
IQ Atlas Num	Reporting area name	Figure 15	Figure 16	Figure 17	Figure 18	Figure 19
2032	Condamine River	63,258	1.99	14,493	0.46	0.23
62	Coomera & Nerang Rivers	9,153	6.74	4,352	3.20	0.48
6	Cooper Creek	22,633	0.23	4,157	0.04	0.18
64	Daintree River	1,856	0.91	842	0.41	0.45
2034	Dawson River	53,479	1.03	11,060	0.21	0.21
2027	Diamantina River	28,808	0.24	5,043	0.04	0.18
2002	Don River	4,742	1.29	1,848	0.50	0.39
100	Ducie River	377	0.11	159	0.05	0.42
82	Dumaresq River	16,001	3.51	5,774	1.27	0.36
15	Edward River	5,474	0.76	1,838	0.25	0.34
37	Eight Mile Creek	625	0.39	308	0.19	0.49
593	Einasleigh River	9,519	0.40	2,434	0.10	0.26
2007	Elloitt River	4,688	6.49	2,599	3.60	0.55
50	Embley River	1,463	0.80	683	0.37	0.47
42	Endeavour River	2,060	0.98	926	0.44	0.45
63	Eyre Creek	13,139	0.18	2,618	0.04	0.20
46	Fitzroy River	29,242	2.53	8,501	0.74	0.29
83	Flinders River	18,324	0.36	3,904	0.08	0.21
3	Georgina River	12,713	0.18	2,541	0.04	0.20
1753	Gilbert River	7,503	0.35	1,973	0.09	0.26
2004	Gregory River	4,325	4.62	2,273	2.43	0.53
66	Hann River	1,803	0.20	591	0.06	0.33
73	Haughton River	4,688	2.14	2,046	0.94	0.44
93	Hay	111	0.04	50	0.02	0.45
79	Herbert River	11,420	1.19	3,537	0.37	0.31
71	Holroyd River	2,072	0.40	765	0.15	0.37
25	Isaac River	20,702	0.92	5,261	0.23	0.25
53	Isis River	2,230	4.13	1,342	2.48	0.60

Reporting area		Estimated volume of dams (ML)	Estimated density of dams (ML/km²)	Regionalised volumetric impact of dams (ML/year)	Regionalised volumetric impact of dams per km² (ML impact/km²)	Regionalised volumetric impact of dams per volume of dams (ML Impact/ML predicted dams)
IQ Atlas Num	Reporting area name	Figure 15	Figure 16	Figure 17	Figure 18	Figure 19
8	Jacky Jacky Creek	772	0.28	334	0.12	0.43
33	Jardine River	1,423	0.46	593	0.19	0.42
47	Jeannie River	1,076	0.31	441	0.13	0.41
11	Kendall River	1,359	0.29	520	0.11	0.38
1625	Kolan River	6,909	2.33	2,796	0.94	0.40
19	L Creek	661	0.35	312	0.16	0.47
58	Lagoon Creek	1,254	0.45	538	0.19	0.43
98	Lake Frome	60	0.38	52	0.32	0.86
23	Leichhardt River	13,808	0.43	3,275	0.10	0.24
95	Lockhart River	2,713	0.99	1,143	0.42	0.42
91	Lockyer Creek	20,534	6.52	7,977	2.53	0.39
75	Logan River	21,933	6.22	8,300	2.35	0.38
85	Lower Burdekin River	9,238	0.89	2,831	0.27	0.31
89	Lower Burnett River	18,148	3.11	6,190	1.06	0.34
104	Lower Mary River	18,512	2.66	6,074	0.87	0.33
2031	Macintyre & Weir Rivers	30,829	1.90	8,317	0.51	0.27
2033	Macintyre Brook	6,591	1.45	2,434	0.54	0.37
9	Mackenzie River	21,774	1.66	6,205	0.47	0.28
1	Maranoa River	14,229	0.69	3,713	0.18	0.26
21	Maroochy River	13,389	9.36	6,236	4.36	0.47
94	Maroochy River	1,148	7.83	931	6.36	0.81
5	Mcdonald River	562	0.22	250	0.10	0.44
45	Mission River	559	0.22	249	0.10	0.45
56	Mitchell River	21,684	0.54	4,852	0.12	0.22
2030	Moonie River	17,937	1.19	4,980	0.33	0.28
17	Morning Inlet	710	0.42	344	0.20	0.48
92	Mossman River	510	1.12	330	0.72	0.65

Reporting area		Estimated volume of dams (ML)	Estimated density of dams (ML/km²)	Regionalised volumetric impact of dams (ML/year)	Regionalised volumetric impact of dams per km² (ML impact/km²)	Regionalised volumetric impact of dams per volume of dams (ML Impact/ML predicted dams)
IQ Atlas Num	Reporting area name	Figure 15	Figure 16	Figure 17	Figure 18	Figure 19
12	Mulgrave River	1,656	1.30	834	0.65	0.50
74	Murray River	1,762	1.63	918	0.85	0.52
38	Nicholson River	13,091	0.38	3,058	0.09	0.23
2006	Nogoa River	25,328	0.90	6,098	0.22	0.24
40	Noosa River	4,164	2.09	1,860	0.93	0.45
52	Norman River	23,359	0.47	4,988	0.10	0.21
55	Normanby River	5,418	0.38	1,570	0.11	0.29
18	North Johnstone River	2,239	2.23	1,178	1.17	0.53
35	North Pine River	6,795	10.94	3,856	6.21	0.57
49	O'Connell River	9,299	3.94	3,922	1.66	0.42
43	Olive River	57	0.03	29	0.01	0.50
65	Palmer River	3,144	0.39	1,046	0.13	0.33
77	Paroo River	20,564	0.54	4,654	0.12	0.23
34	Pascoe River	53	0.03	26	0.01	0.50
26	Pioneer River	3,878	2.48	1,829	1.17	0.47
41	Plane Creek	9,416	3.73	3,914	1.55	0.42
1752	Proserpine River	7,615	3.12	3,204	1.31	0.42
44	Ross River	4,787	3.64	2,330	1.77	0.49
24	Russell River	407	0.63	246	0.38	0.60
87	Saxby River	3,334	0.33	1,056	0.11	0.32
70	Settlement River	648	0.59	345	0.32	0.53
88	Shoalwater	4,222	1.17	1,657	0.46	0.39
60	Skardon River	109	0.26	75	0.18	0.69
2	South Johnstone River	1,439	1.15	730	0.58	0.51
97	South Pine River	5,088	11.66	3,139	7.20	0.62
592	Staaten River	4,035	0.16	1,045	0.04	0.26
39	Stanley River	7,239	4.53	3,343	2.09	0.46
78	Stewart River	720	0.27	317	0.12	0.44

Reporting area		Estimated volume of dams (ML)	Estimated density of dams (ML/km²)	Regionalised volumetric impact of dams (ML/year)	Regionalised volumetric impact of dams per km² (ML impact/km²)	Regionalised volumetric impact of dams per volume of dams (ML Impact/ML predicted dams)
IQ Atlas Num	Reporting area name	Figure 15	Figure 16	Figure 17	Figure 18	Figure 19
10	Styx River	3,964	1.31	1,620	0.54	0.41
84	Suttor River	31,892	0.43	6,192	0.08	0.19
2029	Thomson River	35,291	0.37	6,465	0.07	0.18
67	Tully River	2,741	1.67	1,290	0.79	0.47
86	Upper Burdekin River	23,648	0.66	5,417	0.15	0.23
2003	Upper Burnett River	8,637	0.98	2,747	0.31	0.32
99	Upper Mary River	12,232	4.36	4,936	1.76	0.40
69	Wallam Creeks	21,896	0.44	4,686	0.10	0.21
54	Walsh River	7,304	0.84	2,339	0.27	0.32
2005	Warrego River	26,146	0.49	5,474	0.10	0.21
57	Waterpark Creek	8,330	4.57	3,726	2.04	0.45
72	Watson River	3,806	0.85	1,431	0.32	0.38
7	Wenlock River	1,356	0.19	473	0.07	0.35

