MURRAY–DARLING BASIN COMMISSION

Risks to Shared Water Resources

Mapping the growth, location, surface area and age of man made water bodies, including farm dams, in the Murray-Darling Basin

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Murray–Darling Basin Commission/Geoscience Australia
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Postal Address GPO Box 409, Canberra ACT 2601
Office location Level 4, 51 Allara Street, Canberra City
Australian Capital Territory

Telephone: (02) 6279 0100 international + 61 2 6279 0100
Facsimile: (02) 6248 8053 international + 61 2 6248 8053
E-Mail: info@mdbc.gov.au
Internet: http://www.mdbc.gov.au

For further information contact the Murray-Darling Basin Commission
office on (02) 6279 0100

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Front cover image credit: From Gore Highway between Toowoomba and Goondiwindi.
By Arthur Mostead

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PROJECT TEAM AND ACKNOWLEDGEMENTS

- Philip Tickle (Project Leader)
- Michael Holzapfel (Project Manager)
- Hamish Anderson (Senior Spatial Analyst)
- Janine Luckman (Spatial Analyst)
- Andrew Clive (Spatial Analyst)
- Robert Cook (Spatial Analyst)

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Caveat

This report provides snapshots of the level of man-made water body development including farm dams for the years 1994 and 2005. The report does not quantify the volume of water retained in these dams, the subsequent impact of these dams on stream flow or the purpose for which the dams have been built. This will be determined from future studies. A number of regulatory controls were introduced by jurisdictions on farm dam development between 1994 and 2005. Therefore the effectiveness of these changes in addressing the risk of farm dam development cannot be determined from this study. To understand the impact that introduced regulatory measures have had on the rate of growth of farm dams, will require additional analysis of appropriate years between 1994 and 2005.

EXECUTIVE SUMMARY

The Murray-Darling Basin Commission (MDBC) has identified six risks to the shared water resources of the Murray-Darling Basin. These include:

- Climate change;
- Increased groundwater use;
- Bushfires;
- Afforestation; and
- Reduced flow from irrigation

There is strong evidence that farm dam numbers have increased in number and size over time, with the largest increases following major droughts. Prior to the study described here, the number of farm dams in the Basin were estimated to have increased by 37 percent over the last ten years alone. The associated increase in total farm dam volume is estimated to be 48 percent.

To date all previous studies relating to the impact on farm dams across the basin have been sample-based estimates. With many thousands of farm dams scattered across the landscape, mapping them in sufficient detail has been problematic. Therefore, previous estimates of the number of farm dams across the Basin have been based on a mix of detailed local analysis and extrapolation.

In late 2007 Geoscience Australia and State partners completed the mapping of man-made water bodies including farm dams over an area of approximately 509,000 km^2 or approximately half the Basin, as part of a larger mapping program over most populated and developed areas of Australia focused on the information needs of emergency managers. The work was undertaken as part of the National Topographic Information Coordination Initiative (NTICI) under the auspices of ANZLIC, and the Intergovernmental Committee on Surveying and Mapping (ICSM).

The completion of new baseline mapping from circa 2005 high resolution imagery provided an opportunity to not only provide a snap-shot on the level of farm dam development over the basin in 2005, but also an opportunity to utilise historical moderate resolution LANDSAT imagery to quantify changes in the number of farm dams over time and to map their spatial extent.

Unlike previous studies, this project involved an attempt to undertake a complete census of man-made water bodies over the 509,000 km^2 area, as opposed to previous sample-based methods. Moreover, analyses of changes in small dams that were not previously possible using LANDSAT data could be made using baseline data collected from higher resolution imagery.

Mapping and analyses were completed over 15 of the eastern Murray–Darling Basin catchments comprising a total area of 509,000 km^2, or around 82 percent of the 15 catchments mapped. All upland areas of the 15 catchments were mapped except for the Condamine-Culgoa. In this case all the eastern uplands were mapped and only a small proportion of the western uplands. A total of 519, 931 man-made water bodies were mapped for a nominal year of 2005, the vast majority of which can be classified as farm dams. Not surprisingly, the highest densities of dams are located within peri-urban and rural residential areas around the major population centres. Around 41, 34 and 25 percent of the dams occurred in the upland, slopes and lowlands respectively. A comprehensive accuracy assessment of the baseline data confirmed that for most of the area mapped overall accuracies exceeded 95 percent. Interpretation of these results also suggests that the total number of dam estimates (relating to small dams) in the Namoi, Gwydir and Border Rivers may be under-estimated by up to 10 percent.

The overall increase in dams over the 509,000 km^2 study area is estimated to be 6 percent or 31,000 dams between ~1994 and ~2005. The degree of change however, varies considerably between and within catchments. The overall accuracy of the change analysis is estimated to be approximately 93 percent suggesting that our basin-wide estimate (for the eastern basin) of 6 percent could be closer to 7 percent The catchments estimated to have the greatest overall increase during this period are the Condamine-Culgoa catchments (18%) followed by the Namoi (13%), Moonie (13%) and the Gwydir (12%). Based on the final accuracy assessment we believe that these estimates of change are likely to be under-estimated by 10-20 percent in these catchments, particularly in relation to the very small dams in black soil regions which are below the direct detection capabilities of LANDSAT. Following adjustment of the results to reflect the accuracy assessment, the increase in dams over the Condamine-Culgoa, Namoi, Moonie and Gwydir catchments is therefore likely to be 20, 15 14 and 15 percent respectively. Importantly these statistics represent changes in all man-made water bodies, including on-farm irrigation storages, hillside farm dams, domestic water supply and other man-made structures. Additional attributes in the baseline data are available to break these statistics down further according the function of the water bodies within the limits of State topographic mapping specifications.

While the overall catchment level estimates of change relatively low compared to previously reported statistics, there are significant regions of very high development, particularly within commuting distance of the major regional centres. The regions with the highest levels of development during the period include Canberra, Wagga Wagga, Albury, Tumut, Bathurst, Armidale, Tamworth, Toowoomba and Dalby. In the case of the Toowoomba-Dalby regions, the major increases in dams include both small farm dams and irrigation storages.

Around 50 percent of the new baseline mapping consisted of very small dams (<1000m^2) that had been mapped as points, and for which no surface area information was available for conversion to storage volumes. A stratified sampling method was used to select small dams in each catchment for which surface areas were mapped and combined with dams that had been mapped as polygons. When all large storages >10,000m^2 were removed from the assessment, the average dam size was estimated to be approximately 2100m^2. As might be expected, dam size generally increases as one moves from the uplands through the slopes to the lowlands. The frequency distribution of dam sizes also varies considerably from catchment to catchment. Detailed summaries have been derived of the frequency distribution of dam sizes per catchment that can be directly applied to volume estimates through known surface-area to volume equations.

The results of this study provide significant guidance in terms of the types of monitoring capabilities required to monitor the development of farm dams into the future. At the basin scale, a seemingly large increase of 31,206 dams over a 10 year period only represents an increase of 6 percent in the total number of dams, or around 0.5 percent per year. However, the results also demonstrate the highly localised nature of the change where dramatic increases in the number of farm dams have occurred that may have a highly significant impact on local stream flows.

In terms of ongoing use of remote sensing, the challenge is therefore to balance the need for high resolution and frequent coverage over regions where significant change is likely to occur, with the additional need for systematic monitoring of the entire basin in order to detect change that may not be as predictable. The development of dams is also an indicator of many other changes in the landscape that are occurring which may be directly related to the dams including:

- irrigation development;
- changes in grazing pressure;
- vegetation clearing;
- land use;
- land management practices; or
- rural residential development.

There are also potentially opportunities to utilise cadastral information to detect significant changes in parcel size related to peri-urban or rural residential development before actual development occurs.

Further development of any remote sensing capability for ongoing monitoring of farm dams should therefore ideally be part of an integrated land cover monitoring program being routinely undertaken at a range of spatial and temporal scales. This system should provide the basis for a range of generic needs across government, in addition to specific products for water accounting at seasonal and annual timescales, and at appropriate spatial resolution. Operationally, this might translate into something like: annual 2.5 & 10m coverage over intensive land use and per-urban and rural residential areas; annual 10m coverage over the remainder of the eastern MDB; seasonal coverage (monthly-3 monthly) of the entire basin at 25–60m resolution, and weekly products at 250m–1km resolution.

BACKGROUND

The Murray-Darling Basin Commission (MDBC) has identified six risks to the shared water resources of the Murray-Darling Basin. These include[1]:

- climate change;
- increased groundwater use;
- increased number of farms dams;
- bushfires;
- afforestation; and
- reduced flow from irrigation.

The identified risks have the potential to change flow patterns and water quality in the Murray-Darling Basin and thus undermine the Commission's objective to manage the shared water resources in an efficient, equitable and sustainable manner. Addressing these risks will assist in the continued success of Commission initiatives such as the Living Murray Initiative, the Basin Salinity Management Strategy and the Cap on Water Diversions as well as the future trade in water entitlements. It will also contribute to the implementation of new National Water Accounting systems as part of the National Plan for Water Security.

There is strong evidence that farm dam numbers have increased in number and size over time, with the largest increases following major droughts. Prior to the study described here, the number of farm dams in the Basin was estimated to have increased by 37 percent over the last ten years alone (Agrecon 2005). The associated increase in total farm dam volume is estimated to be 48 percent. These estimates were based on extrapolation from a very small part of the Basin, but are consistent with other previous regional estimates (Good & McMurray 1997; Lowe, Leh & Griffith 2005; Neal et al 2002; and Gutteridge et al 1987).

The impact of an individual dam on water resources is relatively small, but the cumulative impact of farm dams on stream flows can be very significant. The nature of their impact depends on a number of factors: the timing and volume of water extracted from the dams, their size and their position in the landscape.

To date all previous studies relating to the impact of farm dams across the basin have been sample-based estimates. With many thousands of farm dams scattered across the landscape, mapping them in sufficient detail has been problematic. Therefore, previous estimates of the number of farm dams across the Basin have been based on a mix of detailed local analysis and extrapolation (Agrecon 2005). Information on the historical increase in farm dam numbers over time is even more difficult to obtain as the resolution and availability of aerial or remotely-sensed imagery diminishes rapidly with each preceding decade.

In 2004 the Murray–Darling Basin Commission undertook an assessment of the impact of hillside farm dams (Agrecon 2005). Due to budgetary and time constraints and lack of available data, a sample-based technique was used to map farm dams over 79 representative sample areas selected in proportion to 27 landscape classes covering 19 catchments. At each of the 79 locations 1m resolution satellite imagery was analysed over a 7km by 7km area to map the location, surface area and storage capacity of 5832 individual hillside farm dams. Three previous dates of aerial photography were also used to assess the growth in farm dams with reference to 1988, 1994 and 2004. Results from the 79 locations were extrapolated to produce the following basin-wide estimates:

- 502,819 hillside dams
- Combined storage capacity of 2,213GL
- Annual growth in farm dams of 3-4 percent p.a. and an increase of 37 percent between the 1994 cap year and 2004.

The principle limitation of this study acknowledged by the authors related to the small sample size of less than 1 percent of the basin. The authors also stated that the estimates arising from the investigation should be regarded by the Commission as the minimum realistic level and current status of hillside farm dam development.

1 http://www.mdbc.gov.au/nrm/risks_to_shared_water_resources.

In late 2007 Geoscience Australia and State partners completed the mapping of man-made water bodies including farm dams over an area of approximately 509,000 km^2 or approximately half the Basin (see Figure 1), as part of a larger mapping program over most populated and developed areas of Australia which focused on the information needs of emergency managers. The work was undertaken as part of the National Topographic Information Coordination Initiative (NTICI[2]). This initiative is a collaborative mapping program coordinated by Geoscience Australia and the State Land Information agencies under the auspices of ANZLIC – the Spatial Information Council.

Figure 1: Extent of water body and canal mapping undertaken by Geoscience Australia and State jurisdictions over the Murray–Darling Basin (MDB).

2 http://www.icsm.gov.au/icsm/topo/index.html.

The NTICI program involves comprehensive revision of existing topographic mapping, and new mapping of key themes using high resolution imagery such as 2.5m SPOT5, and other very high resolution imagery provided by the States. The aim of the program is to improve the currency and quality of key themes including transport, buildings, utilities and hydrography (particularly man-made water bodies and canals), with a particular emphasis on the needs of emergency service managers who require accurate and current information on the built environment, and features like water bodies for fighting bushfires. These same features are also required by natural resource managers and policy makers.

Although specifications currently vary from state to state, all water bodies that are visible on high resolution imagery have been mapped. Small water bodies have been mapped as points and large water bodies have been mapped as polygons to an interpreted high-water mark, providing an estimated maximum surface area for these dams, and water bodies less than this size have been mapped as points. The size criteria for mapping a water body as a polygon varies depending upon the type of water body and the individual State topographic mapping specifications. Specific details can be found in the later section on Baseline Data Integration and Accuracy Assessment and Appendix A.

The completion of new baseline mapping from circa 2005 high resolution imagery provided an opportunity not only to provide a snap-shot on the level of farm dam development over the basin in 2005, but also an opportunity to utilise historical moderate resolution LANDSAT imagery to quantify changes in the number of farm dams over time and to map their spatial extent.

Unlike previous studies, this project involved an attempt to undertake a complete census of man-made water bodies, including farm dams, over the 509,000 km^2 area, as opposed to previous sample-based methods. Moreover, analyses of changes in small farm dams that were not previously possible using LANDSAT data could be enabled using baseline data collected from higher resolution imagery.

PROJECT AIMS

The aims of this project were to map the growth, location, and surface area of farm dams in the Murray–Darling Basin with reference to the 1994 cap year as requested by the MDBC, and the new circa 2005 baseline man-made water bodies dataset. The project aimed to build on previous projects undertaken by the Commission to further improve the new 2005 baseline mapping undertaken by Geoscience Australia and State partners for the purposes of water accounting. The specific deliverables of the project included a number of spatial databases and tabular analyses for the following catchments listed in Table 1 below.

Table 1. Summary of the area of each catchment, and the areas mapped.

		Lowland	Slopes	Upland			Lowland	Slope	Upland
Catchment Name	**Total Area (km²)**	**Area (km²)**	**Area (km²)**	**Area (km²)**	**Mapped Area (km²)**	**Total Mapped Area (%)**	**Mapped Area %**	**Mapped Area %**	**Mapped Area %**
Border Rivers	48,041	8,508	22,909	16,624	47,306	98%	100%	100%	96%
Broken River	7,099	5,356	1,743		7,099	100%	100%	100%	
Castlereagh River	17,423	6,349	5,663	5,411	17,423	100%	100%	100%	100%
Condamine-Culgoa Rivers	162,595	58,395	75,767	28,433	86,363	53%	52%	58%	42%
Goulburn River	16,857	6,752	4,425	5,680	16,743	99%	99%	99%	99%
Gwydir River	26,585	9,685	6,463	10,437	26,585	100%	100%	100%	100%
Kiewa River	1,911	240	604	1,067	1,911	100%	100%	100%	100%
Lachlan River	90,880	40,160	33,279	17,441	74,544	82%	79%	77%	99%
Macquarie-Bogan Rivers	74,791	26,670	27,064	21,057	61,022	82%	74%	76%	99%
Moonie River	14,342	3,669	10,648	25	14,324	100%	100%	100%	100%
Murray-Riverina	15,039	15,039	-	-	14,823	99%	99%		
Murrumbidgee River	79,285	45,144	15,412	18,729	79,285	96%	92%	100%	100%
Namoi River	42,000	9,635	15,873	16,492	42,000	100%	100%	100%	100%
Ovens River	7,981	2,324	2,074	3,583	7,944	100%	100%	100%	100%
Upper Murray River	15,341	-	3,101	12,240	15,341	100%	0%	100%	100%
TOTALS	**620,171**	**237,926**	**225,025**	**157,219**	**509,895**	82%			

METHODS

Overview

The initial baseline mapping completed by Geoscience Australia and State partners set out to develop comprehensive information of the extent of man-made water bodies including farm dams across eastern Australia, along with other topographic and cultural features. It did not, however, explicitly set out to provide a consistent benchmark across the basin for monitoring purposes. Each state maintains its own topographic data to state specifications developed for the purposes of producing topographic maps and data. One of the requirements of this study was therefore to transform the recent investment in mapping into a baseline water accounting product for analysing the growth in man-made water bodies, including farm dams, over time.

While Geoscience Australia maintains a National Topographic Database at 1:250,000 to a consistent specification (Geodata Version 4.0), recent large scale mapping undertaken through collaborative programs has required the initial mapping (utilised in this study) to be collected according to individual state specifications. These specifications vary according to the attributes relating to the water body and whether the water body is captured as a point or a polygon depending on a range of size criteria. The primary reason for not capturing all water bodies as polygons relates to cost due to the labour intensive methods that have been required historically. Therefore data integration and normalisation were required prior to any analysis to produce a consistent dataset for the entire Basin.

One of the primary drivers for this project was not only to assess the extent and change in farm dam development, but also the potential volume of run-off being affected by the dams. A sound knowledge of the surface area of the dams is therefore required, in addition to surface area to volume equations. A number of previous studies developed surface to volume equations (Agrecon 2005), so the scope of this project was limited to developing summaries of the size class distributions of farm dams for the uplands, slopes and lowland areas of each catchment. Because around half of the mapped dams had been mapped as points, there was a need to select a representative sample from which to derive surface area estimates.

The high resolution imagery used for the mapping was captured during the summers of 2004/05 and 2005/06. Most of the areas mapped were in severe drought which precluded using consistent digital classification techniques because most dams were either at low capacity or empty. Therefore, highly labour intensive manual digitising was required. Geoscience Australia utilises a number of external contractors to undertake major production work, and while independent validation and testing (VAT) is carried out to ensure that mapping meets the required specifications, this testing is only possible over a small number of statistical sampling areas. It is also designed to ensure that topographic mapping standards are achieved, rather than quantifying the degree to which mapping is a complete census of the water bodies as required for this study. Therefore a detailed and comprehensive accuracy assessment was undertaken to quantify the nature of specific errors, identify where theses errors occurred, and estimate the degree to which the mapping represented a complete census of the dams.

Previous work carried out by the Commission and others (Agrecon 2005, Good & McMurray 1997; Neal et al 2002; and Gutteridge et al 1987) demonstrated that it was very difficult to independently map changes in small water bodies such as farm dams using LANDSAT imagery due to its relatively coarse pixel size of 25m. This project was therefore relying on the fact that the 2005 baseline farm dam dataset had been derived from much higher resolution imagery. Rather than attempting to independently map the changes in farm dams with LANDSAT since ~1994, the project was attempting to identify which of the 2005 water bodies was likely to have not been developed prior to 1994. Methods were developed that utilised the very large population of mapped water bodies to develop optimised water indices to train image classifications and constrain the analyses to the location of the 2005 baseline dataset.

The project therefore required a number of specific steps and methodologies which are further detailed below relating to:

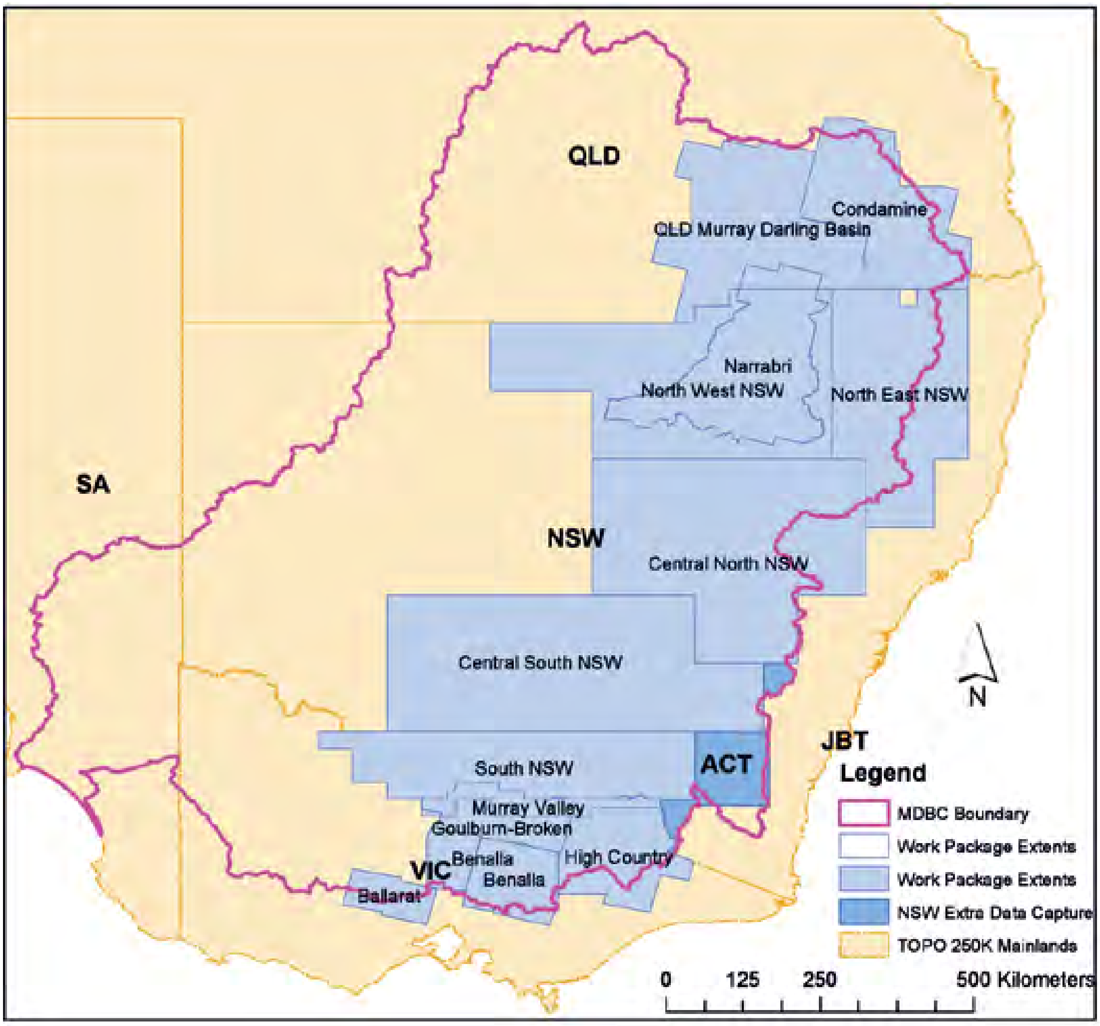
- Baseline Data Integration and Accuracy Assessment
- Change Analysis and Accuracy Assessment
- Dam Size Class Analysis

The specific methodologies and results of these steps are further detailed in Appendices A, B and C.

Baseline Data Integration and Accuracy Assessment

The base data used in this study is comprised of a number of source datasets based on Work Packages completed by contractors to several state specifications. While these water body datasets are inherently simple, there were variations in both specifications and implementation of specifications by the contractors that needed to be addressed. Appendix A provides a detailed description of the specifications relating to the individual work packages in terms of attribute definitions and the size criteria used to map a water body as either a point or a polygon, along with reliability dates and source material. It should be noted that only man-made water bodies have been carried through for analysis. A map index of the work packages can be seen in Figure 2.

Figure 2: Current waterbodies data coverage (in light blue) within GA's Large-scale Mapping Program. The NSW waterbodies data coverage (in dark blue) has been supplemented with data received from NSW LPI and in-house data capture completed for this project.



The specifications and range of reliability dates for the individual work packages are summarised in Table 2 below.

Table 2: Summary of work packages including size criteria and reliability dates.

State	Specifications	Project Area	Size Criteria		Reliability Date
Qld	Geoscience Australia v4.0 Topographic Specifications	Qld Murray Darling Basin	**Polygon Capture** **Point Capture**	Pondage Areas: over 625 m^2 Reservoirs: over 6400 m^2 WaterTanks: under 6400 m^2	2005
		Condamine	**Polygon Capture** **Point Capture**	Pondage Areas: over 600 m^2 Reservoirs: over 600 m^2 WaterTanks: under 600 m^2	2005
NSW	NSW LPI T-Rules	Narrabri North West, North East & Central South NSW	**Polygon Capture** **Point Capture**	HydroArea: over 1600m^2 TankArea: over 30m diameter HydroPoint: under 1600 m^2 TankPoint: under 30m diameter	2004–2005
Vic	VicMap Specifications	Ballarat, Benalla, High Country	**Polygon Capture** **Point Capture**	Water Area Polygon: over 2500m^2 Water Point: under 2500 m^2 Water Struct Point: under 2500 m^2	2004–2006

All the individual datasets were merged into a common schema based on a cut-down Geodata Version 4.0 Specification[3].

An ESRI 9.2 File Geodatabase (gdb) was developed to maintain both the base data and other datasets required for the analyses. These feature datasets are listed below. Comprehensive descriptions and ANZLIC metadata can be found in Appendix A, and with the gdb.

MDBC_dams_Final_08.gdb

1. a_priority. — LANDSAT scene number and priority.
2. b_catchments. — MDBC Catchments.
3. c_terrain. — Terrain.
4. d_workpackage. — Work package index.
5. e_index25k. — 1:25,000 index covering the MDBC.
6. f_final_pt. — Dam points.
7. g_final_py. — Dam polygons.
8. h_final_py_pt. — All polygons from ‘g’ reduced to points.
9. i_complete_pt. — All dams represented as points (f + h).
10. j_frequency. — Frequency results performed on ‘i’.
11. k_area_sample_population. — Polygon dataset used in the dam surface area calculations.

In order to quantify the accuracy of the 2005 baseline dams dataset, a systematic sampling strategy was employed to allow users to assess not only the overall accuracy of the data in terms of the number of water bodies on a per catchment basis, but also to identify and map specific areas which may exhibit higher or lower levels of accuracy for input into future mapping and modelling.

A 1:50,000 mapsheet grid was used in lowland areas, and a 1:25,000 grid was used in the slopes and upland areas. A 2x2km sampling window was located randomly within each grid square. A total of 2432 samples were captured over the entire mapped area. 2.5m SPOT5 imagery was then displayed in pseudo natural colour at 1:5,000 scale and visually interpreted in terms of the number of water bodies that were visible compared to the features that had been captured. The information detailed in the Table 3 was recorded at each location to allow a comprehensive analysis of omission or commission errors, and to map the errors on a mapsheet basis.

3 http://www.ga.gov.au/mapspecs/250k100k/index.jsp.

Table 3: Error checking shapefile attributes with accompanying descriptions.

Attribute Field	Description
Work_Package	Work package name
Map_Points	Total number of points located within the 2km x 2km sample window
Map_Polys	Total number of polygons located within the 2km x 2km sample window
Point_Oms	Dams visible but not recorded in the reference point data (error of omission)
Poly_Oms	Dams visible but not recorded in the reference polygon data (error of omission)
Point_Coms	Number of erroneously captured points recorded
Poly_Coms	Number of erroneously captured polygons recorded
Poly_Map	Number of incorrectly positioned polygons were also recorded
Comments	Additional comments

Detailed analyses were carried out to summarise the proportion of omission and commission errors at the work package level and maps were produced to identify specific areas of the mapping that exhibited variations in the accuracy of mapping. The results of these analyses are summarised below. Given that the data was collected for each individual mapsheet, subsequent error analyses at the catchment level will also be possible (see Appendix A).

Change Analysis and Accuracy Assessment

Twenty six (26) LANDSAT scenes were processed from the archive for the study. Cloud-free scenes were selected during seasonal periods which maximised the potential contrast between growing vegetation and water. These same periods were also most likely to have the water bodies near the maximum water levels (seasons permitting). Generally March was preferred in the southern areas and December in the northern areas (cloud-free scenes permitting). Actual scene dates are provided in Appendix B.

Prior to developing water indices, the LANDSAT imagery was transformed to Top of Atmosphere (TOA) reflectance using the satellite ephemeris data and in-house scripts implemented in ERMAPPER (Chander et al 2007). For relatively "clear" scenes, a reduction in between-scene variability can be achieved through a normalisation of solar irradiance by converting the spectral radiance values to a planetary, or top of atmosphere (TOA) reflectance. The use of the normalised imagery was aimed at minimising the differences in water indices from one scene to the next. Wherever possible multiple scenes collected along a single orbit path on the same date were also used to minimise these effects.

Due to the significant variability in landscapes and seasonal conditions across the study area, three indices were initially chosen for evaluation. These included two water indices and a vegetation index. The purpose of using both a water and vegetation index was to minimise confusion in areas where vegetation may be growing in water bodies, shadow and topographic effects and dark soil areas. The following indices were evaluated:

- W1 = (TM2-TM5)/(TM2+TM5)
- V1 = (TM4-TM3)/(TM4+TM3)
- W2 = (TM2-TM4)/(TM2+TM4)

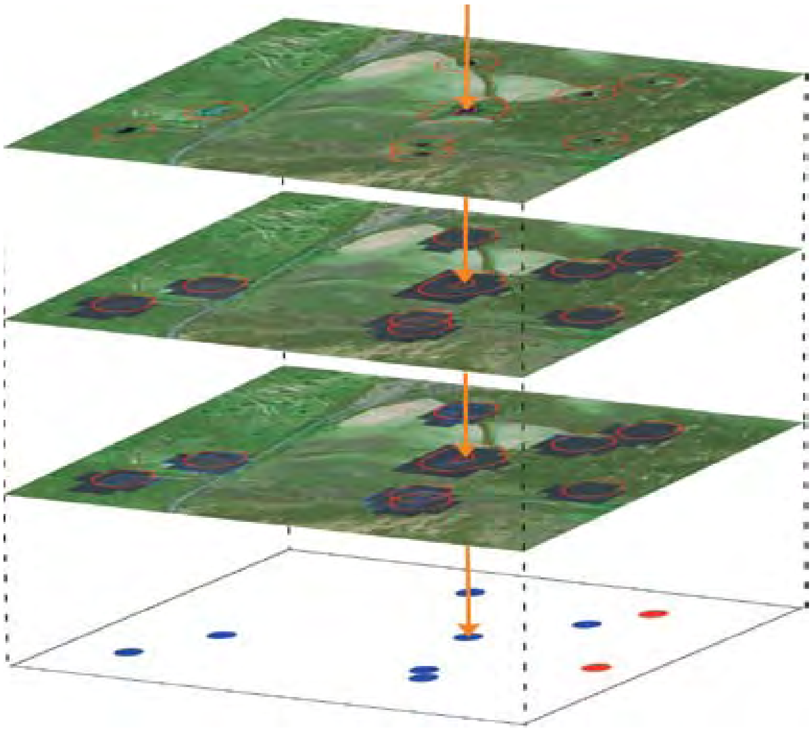
The result of these formulas yields values between -1 and +1. These values were stretched between 0 and 255 such that -1 is stretched to 0; 0 is stretched to 127, and +1 is stretched to 255.

The second water index (W2) was based on Qld EPA research as part of wetland and water body mapping and classification (unpublished). A comparison of the algorithms over all 26 LANDSAT scenes found that W2 did not discriminate as well as W1 due to a higher vegetation response which reduced the water signature. Therefore only the W1 and V1 indices were utilised.

In order to identify optimum thresholds for the indices, 50 points and polygons were selected for each LANDSAT scene from the baseline water body dataset. To account for potential registration issues between the vector data and LANDSAT imagery, the points and polygons were buffered by 50m and rasterised using automated routines in ERMAPPER. The buffered features were then intersected with the water (W1) and vegetation (V1) indices to identify the range of potential index values associated with known water bodies.

Figure 3 below summarises the threshold and change detection process.

Figure 3: Illustrative representation of the threshold process. Figure background is 2005 2.5m SPOT pseudo-natural imagery.



(Top image) Vector data (red) was clipped to each 1994 LANDSAT scene. Points and polygons where then buffered by 50 metres (red) to ensure that the output image allows for enough pixels for a comprehensive threshold process and account for any mis-alignment between vector data and LANDSAT imagery.

(Middle image) A LANDSAT mask image (grey) was then produced in ER Mapper from all buffered polygons and points which intersect a LANDSAT image pixel. This mask image was sampled to derive a number of water and vegetation threshold values prior to setting the thresholds.