Summary of uncertainty in the regionalised impacts

Table 27 Summary of uncertainty in the regionalised impacts

IQ Atlas Num	Reporting area name	Lower confidence limit	Regionalised volumetric impact of dams (ML/year)	Upper confidence limit
80	Albert River	1,360	3,973	11,605
590	Alice River	295	873	2,581
51	Archer River	454	1,333	3,911
2035	Baffle Creek	1,208	3,527	10,297
81	Balonne River	3,287	10,261	32,035
14	Barcoo River	2,454	7,672	23,979
102	Barker & Barambah Creeks	1,514	4,466	13,170
30	Barratta Creek	1,235	3,590	10,432
1626	Barron River	807	2,322	6,681
29	Black River	677	1,936	5,538
96	Bohle River	838	2,425	7,021
27	Bowen River	767	2,250	6,605
103	Boyne & Auburn Rivers	1,483	4,428	13,225
2028	Boyne River	809	2,331	6,716
32	Bremer River	1,999	5,905	17,445
36	Brisbane River	2,154	6,430	19,193
16	Bulloo River	2,167	6,757	21,068
61	Burrum River	1,061	3,069	8,877
22	Caboolture River	1,916	5,711	17,022
2036	Calliope River	958	2,768	7,996
48	Cliffdale Creek	317	919	2,666
20	Cloncurry River	1,196	3,681	11,334
68	Coen River	154	442	1,273
591	Coleman River	144	419	1,222
101	Comet River	1,506	4,524	13,596
2032	Condamine River	4,617	14,493	45,500
62	Coomera & Nerang Rivers	1,488	4,352	12,725
6	Cooper Creek	1,314	4,157	13,156
64	Daintree River	296	842	2,398
2034	Dawson River	3,512	11,060	34,831
2027	Diamantina River	1,580	5,043	16,099

IQ Atlas Num	Reporting area name	Lower confidence limit	Regionalised volumetric impact of dams (ML/year)	Upper confidence limit
2002	Don River	641	1,848	5,328
100	Ducie River	54	159	472
82	Dumaresq River	1,950	5,774	17,098
15	Edward River	631	1,838	5,358
37	Eight Mile Creek	107	308	880
593	Einasleigh River	810	2,434	7,320
2007	Elloitt River	901	2,599	7,495
50	Embley River	240	683	1,943
42	Endeavour River	325	926	2,638
63	Eyre Creek	838	2,618	8,175
46	Fitzroy River	2,806	8,501	25,756
83	Flinders River	1,264	3,904	12,062
3	Georgina River	814	2,541	7,933
1753	Gilbert River	659	1,973	5,912
2004	Gregory River	792	2,273	6,525
66	Hann River	201	591	1,741
73	Haughton River	713	2,046	5,875
93	Hay	16	50	155
79	Herbert River	1,197	3,537	10,453
71	Holroyd River	264	765	2,215
25	Isaac River	1,736	5,261	15,942
53	Isis River	472	1,341	3,815
8	Jacky Jacky Creek	116	334	966
33	Jardine River	207	593	1,703
47	Jeannie River	153	441	1,272
11	Kendall River	179	520	1,508
1625	Kolan River	966	2,796	8,095
19	L Creek	109	312	897
58	Lagoon Creek	188	538	1,542
98	Lake Frome	18	52	152
23	Leichhardt River	1,077	3,275	9,955
95	Lockhart River	399	1,143	3,268
91	Lockyer Creek	2,668	7,977	23,850
75	Logan River	2,771	8,300	24,862
85	Lower Burdekin River	960	2,831	8,349

IQ Atlas Num	Reporting area name	Lower confidence limit	Regionalised volumetric impact of dams (ML/year)	Upper confidence limit
89	Lower Burnett River	2,081	6,190	18,412
104	Lower Mary River	2,039	6,074	18,091
2031	Macintyre & Weir Rivers	2,732	8,317	25,320
2033	Macintyre Brook	839	2,434	7,063
9	Mackenzie River	2,063	6,205	18,665
1	Maranoa River	1,235	3,713	11,166
21	Maroochy River	2,105	6,236	18,475
94	Maroochy River	326	931	2,665
5	Mcdonald River	86	250	725
45	Mission River	86	249	721
56	Mitchell River	1,579	4,852	14,914
2030	Moonie River	1,659	4,980	14,943
17	Morning Inlet	120	344	983
92	Mossman River	117	330	933
12	Mulgrave River	294	834	2,363
74	Murray River	324	918	2,600
38	Nicholson River	1,004	3,058	9,314
2006	Nogoa River	1,995	6,098	18,637
40	Noosa River	649	1,860	5,329
52	Norman River	1,612	4,988	15,433
55	Normanby River	530	1,570	4,647
18	North Johnstone River	415	1,178	3,343
35	North Pine River	1,319	3,856	11,278
49	O'Connell River	1,345	3,922	11,436
43	Olive River	9	29	90
65	Palmer River	358	1,046	3,053
77	Paroo River	1,517	4,654	14,277
34	Pascoe River	8	26	83
26	Pioneer River	640	1,829	5,232
41	Plane Creek	1,342	3,914	11,414
1752	Proserpine River	1,105	3,204	9,294
44	Ross River	811	2,330	6,694
24	Russell River	87	246	699
87	Saxby River	360	1,056	3,101
70	Settlement River	122	345	982

IQ Atlas Num	Reporting area name	Lower confidence limit	Regionalised volumetric impact of dams (ML/year)	Upper confidence limit
88	Shoalwater	576	1,657	4,770
60	Skardon River	26	75	218
2	South Johnstone River	258	730	2,067
97	South Pine River	1,077	3,139	9,148
592	Staaten River	346	1,045	3,155
39	Stanley River	1,153	3,343	9,693
78	Stewart River	110	317	914
10	Styx River	564	1,620	4,650
84	Suttor River	1,969	6,192	19,468
2029	Thomson River	2,037	6,465	20,518
67	Tully River	453	1,290	3,674
86	Upper Burdekin River	1,765	5,417	16,621
2003	Upper Burnett River	935	2,747	8,071
99	Upper Mary River	1,680	4,936	14,504
69	Wallam Creeks	1,516	4,686	14,486
54	Walsh River	798	2,339	6,856
2005	Warrego River	1,763	5,474	17,002
57	Waterpark Creek	1,281	3,726	10,841
72	Watson River	496	1,431	4,128
7	Wenlock River	161	473	1,388

Tables of parameters tested in sensitivity scenarios

Scenario No.	Assessed parameter	(Scenario sub-no.) Change to base case model
2	Method of identifying stock and domestic dams	Assume all dams are stock and domestic
3	Method of determining number and volume of farm dams	Apply size distribution to catchments where number and volume of farm dams is already known
4	Surface area to volume relationship	(a) Lower confidence limit (b) Upper confidence limit
5	Impounded catchment area relationship	(a) Lower confidence limit (b) Upper confidence limit
6	Demand factor	(a) Lower confidence limit (b) Upper confidence limit
7	Stock and domestic farm dam volume regionalisation	(a) Apply equation where total dam volume already reasonably estimated (b) Lower confidence limit (c) Upper confidence limit

Sensitivity scenario outputs

Table 28 Comparison of scenarios 1 and 2 – Sensitivity of identification of stock and domestic dams

Gauge Number	Gauge Name	Volume of dams (ML)			Annual average farm dam impact (ML)		
		Scenario 1	Scenario 2	% change (Scenario 1 to Scenario 2)	Scenario 1	Scenario 2	% change (Scenario 1 to Scenario 2)
119005A	Haughton River at Mount Piccaninny	852	872	2.3%	744	763	2.5%
120106A	Basalt River at Bluff Downs	676	846	25.1%	495	630	27.3%
130319A	Bell Creek at Craiglands	223	223	0.0%	165	165	0.0%
130349A	Don River at Kingsborough	576	578	0.5%	397	399	0.5%
130407A	Nebo Creek at Nebo	155	155	0.0%	134	134	0.0%
142202A	South Pine River at Drapers Crossing	1,639	1,733	5.8%	1,687	1,786	5.8%
143110A	Bremer River at Adams Bridge	659	695	5.6%	641	677	5.7%
143113A	Purga Creek at Loamside	2,815	2,909	3.4%	2,194	2,258	2.9%
143211A	Buaraba Creek at Atkinson Diversion Weir	2,331	2,375	1.9%	1,808	1,842	1.9%
143212A	Tenthill Creek at Tenthill	7,337	8,153	11.1%	3,995	4,379	9.6%
143214A	Flagstone Creek at Windolfs	577	603	4.6%	302	316	4.4%
143303A	Stanley River at Peachester	322	515	60.2%	158	254	60.8%
143306A	Reedy Creek at Upstream Byron Creek	69	78	13.7%	54	61	14.4%
145010A	Running Creek at 5.8km Deickmans Bridge	93	111	19.3%	110	132	19.7%
145011A	Teviot Brook at Croftby	225	244	8.4%	258	280	8.4%
145013A	Christmas Creek at Rudds Lane	334	353	5.6%	344	364	5.9%
145101D	Albert River at Lumeah Number 2	488	556	13.8%	537	609	13.3%
416204A	Weir River at Gunn Bridge	7,565	7,565	0.0%	5,385	5,385	0.0%
416312A	Oaky Creek at Texas	587	591	0.7%	550	554	0.7%
416410A	Macintyre Brook at Barongarook	656	657	0.1%	597	598	0.1%
417201B	Moonie River at Nindigully	24,282	25,709	5.9%	6,045	6,405	6.0%
422304A	Condamine River at Elbow Valley	1,275	1,581	24.0%	1,458	1,777	21.9%
422352A	Hodgson Creek at Balgownie	1,056	1,376	30.3%	868	1,106	27.5%
422407A	Maranoa River at Forestvale	2,746	2,925	6.5%	257	320	24.3%
423204A	Warrego River at Augathella	2,792	2,827	1.2%	275	283	2.8%
424202A	Paroo River at Yarronvale	749	749	0.0%	639	639	0.0%

Table 29 Comparison of scenarios 1 and 3 - Sensitivity of the use of the use of the size distribution

Gauge Number	Gauge Name	Number of dams			Annual average farm dam impact (ML)		
		Scenario 1	Scenario 3	% change (Scenario 1 to Scenario 3)	Scenario 1	Scenario 3	% change (Scenario 1 to Scenario 3)
119005A	Haughton River at Mount Piccaninny	141	219	55.3%	744	750	0.8%
120106A	Basalt River at Bluff Downs	76	209	175.0%	495	527	6.6%
130319A	Bell Creek at Craiglands	59	63	6.8%	165	165	0.4%
130349A	Don River at Kingsborough	148	179	20.9%	397	414	4.2%
130407A	Nebo Creek at Nebo	70	48	-31.4%	134	133	-0.1%
142202A	South Pine River at Drapers Crossing	865	371	-57.1%	1687	1546	-8.4%
143110A	Bremer River at Adams Bridge	219	209	-4.6%	641	653	1.9%
143113A	Purga Creek at Loamside	968	656	-32.2%	2194	2146	-2.2%
143211A	Buaraba Creek at Atkinson Diversion Weir	475	508	6.9%	1808	1882	4.1%
143212A	Tenthill Creek at Tenthill	2409	1550	-35.7%	3995	3987	-0.2%
143214A	Flagstone Creek at Windolfs	332	180	-45.8%	302	293	-3.2%
143303A	Stanley River at Peachester	138	81	-41.3%	158	159	0.4%
143306A	Reedy Creek at Upstream Byron Creek	46	23	-50.0%	54	52	-3.7%
145010A	Running Creek at 5.8km Deickmans Bridge	56	28	-50.0%	110	101	-8.1%
145011A	Teviot Brook at Croftby	124	63	-49.2%	258	240	-7.1%
145013A	Christmas Creek at Rudds Lane	180	85	-52.8%	344	315	-8.6%
145101D	Albert River at Lumeah Number 2	164	141	-14.0%	537	558	3.8%
416204A	Weir River at Gunn Bridge	1159	1601	38.1%	5385	5484	1.9%
416312A	Oaky Creek at Texas	311	180	-42.1%	550	525	-4.7%
416410A	Macintyre Brook at Barongarook	338	207	-38.8%	597	582	-2.5%
417201B	Moonie River at Nindigully	3109	5580	79.5%	6045	6162	1.9%
422304A	Condamine River at Elbow Valley	434	317	-27.0%	1458	1446	-0.8%
422352A	Hodgson Creek at Balgownie	358	258	-27.9%	868	855	-1.5%
422407A	Maranoa River at Forestvale	593	629	6.1%	257	257	-0.3%
423204A	Warrego River at Augathella	416	650	56.3%	275	270	-1.8%
424202A	Paroo River at Yarronvale	62	209	237.1%	639	649	1.7%

Table 30 Comparison of Scenarios 1 and 4a & b - Sensitivity of the surface area to volume relationship confidence limits (change to volume of dams)

Gauge Number	Gauge Name	Volume of dams (ML)			% change	
		Scenario 1	Scenario 4a	Scenario 4b	Scenario 1 to Scenario 4a	Scenario 1 to Scenario 4b
119005A	Haughton River at Mount Piccaninny	852	698	1046	-18.0%	22.7%
120106A	Basalt River at Bluff Downs	676	533	866	-21.3%	28.0%
130319A	Bell Creek at Craiglands	223	191	261	-14.3%	17.0%
130349A	Don River at Kingsborough	576	473	708	-17.8%	23.0%
130407A	Nebo Creek at Nebo	155	135	179	-12.8%	15.2%
142202A	South Pine River at Drapers Crossing	1639	1454	1853	-11.3%	13.1%
143110A	Bremer River at Adams Bridge	659	561	777	-14.8%	18.0%
143113A	Purga Creek at Loamside	2815	2421	3289	-14.0%	16.8%
143211A	Buaraba Creek at Atkinson Diversion Weir	2331	1869	2935	-19.8%	25.9%
143212A	Tenthill Creek at Tenthill	7337	6156	8826	-16.1%	20.3%
143214A	Flagstone Creek at Windolfs	577	516	646	-10.5%	12.0%
143303A	Stanley River at Peachester	322	282	367	-12.2%	14.2%
143306A	Reedy Creek at Upstream Byron Creek	69	62	76	-9.5%	10.7%
145010A	Running Creek at 5.8km Deickmans Bridge	93	83	104	-10.9%	12.5%
145011A	Teviot Brook at Croftby	225	202	252	-10.2%	11.6%
145013A	Christmas Creek at Rudds Lane	334	297	376	-11.1%	12.7%
145101D	Albert River at Lumeah Number 2	488	406	591	-16.8%	21.2%
416204A	Weir River at Gunn Bridge	7565	6145	9377	-18.8%	23.9%
416312A	Oaky Creek at Texas	587	527	656	-10.3%	11.7%
416410A	Macintyre Brook at Barongarook	656	582	742	-11.2%	13.1%
417201B	Moonie River at Nindigully	24282	19771	30006	-18.6%	23.6%
422304A	Condamine River at Elbow Valley	1275	1070	1535	-16.1%	20.4%
422352A	Hodgson Creek at Balgownie	1056	896	1252	-15.1%	18.6%
422407A	Maranoa River at Forestvale	2746	2348	3222	-14.5%	17.3%
423204A	Warrego River at Augathella	2792	2351	3327	-15.8%	19.1%
424202A	Paroo River at Yarronvale	749	611	922	-18.5%	23.1%