(Bottom image) The buffered points (red), the mask image (grey), and the threshold output polygon once the threshold values were determined (blue). The output polygons (blue) represents the pixels meeting the criteria, which refer to dam features present prior to the image date of 1994. The two red points are either dams developed after 1994 or are features below the resolution LANDSAT imagery.

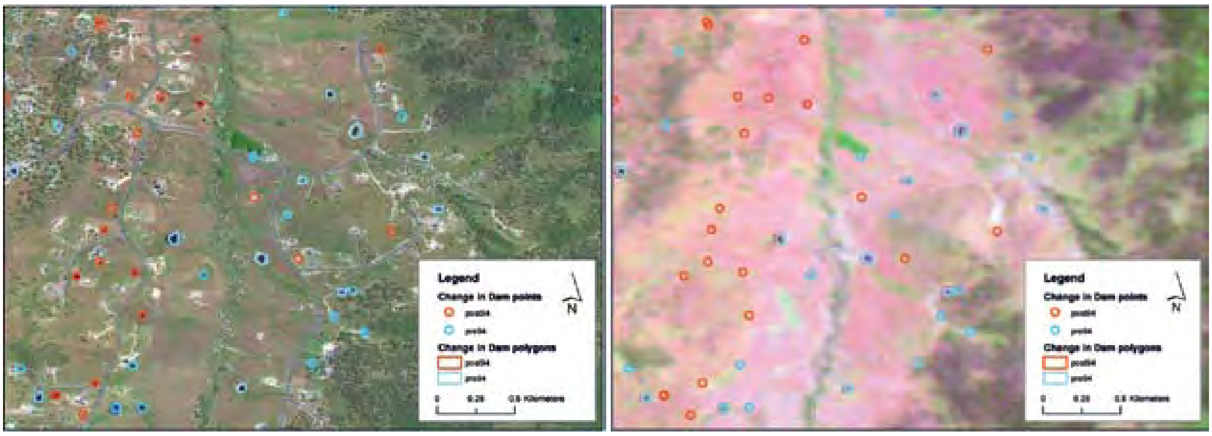
A considerable amount of calibration was undertaken across a wide number of landscapes to identify optimum water and vegetation index threshold values. A particular emphasis was placed on testing a range of index values in black soil plain areas where confusion is often encountered. In these areas the spread of water index values was generally much higher than other areas (scenes 1,2,7,8,14,15,21 and 22). Figure B3 in Appendix B provides the range of index values for each individual scene. Finally, single W1 and V1 indices were selected for application across all scenes. These were:

- a minimum of W1=86
- a maximum of V1=188.

Masks were then generated for each of the 26 1994 LANDSAT scenes using the above index values. The entire baseline water body dataset was buffered and intersected with the LANDSAT imagery to identify water bodies that did not meet the threshold criteria in 1994. These water bodies were then flagged in the database as being candidate post-1994 dams, prior to Validation and Testing. The results of the change analysis are detailed in the results section.

Validation and accuracy assessment of historical remote sensing analysis is always problematic when limited "ground truth" data is available for the period of imaging. The previous study undertaken by the Commission utilised a small number of historical aerial photographs (Agrecon 2005) over 79 locations to undertake the analyses, representing around 1 percent of the study area. Given the much larger area of this study, we did not believe that such a small sample would provide a representative, or statistically robust source of "truth". As an alternative, legacy SPOT2 and SPOT4 imagery held by Geoscience Australia was used which covered 85 percent of the area mapped. The 10m panchromatic imagery was acquired between 1993 and 2000, and approximately one third of the SPOT imagery was acquired between 1993 and 1997. For areas where the SPOT acquisition dates were after 1997, it was used a reference only to aid in the visual interpretation of the change results against the 1994 LANDSAT imagery. Figure 4 below provides an example of the SPOT5 2.5m imagery used to undertake the baseline mapping and LANDSAT over the same location, including dams that were developed after 1994.

Figure 4: (Left) 2.5m SPOT Image 1:10,000 Farm Dams Pre and Post 1994 (Burra, NSW). (Right) 1994 LANDSAT imagery over the same area.



The accuracy assessment of the change analysis was undertaken using the 1:50,000 map grids and a similar method as used for the baseline data described previously. To take account of the much smaller number of water bodies in the change analysis, the random sampling window was increased to 4km x 4km. A total of 1519 locations were assessed and recorded which included a double sampling in the overlap area of adjoining LANDSAT scenes of 38 percent. The points and polygons within this area were then recorded and verified against 10m SPOT PAN and LANDSAT imagery. Both pre and post 1994 water bodies were recorded to provide an unbiased assessment of the overall accuracy of using LANDSAT imagery for the change analysis. The information detailed in Table 4 below was recorded at each location to allow a comprehensive analysis of omission or commission errors, and to map the errors on a mapsheet basis.

Table 4: Error checking shapefile attributes with accompanying descriptions.

Attribute Field	Description
LS5_scene	LANDSAT Scene number
SPOT_scene	10m SPOT PAN scene name was recorded here
OP1_points	Total number of pre-1994 points located within the 4km x 4km sample window
OP1_polys	Total number of pre-1994 polygons located within the 4km x 4km sample window
OP2_points	Total number of post-1994 points located within the 4km x 4km sample window
OP2_polys	Total number of post-1994 polygons located within the 4km x 4km sample window
OP1_pt_er	Number of pre-1994 errors; an error was recorded if the point was not visible on LANDSAT or SPOT PAN imagery
OP1_ply_er	Number of pre-1994 errors; an error was recorded if the polygon was not visible on LANDSAT or SPOT PAN imagery
OP2_pt_er	Number of post-1994 errors; an error was recorded if the point was visible on LANDSAT or SPOT PAN imagery
OP2_ply_er	Number of post-1994 errors; an error was recorded if the polygon was visible on LANDSAT or SPOT PAN imagery

Detailed analyses were carried out to summarise the proportion of omission and commission errors at the LANDSAT scene level and maps were produced to identify specific areas of the mapping that exhibited variations in the accuracy of the change analysis. The results of these analyses are summarised below. Given that the data was collected for each map grid subsequent error analyses at the catchment level will also be possible.

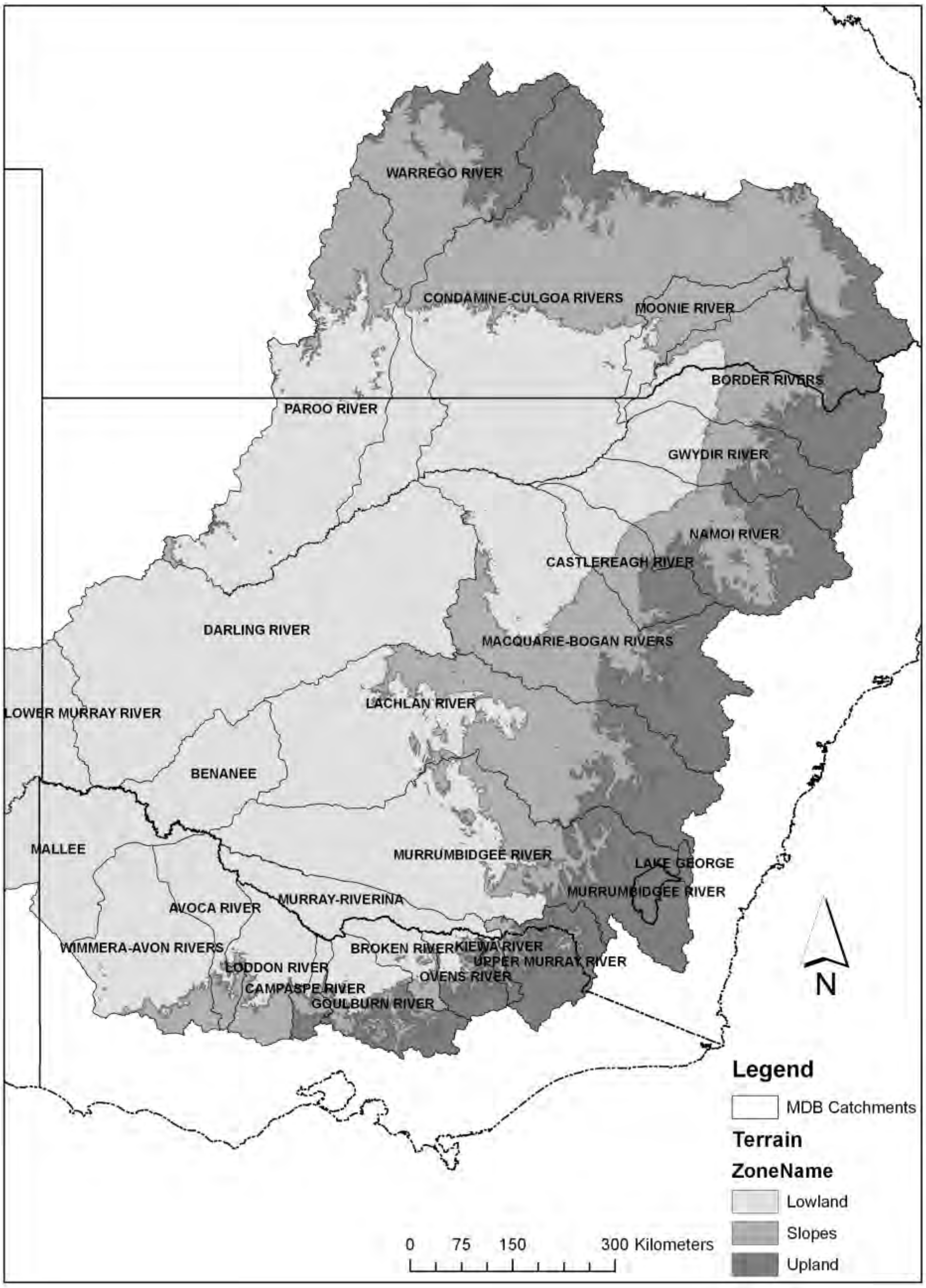
Dam Size Analysis

Approximately half of the dams included in the 2005 baseline mapping did not meet the necessary size thresholds and were captured as points, rather than polygons. The primary reason for not capturing all water bodies relates to cost associated with the labour intensive methods that have been required historically.

While direct surface area estimates are possible for those dams captured as polygons, an alternative approach was required for the points. In order to develop robust summaries for each catchment, a stratification was applied based on a Terrain Types dataset provided by the Commission which breaks each catchment into "Uplands", "Slopes" and "Lowlands", as shown in Figure 5 below. The terrain classification was defined as 0-200m for lowlands, 200–400m for slopes and >400m for uplands (including montane areas).

A minimum of 25 dam points were selected for each terrain type and catchment resulting in 39 sampling strata. For each of the selected dams, SPOT5 2.5m pseudo-natural colour imagery was used to interpret and capture the high water mark of the dam in order to generate a maximum high-water surface area extent. All the dam boundaries were compiled into a single Geodatabase. In order not to bias statistical analyses a similar number of dams from the baseline polygon dataset within each catchment and terrain type were pooled to generate summary statistics relating to surface area size class distribution of the dams. The summary areas are reported in the results section and Appendix C.

Figure 5: Murray–Darling Basin showing sub-catchments and terrain types. Dam area statistics are available for each terrain type and for each of the 15 specified catchments.



RESULTS

This report provides a snapshot of the number of man-made water bodies that existed in the years 1994 and 2005 in most of areas in the Murray-Darling Basin where there is significant surface runoff. The man-made water bodies identified in this study are generally referred to in this report as "dams" and include farm dams (a term generally used to describe dams on freehold land that have their own catchment), off-stream dams, irrigation reuse storages, public storages and storages contained within water delivery systems. In dryland areas the vast majority of the man-made water bodies identified will be farm dams whereas in irrigation districts that share common headworks (such as those in northern Victoria) the majority of man-made water bodies identified will be reuse storages. Off-stream dams, irrigation reuse storages and storages contained within water delivery systems do not have any significant catchment area and therefore do not take additional water from the environment. In those States of the MDB that require new farm dams in specific categories to hold a water entitlement, the construction of these types of farm dams will not take additional water from the Murray system as a cap and trade system is used (for example, all irrigation and commercial use farm dams in Victoria). Additional work would be required to separate the man-made water bodies identified in this study into the relevant categories.

In addition a number of regulatory controls were introduced by jurisdictions on farm dam development between 1994 and 2005. Therefore the effectiveness of these new regulatory controls in addressing the risk of farm dam development cannot be determined from this study. To understand the impact that introduced regulatory measures have had on the rate of growth of farm dams would require additional analysis of appropriate years between 1994 and 2005.

Baseline Mapping

Mapping and analyses were completed over 15 of the eastern Murray–Darling Basin catchments comprising a total area of 509,000 km^2, or around 82 percent of the 15 catchments mapped. All upland areas of the 15 catchments were mapped except for the Condamine-Culgoa. In this case all the eastern uplands were mapped and only a small proportion of the western uplands (See Figures 1 and 5). A total of 519, 931 dams were mapped for a nominal year of 2005. Figure 6 illustrates the distribution and density of the dams across the basin. Not surprisingly, the highest densities of dams are located within peri-urban and rural residential areas around the major population centres. Around 41, 34 and 25 percent of the dams occurred in the upland, slopes and lowlands respectively. Comprehensive statistics on the number of dams per catchment and terrain type can be found in Table 7 below.

In interpreting the results of the project and undertaking further analyses it is critically important to keep in mind how any variation in output accuracies may impact on estimates. Some 2,432 estimates of omissions (missed) and commissions (mapping of features not present) were made to ascertain whether the final mapping over- or under-estimated the total number of dams.

Table 5 below provides a summary of the global accuracy estimates on a work package basis. Further detailed statistics are available in Appendix A. For the 10 work packages, 6 achieved overall accuracies exceeding 98 percent, with Central South NSW, North West and North East NSW and Vic High Country having accuracies of 96, 91, 92 and 106 percent respectively. These figures can be interpreted to suggest that our estimates in the Namoi, Gwydir and Border Rivers catchments may be under-estimated by around 10 percent, and our estimates for the Upper Murray catchment in Vic may be over-estimated by 6 percent.

Table 5: Summary of accuracy statistics for all work packages utilised in the reference point and polygon datasets (post in-house data upgrade). Additional summaries can be found in Appendix A.

DESCRIPTION	WORK PACKAGE									
	Benalla (%)	Central North NSW (%)	Central South NSW (%)	Condamine (%)	Goulburn – Broken (%)	High Country (%)	North East NSW (%)	North West NSW (%)	South NSW (%)	Qld Murray – Darling (%)
GLOBAL STATISTICS	NOTE: For each of the three calculations below, if the result is <100%, then there are more omissions than commissions (likely under-estimate of the population). If the result is >100%, then there are more commissions than omissions (likely over-estimate of the population).									
Percentage of the total number of mapped dam points (- commissions + omissions □ total points).	98.2	97.2	96.3	97.9	100.1	105.1	91.0	83.2	99.1	101.4
Percentage of the total number of mapped dam polygons (- commissions + omissions □ total polygons).	99.6	99.4	96.5	100.8	100.0	111.1	92.2	95.4	98.1	98.1
Percentage of the total number of mapped dam points & polygons (- commissions + omissions □ total points & polygons).	98.5	98.3	96.4	99.2	100.1	105.9	91.6	90.6	98.7	100.1

Figure 6: Water body density per square kilometre throughout the study area generated from the 2005 baseline.

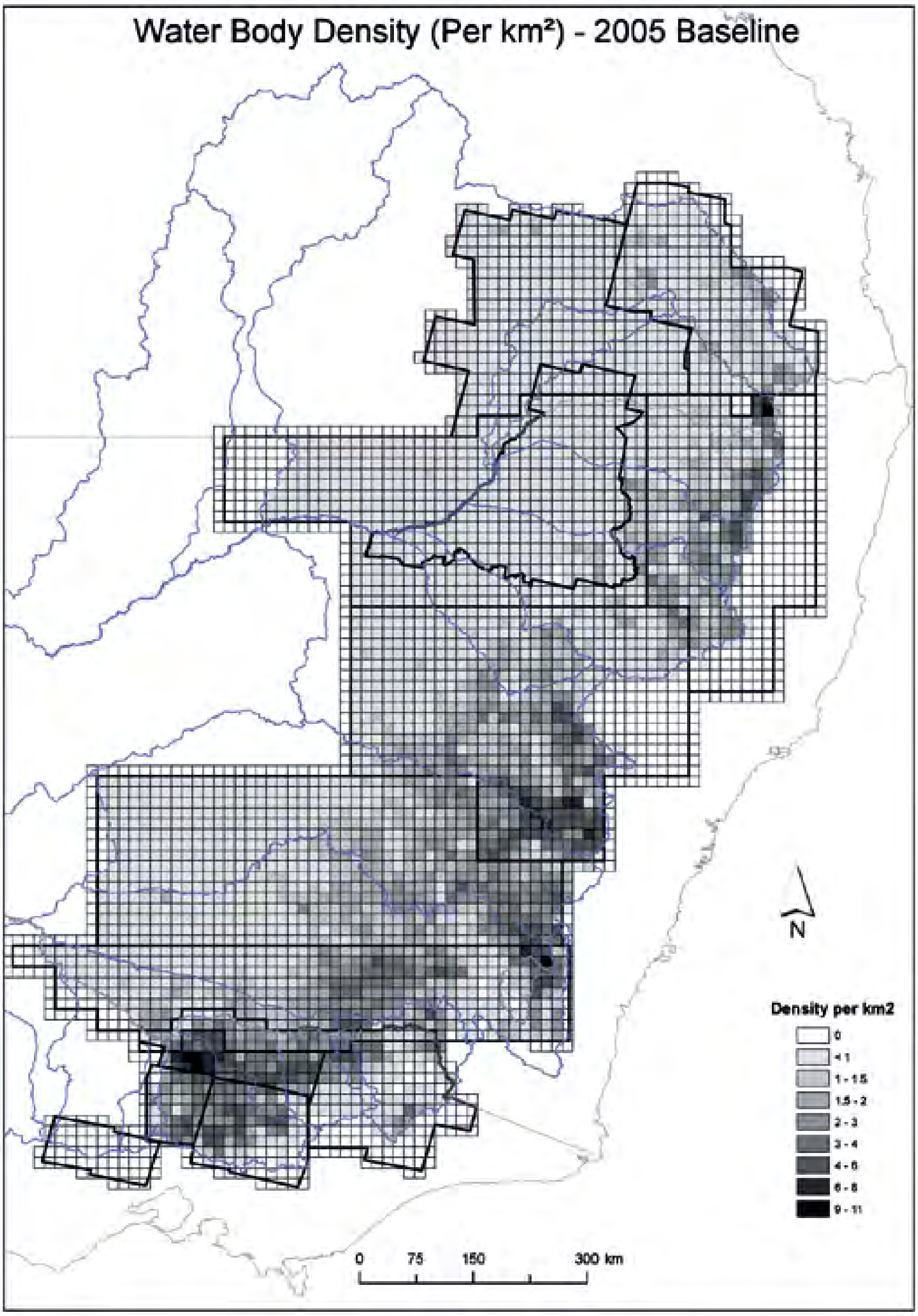
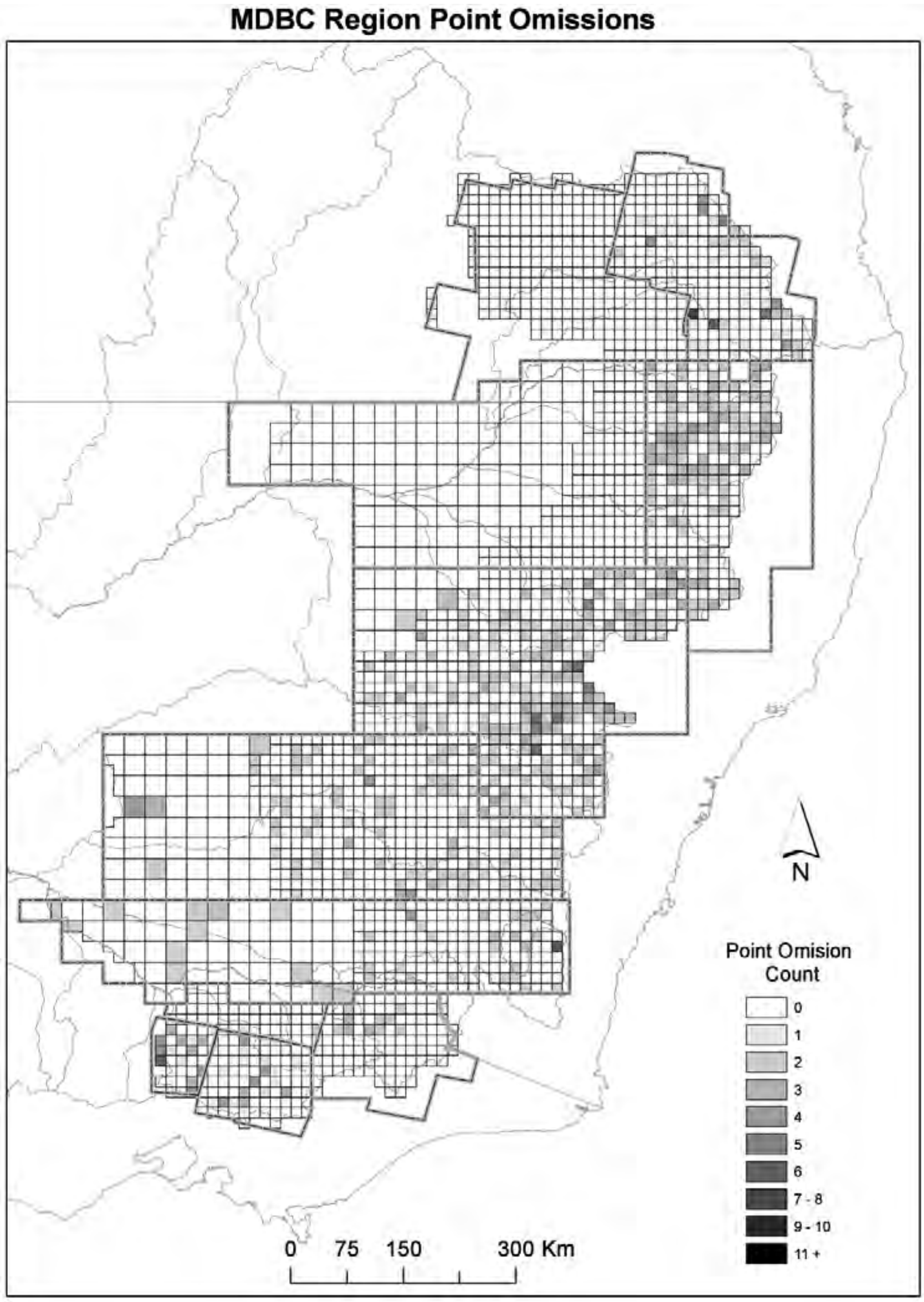


Figure 7 below shows where the errors of omission and commission exist for small dams captured as points. In the areas previously mentioned, the under-estimates (omissions) were largely caused by difficulties in interpreting and capturing very small dams in the black-soil plain areas. Additional error maps can be found in Appendix A. The areas in the high country, where over-mapping of the dams occurred, was largely due to dark areas on the imagery relating to springs and shadows of trees being mis-interpreted as empty dams. It would be expected that the issues highlighted here would not be as significant outside of drought conditions when dams are likely to have more water in them and may be mapped using digital image classification techniques.

Figure 7: Data assessment detailing the number of omitted points (point errors) detected during independent accuracy assessment. Additional error maps can be seen in Appendix A.



Change Analysis

Table 6 below provides a summary of the overall change in the number of dams per catchment and terrain type between ~1994 and ~2005. Because of the limitations of mapping small dams with LANDSAT, and the relatively small amount of change, it is important that interpretation or further analysis of the change should also take into account information relating to estimates of the overall accuracy of the baseline data and the change analysis. Table B4 in Appendix B presents a detailed summary of the accuracy of the change analysis on a per scene basis.

Table 6: Dam changes per catchment between 1994 and 2005.

Catchments	Lowlands % Change	Slopes % Change	Uplands % Change	Total % Change
Condamine-Culgoa Rivers	0	29	9	18
Namoi River	0	7	18	13
Moonie River	0	18	0	13
Gwydir River	0	6	15	12
Lachlan River	3	7	7	7
Upper Murray River	0	5	7	6
Kiewa River	5	6	5	6
Macquarie-Bogan Rivers	0	0	9	6
Murrumbidgee River	2	6	6	5
Broken River	1	1	5	4
Border Rivers	0	2	5	4
Ovens River	0	2	4	1
Goulburn River	1	0	1	1
Castlereagh River	0	0	0	0
Murray-Riverina	0	0	0	0

Total % Change	**6**
Number of Dams Pre 1994	**488,725**
Number of Dams Post 1994	**31,206**
Number of Total Dams	**519,931**

The overall increase in dams over the 509,000 km^2 study area is estimated to be 6 percent or 31,000 dams between ~1994 and ~2005. The degree of change, however, varied considerably between and within catchments. The overall accuracy of the change analysis is estimated to be approximately 93 percent suggesting that our basin-wide estimate of 6 percent could be closer to 7 percent The catchments estimated with the greatest overall change during this period are the Condamine-Culgoa catchments (18%), followed by the Namoi (13%), Moonie (13%) and the Gwydir (12%). Based on the final accuracy assessment (see Table B4, Appendix B) we believe that these estimates of change are likely to be under-estimated by 10-20 percent, particularly in relation to the very small dams. Using the individual accuracy assessments detailed in Appendix B, the increase in dams over the Condamine-Culgoa, Namoi, Moonie and Gwydir catchments are therefore likely to be 20, 15, 14, and 15 percent respectively.

Among the reasons for the likely under-estimation are:

- clustering of very small dams in rural residential areas around major population centres is very difficult to assess with LANDSAT imagery, although there are clear overall trends;
- difficulty in detecting small dams in areas of black soil leads to a general over-estimation of water bodies using LANDSAT and therefore an under-estimation of change using the methods applied in the study; and
- a limitation of the automated change detection method does not account for existing dams that are modified. For example a small irrigation storage that has been enlarged will not be reported as a change using the automated methods. These areas require manual interpretation which is a minor task, given the relatively small number of large irrigation reservoirs involved.

The change analysis over the Murrumbidgee produced an overall increase in dams of 5 percent with 6 percent increases being recorded in the uplands and slopes. Due to the clustering of very small dams in rural residential areas, which are below the detectable limits of LANDSAT, the final accuracy assessment suggests that the change may be under-estimated by 42 percent. This would increase the estimate of catchment-wide change between 2 and 7.1 percent.

Figure 8 provides a depiction of the spatial variability in dam development between 1994 and 2005. The maps show both the percentage change and the total counts of new dams per map grid (144 km^2). It is important to interpret the change using both these maps in addition to the baseline maps. For example, a mapsheet with only 1 dam in 1994 that increased to 2 dams in 2005 would be recorded as 100 percent change.

While statistics for the overall catchment are relatively low in comparison to previously reported statistics, there are significant regions of very high development, particularly within commuting distance of the major regional centres. The regions with the highest levels of development during the period include Canberra, Wagga Wagga, Albury, Tumut, Bathurst, Armidale, Tamworth, Toowoomba and Dalby. In the case of the Toowoomba-Dalby region, the major increases in dams include both small dams and irrigation storages.

Importantly these statistics represent changes in all man-made water bodies, including on-farm irrigation storages, hillside farm dams, domestic water supply and other man-made structures. Additional attributes in the baseline data are available to break these statistics down further according the function of the water bodies within the limits of State topographic mapping specifications.

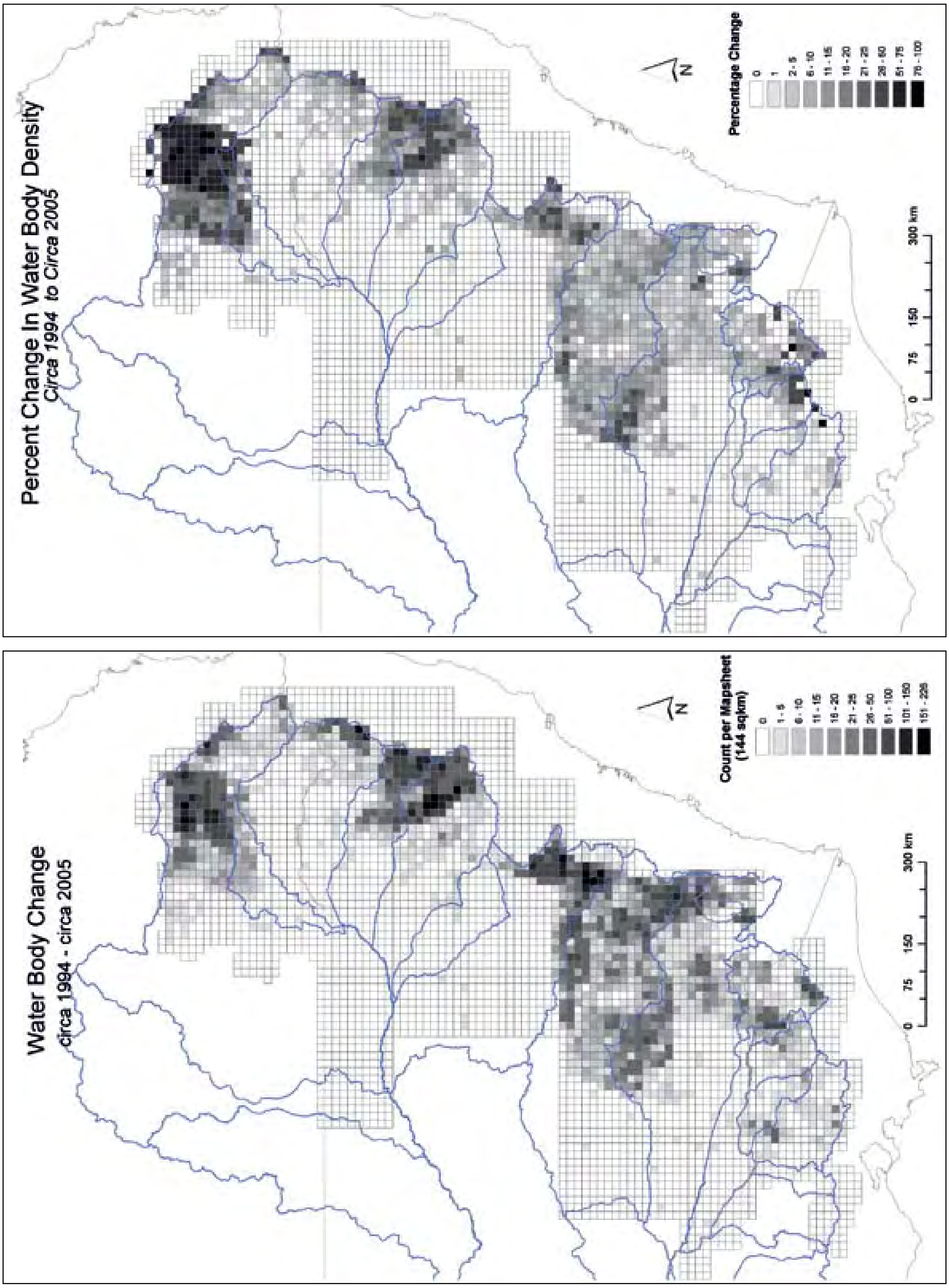


Figure 8 (a and b): Changes in dam density between circa 1994 – circa 2005. Left (a) is the number of new dams detected since circa 1994 and right (b) is the change as a percentage.