Table 31 Comparison of Scenarios 1 and 4a & b - Sensitivity of the surface area to volume relationship confidence limits (change to average annual impact)

Gauge Number	Gauge Name	Annual average farm dam impact (ML)			% change	
		Scenario 1	Scenario 4a	Scenario 4b	Scenario 1 to Scenario 4a	Scenario 1 to Scenario 4b
119005A	Haughton River at Mount Piccaninny	744	596	904	-19.9%	21.6%
120106A	Basalt River at Bluff Downs	495	379	630	-23.3%	27.3%
130319A	Bell Creek at Craiglands	165	141	190	-14.2%	15.4%
130349A	Don River at Kingsborough	397	324	484	-18.4%	21.9%
130407A	Nebo Creek at Nebo	134	117	152	-12.7%	13.9%
142202A	South Pine River at Drapers Crossing	1687	1567	1819	-7.1%	7.8%
143110A	Bremer River at Adams Bridge	641	579	712	-9.7%	11.1%
143113A	Purga Creek at Loamside	2194	1958	2464	-10.8%	12.3%
143211A	Buaraba Creek at Atkinson Diversion Weir	1808	1537	2142	-14.9%	18.5%
143212A	Tenthill Creek at Tenthill	3995	3522	4566	-11.8%	14.3%
143214A	Flagstone Creek at Windolfs	302	276	332	-8.8%	9.7%
143303A	Stanley River at Peachester	158	138	181	-12.7%	14.7%
143306A	Reedy Creek at Upstream Byron Creek	54	49	59	-8.7%	9.1%
145010A	Running Creek at 5.8km Deickmans Bridge	110	104	116	-5.3%	5.6%
145011A	Teviot Brook at Croftby	258	243	274	-5.7%	6.2%
145013A	Christmas Creek at Rudds Lane	344	325	366	-5.7%	6.3%
145101D	Albert River at Lumeah Number 2	537	494	590	-8.0%	9.7%
416204A	Weir River at Gunn Bridge	5385	4514	6446	-16.2%	19.7%
416312A	Oaky Creek at Texas	550	507	598	-7.9%	8.6%
416410A	Macintyre Brook at Barongarook	597	541	658	-9.3%	10.2%
417201B	Moonie River at Nindigully	6045	5006	7287	-17.2%	20.6%
422304A	Condamine River at Elbow Valley	1458	1329	1609	-8.8%	10.4%
422352A	Hodgson Creek at Balgownie	868	765	987	-11.9%	13.7%
422407A	Maranoa River at Forestvale	257	130	428	-49.7%	66.4%
423204A	Warrego River at Augathella	275	178	396	-35.1%	43.9%
424202A	Paroo River at Yarronvale	639	490	807	-23.3%	26.4%

Table 32 Comparison of scenarios 1 and 5a & b - Sensitivity of the local catchment area relationship confidence limits (change to local catchment area)

Gauge Number	Gauge Name	Local catchment area (km^2)			% change	
		Scenario 1	Scenario 5a	Scenario 5b	Scenario 1 to Scenario 5a	Scenario 1 to Scenario 5b
119005A	Haughton River at Mount Piccaninny	29	27	32	-8.2%	8.6%
120106A	Basalt River at Bluff Downs	35	32	38	-7.9%	8.3%
130319A	Bell Creek at Craiglands	9	9	10	-7.5%	7.8%
130349A	Don River at Kingsborough	21	20	23	-7.1%	7.4%
130407A	Nebo Creek at Nebo	5	5	5	-9.1%	9.5%
142202A	South Pine River at Drapers Crossing	42	41	43	-2.7%	2.7%
143110A	Bremer River at Adams Bridge	25	24	25	-2.9%	3.0%
143113A	Purga Creek at Loamside	75	73	76	-2.3%	2.3%
143211A	Buaraba Creek at Atkinson Diversion Weir	65	63	67	-2.7%	2.7%
143212A	Tenthill Creek at Tenthill	149	145	153	-2.4%	2.4%
143214A	Flagstone Creek at Windolfs	20	20	21	-3.6%	3.6%
143303A	Stanley River at Peachester	15	14	15	-3.5%	3.5%
143306A	Reedy Creek at Upstream Byron Creek	2	2	3	-6.7%	6.7%
145010A	Running Creek at 5.8km Deickmans Bridge	2	2	2	-11.4%	11.4%
145011A	Teviot Brook at Croftby	10	9	10	-3.9%	4.0%
145013A	Christmas Creek at Rudds Lane	11	10	11	-5.3%	5.4%
145101D	Albert River at Lumeah Number 2	15	15	16	-4.6%	4.6%
416204A	Weir River at Gunn Bridge	344	327	361	-4.9%	5.0%
416312A	Oaky Creek at Texas	32	31	34	-4.7%	4.8%
416410A	Macintyre Brook at Barongarook	35	33	37	-5.3%	5.4%
417201B	Moonie River at Nindigully	939	894	986	-4.8%	5.0%
422304A	Condamine River at Elbow Valley	44	43	46	-3.4%	3.5%
422352A	Hodgson Creek at Balgownie	56	54	59	-4.3%	4.4%
422407A	Maranoa River at Forestvale	25	19	32	-24.5%	28.0%
423204A	Warrego River at Augathella	51	43	60	-16.0%	17.4%
424202A	Paroo River at Yarronvale	34	31	38	-9.5%	10.0%

Table 33 Comparison of scenarios 1 and 5a & b - Sensitivity of the local catchment area relationship confidence limits (change to average annual impact)

Gauge Number	Gauge Name	Annual average farm dam impact (ML)			% change	
		Scenario 1	Scenario 5a	Scenario 5b	Scenario 1 to Scenario 5a	Scenario 1 to Scenario 5b
119005A	Haughton River at Mount Piccaninny	744	728	759	-2.2%	2.0%
120106A	Basalt River at Bluff Downs	495	479	511	-3.2%	3.2%
130319A	Bell Creek at Craiglands	165	160	169	-2.8%	2.7%
130349A	Don River at Kingsborough	397	386	408	-2.8%	2.8%
130407A	Nebo Creek at Nebo	134	131	136	-2.0%	2.0%
142202A	South Pine River at Drapers Crossing	1687	1683	1691	-0.2%	0.2%
143110A	Bremer River at Adams Bridge	641	638	643	-0.4%	0.4%
143113A	Purga Creek at Loamside	2194	2169	2220	-1.2%	1.2%
143211A	Buaraba Creek at Atkinson Diversion Weir	1808	1793	1822	-0.8%	0.8%
143212A	Tenthill Creek at Tenthill	3995	3934	4056	-1.5%	1.5%
143214A	Flagstone Creek at Windolfs	302	298	307	-1.5%	1.5%
143303A	Stanley River at Peachester	158	158	158	0.0%	0.0%
143306A	Reedy Creek at Upstream Byron Creek	54	53	54	-1.7%	1.5%
145010A	Running Creek at 5.8km Deickmans Bridge	110	110	110	-0.3%	0.2%
145011A	Teviot Brook at Croftby	258	257	259	-0.4%	0.4%
145013A	Christmas Creek at Rudds Lane	344	343	344	-0.2%	0.1%
145101D	Albert River at Lumeah Number 2	537	537	538	-0.1%	0.1%
416204A	Weir River at Gunn Bridge	5385	5264	5503	-2.2%	2.2%
416312A	Oaky Creek at Texas	550	540	561	-2.0%	2.0%
416410A	Macintyre Brook at Barongarook	597	583	611	-2.3%	2.3%
417201B	Moonie River at Nindigully	6045	5799	6292	-4.1%	4.1%
422304A	Condamine River at Elbow Valley	1458	1451	1465	-0.5%	0.4%
422352A	Hodgson Creek at Balgownie	868	850	885	-2.0%	2.0%
422407A	Maranoa River at Forestvale	257	199	323	-22.7%	25.3%
423204A	Warrego River at Augathella	275	239	313	-13.2%	13.8%
424202A	Paroo River at Yarronvale	639	604	673	-5.5%	5.3%