Table 7: Final statistics detailing total number of dams and the change in dam numbers for each catchment and landscape type (lowlands, slopes and uplands). Dam Size Analysis

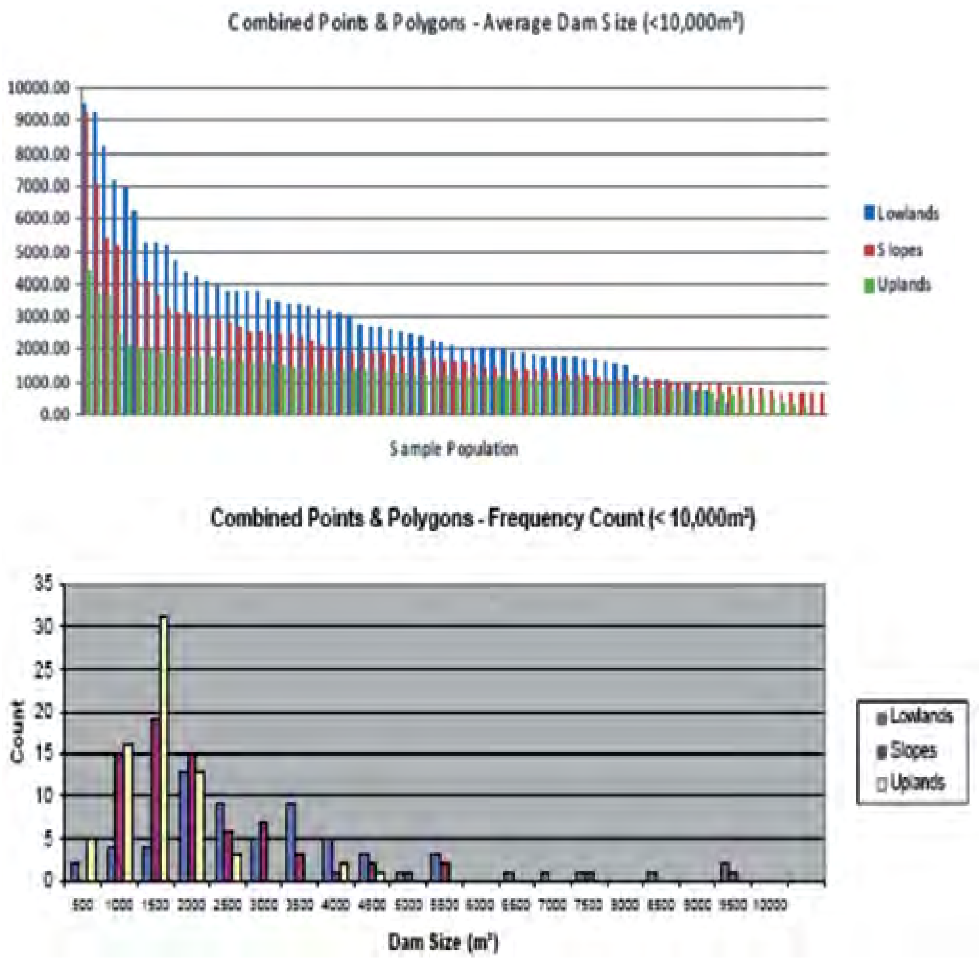
		BORDER RIVERS	BROKEN RIVER	CASTLEREAGH RIVER	CONDAMINE-CULGOA RIVERS	GOULBURN RIVER	GWYDIR RIVER	KIEWA RIVER	LACHLAN RIVER	LAKE GEORGE	MACQUARIE-BOGAN RIVERS	MOONIE RIVER	MURRAY-RIVERINA	MURRUMBIDGEE RIVER	NAMOI RIVER	OVENS RIVER	UPPER MURRAY RIVER	TOTALS
TOTAL DAMS 2005		35,779	20,629	12,937	34,825	45,742	24,013	4,390	85,892	2,093	81,509	3,928	14,514	91,140	31,643	14,196	16,701	519,931
LOWLANDS	DAMS PRE 94	2,916	16,216	2,336	5,489	25,824	2,433	671	7,800	0	6,559	1,002	14,497	33,774	2,527	7,535	0	129,579
	NEW DAMS POST 94	2	85	0	0	131	1	32	220	0	4	2	17	835	0	17	0	1,346
	TOTAL DAMS	2,918	16,301	2,336	5,489	25,955	2,434	703	8,020	0	6,563	1,004	14,514	34,609	2,527	7,552	0	130,925
	% CHANGE	0	1	0	0	1	0	5	3	0	0	0	0	2	0	0	0	1
SLOPES	DAMS PRE 94	9,100	4,285	4,526	12,667	14,863	4,656	2,954	33,799	0	22,616	2,407	0	25,969	10,086	5,512	9,026	162,466
	NEW DAMS POST 94	144	43	4	5,106	71	288	205	2,637	0	109	517	0	1,608	741	130	456	12,059
	TOTAL DAMS	9,244	4,328	4,530	17,773	14,934	4,944	3,159	36,436	0	22,725	2,924	0	27,577	10,827	5,642	9,482	174,525
	% CHANGE	2	1	0	29	0	6	6	7	0	0	18	0	6	7	2	5	7
UPLANDS	DAMS PRE 94	22,394	0	6,058	10,526	4,802	14,158	503	38,616	1,922	47,717	0	0	27,276	15,025	958	6,725	196,680
	NEW DAMS POST 94	1,223	0	13	1,037	51	2,477	25	2,820	171	4,504	0	0	1,678	3,264	44	494	17,801
	TOTAL DAMS	23,617	0	6,071	11,563	4,853	16,635	528	41,436	2,093	52,221	0	0	28,954	18,289	1,002	7,219	214,481
	% CHANGE	5	0	0	9	1	15	5	7	8	9	0	0	6	18	4	7	8
TOTALS	DAMS PRE 94	34,410	20,501	12,920	28,682	45,489	21,247	4,128	80,215	1,922	76,892	3,409	14,497	87,019	27,638	14,005	15,751	488,725
	NEW DAMS POST 94	1,369	128	17	6,143	253	2,766	262	5,677	171	4,617	519	17	4,121	4,005	191	950	31,206
	TOTAL DAMS	35,779	20,629	12,937	34,825	45,742	24,013	4,390	85,892	2,093	81,509	3,928	14,514	91,140	31,643	14,196	16,701	519,931
	% CHANGE	4	1	0	18	1	12	6	7	8	6	13	0	5	13	1	6	6
TOTAL LAND AREA (sq km)		48,041	7,099	17,423	162,596	16,857	26,585	1,912	90,879	942	74,791	14,342	15,039	81,643	41,999	7,981	15,341	623,471
TOTAL MAPPED AREA (sq km)		47,364	7,099	17,423	90,616	15,595	26,585	1,811	74,543	941	61,020	14,342	14,802	75,433	41,169	7,488	13,243	509,474
PERCENT OF AREA MAPPED (%)		99	100	100	56	93	100	95	82	100	82	100	98	92	98	94	86	82

Dam Size Analysis

The baseline mapping process included all man-made water bodies including large reservoirs used for electricity generation and domestic supply. Table 8 provides summary statistics for the lowlands, slopes and upland regions of each catchment. The global average dam size of 14,921m^2 is highly skewed by a few very large storages. When all storages >10,000m^2 are removed the global average dam size is reduced to 2131m^2. Table 8 provides percentile summaries for each catchment. As might be expected, dam size generally increases as one moves from the uplands, through the slopes to the lowlands.

The distribution of dams sizes varies considerably from catchment to catchment. Figure 9 below provides a summary frequency distribution of dam sizes based on the sample population for the Namoi catchment. Additional summaries for each catchment are available in Appendix C.

Figure 9: Dam size class distribution for the Namoi Catchment for Lowland, Slopes and Upland areas.



The statistics collated here on dam surface area can be directly applied to volume estimates through known surface-area to volume equations. Moreover, the dams, on which the statistics are based, have been captured into a separate spatial database to allow for further spatially explicit analysis.

Table 8: Summary of dam sizes for catchments and their constituent terrains (lowland, slopes and upland). Note that these averages are for global average dam sizes and dam sizes <10,000m². The selected average of dams less than 10,000m² was done to remove bias introduced from large-area water storage sites.

	Lowlands					Slopes					Uplands				
Catchment	Average Dam Size (m²)	Average Area < 10,000m²	25th %	50th %	75th %	Average Dam Size (m²)	Average Area <10,000m²	25th %	50th %	75th %	Average Dam Size (m²)	Average Area < 10,000m²	25th %	50th %	75th %
Border Rivers	1831	1831	926	1407	2390	13825	2202	970	1751	2865	1612	1317	656	941	1396
Broken River	4858	1690	525	1122	2636	3660	1983	853	1442	2973					
Castlereagh River	2012	2012	1071	1635	2278	1719	1719	1100	1516	2155	1257	1257	873	1198	1603
Condamine-Culgoa Rivers	23101	2777	1324	2323	3663	32494	2718	1461	2611	6597	4863	1947	1032	1384	2797
Goulburn River	6472	2049	777	1403	3337	3798	2417	1037	1984	3277	3250	2159	899	1524	3481
Gwydir River	74692	3008	2104	3202	4610	9675	2163	1092	2029	3229	1909	1627	781	1385	2367
Kiewa river	4873	1955	1007	1614	2952	2581	2093	908	1431	2800	51304	1905	870	1273	2613
Lachlan River	13804	1905	936	1436	2997	1770	1770	840	1378	2138	2613	1637	921	1173	1740
Macquarie-Bogan Rivers	23300	1906	927	1749	2552	4554	1498	978	1372	1867	1667	1467	849	1111	1666
Moonie River	21807	3014	1471	2350	6400	7934	3583	1901	2976	8542					
Murray Riverina	4429	1433	669	1018	1956										
Murrumbidgee River	2088	1769	910	1352	2346	1740	1740	913	1344	2240	1887	1531	839	1264	1916
Naomi River	23634	3013	1808	3082	6964	7944	2026	1067	1670	2570	1505	1296	910	1206	1596
Ovens River	1994	1475	869	1171	1821	3360	1947	891	1540	3147	5015	2501	919	2050	3748
Upper Murray						2740	1908	679	1168	2261	2270	1590	679	985	1996

DISCUSSION

This project not only provides a benchmark for on-going planning and policy support in relation to risks to shared water resources, but also for on-going monitoring and accounting.

The results from this work suggest that previous estimates of basin-wide increases in hillside dams over the 10 year period following the 1994 cap year have been significantly over-estimated, and that it is crucial to consider regional variability when assessing the potential impact of dam development. Based on observations taken during mapping the dams for these two dates, it is clear that there are higher concentrations of dams within commuting distance of regional population centres such as Canberra, Wagga Wagga, Albury, Tumut, Bathurst, Armidale, Tamworth, Toowoomba and Dalby, and that the numbers of these dams has grown significantly during this period.

The high levels of validation and accuracy assessment undertaken during this study provide a benchmark in quality assurance that should not only provide greater confidence in policy decisions but also provide greater understanding and opportunities for modelling and further analysis of this data in the future.

Prior to this study, all assessments of change in the number of hillside dams have relied on very small sample-based estimates. By contrast this project has been based on wall-to-wall mapping using contemporary high resolution satellite imagery to provide baseline estimates of the total population of dams to known levels of accuracy. The use of baseline data collected from high resolution imagery has significantly improved our capacity to analyse historical time-series of moderate resolution imagery such as LANDSAT, and again, assess both the overall quality of outputs and identify specific instances where the quality of outputs may vary. With the systems and methods now in place additional LANDSAT time-periods can easily be used to assess specific dates of interest around the basin in the areas identified by this study.

The automated change detection processes used in this project do not adequately account for assessing change relating to existing dams modified during the period of analyses. Typically, the regions where the method did not work satisfactorily were the irrigation areas, rather than upland areas. For example, a small irrigation storage that had been enlarged was not reported as a change using the automated methods. Given the overall number of irrigation storages relative to the smaller dams, this limitation has not significantly impacted on the accuracy of the overall change figures reported. However, as this data will be further analysed and converted to storage volumes, these issues will need to be resolved. Due to the fact that these storages are relatively large, it will be possible to simply compare the mapped boundaries from the 2005 baseline with the 1994 water indices generated from the LANDSAT using digital analysis techniques, along with visual interpretation to resolve any inconsistencies. As the extent of the irrigation areas is well known, this will be a minor additional project, which we believe should be funded as a priority.

In two other circumstances the method was limiting: areas of clustering of very small dams in rural residential areas; and small dams in areas of black soil. In both these instances, the LANDSAT underestimated the degree of change. These areas were, however, generally areas where high-levels of change had already been detected. The general "signal" of significant landscape change had therefore been detected even though LANDSAT was not capable of resolving the fine detail. Using additional LANDSAT time-periods would likely improve these estimates in the future.

While the overall levels of accuracy demonstrated in this study are very good, there are no doubt limitations to on-going monitoring of very small dam development with moderate resolution such as LANDSAT. Future monitoring programs will need to continue using higher resolution imagery such as SPOT5 or equivalent sensors to update the baseline mapping periodically at large scale. There are also further opportunities to use future imagery collected in non-drought conditions to digitally classify changes in the surface water extent of existing dams. Moreover, dams mapped as points (approximately 50%) in the baseline mapping could be captured as polygons using these techniques, which are far less labour intensive than the initial methods used.

The results of this study provide significant guidance in terms of the capabilities that are required to monitor the development of dams into the future. At the basin scale, a seemingly large increase of 31,206 dams over a 10 year period only represents an increase of 6 percent in the total number of dams, or around 0.5 percent per year. However, the results also demonstrate the highly localised nature of the change: where dramatic increases in dams have occurred these may have a highly significant impact on local stream flows.

In addition to remote sensing there may be significant opportunities to utilise other information sources to track some components of planned development which may present a risk to shared water resources. For example, by analysing changes in cadastral boundaries, areas being sub-divided for future rural-residential development could be identified at the planning stages, prior to any development. This information could also be used to target high resolution monitoring using remote sensing. The Australian Bureau of Statistics (ABS) has recently undertaken an initial trial relating to urban expansion using this method (pers. comm.). The ABS, Geoscience Australia and the Bureau of Rural Sciences are currently exploring opportunities to undertake further trials to integrate the cadastral and remote sensing information.

In terms of ongoing use of remote sensing, the challenge is therefore to balance the need for high resolution and frequent coverage over regions where significant change is likely to occur, with any additional need for systematic monitoring of the entire basin in order to detect change that may not be so predictable. The development of dams is also an indicator of many other changes in the landscape which may be directly related to the dams including: irrigation development; changes in grazing pressure; vegetation clearing; land use; land management practices; and rural residential development.

The further development of any remote sensing capability for ongoing monitoring of dams should therefore ideally be part of an integrated routine land cover monitoring program undertaken at a range of spatial and temporal scales. This system should provide the basis for a range of generic needs (as described above) in addition to specific products for water accounting at seasonal and annual timescales, and at appropriate spatial resolution. Operationally, this might translate into something like annual 2.5 & 10m coverage over intensive land use and per-urban and rural residential areas; annual 10m coverage over the remainder of the eastern MDB; seasonal coverage (monthly-3 monthly) of the entire basin at 25–60m resolution; and weekly products at 250m–1km resolution.

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APPENDIX A: BASELINE DATA INTEGRATION AND ACCURACY ASSESSMENT

MURRAY–DARLING BASIN COMMISSION / GEOSCIENCE AUSTRALIA
(AGREEMENT No. MD949)

MAPPING THE GROWTH, LOCATION, SURFACE AREA AND AGE OF FARM DAMS
IN THE MURRAY-DARLING BASIN

Geoscience Australia
March 2008

Water Body Base Topographic Data, Descriptions and Coverage

QUEENSLAND

Data Snapshot

Table A1: Summary of Queensland work packages size criteria for man-made water bodies. Please note: a significant change to size criteria occurred between the Condamine and QLD Murray–Darling Basin Projects (600m^2 to 6400m^2).

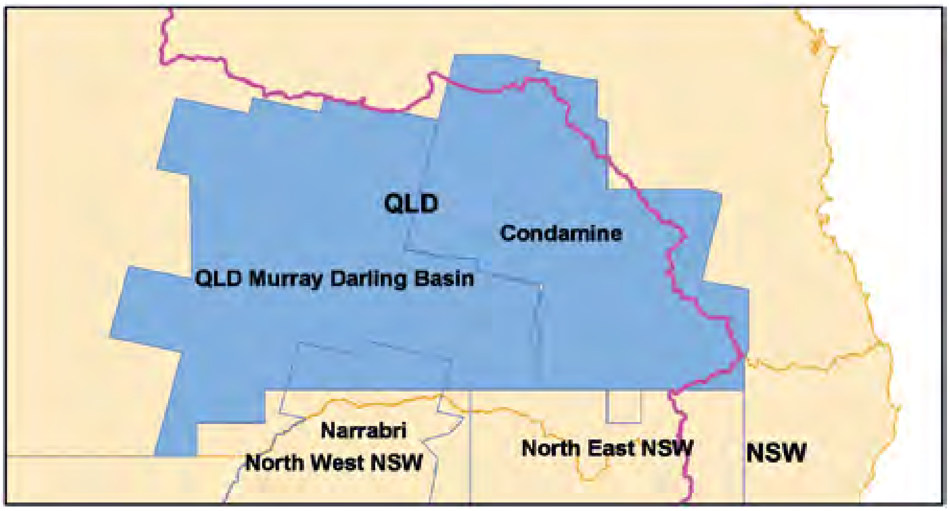
Project Area	Size Criteria	Reliability Date	Feature Source
QLD Murray–Darling Basin	**Polygon Capture** Lakes: over 2500m^2 Pondage Areas: over 625m^2 Reservoirs: over 6400m^2 **Point Capture** WaterTanks (small reservoirs): under 6400m^2	2005	60cm Orthophotography (part) SPOT 2.5m Satellite Imagery
Condamine	**Polygon Capture** Lakes: over 600m^2 Pondage Areas: over 600m^2 Reservoirs: over 600m^2 **Point Capture** WaterTanks (small reservoirs): under 600m^2	2005	60cm Orthophotography (part) SPOT 2.5m Satellite Imagery

Data Structure

Figure A1: Data structure of Queensland water bodies as specified by GA V.4 specifications.

Project Areas

Figure A2: Geoscience Australia's current Large-scale Mapping Projects in Queensland.



Feature Definitions (GA v4.0 Specifications)

Table A2: Feature definitions for each feature type.

Feature Type	Definition
Pondage Areas	
Aquaculture Area	Shallow beds, usually segmented by constructed walls, for the use of aquaculture.
Salt Evaporator	A flat area, usually segmented, used for the commercial production of salt by evaporation.
Settling Pond	Shallow beds, usually segmented by constructed walls, for the treatment of sewage or other wastes.
Reservoirs	
Flood Irrigation Storage	A body of water collected and stored behind a constructed barrier for the specific use of fFlood iIrrigation fFarming.
Town Rural Storage	A body of water collected and stored behind a constructed barrier for some specific use (with the exception of fFlood iIrrigation sStorage).
Water Tanks	
Water Tank:	A feature constructed on or below the ground for the storage of water.

Size Criteria (GA v4.0 Specifications)

QLD Murray–Darling Basin Project:

Table A3: Point and polygon size criteria.

Polygon Capture	
Pondage Areas	over 625m^2
Reservoirs	over 6400m^2
Point Capture	
WaterTanks (small reservoirs)	under 6400m^2

Condamine Project:

Table A4: Point and polygon size criteria.

Polygon Capture	
Pondage Areas	over 600m^2
Reservoirs	over 600m^2
Point Capture	
WaterTanks (small reservoirs)	under 600m^2

Capture Source and Reliability Dates

QLD Murray–Darling Basin Project:

Table A5: Capture source and reliability dates.

Capture Source	Reliability Dates
60cm orthophotography	28/10/2001 to 25/11/2003
SPOT 2.5m Satellite Imagery	6/5/2004 to 3/11/2005

Condamine Project:

Table A6: Capture source and reliability dates.

Capture Source	Reliability Dates
60cm orthophotography (Toowoomba 100K tile only)	5/10/2005
SPOT 2.5m Satellite Imagery	1/1/2005

NEW SOUTH WALES

Data Snapshot

Table A7: Summary of New South Wales work packages size criteria for man-made water bodies.
– Passed VAT, – Currently in VAT or VAT fail, – In-house post production work completed

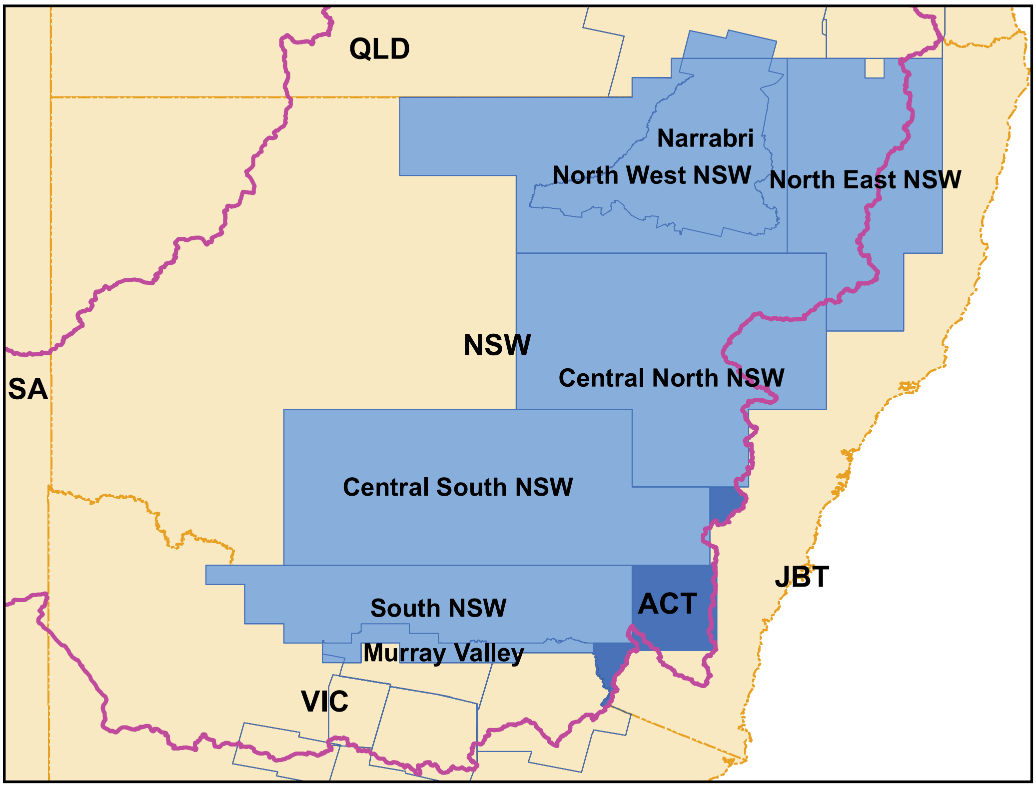
Project Area	Size Criteria	Reliability Date	Feature Source
Narrabri	**Polygon Capture** HydroArea: over 1600m^2 TankArea: over 30m diameter **Point Capture** HydroPoint: under 1600m^2 TankPoint: under 30m diameter	2004	SPOT 2.5m Satellite Imagery
North West, North East & Central South NSW	as above	2004–2005	SPOT 2.5m Satellite Imagery
NSW (Original LPI data)	as above	various	various

Data Structure

Figure A3: Data structure of New South Wales water bodies as specified by LPI specifications.

Project Areas

Figure A4: Geoscience Australia's current Large-scale Mapping Projects in New South Wales.



Feature Definitions (NSW LPI T-Rules)

Table A8: Feature definitions for each feature type.

Feature Type	Definition
Hydro Area and Hydro Point	
Lake, Perennial	A water body, which normally contains water for the whole year, except during unusually dry periods. A general criteria used for classification is that water is present for at least nine out of ten years.
Lake, Non-Perennial (or Intermittent)	A water body which normally contains water for several months of the year, except during unusually dry periods.
Lake, Dry	A water body which rarely contains water, except for short periods not related to seasons.
Reservoir, Dam, Ground Tank	A man-made feature constructed in the ground for the storage of water. May consist of an earth barrier across a watercourse to form a reservoir for pastoral, private or industrial purposes including town water supply.
Tank Area and Tank Point	
Tank-RuralWater	A tank used to store drinking or raw water for rural use.
Tank-UrbanWater	A tank used to store drinking water for a community.
Tank-Gas	A tank used to store gas.
Tank-Oil	A tank used to store oil or other petroleum products.
Tank-Sewage	A tank used to store sewage.

Size Criteria (NSW LPI T-Rules)

Narrabri Project and North West, North East & Central South NSW Projects:

Table A9: Point and polygon size criteria.

Polygon Capture	
HydroArea	over 1600m^2
TankArea	over 30m diameter
Point Capture	
HydroPoint	under 1600m^2
TankPoint	under 30m diameter

Capture Source and Reliability Dates

Narrabri Project:

Table A10: Capture source and reliability dates.

Capture Source	Reliability Dates
SPOT ^{2}.5m Satellite Imagery	1/11/2004

North West, North East & Central South NSW Projects:

Table A11: Capture source and reliability dates.

Capture Source	Reliability Dates
SPOT 2.5m Imagery	9/11/2005 to 21/6/2005 (north west)
SPOT 2.5m Imagery	15/11/2004 to 7/8/2005 (north east)
SPOT 2.5m Imagery	30/10/2004 to 2/8/2005 (central south)

VICTORIA

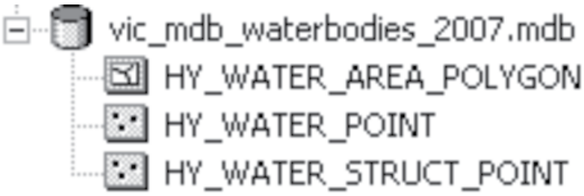
Data Snapshot

Table A12: Summary of Victoria work packages size criteria for man-made water bodies.

Project Area	Size Criteria	Reliability Date	Feature Source
Ballarat	Polygon Capture HY_WATER_AREA_POLYGON: over 2500m^2 Point Capture HY_WATER_POINT: under 2500 m^2 HY_WATER_STRUCT_POINT: under 2500 m^2	2006	SPOT 2.5m Satellite Imagery
Benalla	as above	2004	SPOT 2.5m Satellite Imagery
High Country	as above	2004–2006	Orthophotography SPOT 2.5m Satellite Imagery

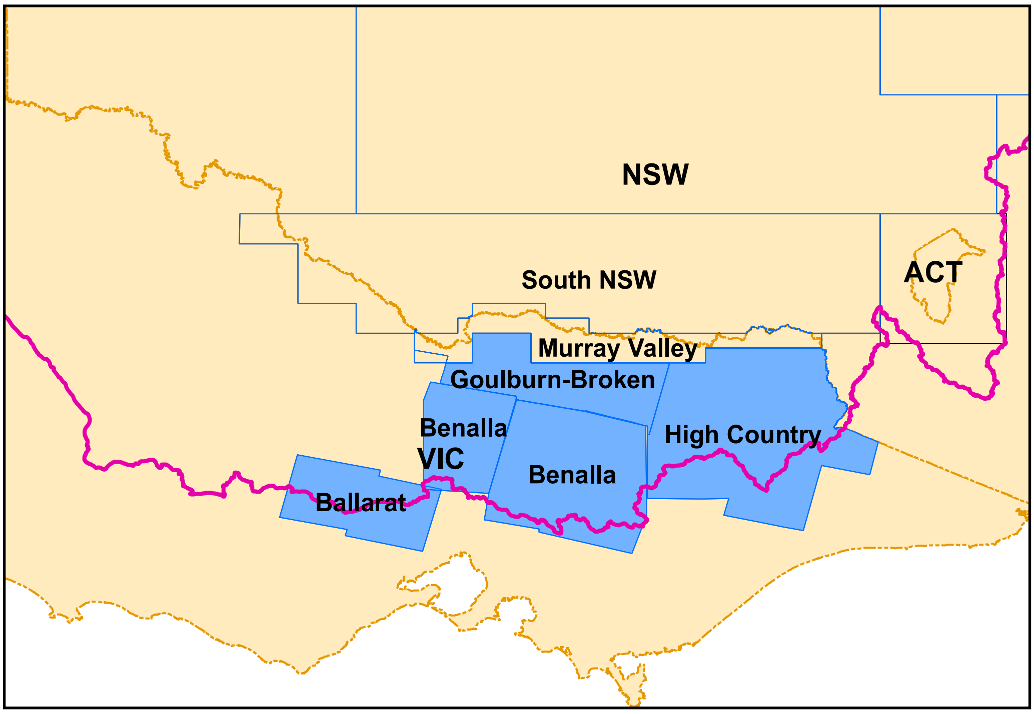
Data Structure

Figure A5: Data structure of Victorian water bodies as specified by VicMap specifications.



Project Areas

Figure A6: Geoscience Australia's current Large-scale Mapping Projects in Victoria.



Feature Definitions (VicMap Specifications)

Table A13: Feature definitions for each feature type.

Feature Type	Definition
HY_WATER_AREA_POLYGON	
Lake	A inland area of standing water on a permanent basis, a lake bed containing water intermittently or an outdoor swimming pool of competition dimension.
Flat	A level tract which may be subject to inundation on a regular or irregular basis.
Wetland	A vegetated area which is inundated or saturated with water.
Pondage	All areas of shallow water with walls or banks created for a specific purpose.
HY_WATER_POINT	
Waterbody Point (wb_dam)	Lake entity with point representation.
Spring	The place where water issues from the ground naturally.
Rapids	An area of broken, fast flowing water in a stream, where the slope of the bed increases (but without a prominent break of slope which might result in a cascade or waterfall), or where a gently dipping bar of harder rock outcrops.
Waterfall	The sudden descent of water over a step or ledge in the bed of a river.
HY_WATER_STRUCT_POINT	
Tank Water	A structure used for the storage of fluids.
Swimming Pool	Waterbody Point
Well	A pit or hole dug or bored into the earth, for the extraction of oil, water and other fluids or gases

Size Criteria (VicMap Specifications)

Ballarat, Benalla and High Country Projects:

Table A14: Point and polygon size criteria.

Polygon Capture	
HY_WATER_AREA_POLYGON	over 2500m^2
Point Capture	
HY_WATER_POINT	under 2500m^2
HY_WATER_STRUCT_POINT	under 2500m^2

Capture Source and Reliability Dates

Ballarat Project:

Table A15: Capture source and reliability dates.

Capture Source	Reliability Dates
SPOT 2.5m Satellite Imagery	14/1/2006 to 25/1/2006

Benalla Project:

Table A16: Capture source and reliability dates.

Capture Source	Reliability Dates
SPOT 2.5m Satellite Imagery	4/4/2004 to 24/11/2004

High Country Project:

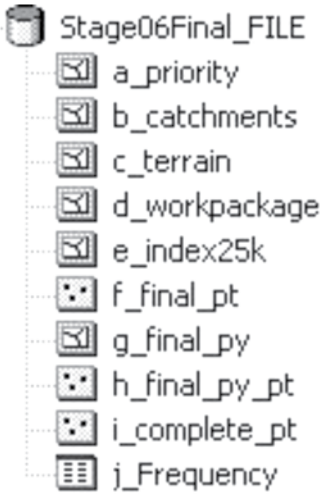
Table A17: Capture source and reliability dates.

Capture Source	Reliability Dates
Orthophotography	1/3/2004 to 12/3/2006
SPOT 2.5m Satellite Imagery	7/4/2003 to 20/2/2006

Final Data Format

Data Structure

Figure A7: Structure of the final data personal geodatabase where:



a. is our priority index with both LANDSAT scene_noscene no and priority.

b. is all catchments in the MDBC.

c. is terrain; lowlands, slopes and uplands.

d. our work package indexx.

e. the 1:25,000 index covering the whole MDBC with Contains Data attribute YES or NO

f. all the points with duplicates removed.

g. all the polygons with duplicates removed.

i. all the dams represented as points with complete feature level metadata.

j. frequency results performed on i.

Supplied Data and Metadata

Supplied data

1) **MDBC_dams_Final_08.gdb**

a_priority.	LANDSAT scene number and priority.
b_catchments.	MDBC Catchments.
c_terrain.	Terrain.
d_workpackage.	Work package index.
e_index25k.	1:25,000 index covering the MDBC.
f_final_pt.	Dam points.
g_final_py.	Dam polygons.
h_final_py_pt.	All polygons from 'g' reduced to points.
i_complete_pt.	All dams represented as points (f + h).
j_frequency.	Frequency results performed on 'i'.
k_area_sample_population.	Polygon dataset used in the dam surface area calculations.

2) **Base_Data_Error_Statistics.xls**
Summary statistics compiled from error checking of the base topographic data.

3) **Change_Data_Error_Calculations.xls**
Summary statistics compiled from error checking of the change detection outputs.

4) **Change_Analysis_Calculations.xls**
Summary statistics compiled from LANDSAT imagery of threshold values used in the change detection process.