Table 34 Comparison of scenarios 1 and 6a & b - Sensitivity of the demand factor confidence limits (change to demand factor)

Gauge Number	Gauge Name	Annual demand (ML/yr)			% change	
		Scenario 1	Scenario 6a	Scenario 6b	Scenario 1 to Scenario 6a	Scenario 1 to Scenario 6b
119005A	Haughton River at Mount Piccaninny	426	315	614	-26.0%	44.0%
120106A	Basalt River at Bluff Downs	338	250	487	-26.0%	44.0%
130319A	Bell Creek at Craiglands	111	82	161	-26.0%	44.0%
130349A	Don River at Kingsborough	288	213	414	-26.0%	44.0%
130407A	Nebo Creek at Nebo	78	57	112	-26.0%	44.0%
142202A	South Pine River at Drapers Crossing	819	606	1180	-26.0%	44.0%
143110A	Bremer River at Adams Bridge	329	244	474	-26.0%	44.0%
143113A	Purga Creek at Loamside	1407	1041	2026	-26.0%	44.0%
143211A	Buaraba Creek at Atkinson Diversion Weir	1166	863	1679	-26.0%	44.0%
143212A	Tenthill Creek at Tenthill	3668	2715	5282	-26.0%	44.0%
143214A	Flagstone Creek at Windolfs	288	213	415	-26.0%	44.0%
143303A	Stanley River at Peachester	161	119	231	-26.0%	44.0%
143306A	Reedy Creek at Upstream Byron Creek	34	26	50	-26.0%	44.0%
145010A	Running Creek at 5.8km Deickmans Bridge	46	34	67	-26.0%	44.0%
145011A	Teviot Brook at Croftby	113	83	162	-26.0%	44.0%
145013A	Christmas Creek at Rudds Lane	167	124	240	-26.0%	44.0%
145101D	Albert River at Lumeah Number 2	244	181	351	-26.0%	44.0%
416204A	Weir River at Gunn Bridge	3783	2799	5447	-26.0%	44.0%
416312A	Oaky Creek at Texas	294	217	423	-26.0%	44.0%
416410A	Macintyre Brook at Barongarook	328	243	472	-26.0%	44.0%
417201B	Moonie River at Nindigully	12141	8985	17483	-26.0%	44.0%
422304A	Condamine River at Elbow Valley	637	472	918	-26.0%	44.0%
422352A	Hodgson Creek at Balgownie	528	391	760	-26.0%	44.0%
422407A	Maranoa River at Forestvale	1373	1016	1977	-26.0%	44.0%
423204A	Warrego River at Augathella	1396	1033	2011	-26.0%	44.0%
424202A	Paroo River at Yarronvale	375	277	539	-26.0%	44.0%

Table 35 Comparison of scenarios 1 and 6a & b - Sensitivity of the demand factor confidence limits (change to average annual impact)

Gauge Number	Gauge Name	Annual average farm dam impact (ML)			% change	
		Scenario 1	Scenario 6a	Scenario 6b	Scenario 1 to Scenario 6a	Scenario 1 to Scenario 6b
119005A	Haughton River at Mount Piccaninny	744	708	793	-4.8%	6.7%
120106A	Basalt River at Bluff Downs	495	479	517	-3.3%	4.6%
130319A	Bell Creek at Craiglands	165	158	174	-3.8%	5.3%
130349A	Don River at Kingsborough	397	384	416	-3.4%	4.8%
130407A	Nebo Creek at Nebo	134	128	142	-4.4%	6.6%
142202A	South Pine River at Drapers Crossing	1687	1518	1954	-10.0%	15.8%
143110A	Bremer River at Adams Bridge	641	591	716	-7.7%	11.7%
143113A	Purga Creek at Loamside	2194	2117	2299	-3.5%	4.8%
143211A	Buaraba Creek at Atkinson Diversion Weir	1808	1692	1976	-6.4%	9.3%
143212A	Tenthill Creek at Tenthill	3995	3846	4204	-3.7%	5.2%
143214A	Flagstone Creek at Windolfs	302	291	319	-3.7%	5.7%
143303A	Stanley River at Peachester	158	117	226	-25.7%	43.2%
143306A	Reedy Creek at Upstream Byron Creek	54	48	61	-10.0%	14.4%
145010A	Running Creek at 5.8km Deickmans Bridge	110	98	129	-10.6%	17.7%
145011A	Teviot Brook at Croftby	258	234	296	-9.2%	14.7%
145013A	Christmas Creek at Rudds Lane	344	302	414	-12.3%	20.4%
145101D	Albert River at Lumeah Number 2	537	475	640	-11.6%	19.2%
416204A	Weir River at Gunn Bridge	5385	5255	5580	-2.4%	3.6%
416312A	Oaky Creek at Texas	550	531	580	-3.6%	5.4%
416410A	Macintyre Brook at Barongarook	597	578	624	-3.2%	4.5%
417201B	Moonie River at Nindigully	6045	6000	6113	-0.7%	1.1%
422304A	Condamine River at Elbow Valley	1458	1332	1648	-8.7%	13.0%
422352A	Hodgson Creek at Balgownie	868	838	909	-3.5%	4.7%
422407A	Maranoa River at Forestvale	257	257	259	-0.3%	0.5%
423204A	Warrego River at Augathella	275	274	277	-0.4%	0.6%
424202A	Paroo River at Yarronvale	639	628	654	-1.7%	2.4%

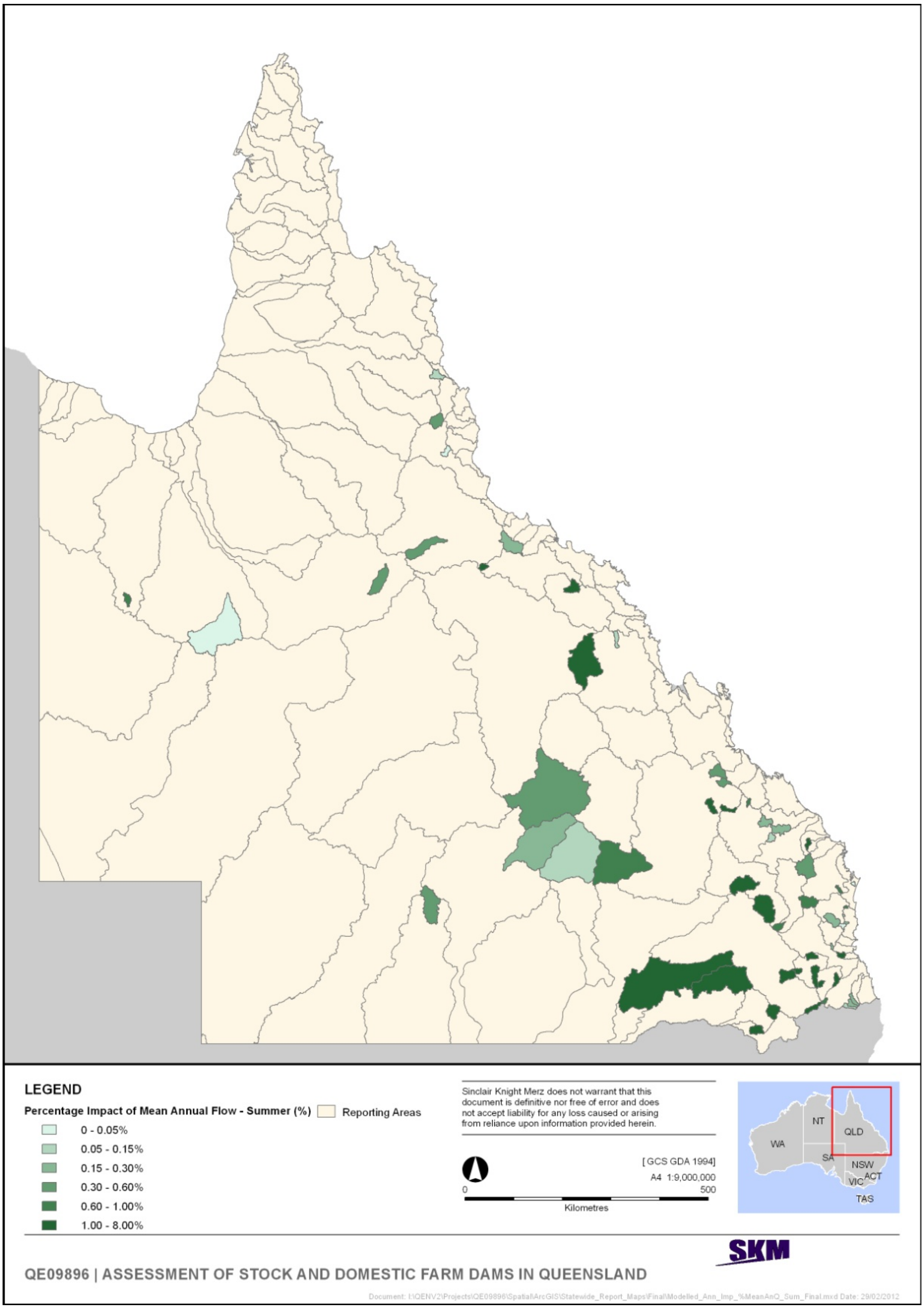
Table 36 Comparison of scenarios 1 and 7a, b & c - Sensitivity of the regionalisation of dam volume and confidence limits (change to volume of dams)

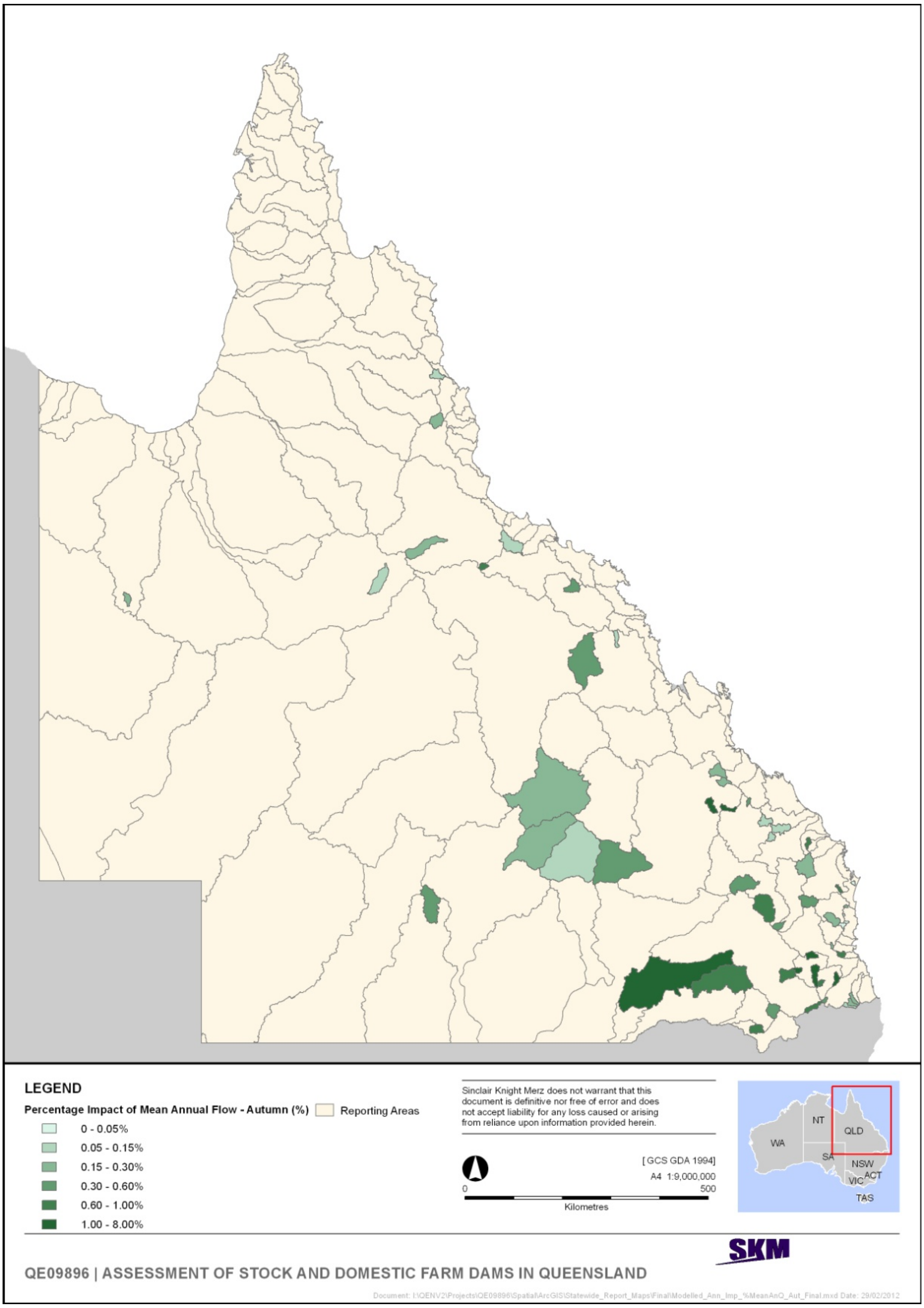
Gauge Number	Gauge Name	Volume of dams (ML)				% change		
		Scenario 1	Scenario 7a	Scenario 7b	Scenario 7c	Scenario 1 to Scenario 7a	Scenario 1 to Scenario 7b	Scenario 1 to Scenario 7c
119005A	Haughton River at Mount Piccaninny	852	1454	671	3151	70.6%	-21.3%	269.7%
120106A	Basalt River at Bluff Downs	676	842	386	1839	24.5%	-43.0%	171.9%
130319A	Bell Creek at Craiglands	223	143	65	317	-35.7%	-71.0%	42.2%
130349A	Don River at Kingsborough	576	769	353	1674	33.6%	-38.6%	190.8%
130407A	Nebo Creek at Nebo	155	329	150	722	111.7%	-3.6%	364.7%
142202A	South Pine River at Drapers Crossing	1639	2130	978	4637	29.9%	-40.3%	182.9%
143110A	Bremer River at Adams Bridge	659	444	203	970	-32.5%	-69.1%	47.3%
143113A	Purga Creek at Loamside	2815	2391	1105	5175	-15.1%	-60.8%	83.9%
143211A	Buaraba Creek at Atkinson Diversion Weir	2331	1427	658	3097	-38.8%	-71.8%	32.8%
143212A	Tenthill Creek at Tenthill	7337	5720	2629	12444	-22.0%	-64.2%	69.6%
143214A	Flagstone Creek at Windolfs	577	766	353	1663	32.8%	-38.8%	188.4%
143303A	Stanley River at Peachester	322	925	419	2041	187.6%	30.3%	534.8%
143306A	Reedy Creek at Upstream Byron Creek	69	79	35	178	14.5%	-49.1%	157.6%
145010A	Running Creek at 5.8km Deickmans Bridge	93	181	82	399	95.8%	-11.0%	330.8%
145011A	Teviot Brook at Croftby	225	186	84	411	-17.4%	-62.6%	82.4%
145013A	Christmas Creek at Rudds Lane	334	192	88	423	-42.4%	-73.8%	26.6%
145101D	Albert River at Lumeah Number 2	488	417	191	910	-14.6%	-60.9%	86.5%
416204A	Weir River at Gunn Bridge	7565	6298	2898	13683	-16.8%	-61.7%	80.9%
416312A	Oaky Creek at Texas	587	774	354	1689	31.8%	-39.7%	187.7%
416410A	Macintyre Brook at Barongarook	656	568	260	1241	-13.5%	-60.4%	89.1%
417201B	Moonie River at Nindigully	24282	14169	6470	31028	-41.6%	-73.4%	27.8%
422304A	Condamine River at Elbow Valley	1275	1470	679	3183	15.3%	-46.8%	149.7%
422352A	Hodgson Creek at Balgownie	1056	2845	1315	6153	169.4%	24.5%	482.7%
422407A	Maranoa River at Forestvale	2746	3830	1760	8334	39.4%	-35.9%	203.5%
423204A	Warrego River at Augathella	2792	4178	1913	9124	49.6%	-31.5%	226.8%
424202A	Paroo River at Yarronvale	749	365	159	843	-51.2%	-78.8%	12.5%