5) **Dam_Size_Calculations.xls**
Summary statistics compiled from the surface area analysis of dam points and polygons.

Metadata

Below is a text version of a metadata statement created for the supplied data (personal geodatabase only) and does not apply to the supplied excel spreadsheets including *base data error statistics, change data error calculations, dam size calculations or change analysis calculations*. The metadata has been attributed using the ANZLIC Metadata plug-in for AcrGIS9.2. It is provided here for reference purposes.

Title: "Mapping the growth, location, surface area and age of farm dams in the Murray–Darling Basin".

ANZLIC Identifier

Custodian: Geoscience Australia (GA), Murray–Darling Basin Commission (MDBC).
Jurisdiction: Murray–Darling Basin including the States of Queensland, New South Wales and Victoria.

Description

Abstract: Man-made water body change detection products and selected base data supplied to MDBC under contract from GA (Agreement No. MD949).
Theme: Hydrology.
Defined Region:
North: -25.999620
South: -37.850000
East: 152.534220
West: 142.999320

Data Currency

Beginning Date: July 2007.
End Date: March 2008.

Data Status

Progress: Completed.
Update: No additional change detection planned.

Access

Stored Data Format: geodatabase (gdb).
Access Restrictions: Produced under contract for the Murray–Darling Basin Commission (MDBC Agreement No. MD949).

Data Quality

Lineage: Data originally acquired for the purposes of eEmergency management and sourced from GA – NMIG (National Mapping Information Group) with data captured under a panel arrangement with commercial third party entities acting on GA's behalf. Selected base datasets originally supplied by State agencies with significant revision of eEmergency management themes utilising aerial photography and satellite imagery sources. Selected datasets of the completed GRDA dataset have also undergone selected revision and subsequent validation to improve base data quality.

Positional Accuracy: Captured and positioned using 2.5m SPOT imagery mosaics (various dates) and aerial photo mosaics (various dates) where available. A summary of data accuracy for each constituent Work Package (WP) is included below:

Work Package: **Narrabri**
Stated Accuracy: 90% of all features captured to within +/- 5 metres.
Imagery/Date: SPOT 10 metre, XS
SPOT 2.5 metre, panchromatic
SPOT 2.5 metre, pseudo-natural
(Reliability Date: November 2004)

Work Package: **Condamine** (Parts A and B)
Stated Accuracy: 90% of all features captured to within +/- 5 metres.
Imagery/Date: Orthophotography, 60cm (Reliability Date: 2005)
SPOT 10 metre, XS
SPOT 2.5 metre, panchromatic
SPOT 2.5 metre, pseudo-natural
(Reliability Date: 2005)

Work Package: **NSW Central Division** (North East, North West, Central North, Central South, South)
Stated Accuracy: 90% of all features captured to within +/- 5 metres.
Imagery/Date: SPOT 10 metre, XS
SPOT 2.5 metre, panchromatic
SPOT 2.5 metre, pseudo-natural (Reliability Date: 2005)

Work Package: **North East Victoria** (Murray Valley, Goulburn-Broken, High Country)
Stated Accuracy: 90% of all features captured to within +/- 17.5 metres.
Imagery/Date: SPOT 10 metre, XS
SPOT 2.5 metre, panchromatic
SPOT 2.5 metre, pseudo-natural (Reliability Date: 2003-4)

Work Package: **Benalla**
Stated Accuracy: 90% of all features captured to within +/- 17.5 metres.
Imagery/Date: SPOT 10 metre, XS
SPOT 2.5 metre, panchromatic
SPOT 2.5 metre, pseudo-natural (Reliability Date: 2004)

Work Package: **QldLD Murray–Darling Basin** (Waggamba, Tara, Roma-Surat, Balonne)
Stated Accuracy: 90% of all features captured to within +/- 10 metres.
Imagery/Date: Orthophotography, 60cm (Reliability Date: 2003)
SPOT 10 metre, XS
SPOT 2.5 metre, panchromatic
SPOT 2.5 metre, pseudo-natural
(Reliability Date: 2005)

Attribute Accuracy: Data was captured and attributed to State specifications. Further modification was required to merge the data into a common standard. The Queensland Specification was chosen due to its close approximation to internal GA version 4.0 specifications.

Logical Consistency: Data captured to State specifications (QldLD, NSW and VicIC). Rules of logical consistency were applied to provide commonality between different hydrological themes.

Completeness: All constituent datasets have been checked by an impartial and independent Validation and Test cell (VAT) to internal GA specifications. Further checking of the merged base topographic products as part of the MDBC Water Body Project was also undertaken utilising a random sampling approach based on 1:25,000 and 1:50,000 map grids using a sample window of 2km x 2km for each of the 1:25,000 or 1:50,000 map squares (refer to Base_Data_Error_Statistics.xls). Approximately 4% of the total population of points and polygons were sampled.

The constituent datasets have undergone the following independent Validation and Test (VAT):

Work Package	Project Status
QLD MDB	Completed with in-house data upgrade
Condamine	Completed with in-house data upgrade
Narrabri	Completed with in-house data upgrade
Goulburn-Broken	Completed with in-house data upgrade
Murray Valley	Completed with in-house data upgrade
High Country	Completed with in-house data upgrade
Benalla	Completed with in-house data upgrade
North West NSW	Completed with in-house data upgrade
North East NSW	Completed 2007
Central North NSW	Completed with in-house data upgrade
Central South NSW	Completed 2007
South NSW	Completed with in-house data upgrade

Checking of the final change products as part of the MDBC Water Body Project was also undertaken utilising a random sampling approach based on a 1:25,000 map grid using a sample window of 4km x 4km for each of the 1:25,000 map squares (refer to Change_Data_Error_Calculations.xls).

Contact Information

Organisation: Geoscience Australia
Position: Senior Research Geographer
Phone: (02) 6299498
Email: michael.holzapfel@ga.gov.au

Supplementary information

This information is supplied under contract to the Murray–Darling Basin Commission (MDBC) from Geoscience Australia (GA) for the purposes of identifying change in water body points and polygons from 1994 (circa) to present (2007). Base data was acquired by GA – Geographic Revision and Data Acquisition (GRDA) under a Co-operative agreement with participating State agencies. Base topographic data was supplied from the States with all features (including new features) being captured, positioned and validated against satellite imagery and aerial photography (where available).

Note that the data has been captured to different State specifications so differences in size criteria or attribution may occur. All reasonable efforts have been made to synthesise the data into a common standard but differences are still evident. Refer to the final documentation for information on the different State specifications.

Size criteria

Different size criteria for points and polygons were used based on their State specifications. Outlined below is a summary for each State and Work Package and their relevant size criteria for point and polygon capture:

Project Area	*Feature*	*Size Criteria*
QLD Murray–Darling Basin	Polygons:	Pondage Areas: over 625 m^2
		Reservoirs: over 6400 m^2
	Points	Under 6400 m^2
Condamine	Polygons	Over 600 m^2
	Points	Under 600 m^2
Narrabri, North West, North East & Central South NSW	Polygons	Over 1600 m^2
	Points	Under 1600 m^2
Benalla, High Country	Polygons	Over 2500m^2
	Points	Under 2500 m^2

Dam Change Data

For the dam threshold data, allocation of pre94 and post94 dam attributes was performed on the base topographic data. Relevant base datasets were also merged with the point and polygon results to aid in interpretation. Refer below.

Dam Change Data – Points and Polygons

Attribute	*Description*	*Length*	*Comments*
Objectid	ObjectID	4	Object ID
Shape	Point /Polygon	-	Point or Polygon
Featuretype	Text	32	Feature type (State spec. dependant)
Featurereliability	Date	8	Feature reliability date
Textnote	Text	50	Text note
State	Text	10	State (Qld, NSW, Vic)
Change	Text	6	Pre-1994 or post-1994
Swath_no	Long Integer		LANDSAT swath number
Priority	Short Integer		LANDSAT priority (for data merging purposes)
Bname	Text	30	Catchment Name
Bnum	Text	5	Catchment reference number
ZoneName	Text	50	Terrain type
Name	Text	70	Work Package Name
MapNumber	Text	8	1:25,000 scale map number

Dam Size Area Calculation Sample Population

For the dam size area calculations a random sample of points and polygons were selected from the base topographic data. Points were then digitised to polygons and merged with the existing polygons. Refer below.

Dam Size Area Calculation Sample Population

Attribute fields	*Description*	*Length*	*Comments*
FID	ObjectID		Object ID (Automatically generated)
Shape	Polygon		Polygon (Automatically generated)
Shape_Length	Double		Length (Automatically generated)
Shape_Area	Double		Area (Automatically generated)
Dam_Source	Text	10	Point or Polygon
Catch_Terrain	Text	50	Terrain
Objectid	Long integer	9	Object ID of source polygon dataset for reference
Featuretype	Text	32	Feature type
F_Area	Text		Area calculation (calculated in ALBERS)

Supplied GDB Structure

Structure of the final data personal geodatabase is summarised below where:

a_priority.	LANDSAT scene number and priority.
b_catchments.	MDBC Catchments.
c_terrain.	Terrain.
d_workpackage.	Work package index.
e_index25k.	1:25,000 index covering the MDBC.
f_final_pt.	Dam points.
g_final_py.	Dam polygons.
h_final_py_pt.	All polygons from 'g' reduced to points.
i_complete_pt.	All dams represented as points (f + h).
j_frequency.	Frequency results performed on 'i'.
k_area_sample_population.	Polygon dataset used in the dam surface area calculations.

Summary of Data Quality Statistics For All Work Packages

Table A20: Summary of statistics for all constituent work packages utilised in the reference point and polygon datasets (post in-house data upgrade). Statistics compliment figures A4–A7.

	WORK PACKAGE									
DESCRIPTION	Benalla (%)	Central North NSW (%)	Central South NSW (%)	Condamine (%)	Goulburn – Broken (%)	High Country (%)	North East NSW (%)	North West NSW (%)	South NSW (%)	Qld Murray – Darling (%)
Additional point dams required (omissions) as a percentage of the total number of dams mapped with points.	3.67	6.87	6.71	7.87	0.0	1.67	10.97	27.00	4.41	1.65
As for figure above less commissions.	3.61	6.68	6.46	7.70	0.0	1.76	9.97	22.47	4.37	1.67
Additional polygon dams required (omissions) as a percentage of the total number of dams mapped with polygons.	0.74	0.98	4.11	2.14	0.0	1.67	8.95	8.54	3.77	3.04
As for figure above less commissions.	0.74	0.98	3.97	2.15	0.0	1.85	8.26	8.15	3.69	2.98
Percentage of the point dams mapped (commissions) that should not have been.	1.9	4.0	2.9	5.7	0.1	6.6	1.0	6.9	3.5	3.0
Percentage of the polygonised dams mapped (commissions) that should not have been.	0.4	0.4	0.5	2.9	0.0	11.7	0.5	3.8	1.8	1.1
Percentage of points and polygons omitted against the number of points and polygons mapped.	3.0	4.1	5.1	5.2	0.0	1.7	9.96	17.0	4.1	2.2
Percentage of points and polygons committed against the number of points and polygons mapped.	1.5	2.3	1.4	4.4	0.1	7.2	0.79	6.6	2.8	2.3
Percentage of points and polygons omitted against the total number of points and polygons omitted and mapped.	2.9	3.9	4.8	4.9	0.0	1.6	9.1	14.5	4.0	2.1
Percentage of all mapped points & polygons minus all point & polygon commissions against the total of all point & polygon omissions.	3.0	4.2	5.1	5.4	0.0	1.8	10.0	17.9	4.3	2.2
Percentage of points and polygons committed against the total number of points and polygons committed and mapped.	1.5	2.4	1.4	4.6	0.1	7.8	0.8	7.0	2.9	2.3
GLOBAL STATISTICS	NOTE: For each of the three calculations below, if the result is less than <100%, then there are more omissions than commissions. If the result is greater than> 100%, then there are more commissions than omissions.									
Percentage of the total number of mapped dam points (- commissions + omissions ☐ total points).	98.2	97.2	96.3	97.9	100.1	105.1	91.0	83.2	99.1	101.4
Percentage of the total number of mapped dam polygons (- commissions + omissions ☐ total polygons).	99.6	99.4	96.5	100.8	100.0	111.1	92.2	95.4	98.1	98.1
Percentage of the total number of mapped dam points & polygons (- commissions + omissions ☐ total points & polygons).	98.5	98.3	96.4	99.2	100.1	105.9	91.6	90.6	98.7	100.1

Figure A8: Data assessment detailing the number of incorrectly captured points (point errors) after an in-house data upgrade. A 1:50,000 map grid was used in lowland areas and a 1:25,000 map grid over slopes and upland areas. The sampling method consisted of a random 2km x 2km sampling window within each 1:50,000 or 1:25,000 grid square. The points and polygons within this area were then verified against recent 2.5m pseudo-natural SPOT imagery and recent aerial photography (where available).

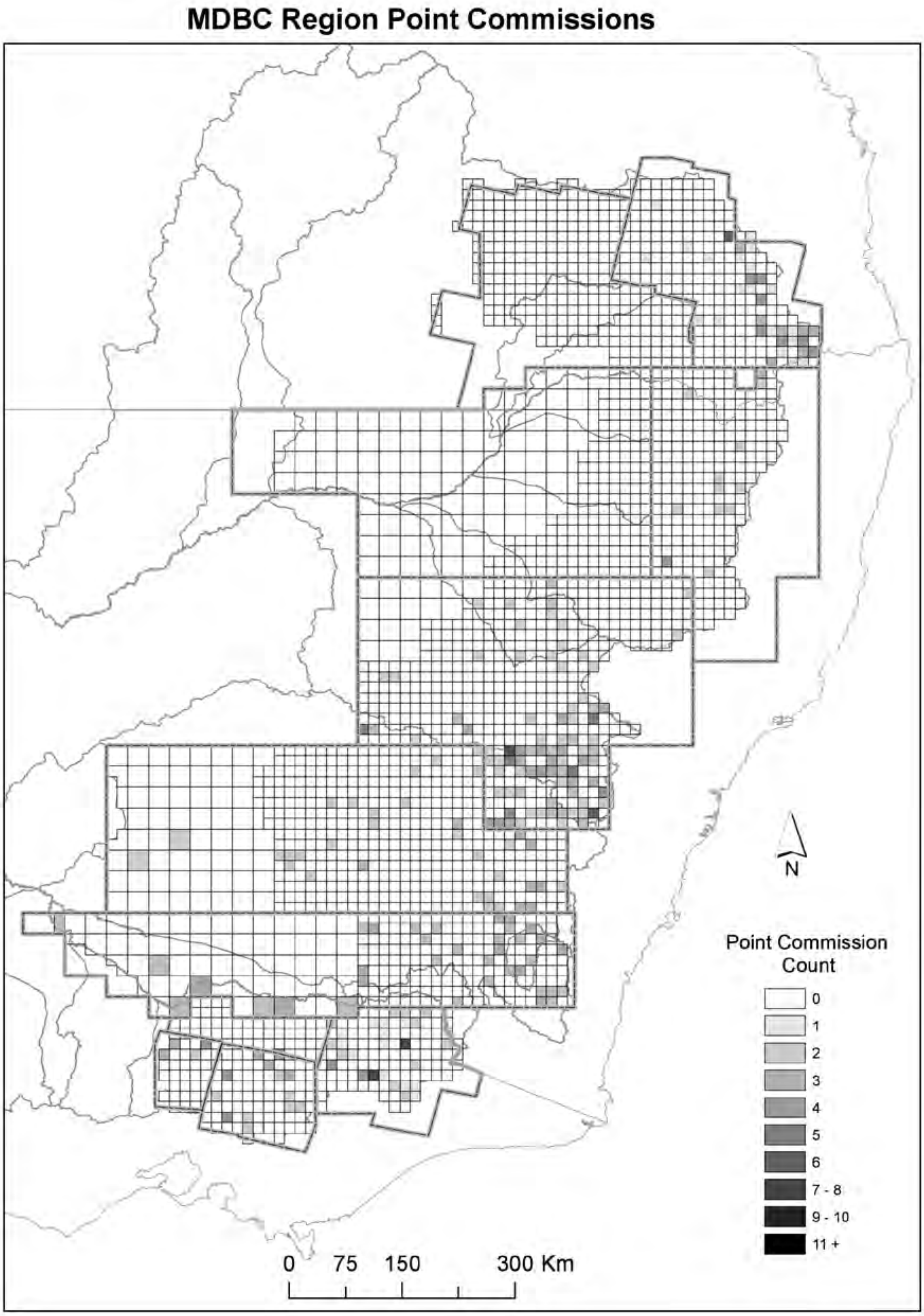


Figure A9: Data assessment detailing the number of omitted points (point errors) after an in-house data upgrade. Error counts indicate that the A 1:50,000 map grid was used in lowland areas and a 1:25,000 map grid over slopes and upland areas. The sampling method consisted of a random 2km x 2km sampling window within each 1:50,000 or 1:25,000 grid square. The points and polygons within this area were then verified against recent 2.5m pseudo-natural SPOT imagery and recent aerial photography (where available).

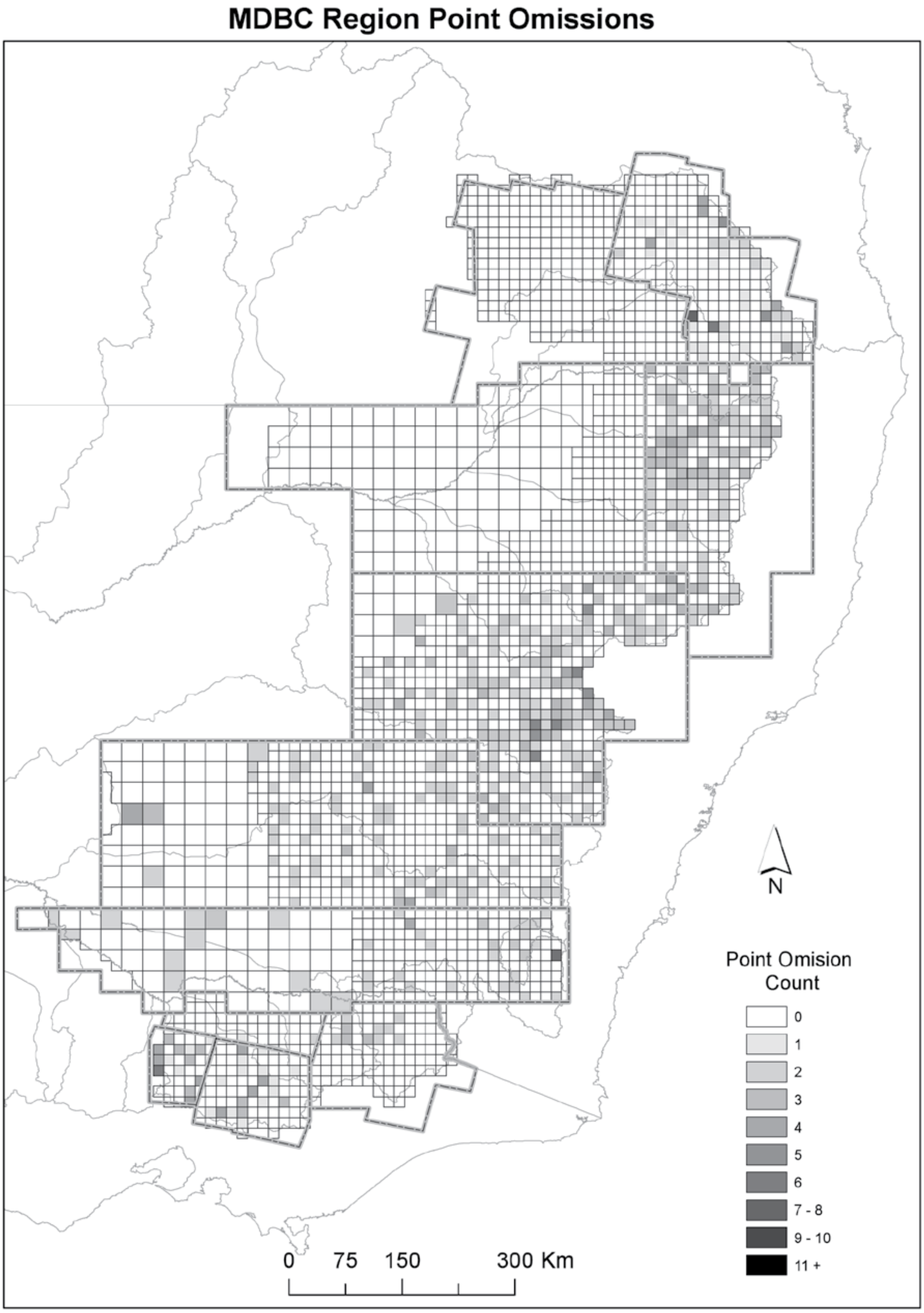


Figure A10: Data assessment detailing the number of incorrectly captured polygons (polygon errors) after an in-house data upgrade. A 1:50,000 map grid was used in lowland areas and a 1:25,000 map grid over slopes and upland areas. The sampling method consisted of a random 2km x 2km sampling window within each 1:50,000 or 1:25,000 grid square. The points and polygons within this area were then verified against recent 2.5m pseudo-natural SPOT imagery and recent aerial photography (where available).

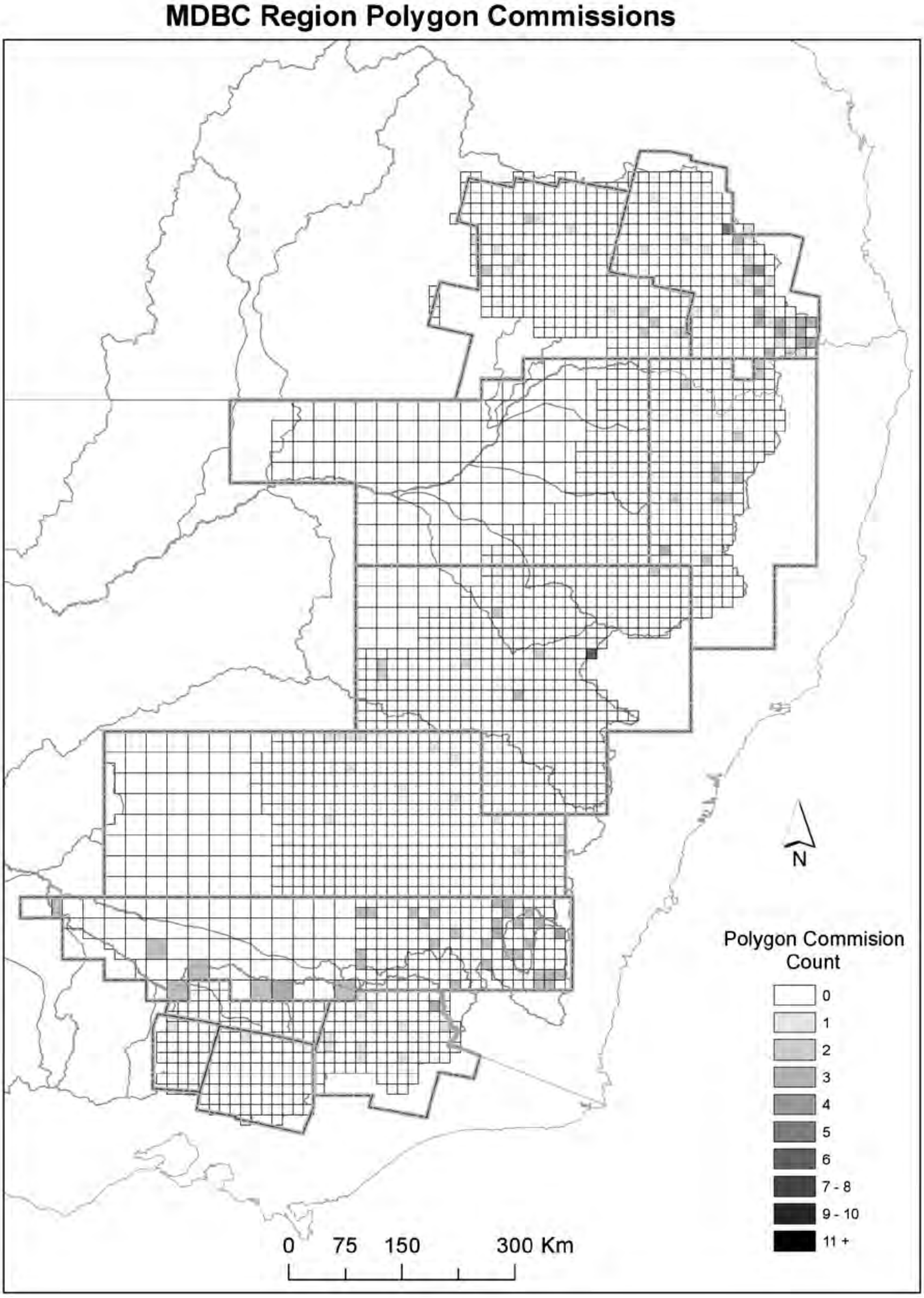
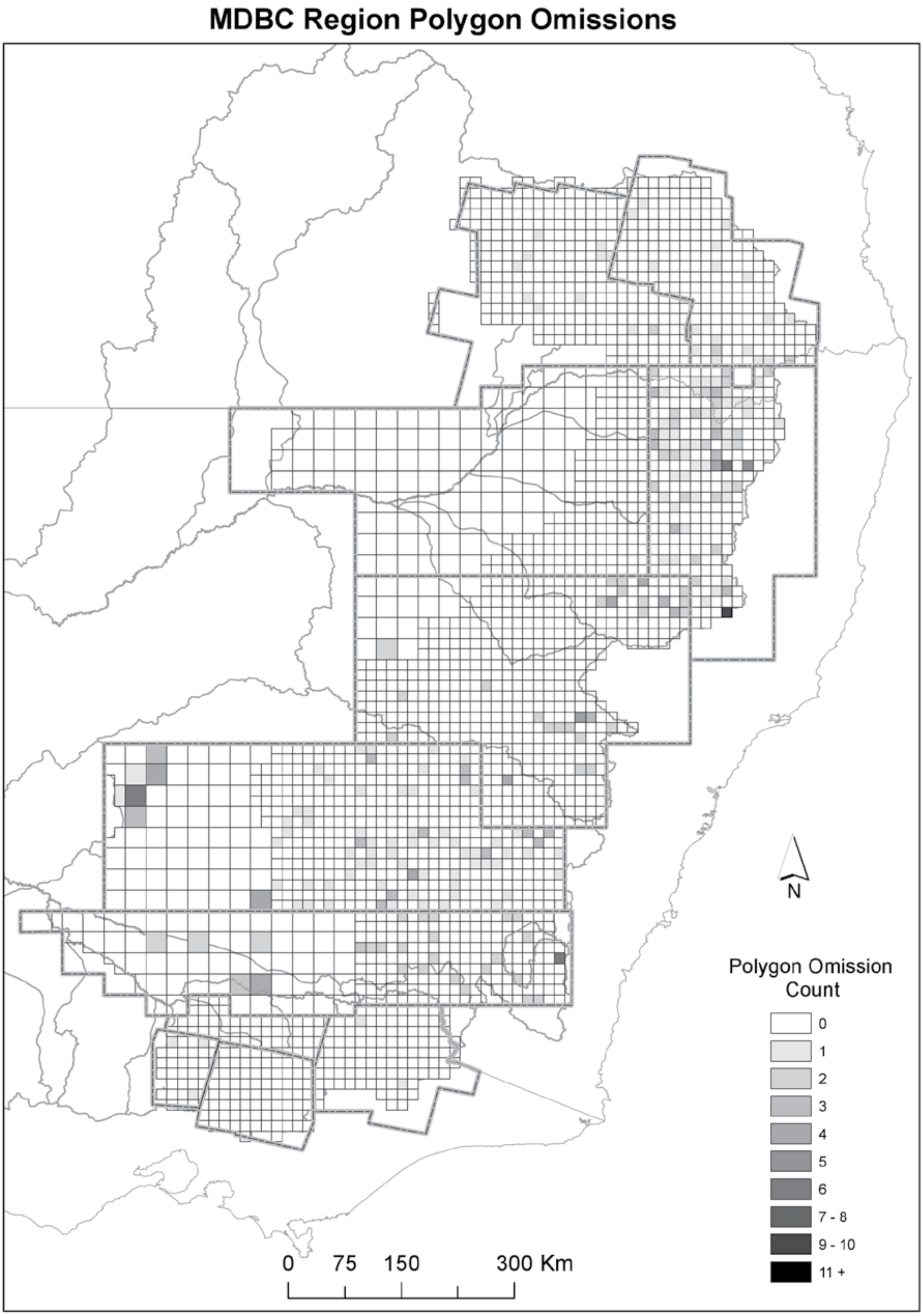


Figure A11: Data assessment detailing the number of omitted polygons (polygon errors) after an in-house data upgrade. A 1:50,000 map grid was used in lowland areas and a 1:25,000 map grid over slopes and upland areas. The sampling method consisted of a random 2km x 2km sampling window within each 1:50,000 or 1:25,000 grid square. The points and polygons within this area were then verified against recent 2.5m pseudo-natural SPOT imagery and recent aerial photography (where available)



APPENDIX B: CHANGE ANALYSIS AND ACCURACY ASSESSMENT

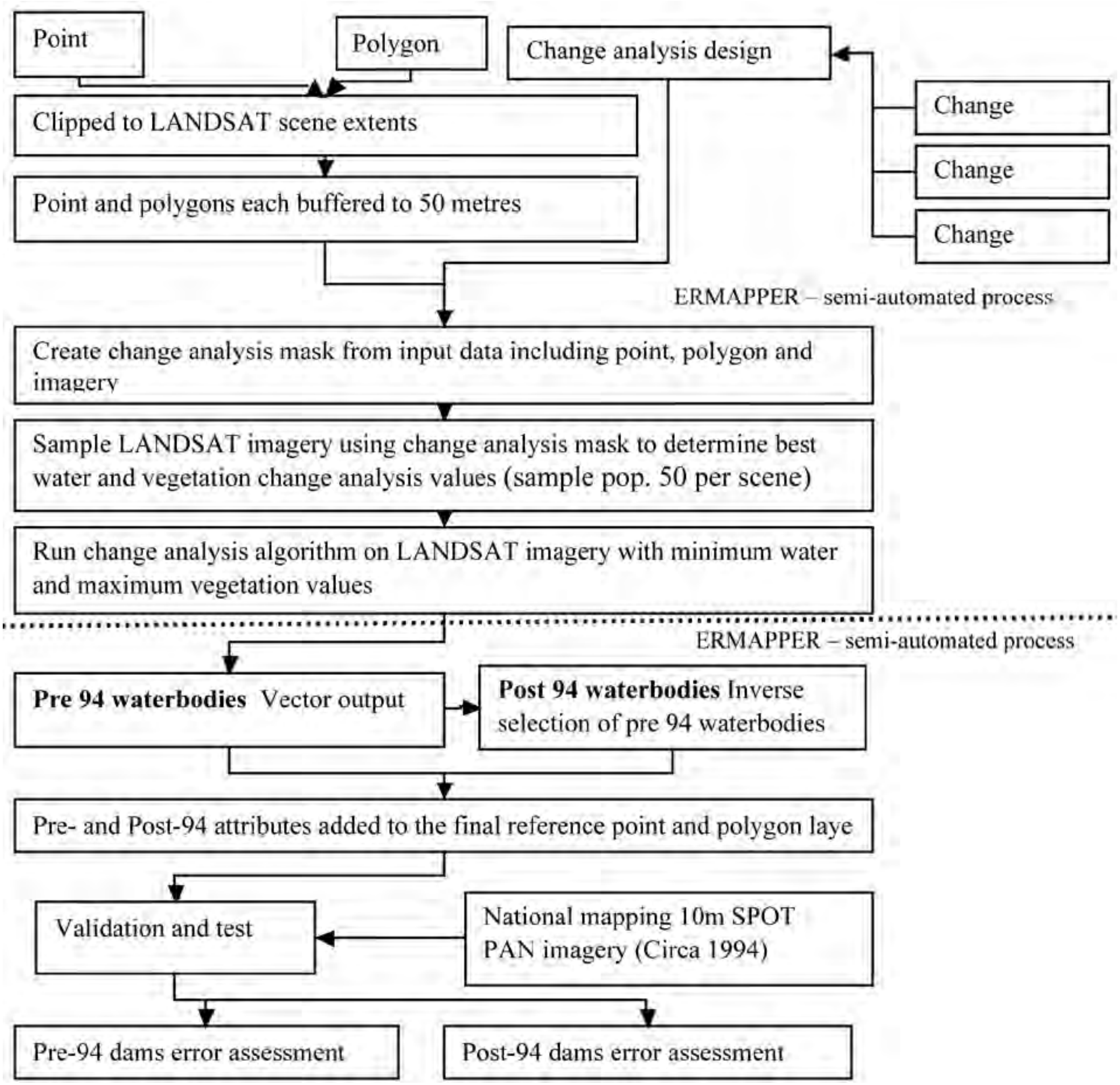
MURRAY–DARLING BASIN COMMISSION / GEOSCIENCE AUSTRALIA
(AGREEMENT No. MD949)

MAPPING THE GROWTH, LOCATION, SURFACE AREA AND AGE OF FARM DAMS IN THE MURRAY-DARLING BASIN

Geoscience Australia
March 2008

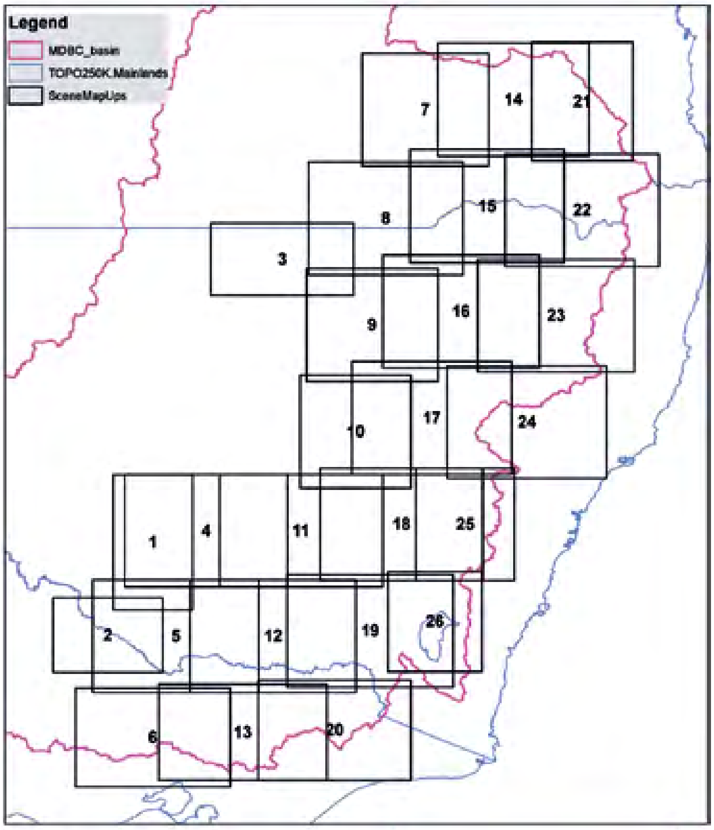
Change Analysis Workflow

Figure B1: Diagrammatic representation of the change analysis process from data input through to final validation and test.