Table 37 Comparison of scenarios 1 and 7a, b & c - Sensitivity of the regionalisation of dam volume and confidence limits (change to average annual impact)

Gauge Number	Gauge Name	Average annual impact (ML)				% change		
		Scenario 1	Scenario 7a	Scenario 7b	Scenario 7c	Scenario 1 to Scenario 7a	Scenario 1 to Scenario 7b	Scenario 1 to Scenario 7c
119005A	Haughton River at Mount Piccaninny	744	1320	577	2869	77.5%	-22.5%	285.7%
120106A	Basalt River at Bluff Downs	495	662	254	1460	33.7%	-48.6%	195.0%
130319A	Bell Creek at Craiglands	165	98	24	236	-40.7%	-85.2%	43.4%
130349A	Don River at Kingsborough	397	557	230	1193	40.2%	-42.2%	200.6%
130407A	Nebo Creek at Nebo	134	290	128	637	117.1%	-4.3%	377.3%
142202A	South Pine River at Drapers Crossing	1687	1990	926	4341	17.9%	-45.1%	157.3%
143110A	Bremer River at Adams Bridge	641	438	206	903	-31.7%	-67.9%	41.0%
143113A	Purga Creek at Loamside	2194	1838	905	3731	-16.2%	-58.7%	70.0%
143211A	Buaraba Creek at Atkinson Diversion Weir	1808	1194	587	2493	-33.9%	-67.5%	37.9%
143212A	Tenthill Creek at Tenthill	3995	3165	1587	6417	-20.8%	-60.3%	60.6%
143214A	Flagstone Creek at Windolfs	302	373	180	744	23.5%	-40.4%	146.0%
143303A	Stanley River at Peachester	158	457	207	1009	189.1%	30.8%	538.2%
143306A	Reedy Creek at Upstream Byron Creek	54	58	25	132	8.6%	-53.3%	145.5%
145010A	Running Creek at 5.8km Deickmans Bridge	110	199	89	432	80.8%	-19.2%	293.2%
145011A	Teviot Brook at Croftby	258	198	89	428	-23.2%	-65.5%	65.9%
145013A	Christmas Creek at Rudds Lane	344	185	82	403	-46.2%	-76.3%	17.1%
145101D	Albert River at Lumeah Number 2	537	473	219	992	-12.0%	-59.2%	84.5%
416204A	Weir River at Gunn Bridge	5385	4560	2010	9628	-15.3%	-62.7%	78.8%
416312A	Oaky Creek at Texas	550	667	310	1340	21.1%	-43.7%	143.5%
416410A	Macintyre Brook at Barongarook	597	501	212	1034	-16.0%	-64.5%	73.2%
417201B	Moonie River at Nindigully	6045	3506	1223	7773	-42.0%	-79.8%	28.6%
422304A	Condamine River at Elbow Valley	1458	1656	816	3518	13.6%	-44.1%	141.3%
422352A	Hodgson Creek at Balgownie	868	2145	1057	4149	147.2%	21.9%	378.2%
422407A	Maranoa River at Forestvale	257	640	10	2252	148.8%	-96.2%	775.0%
423204A	Warrego River at Augathella	275	582	87	1635	111.7%	-68.3%	494.3%
424202A	Paroo River at Yarronvale	639	187	11	751	-70.8%	-98.2%	17.5%