LANDSAT Imagery

Figure B2: LANDSAT scene extents and numbering convention (lefttop). LANDSAT Scenes have undergone 'top of atmosphere reflectance' corrected which has resulted in better colour balancing and matching between scenes (rightbottom)



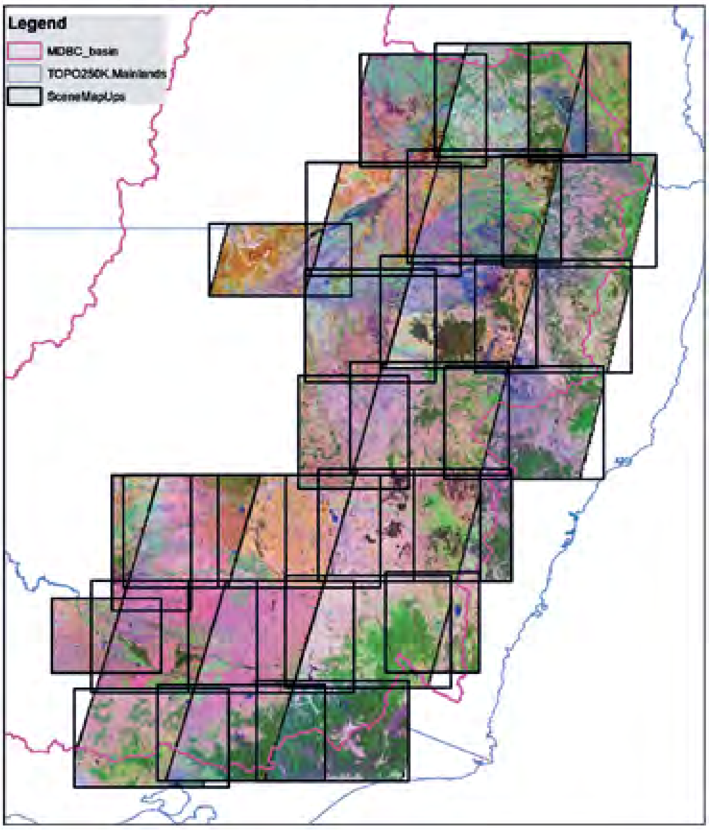


Table B1: Requested imagery dates supplied from MDBC

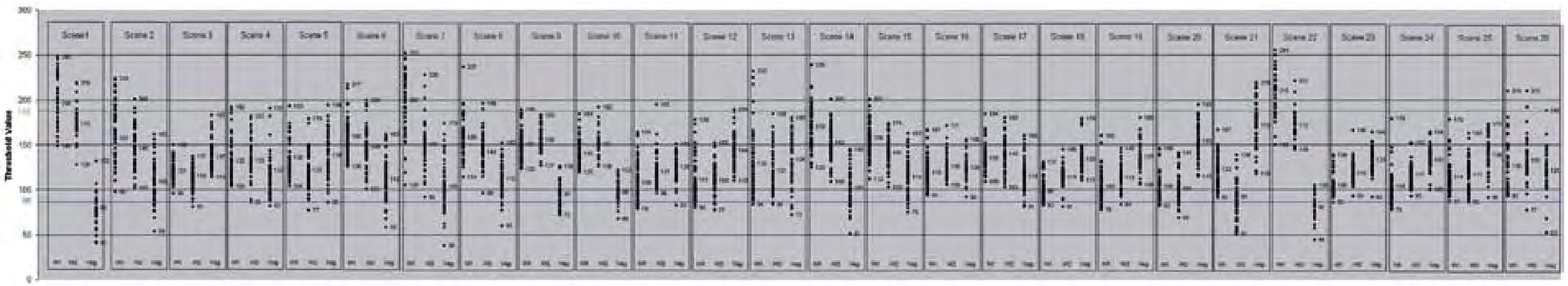
Catchment	Recommended Imagery dates
Maranoa-Balonne	Late February/Early March
Condamine	Late February/Early March
Border Rivers (West)	Late February/Early March
Western	Late February/Early March
Gwydir	Late February/Early March
Namoi	Late February/Early March
Central West (West)	Late February/Early March
Lachlan	Late February/Early March
Murrumbidgee	Late February/Early March
Murray	Late February/Early March
North Central	Late February/Early March
Goulbourn	Late February/Early March
North East	Late February/Early March
Border Rivers (East)	March
Namoi (South)	Late November/Early December
Central West (East)	Late November/Early December

Table B2: Imagery dates supplied by ACRES

LANDSAT Scene number	Imagery Month	Imagery Date
1	March	12/05/1994
2	March	25/03/1994
3	March	3/04/1994
4	March	3/04/1994
5	March	3/04/1994
6	March	5/05/1994
7	March	11/03/1994
8	March	27/03/1994
9	December	14/05/1994
10	December	14/05/1994
11	March	22/11/1994
12	March	22/01/1994
13	March	22/01/1994
14	March	7/05/1994
15	March	20/03/1994
16	December	17/12/1994
17	December	21/04/1994
18	March	17/12/1994
19	March	17/12/1994
20	March	17/12/1994
21	March	13/03/1994
22	March	16/05/1994
23	December	8/11/1994
24	December	8/11/1994
25	March	21/09/1994
26	March	10/12/1994

Water and Vegetation Index Thresholds

Figure B3: Graph showing the spread of change analysis values determined from a sample population of 50 per LANDSAT scene. The determination of what change analysis values to use necessitated a rigorous sampling procedure for each LANDSAT scene to determine what could be an optimum and defensible use of change analysis values. W1 and W2 refer to different water thresholds that were evaluated during initial algorithm testing (refer to algorithm design and testing). W1 is the water value that is used for these results. The vegetation change analysis was consistent across evaluated algorithms. Evaluation of compiled water and vegetation change analysis values allowed for a set of global change analysis to be used hence producing a more consistent result and minimising the risk of non-duplicate entities in overlapping LANDSAT scenes. The global water change analysis that was used was 86 (minimum sampled water value) and the global vegetation value was 188 (maximum sampled vegetation value).Note that for scenes that cover black-soil plains (scenes1,2,7,8,14,15,21 and 22) the spread of water values are much higher than the global average. In these scenes the likelihood of erroneous classification into pre-and post-94 is higher as the black soil plains and their elevated moisture content will interfere and bias the results in favour of the pre-94 classification. Modification of the water change analysis to a higher value will only slightly correct this bias and manual intervention is likely to be required.



Legacy SPOT Imagery used for Change Validation

Figure B4: Map showing the difference in cover between legacy 10m SPOT PAN imagery (brown) and MDBC Aerial photography scenes used in previous farm dam analysis (red).

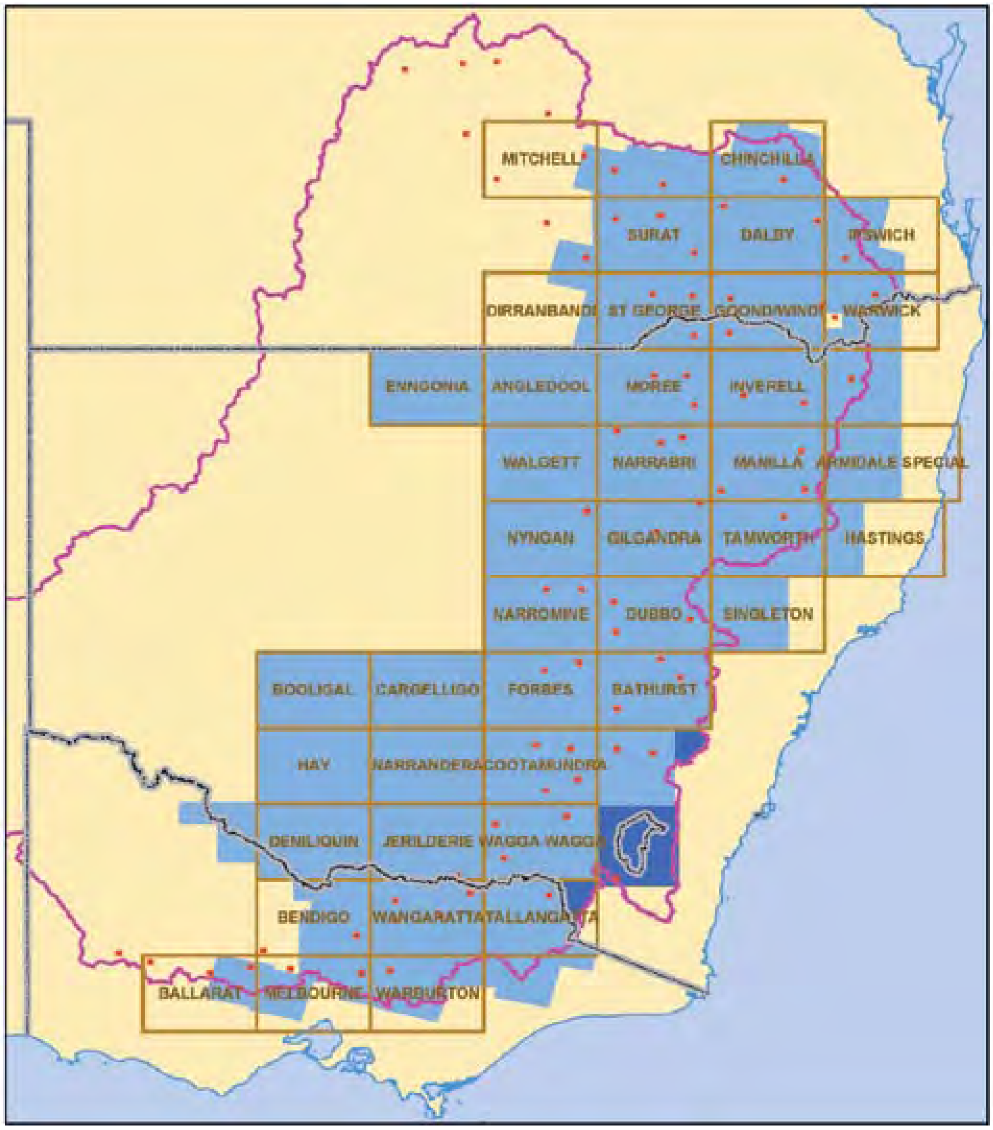


Figure B5: Old legacy 10m SPOT PAN coverage used in the VAT of change analysis products. Grey background corresponds to LANDSAT coverage. Imagery dates are tabulated below.

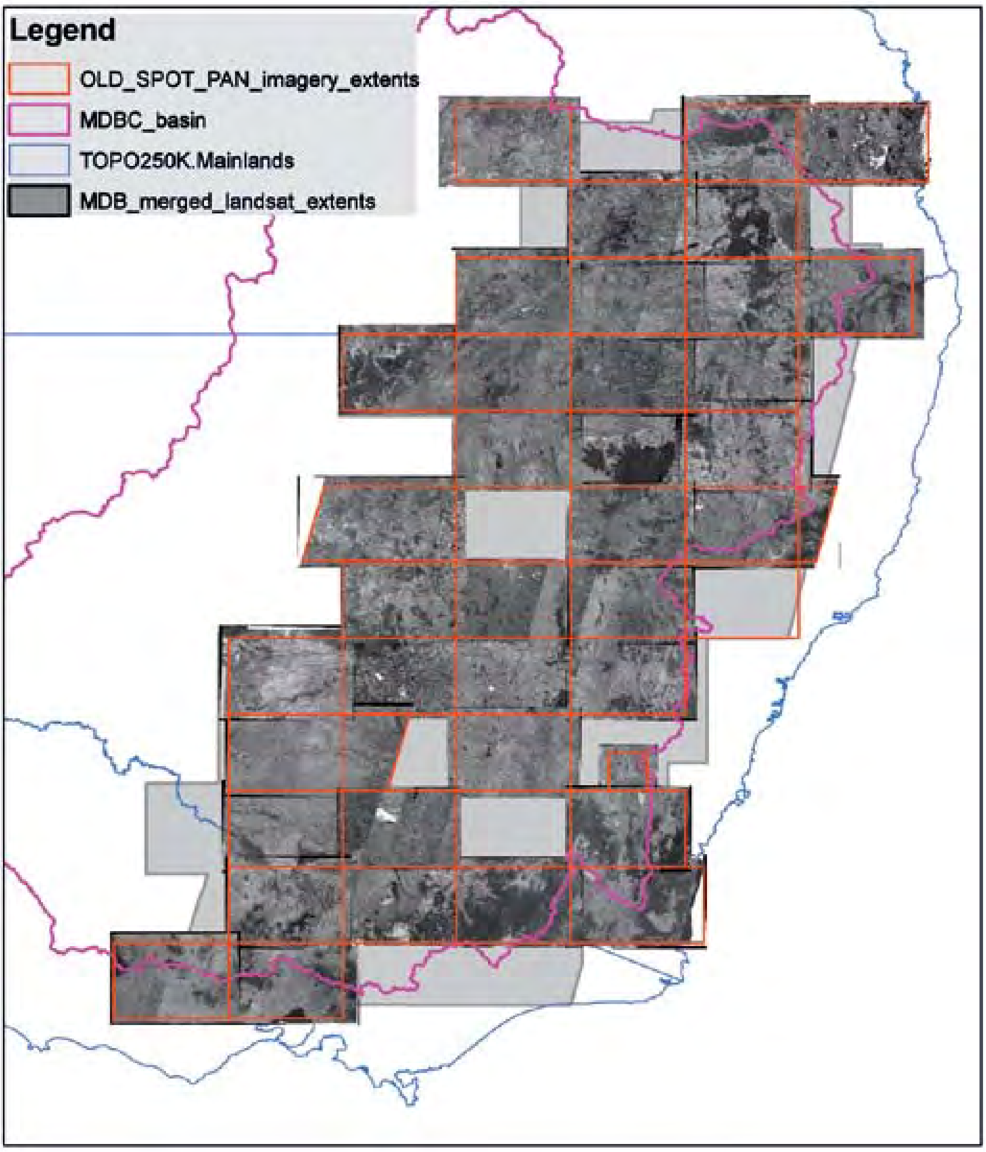


Table B3: List of Geoscience Australia legacy SPOT PAN imagery used for the validation and test of change analysis outputs (pre and post-94 dams). Note that where imagery dates exceed 1997 the SPOT PAN imagery is used for reference only and error assessments are made from LANDSAT imagery. The SPOT PAN imagery enhances the reliability of the outputs as SPOT coverage covers 85% of the data extents compared to <1% if using the MDBC supplied aerial photography.

SPOT Scene used	Acquisition Date (year)	SPOT Scene used	Acquisition Date (year)
d5207_pan_	1994, 1995	i5505_pan	1998
G5511_pan	1997	i5506_pan	1995
G5516_pan	1999, 2000	i5507_pan	1997, 1998
G5609_pan	1998, 1999	i5508_pan	1996
G5610_pan	1994 1995	i5509_pan	1997
G5613_pan	1999, 2000	i5511_pan	1993, 1994
H5503_pan	1998	i5513_pan	1997
H5504_pan	1994, 1995, 1997	i5514_pan	1993, 1994
H5506_pan	1997	i5516_pan	1995
H5507_pan	1994, 1995, 1996	j5501_pan	1999, 2000
H5508_pan	1996	j5502_pan	1993, 1995
H5511_pan	1997	j5503_pan	1998, 1999
H5514_pan	1997	j5504_pan	1993, 1994, 1996
H5516_pan	1996	j5505_pan	1998
H5601_pan	1999, 2000	Balranald_mosaic_pan	1999, 2000
H5609_pan	1999, 2000	inverell_tamworth_mosaic_pan	1999, 2000
H5613_pan	1997, 1998	spot_z55_pan_mosaic_pan	1999, 2000
i5502_pan	1998	spot_z56_pan_mosaic_pan	1999, 2000
i5503_pan	1994, 1995	warwick_pan	1999, 2000
i5504_pan	1997, 1998		

Change Analysis Error Assessment

Table B4: Summary error checking statistics for pre- and post-94 dams.

	Pre 1994 point and polygons[1] (Count)	Post 1994 point and polygons[2] (Count)	Pre 1994 point and poly errors[3] (Count)	Post 1994 point and poly errors[4] (Count)	Pre 1994 Dams Accuracy[5] (%)	Post-1994 Dams Accuracy[6] (%)
Scene 1	433	1	96	1	78	99
Scene 2	269	2	20	2	93	91
Scene 3	201	0	0	0	100	NA[7]
Scene 4	750	6	100	3	87	97
Scene 5	1957	17	208	0	89	100
Scene 6	1575	2	124	1	92	99
Scene 7	657	31	32	0	95	100
Scene 8	628	5	33	0	95	100
Scene 9	541	2	20	2	96	91
Scene 10	848	0	45	0	95	100
Scene 11	1079	168	41	7	96	97
Scene 12	2622	90	70	2	97	99
Scene 13	1551	73	49	7	97	94
Scene 14	612	2	26	0	96	100
Scene 15	1186	13	112	3	91	98
Scene 16	1396	126	72	38	95	81
Scene 17	2666	0	156	0	94	100
Scene 18	884	282	2	25	100	91
Scene 19	669	384	2	162	100	58
Scene 20	243	81	1	10	100	88
Scene 21	126	40	2	5	98	88
Scene 22	1602	19	121	0	92	100
Scene 23	445	263	5	66	99	75
Scene 24	322	156	2	15	99	91
Scene 25	363	4	15	0	96	100
Scene 26	386	114	13	1	97	99
Total	**24011**	**1881**	**1367**	**350**	**95**	**93**

Notes:

1 Pre 1994 point and polygons represent the counts of pre-1994 dams attributed from the change analysis process using LANDSAT imagery.

2 Post 1994 point and polygons represent the counts of post-1994 dams attributed from the change analysis process using LANDSAT imagery.

3 Pre 1994 point and poly errors represent the counts of pre-1994 dam errors determined from LANDSAT and SPOT PAN imagery. These values represent the number of Post-1994 dams that have been incorrectly attributed as a result of biasing factors in the change analysis process. Modified dams, canals, drains, black soil plains and other high moisture soils will bias the attribution of dams toward pre-1994.

4 Post 1994 point and poly errors represent the counts of post-1994 dam errors determined from LANDSAT and SPOT PAN imagery. These values represent the number of Pre-1994 dams that have been incorrectly attributed.

5 Pre 1994 Dams Accuracy. Accuracy assessment is determined by the expression: *100%-error assessment. Formula is: 100-((error population)/(sample population))* or in detail can be written as: *100-((pre94point error +pre94poly error)/(pre94point sample pop. + pre94poly sample pop. + post94 error)).*

6 Post-1994 Dams Accuracy. Accuracy assessment is determined by the expression: *100%-error assessment. Formula is: 100-((error population)/(sample population))* or in detail can be written as: *100-((post94point error + post94poly error)/(post94point sample pop. + post94poly sample pop. + pre94 error)).*

7 Low confidence a result of low sample population. Refer to sample population size.

Change Analysis Results:. Polygon and Point Error Distribution

Figure B6: Data assessment of the final pre- and post-1994 dam change analysis results (polygons only) detailing the number of incorrectly attributed polygons (either pre- or post-1994).

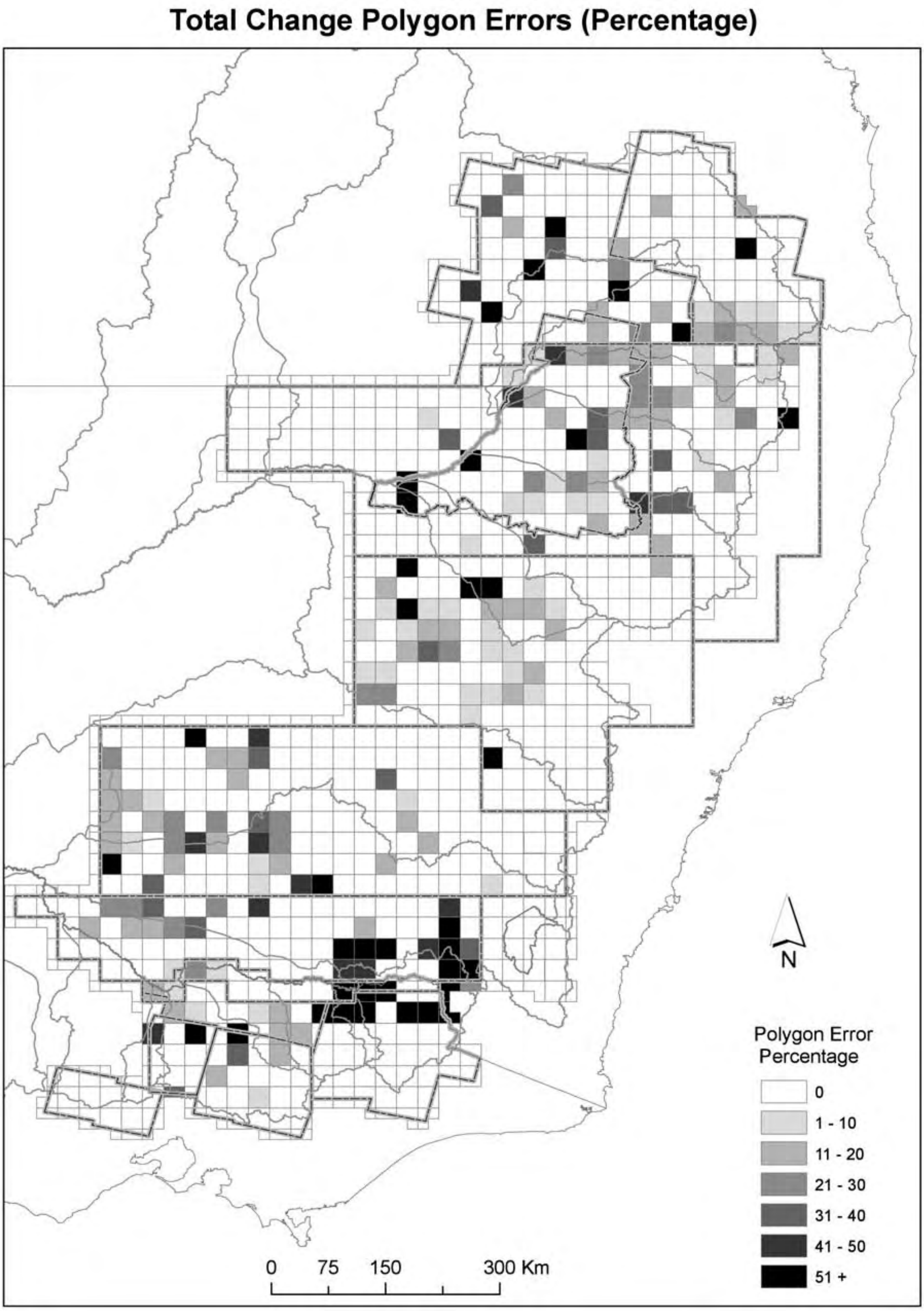


Figure B7: Data assessment of the final pre- and post-1994 dam change analysis results (points only) detailing the number of incorrectly attributed points (either pre- or post-1994).

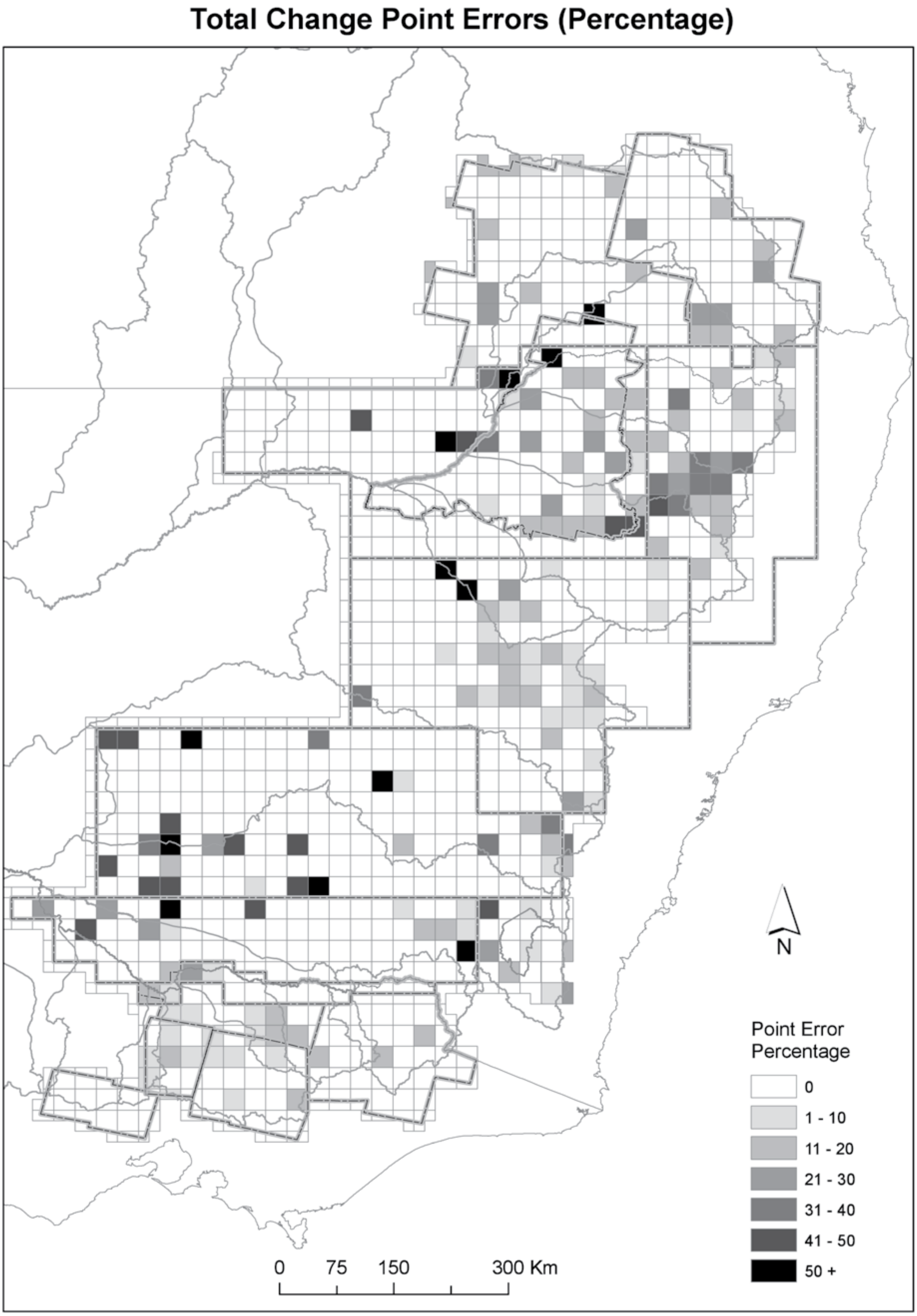


Figure B8: Data assessment of the final pre- and post-1994 dam change analysis results (polygons only) detailing the number of incorrectly attributed polygons (either pre- or post-1994).

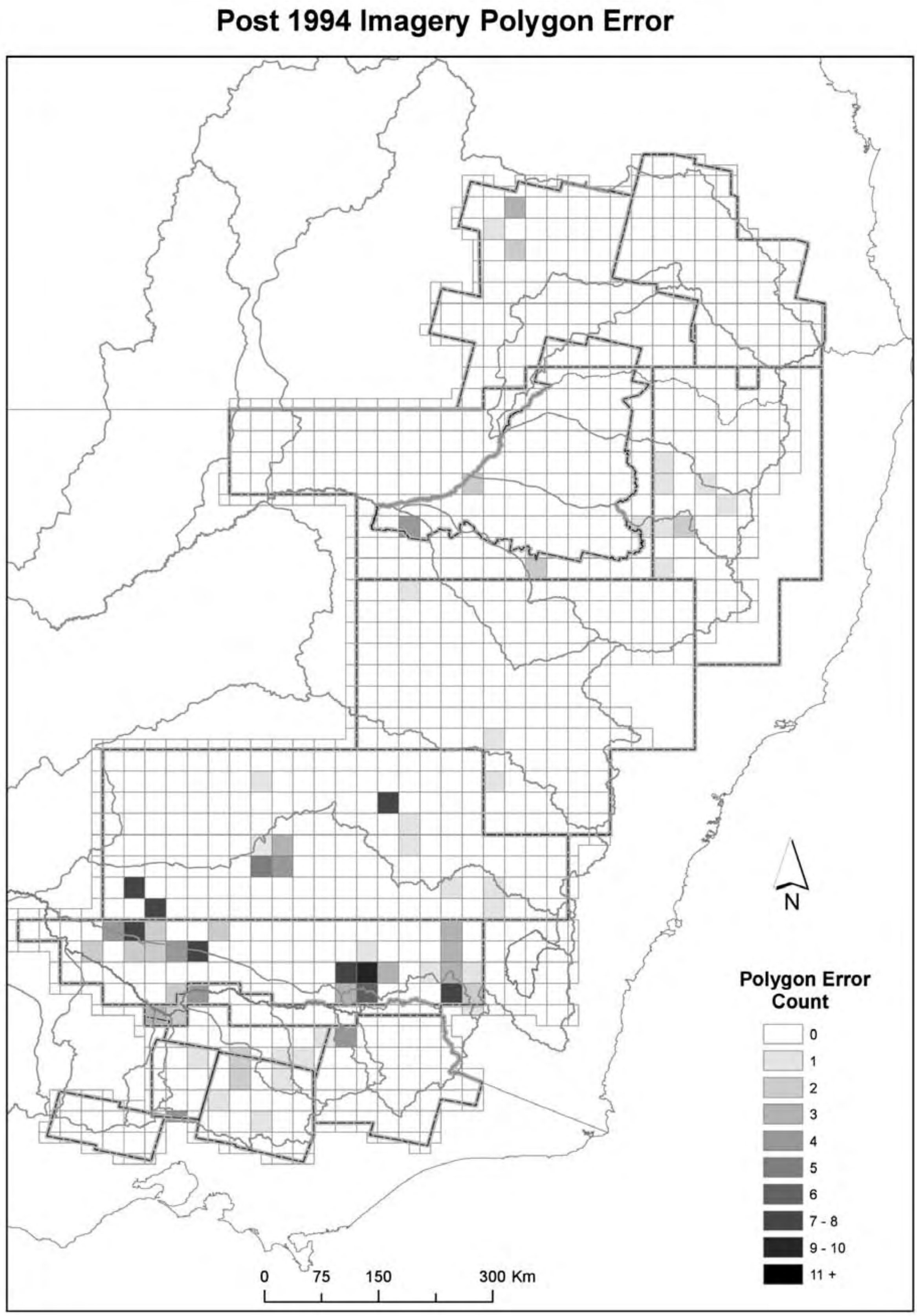
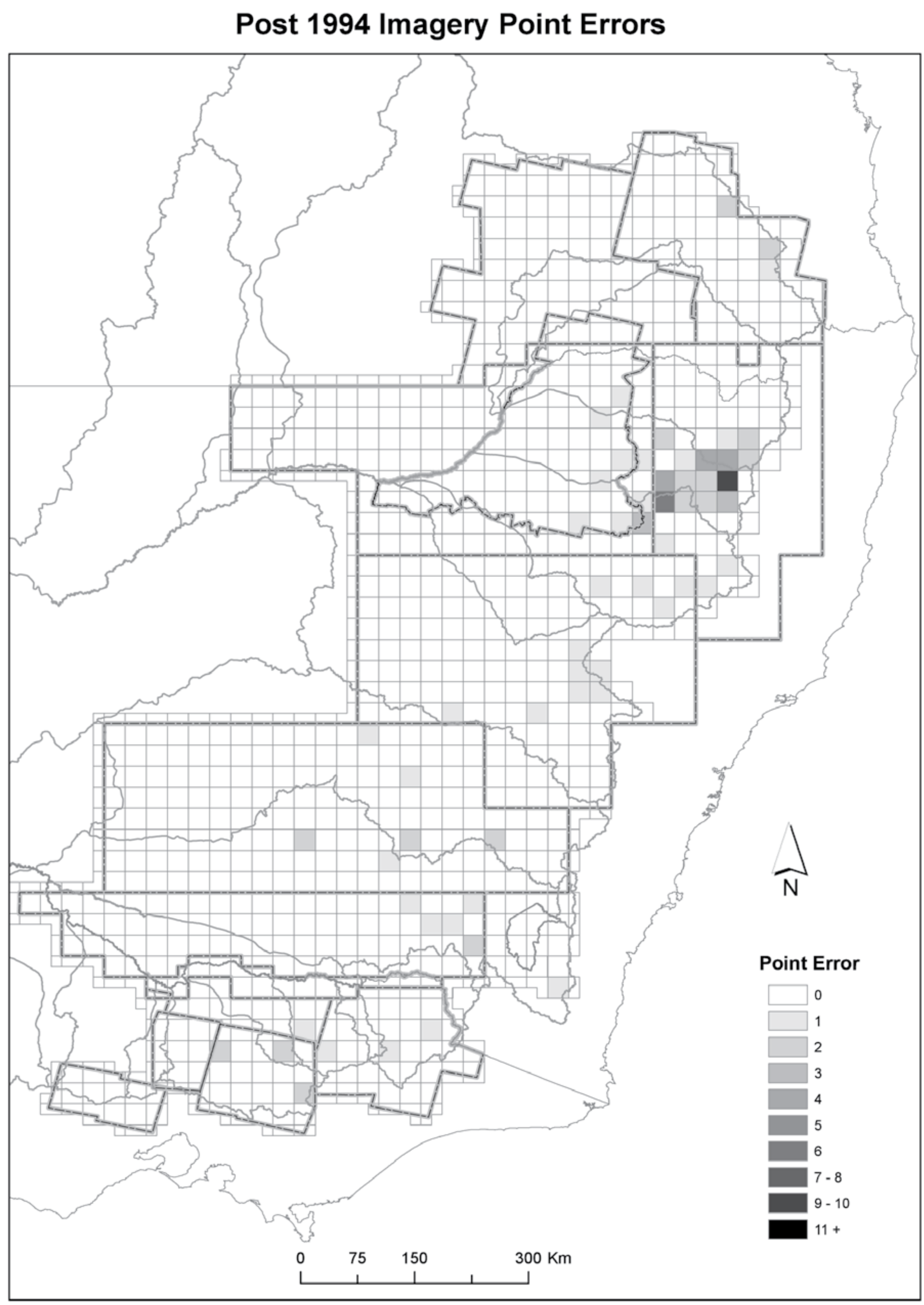


Figure B9: Data assessment of the final pre- and post-1994 dam change analysis results (points only) detailing the number of incorrectly attributed polygons (either pre- or post-1994).



APPENDIX C: DAM SIZE CLASS ANALYSIS

MURRAY–DARLING BASIN COMMISSION / GEOSCIENCE AUSTRALIA
(AGREEMENT No. MD949)

MAPPING THE GROWTH, LOCATION, SURFACE AREA AND AGE OF FARM DAMS
IN THE MURRAY-DARLING BASIN

Geoscience Australia
March 2008

Dam Size Analysis Process

Figure C1: Diagrammatic representation of the dam size analysis process from data input through to generation of area statistics

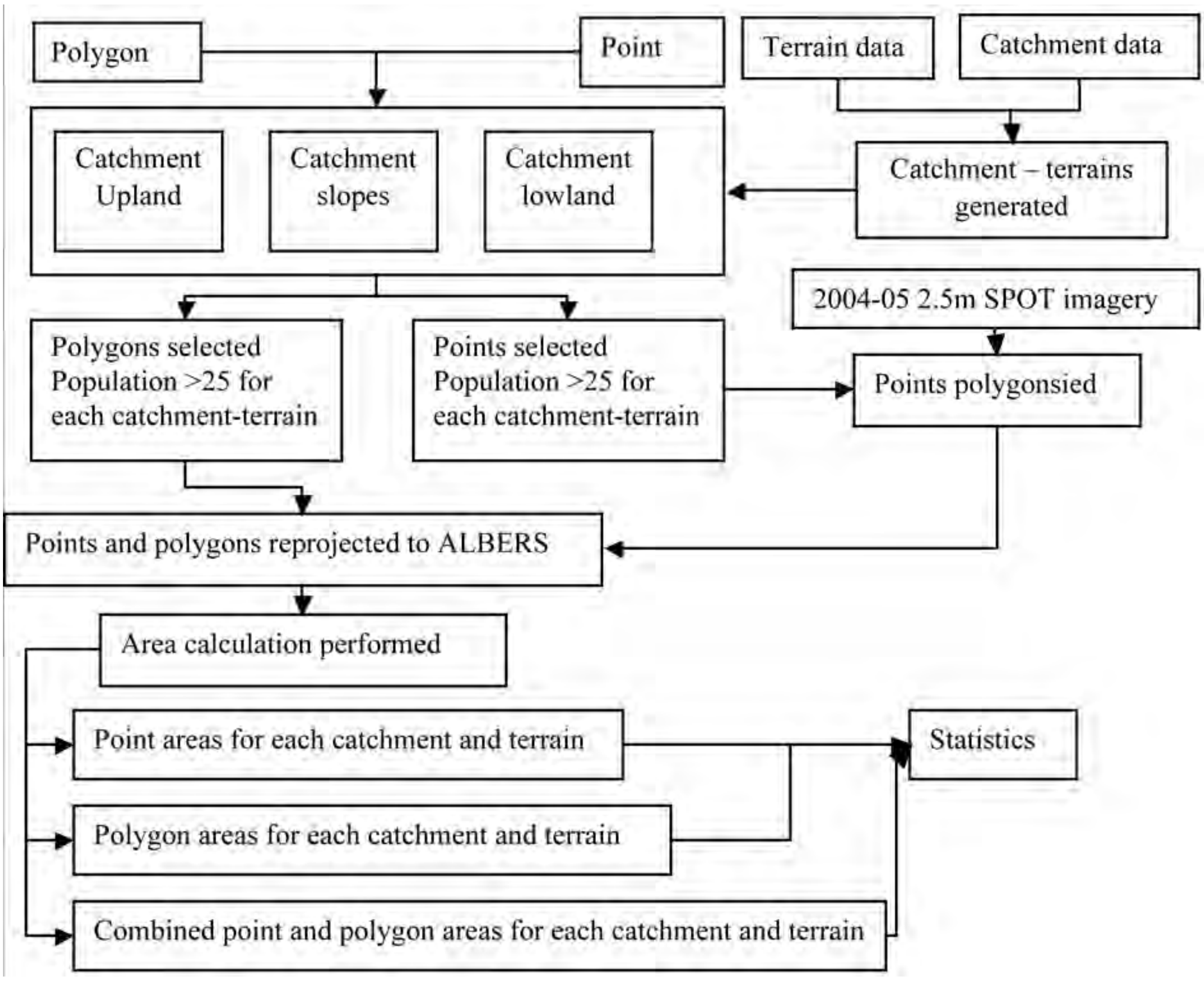


Figure C2: Graph showing the global average of randomly selected dam sizes for each terrain in each catchment.

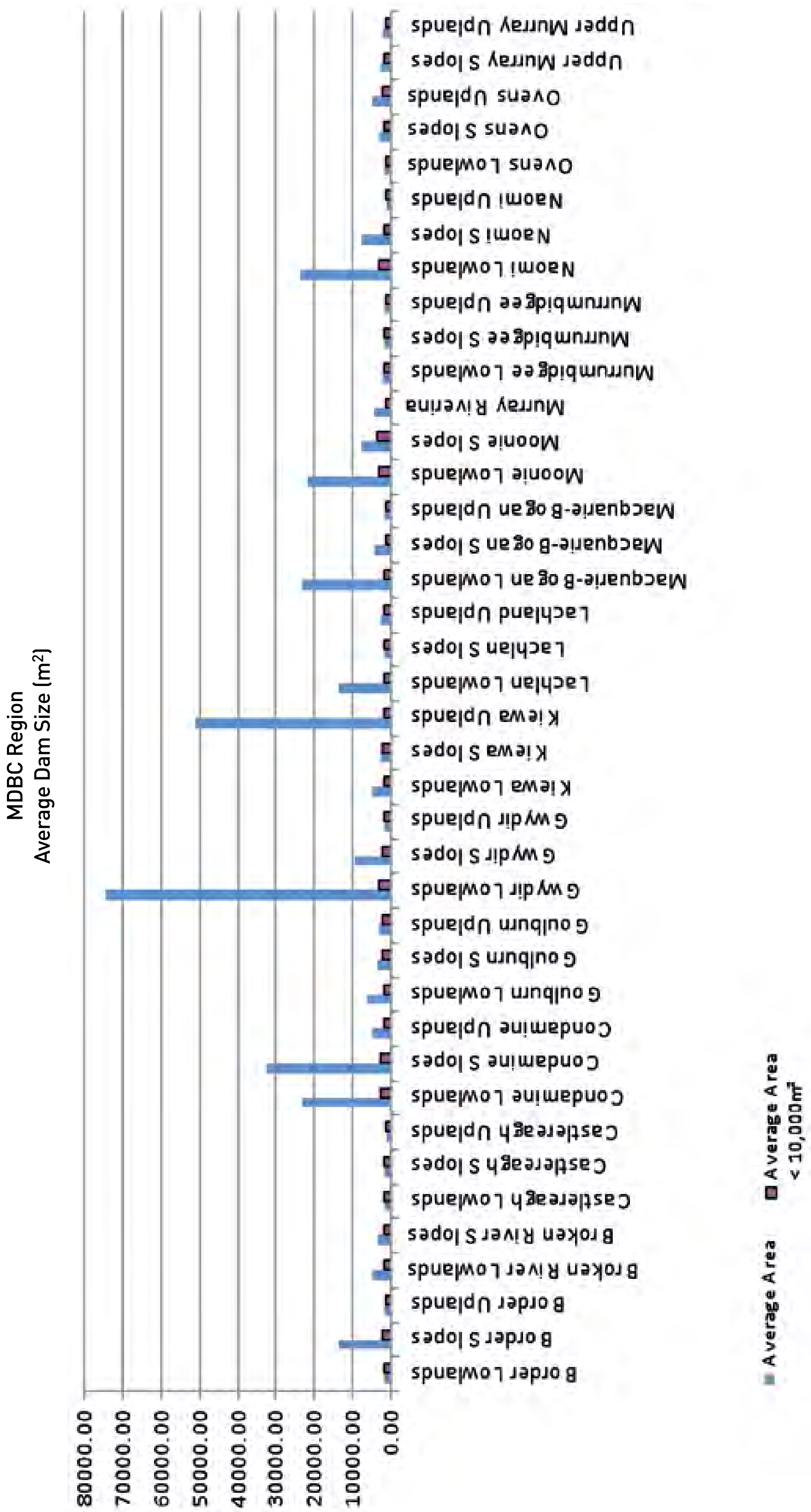


Figure C3: Graph showing the average of randomly selected dam sizes for each terrain in each catchment that are less than 10,000 m². More detail is provided in Figures C4–C6.

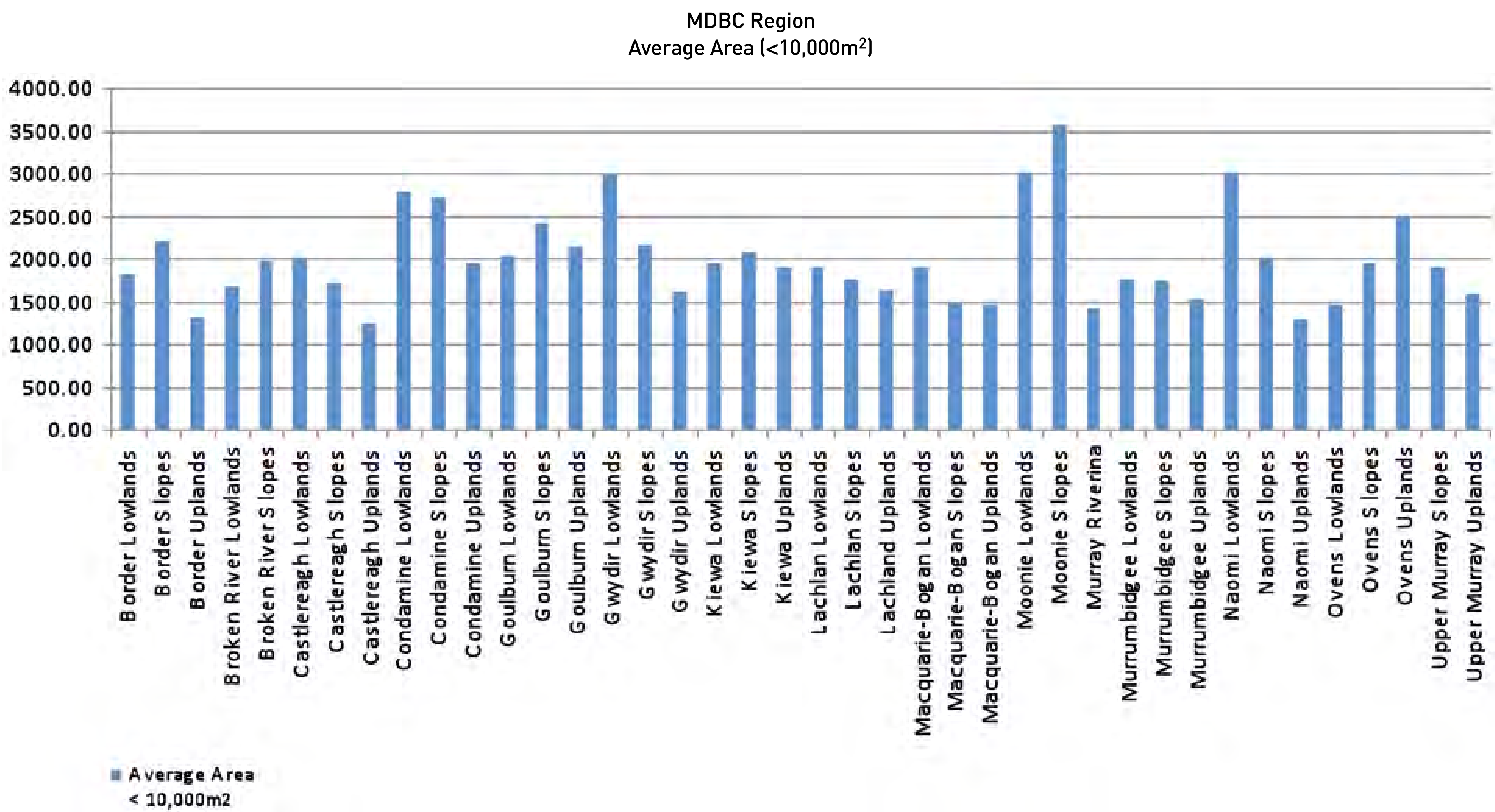


Figure C4:

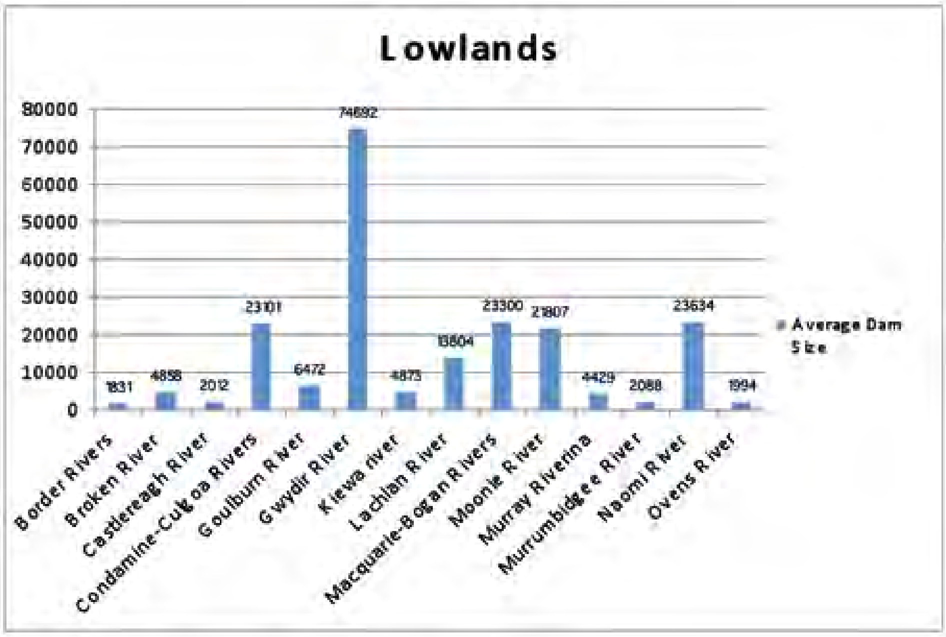


Figure C5:

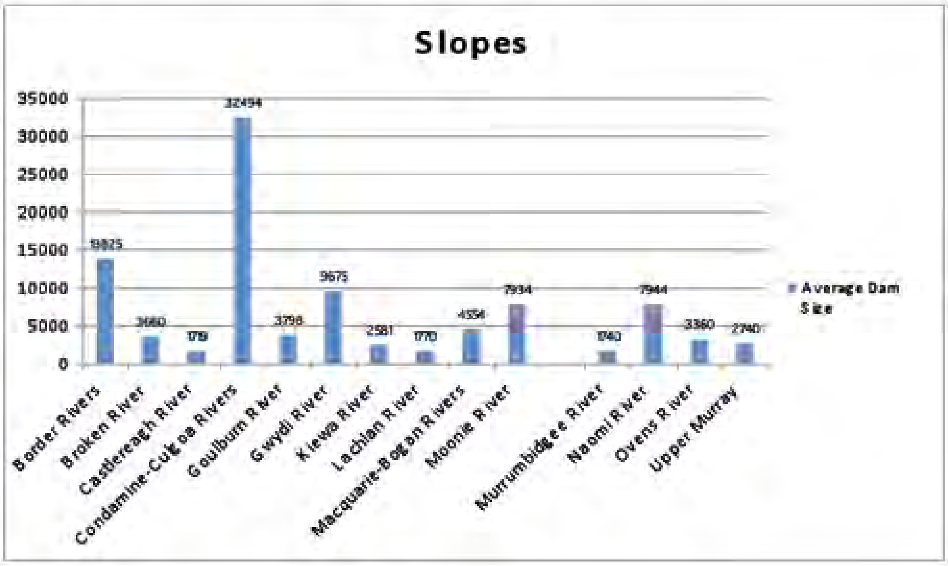
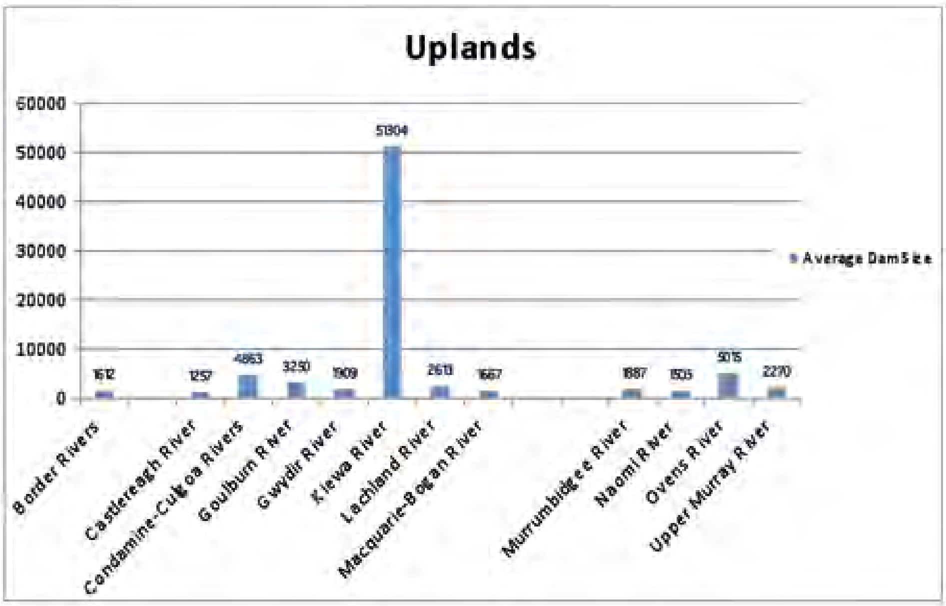
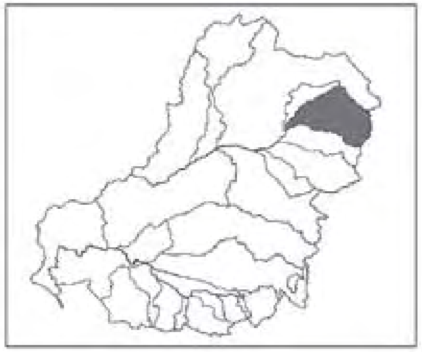


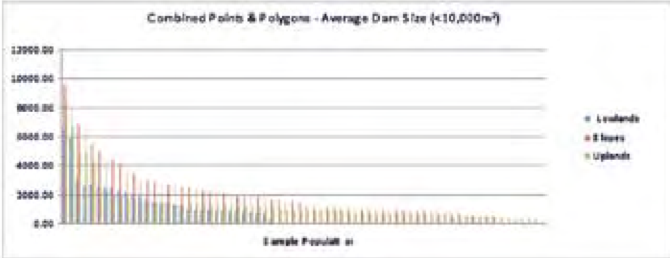
Figure C6:

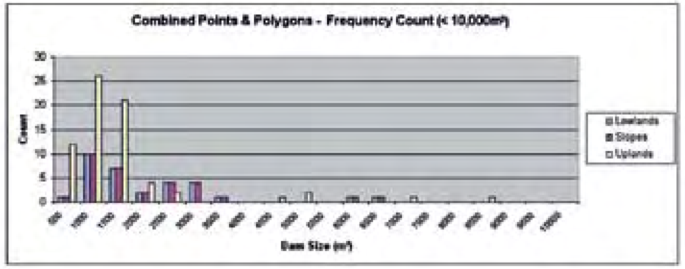


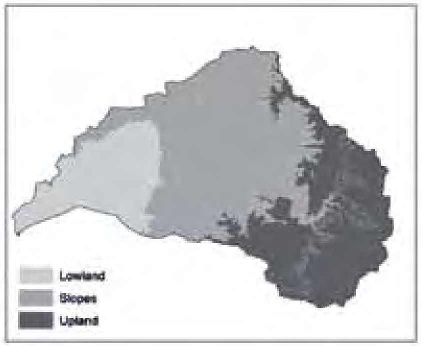
BORDER RIVERS

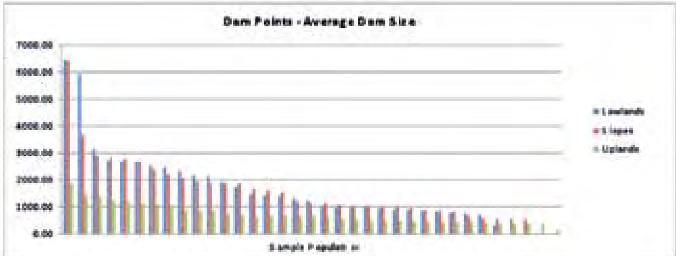
Figures C7–C15: Border Rivers Results

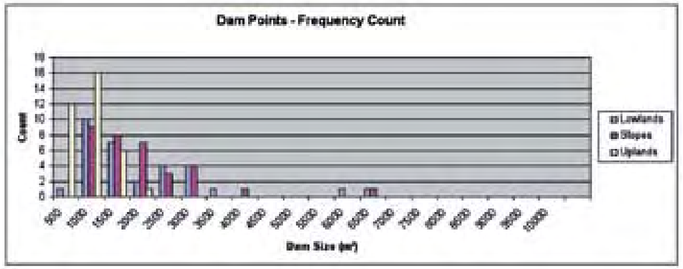


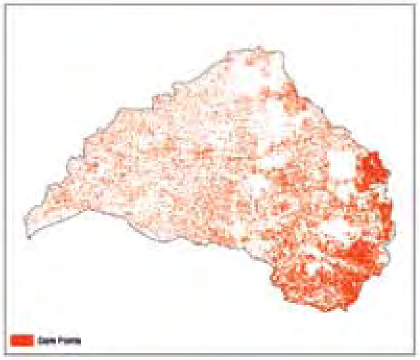


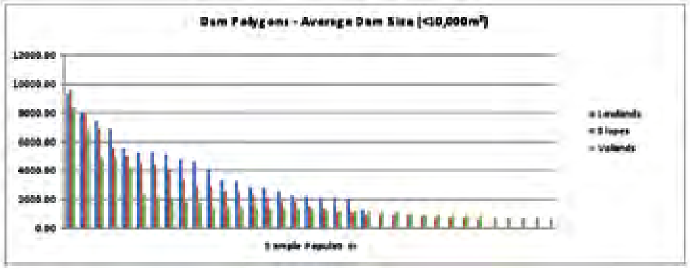


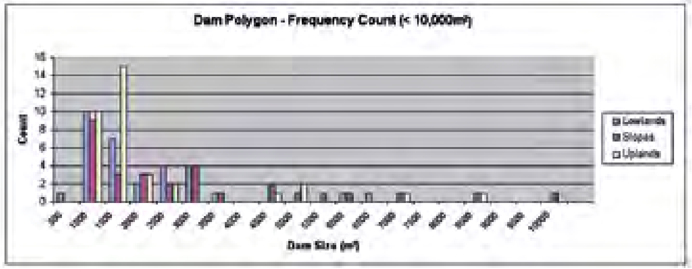






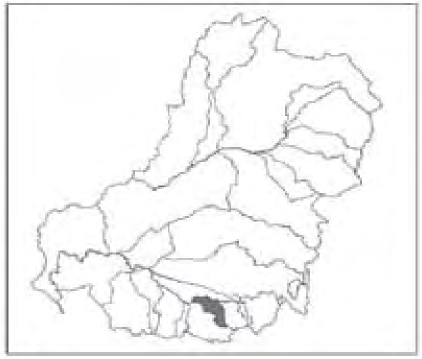


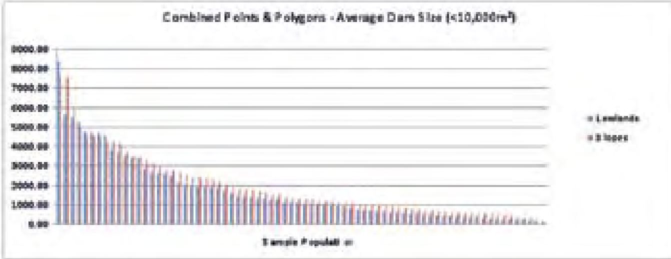


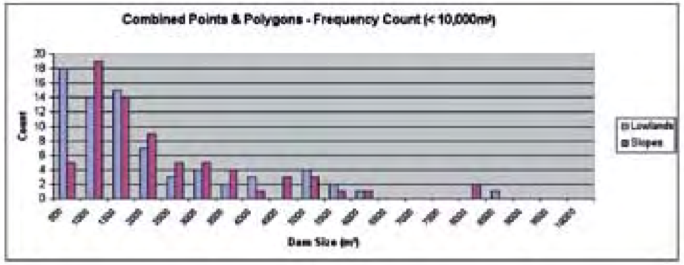


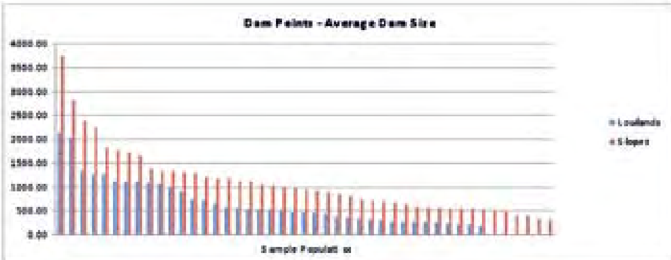
BROKEN RIVER

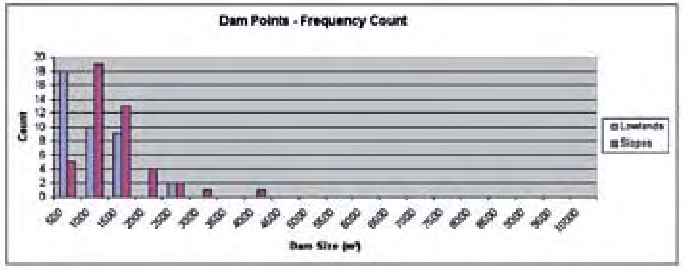
Figures C16–C24: Broken River Results

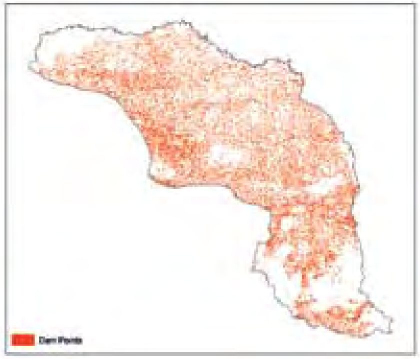


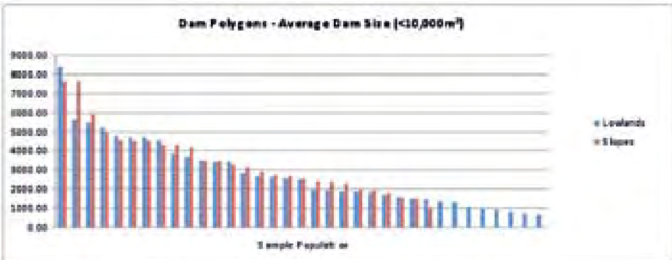


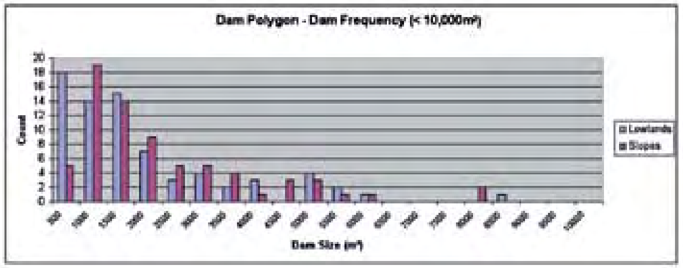






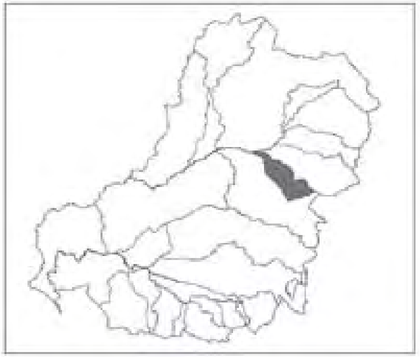


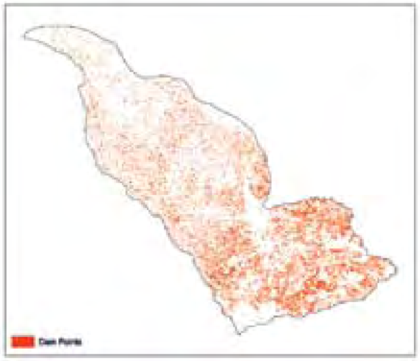


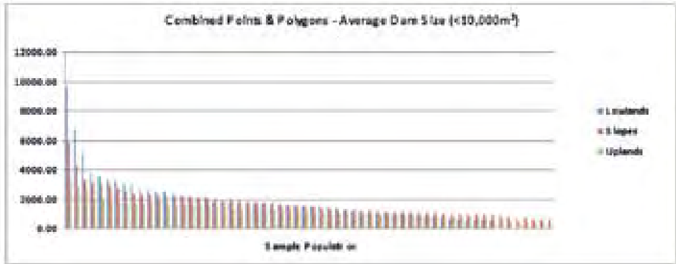


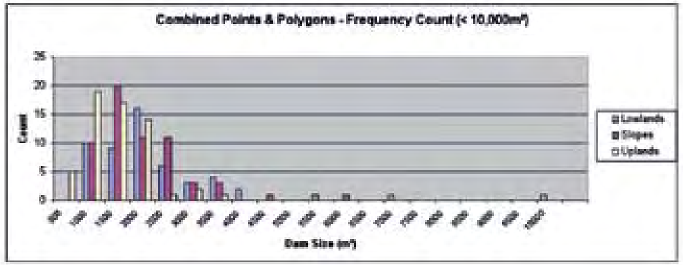
CASTLEREAGH RIVER

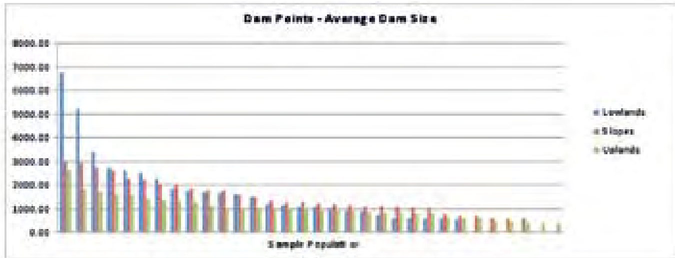
Figures C25–C33: Castlereagh River Results