Seasonality of impacts




LEGEND
Percentage Impact of Mean Annual Flow - Autumn (%)
0 - 0.05%
0.05 - 0.15%
0.15 - 0.30%
0.30 - 0.60%
0.60 - 1.00%
1.00 - 8.00%
Reporting Areas
Sinclair Knight Merz does not warrant that this document is definitive nor free of error and does not accept liability for any loss caused or arising from reliance upon information provided herein.
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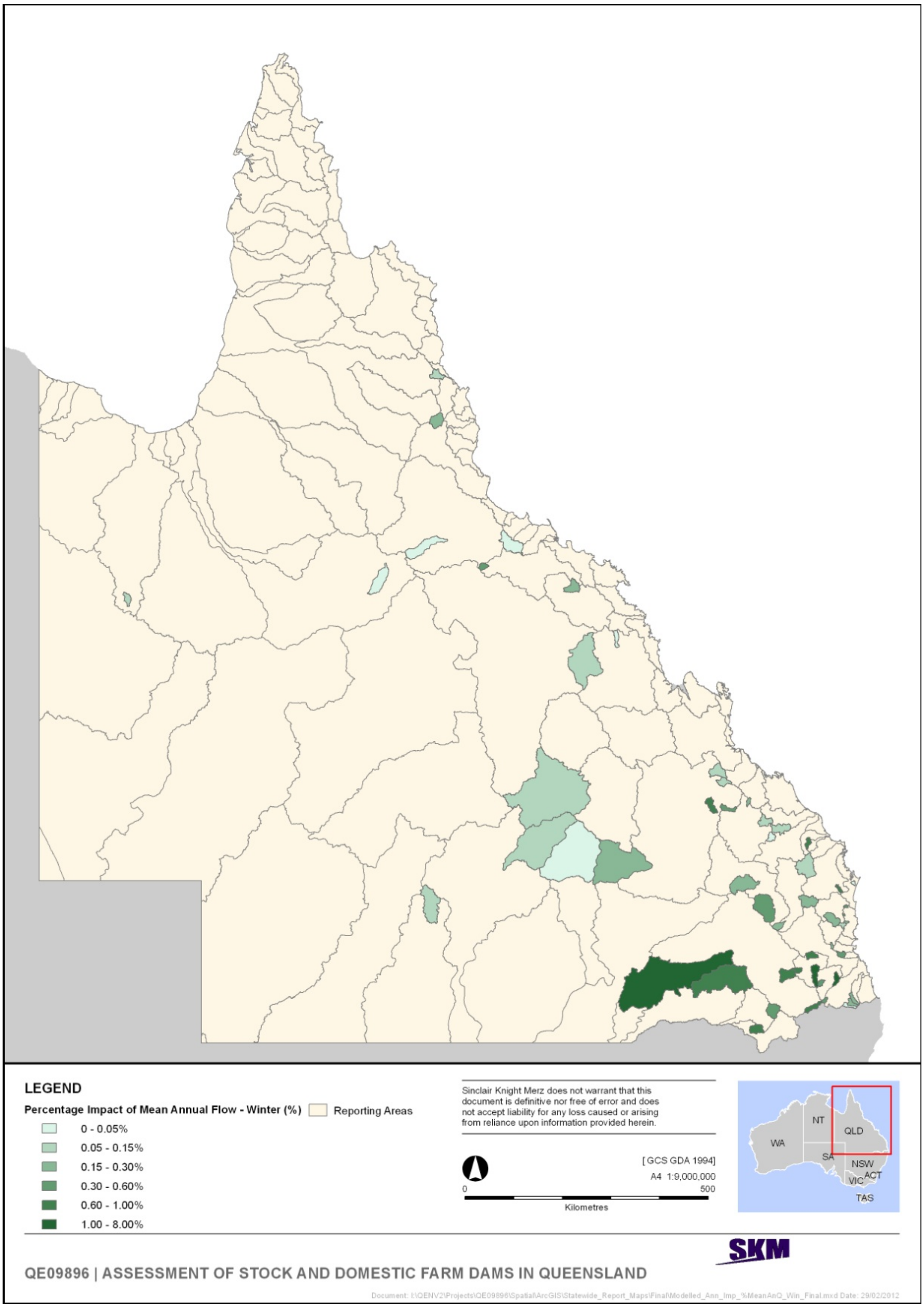
QE09896 | ASSESSMENT OF STOCK AND DOMESTIC FARM DAMS IN QUEENSLAND


LEGEND
Percentage Impact of Mean Annual Flow - Winter (%)
Reporting Areas
0 - 0.05%
0.05 - 0.15%
0.15 - 0.30%
0.30 - 0.60%
0.60 - 1.00%
1.00 - 8.00%
Sinclair Knight Merz does not warrant that this document is definitive nor free of error and does not accept liability for any loss caused or arising from reliance upon information provided herein.
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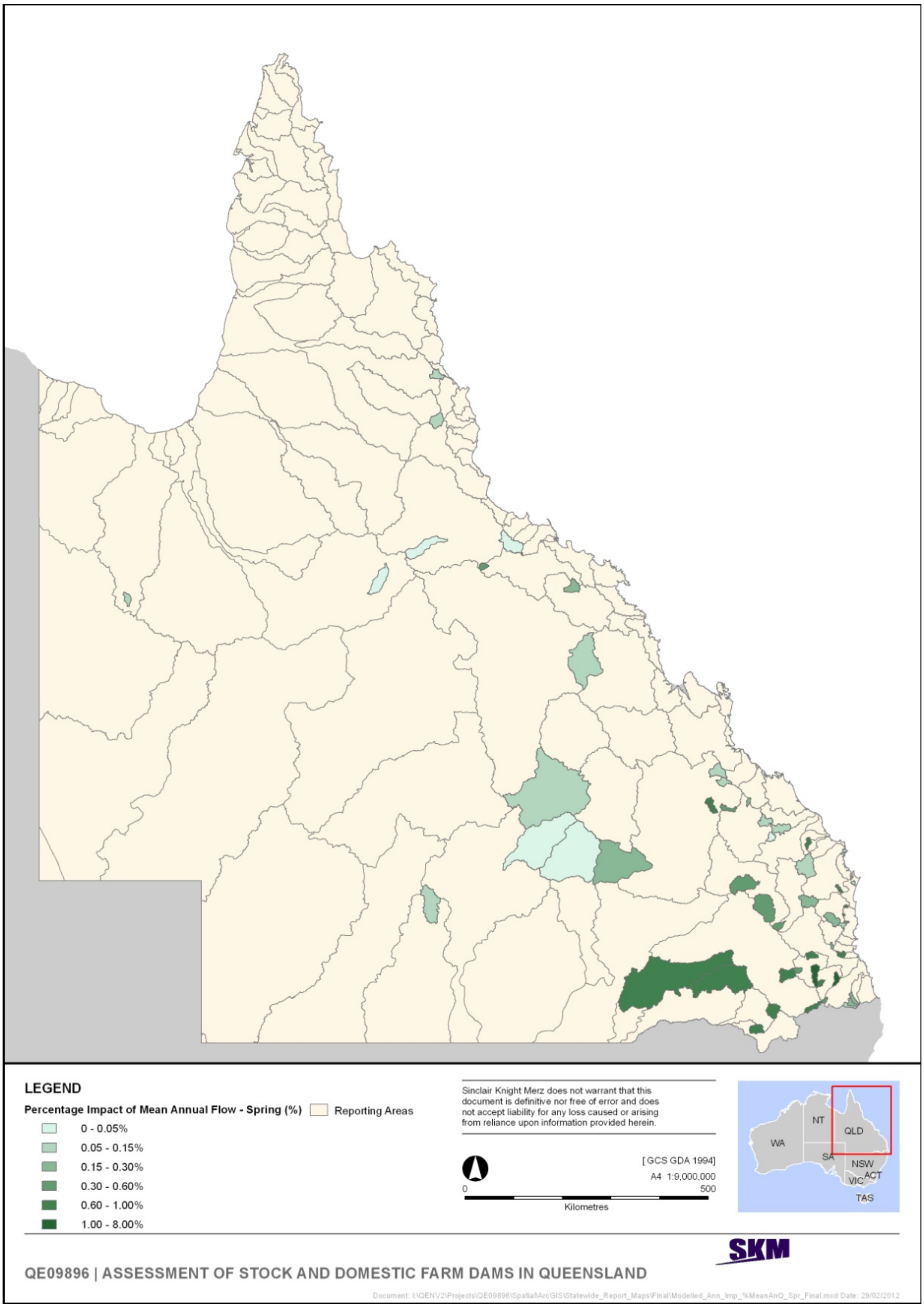
QE09896 | ASSESSMENT OF STOCK AND DOMESTIC FARM DAMS IN QUEENSLAND
Document: I:\QENV2\Projects\QE09896\Spatial\ArcGIS\Statewide_Report_Maps\Final\Modelled_Ann_Imp_%MeanAnQ_Win_Final.mxd Date: 29/02/2012


LEGEND
Percentage Impact of Mean Annual Flow - Spring (%)
Reporting Areas
0 - 0.05%
0.05 - 0.15%
0.15 - 0.30%
0.30 - 0.60%
0.60 - 1.00%
1.00 - 8.00%
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QE09896 | ASSESSMENT OF STOCK AND DOMESTIC FARM DAMS IN QUEENSLAND
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SINCLAIR KNIGHT MERZ
SKM

Glossary and acronyms

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.	
Remnant area	Where a reporting area includes one or more modelling catchment, a remnant area has been defined that is represents the part of the reporting area that has not been modelled	
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).	

Term	Definition	Units
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
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	

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