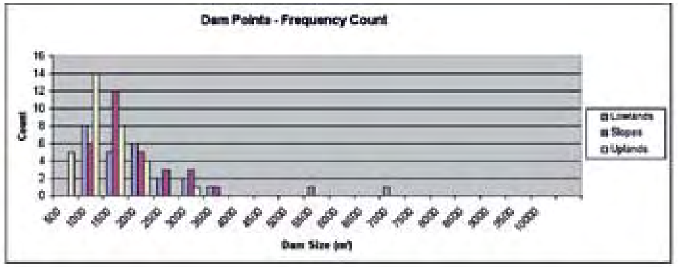


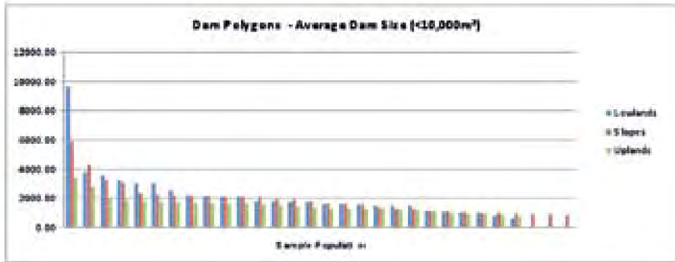


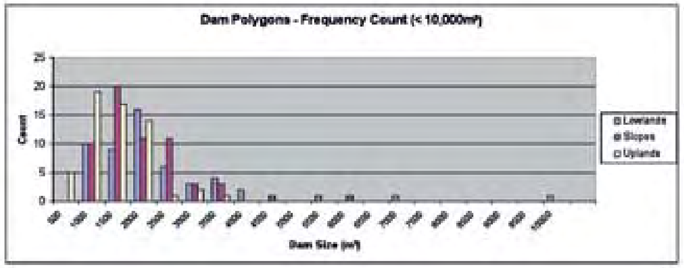






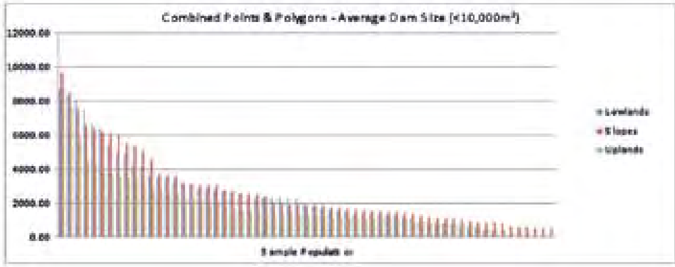


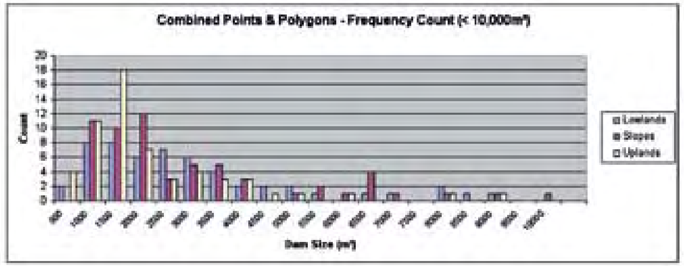


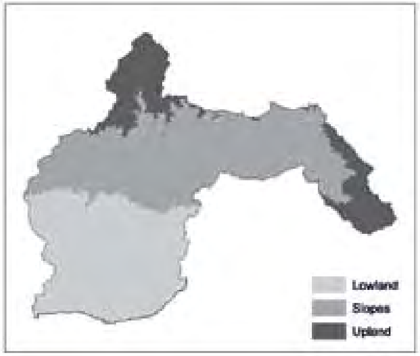


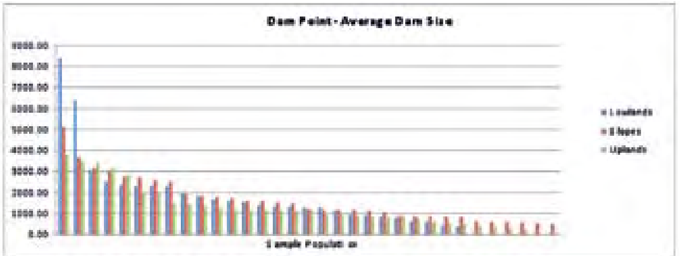
CONDAMINE-CULGOA RIVERS

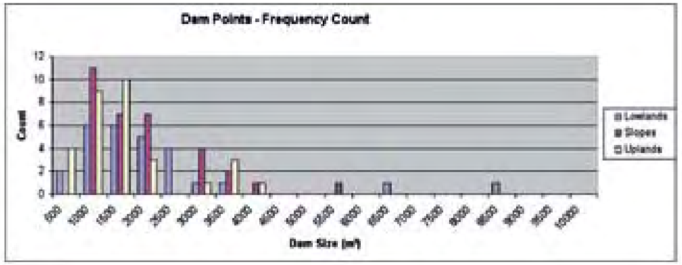
Figures C34–C42: Condamine–Culgoa Rivers Results

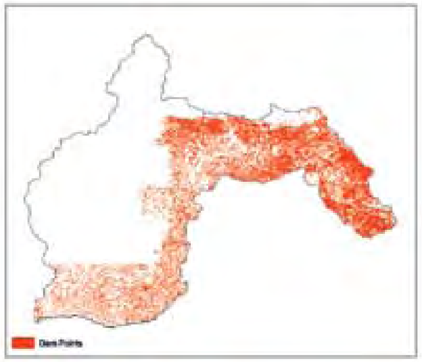


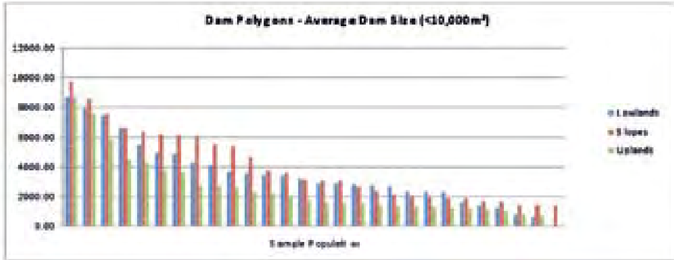


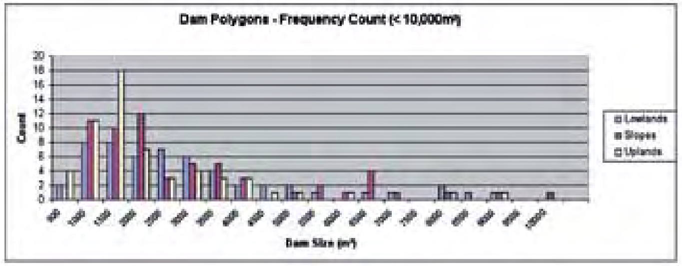






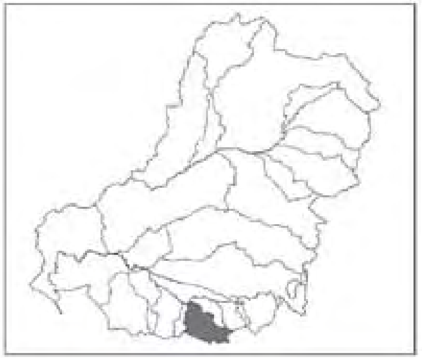


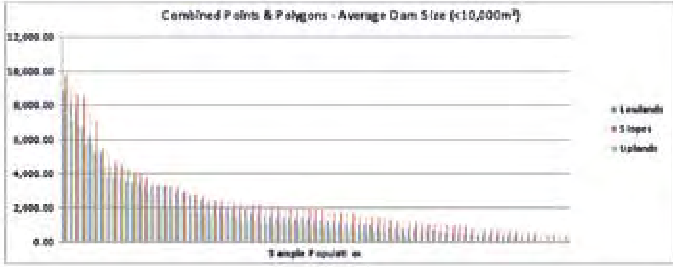


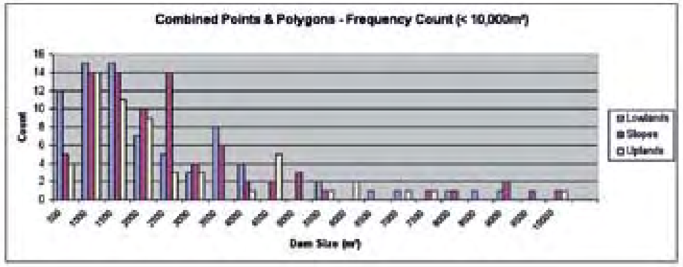


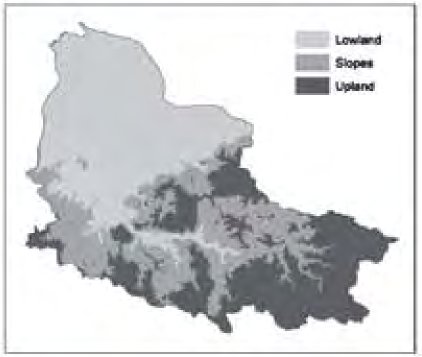
GOULBURN RIVER

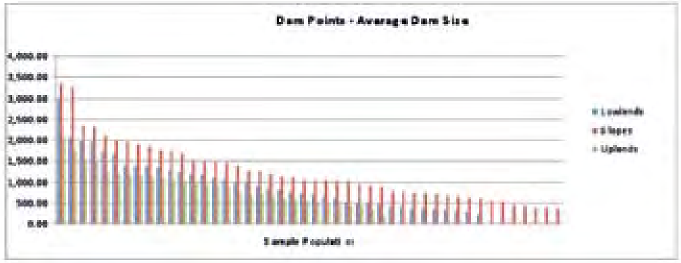
Figures C43–C51: Goulburn River Results

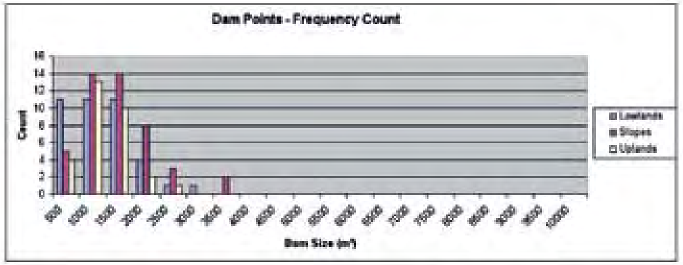


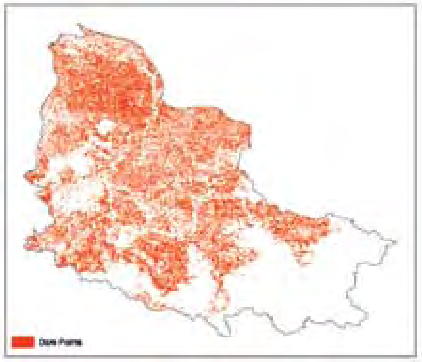


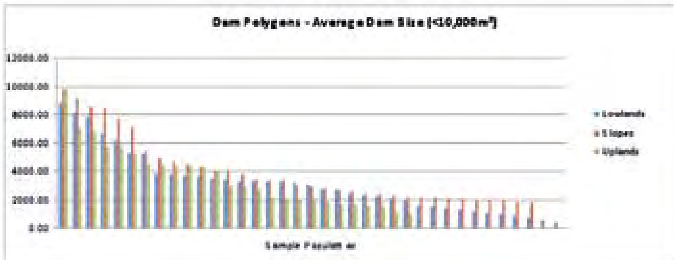


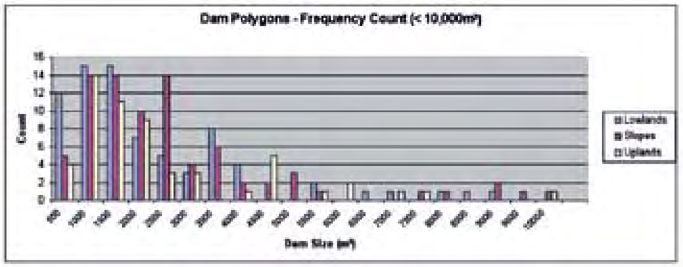






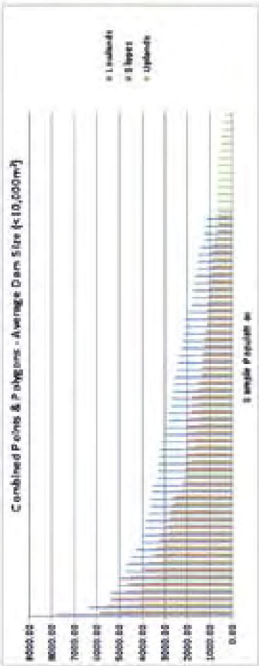


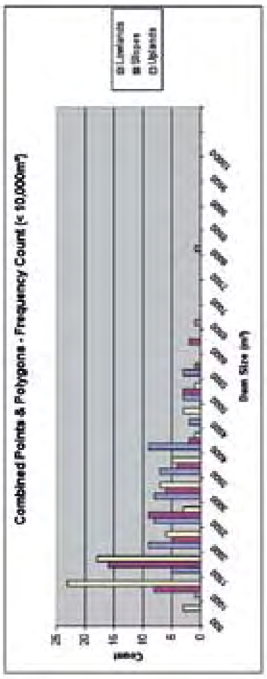


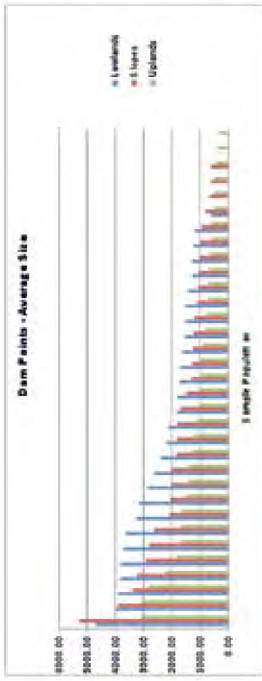


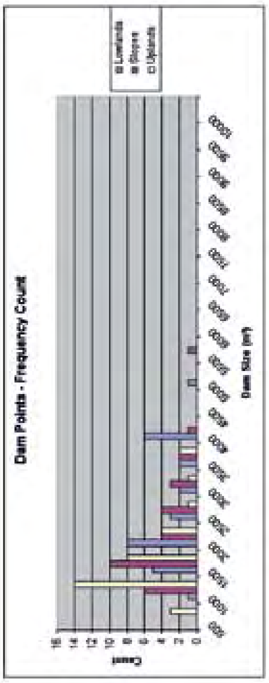
GWYDIR RIVER

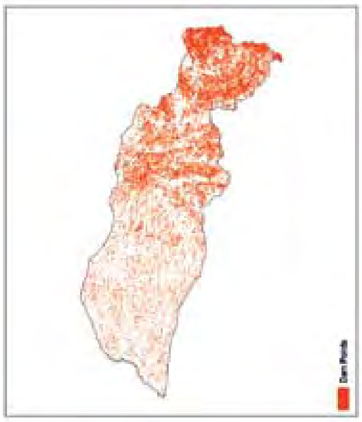
Figures C52–C60: Gwydir River Results

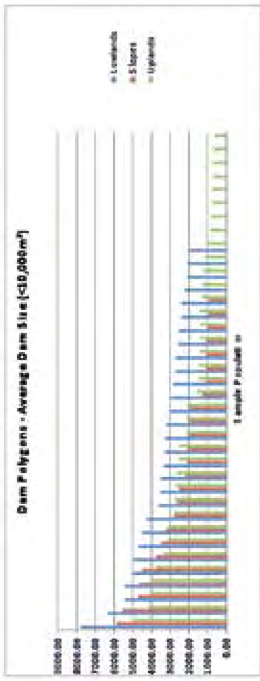


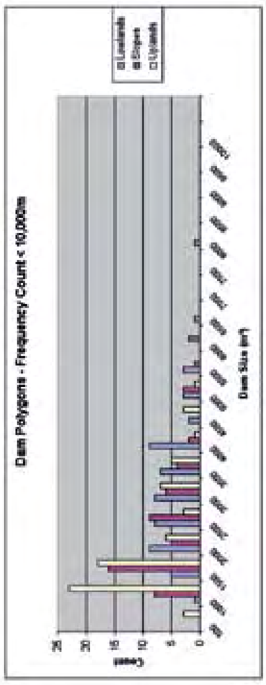






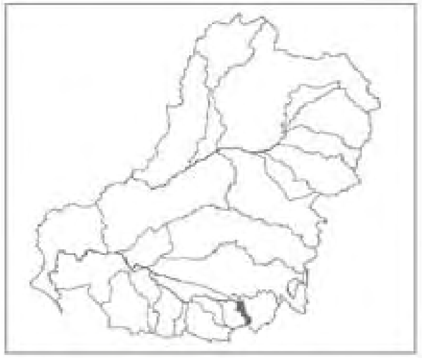


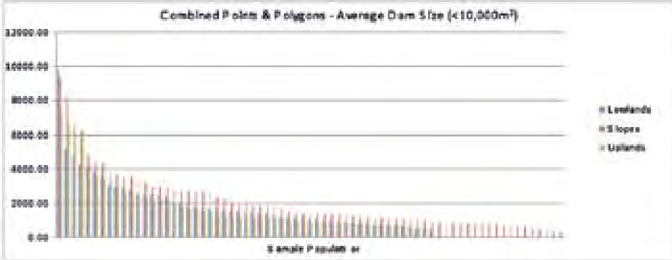


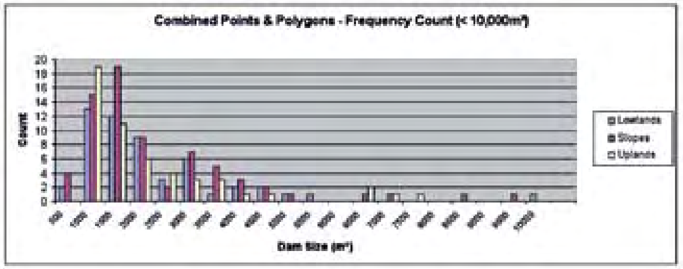


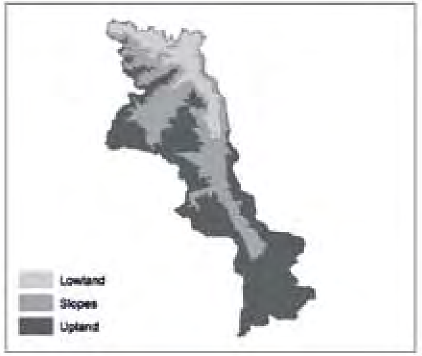
KIEWA RIVER

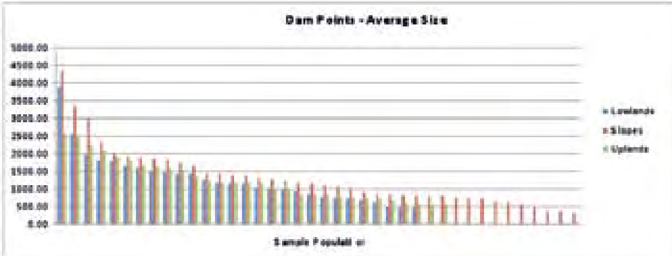
Figures C61–C69: Kiewa River Results

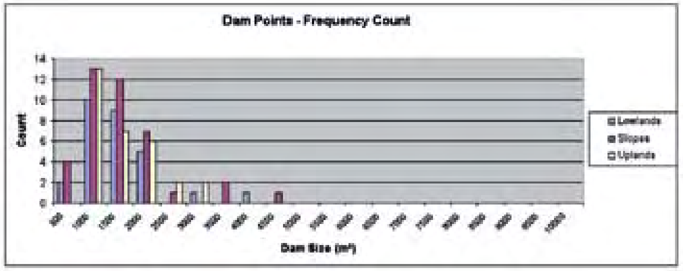


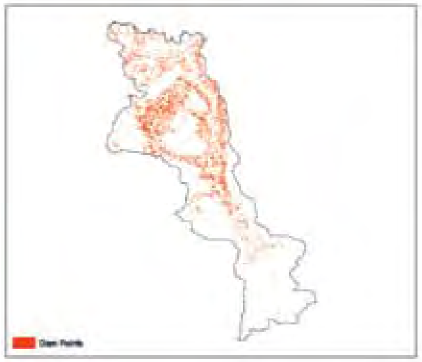


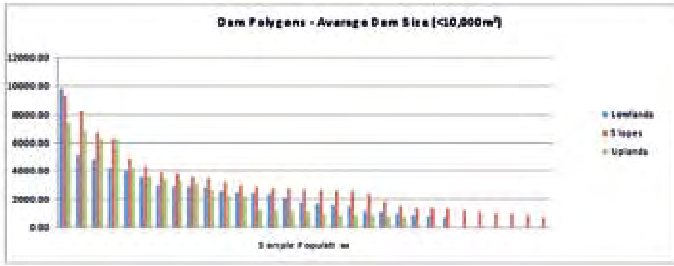


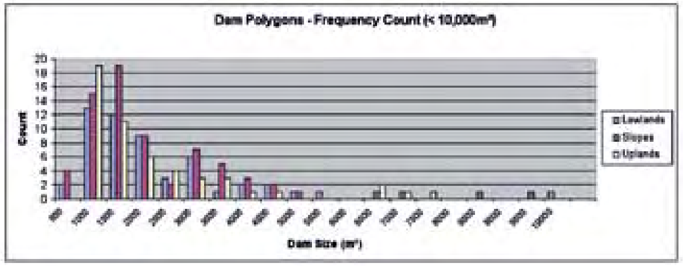






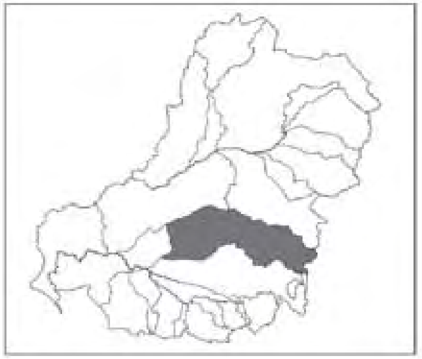


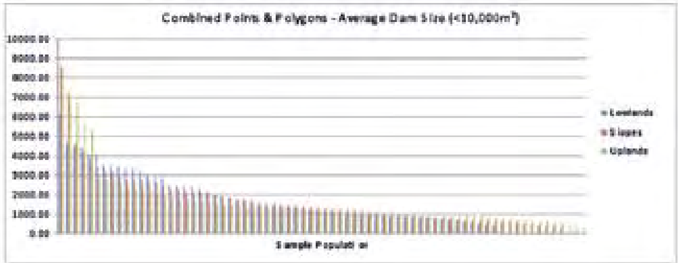


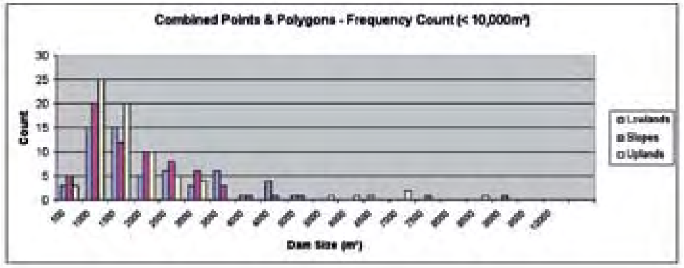


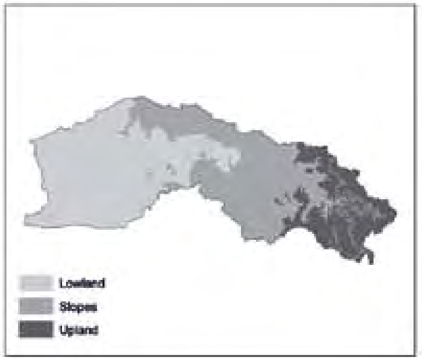
Figures C70–C78: Lachlan River Results

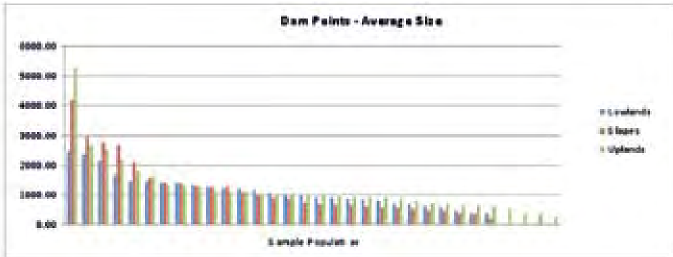
LACHLAN RIVER

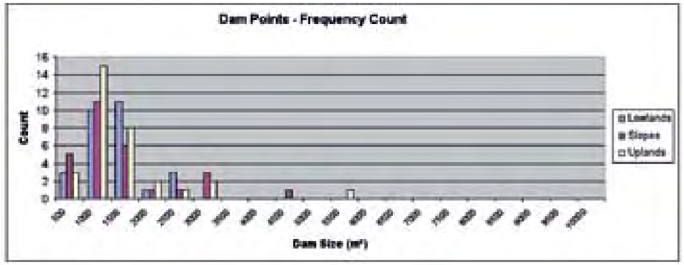


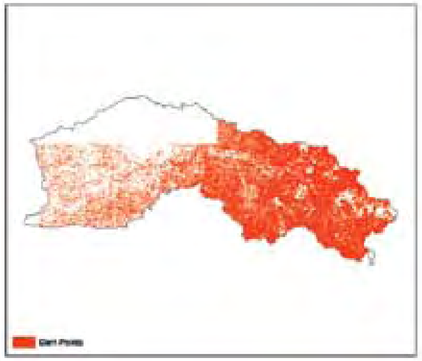


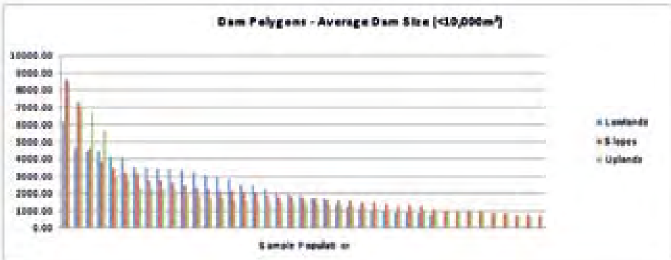


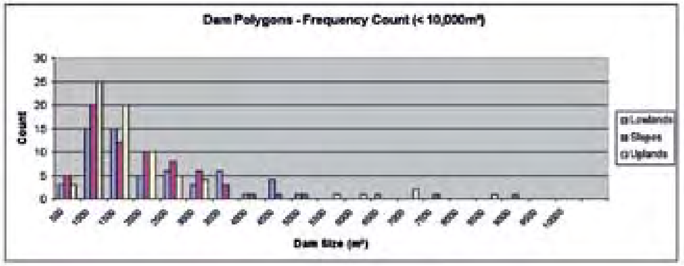






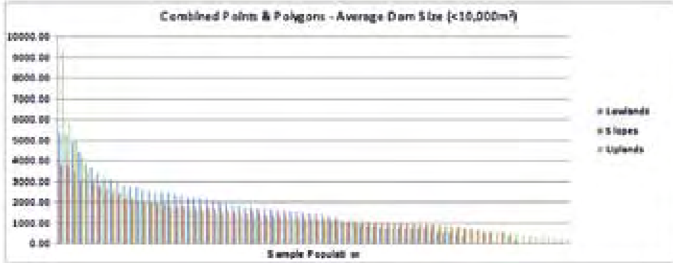


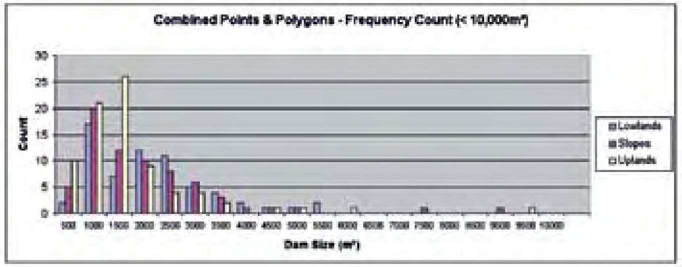


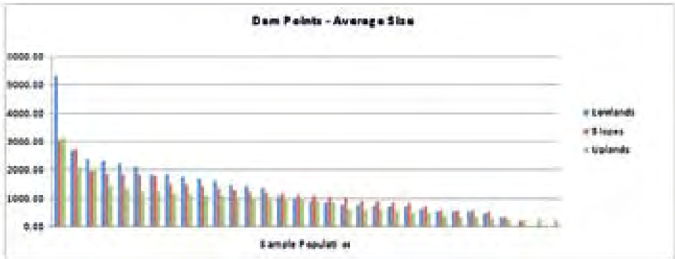


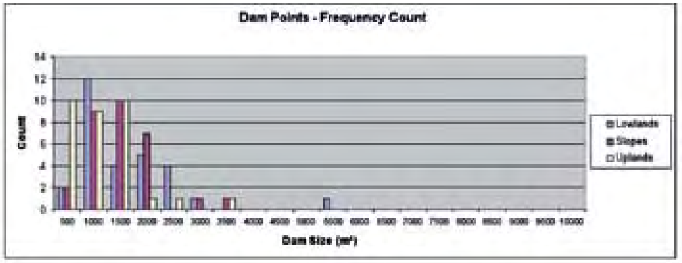
MACQUARIE-BOGAN RIVER

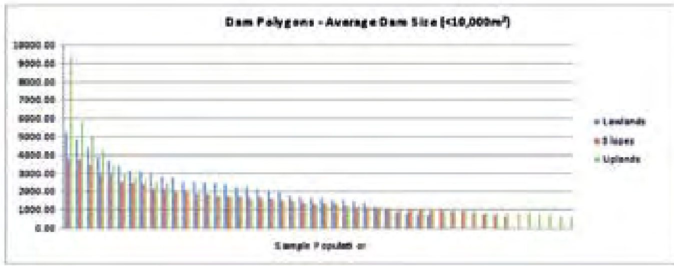
Figures C79–C87: Macquarie-Bogan Rivers Results

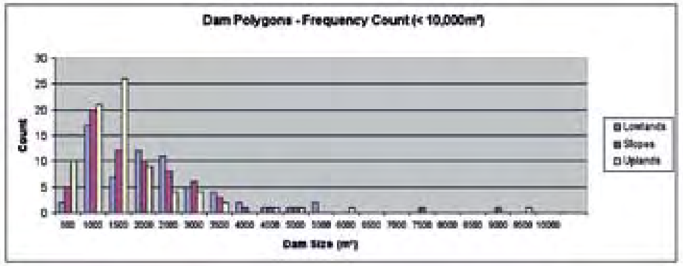






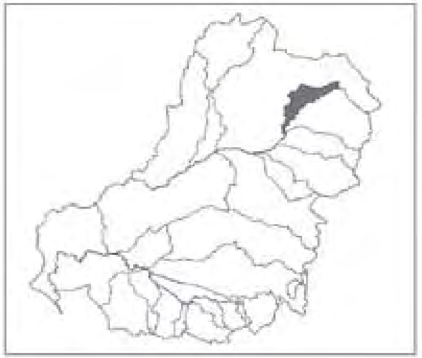


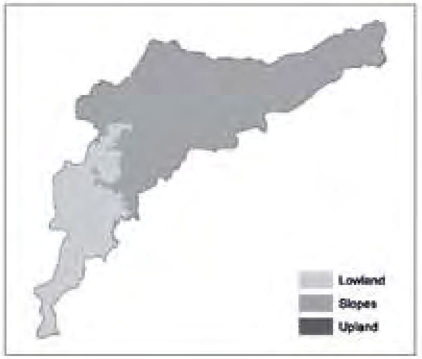


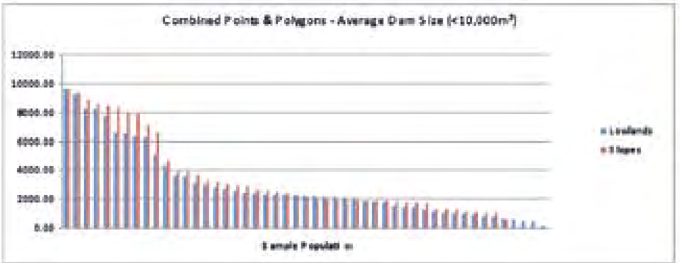


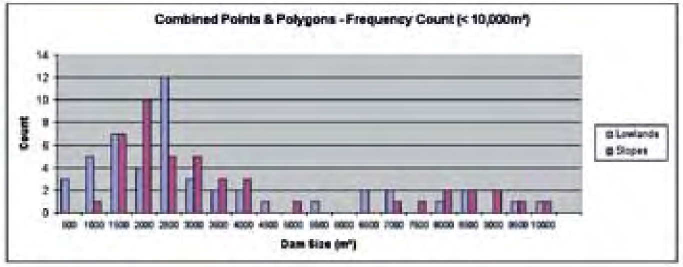
MOONIE RIVER

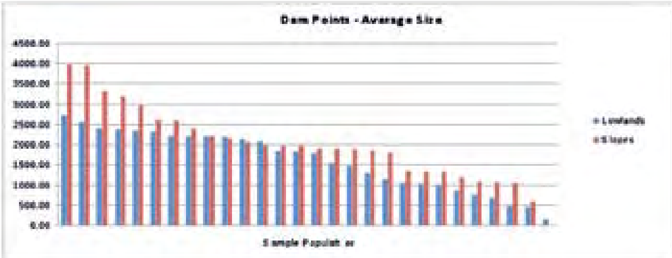
Figures C88–C96: Moonie River Results

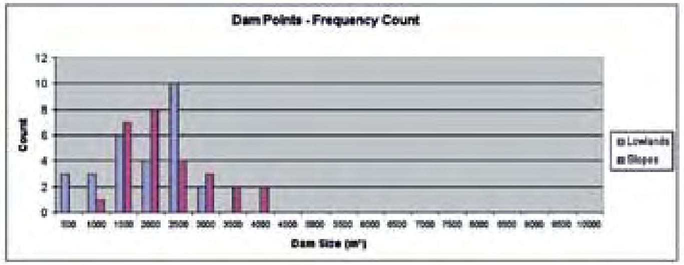


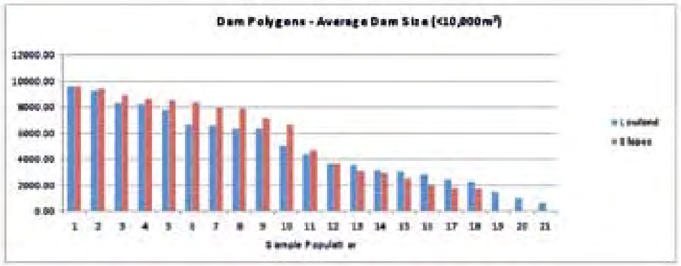


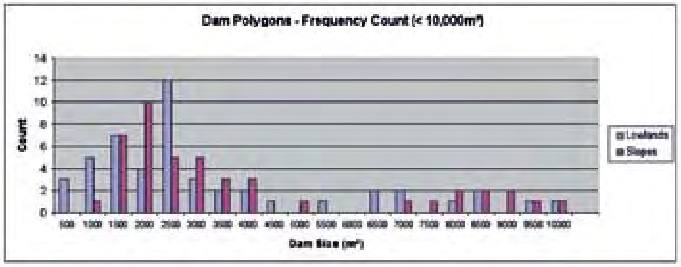






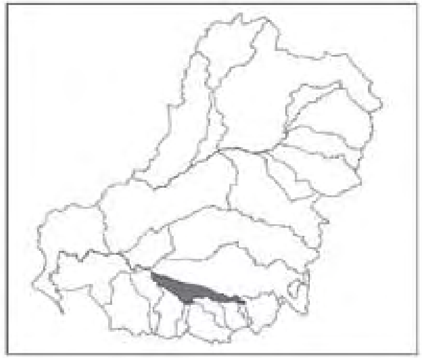


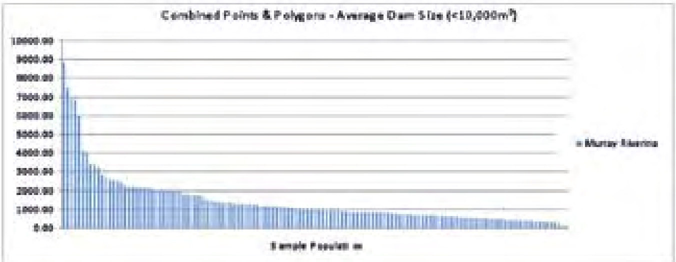


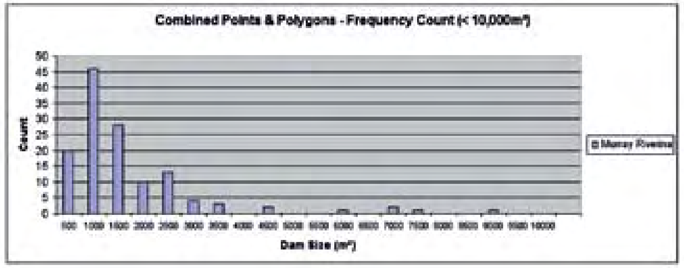


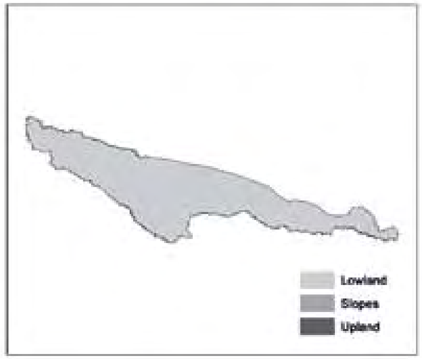
Figures C97–C105: Murray-Riverina Results

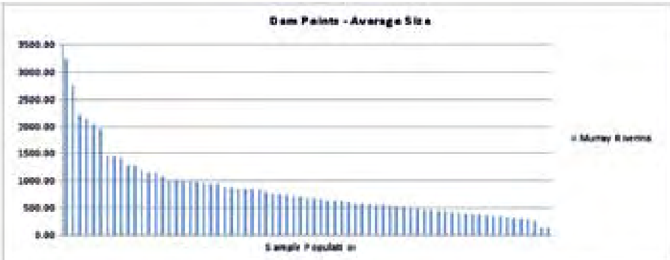
MURRAY–RIVERINA

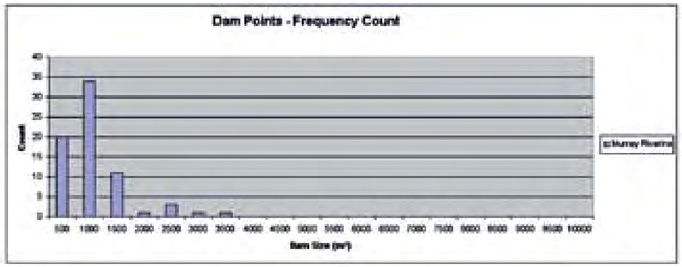


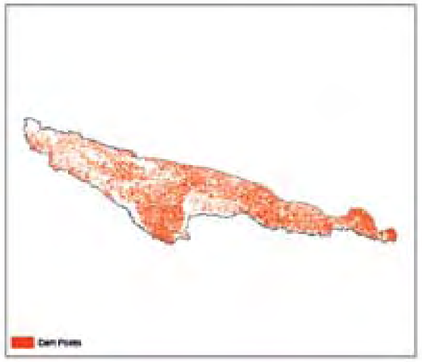


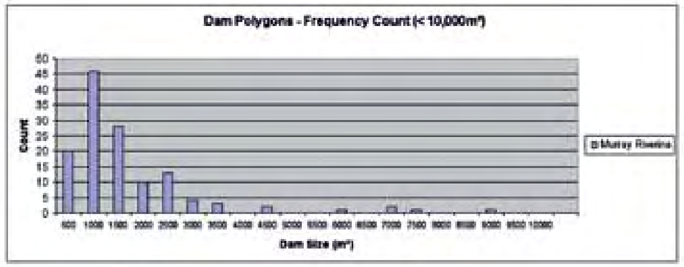






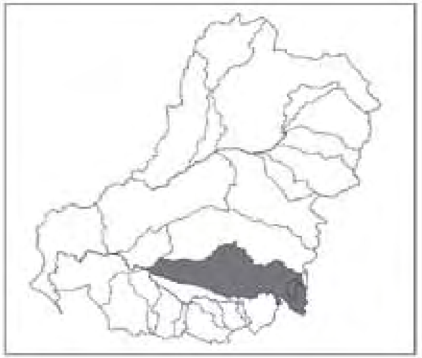


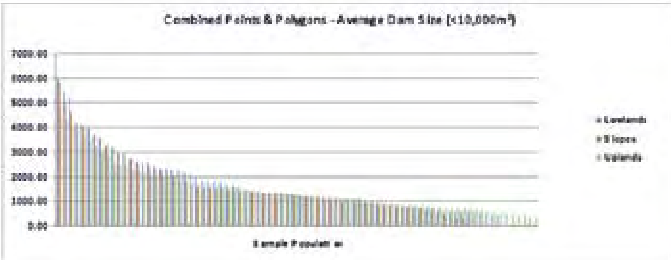


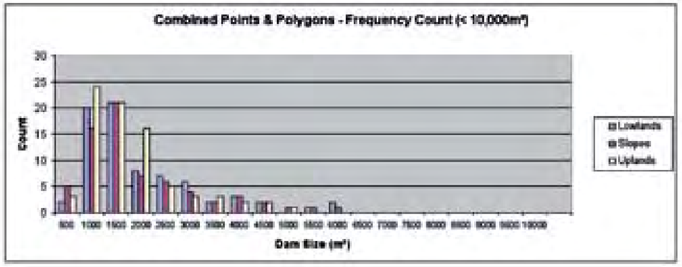


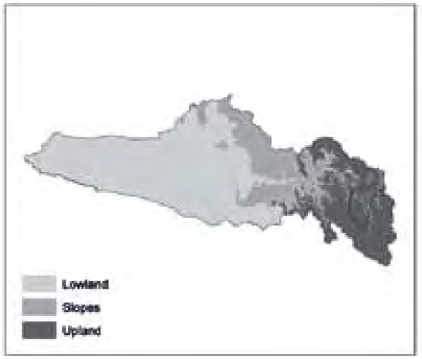
MURRUMBIDGEE RIVER

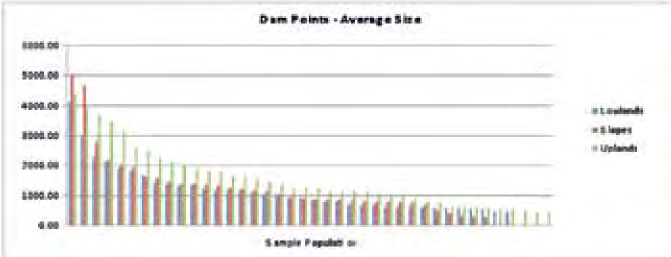
Figures C106–C114: Murrumbidgee River Results

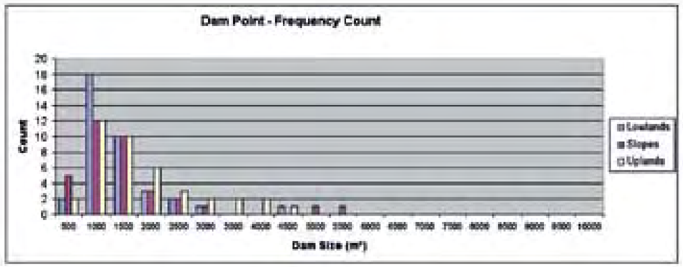


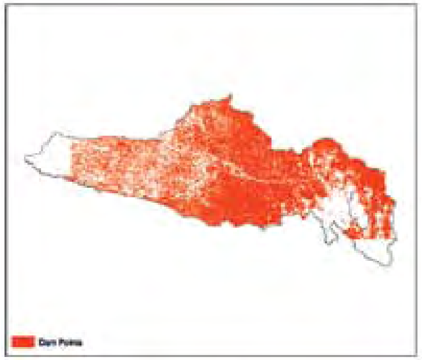


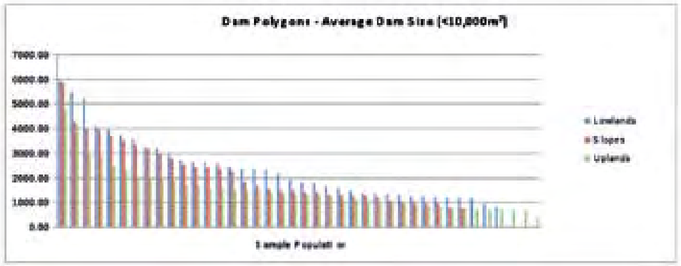


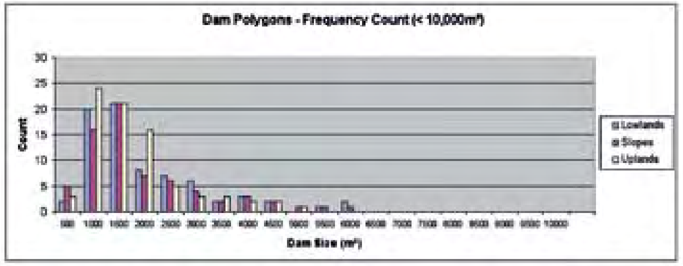






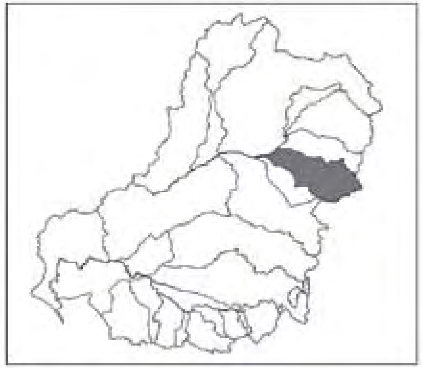


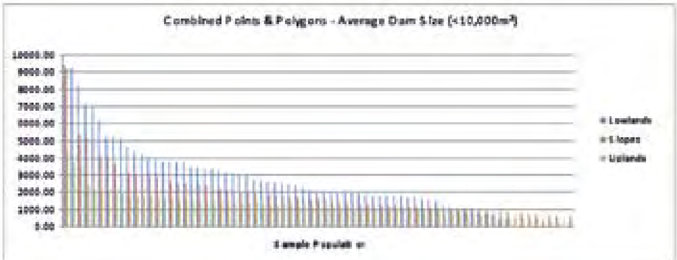


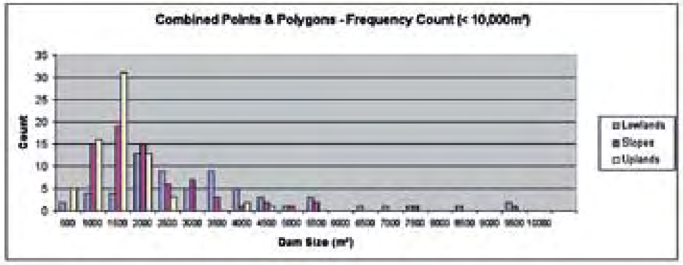


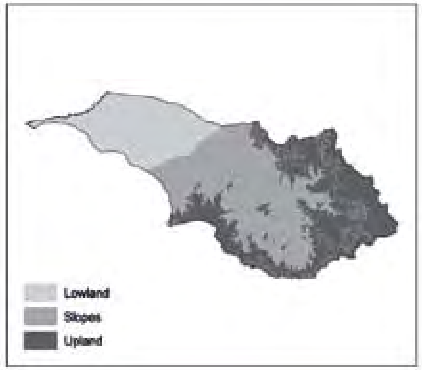
NAMOI RIVER

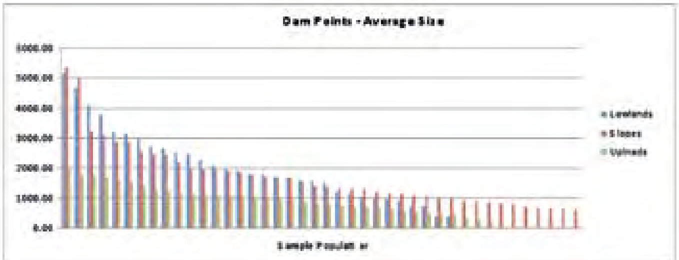
Figures C115–C123: Namoi River Results

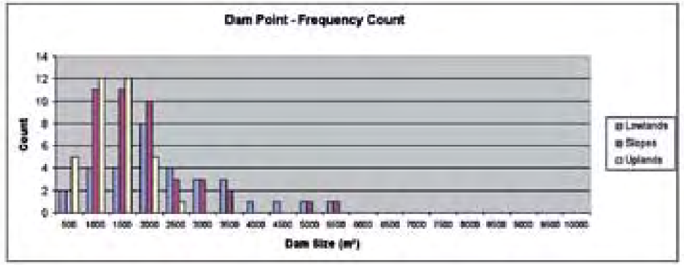


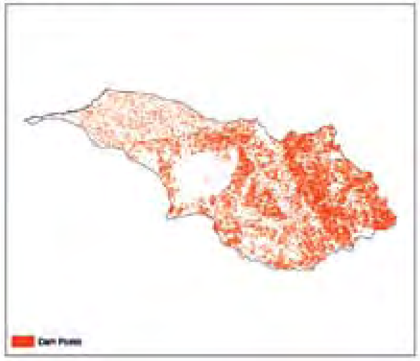


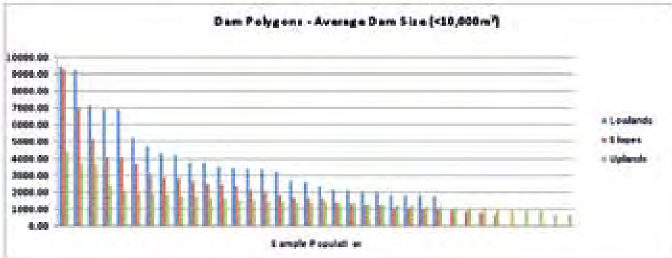


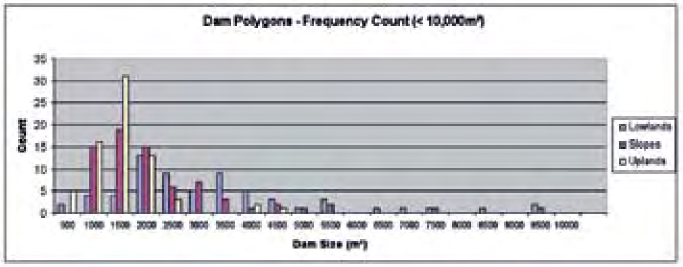






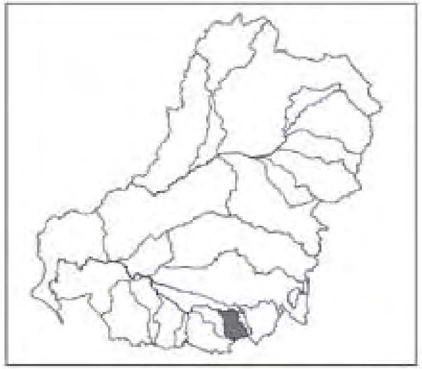


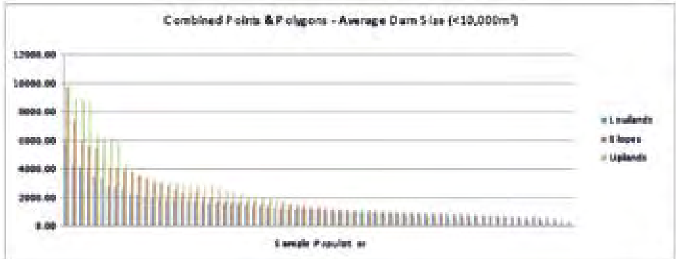


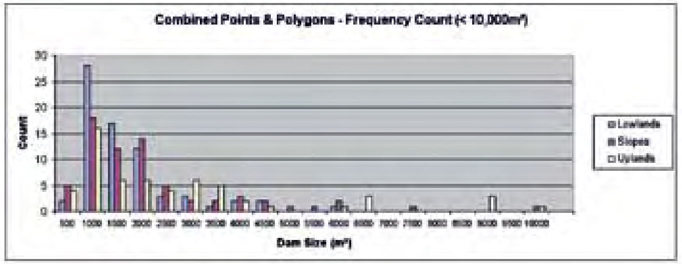


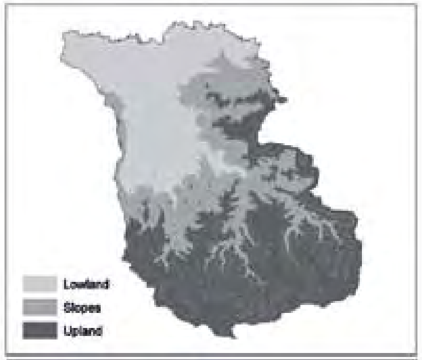
OVENS RIVER

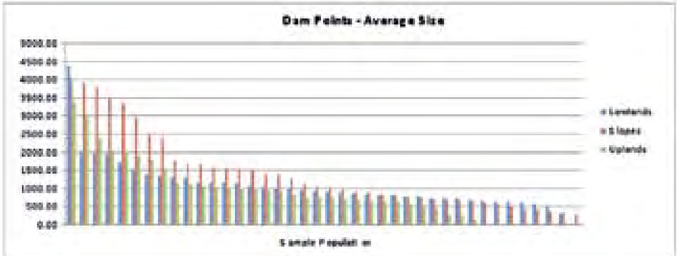
Figures C124–C132: Ovens River Results

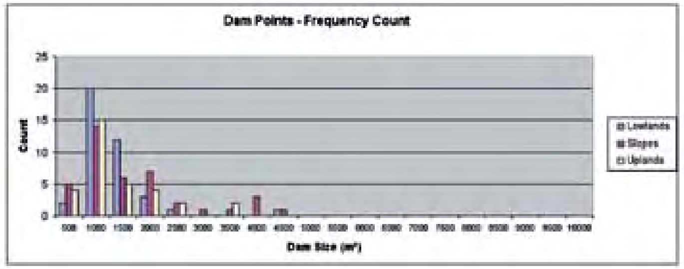


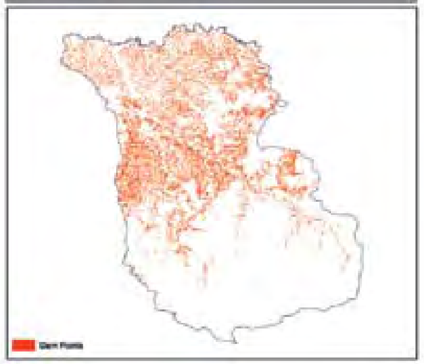


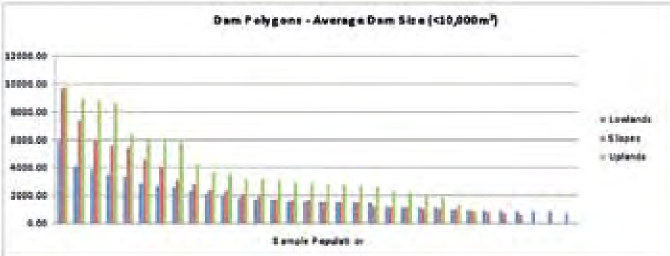


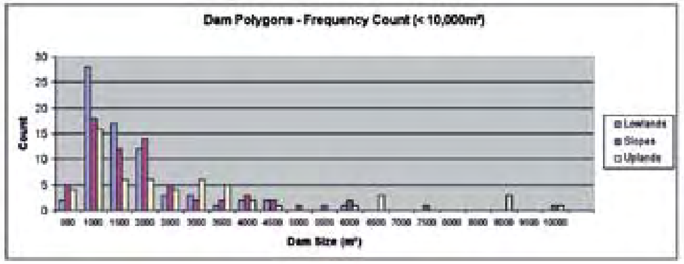






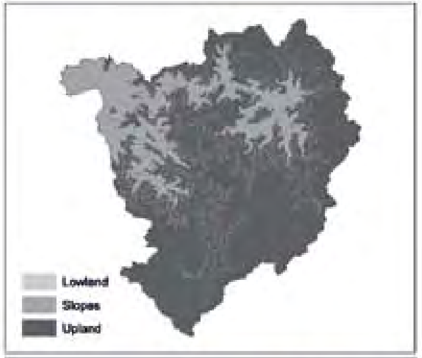


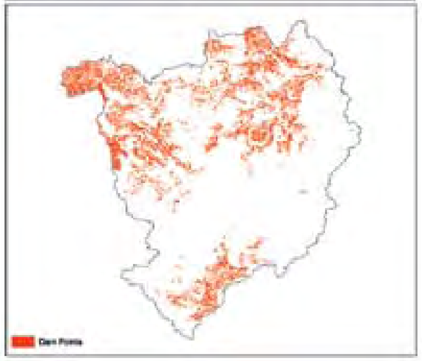


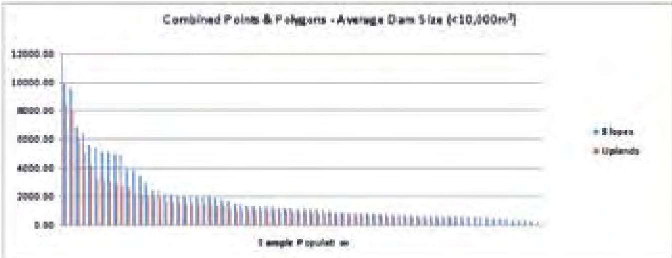


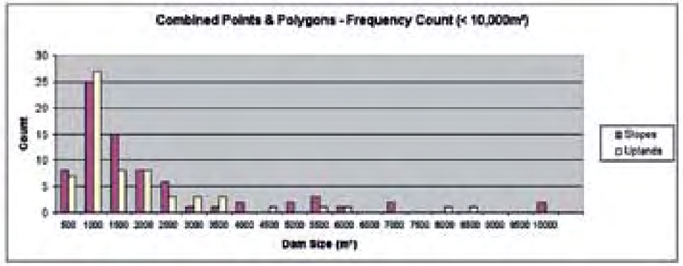
UPPER MURRAY RIVER

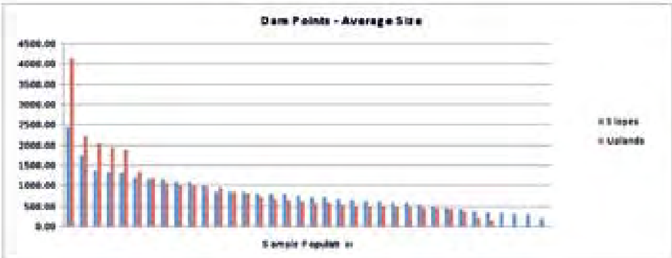
Figures C133–C141: Upper Murray River Results

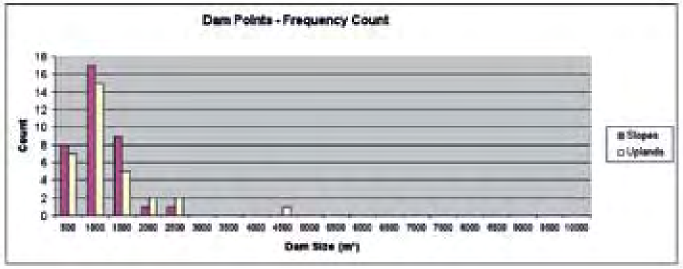


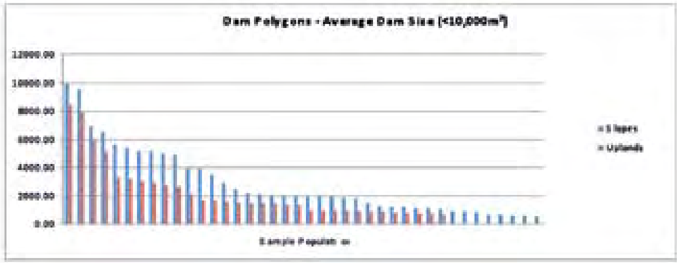


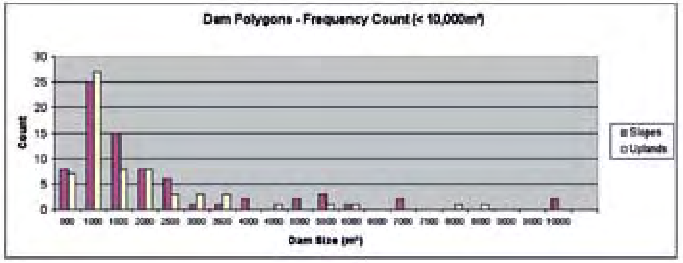












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Murray-Darling Basin Commission

GPO Box 409 Canberra ACT 2601

Tel 02 6279 0100 Fax 02 6248 8053

www.mdbc.gov.au