remote sensing

Supplementary Information

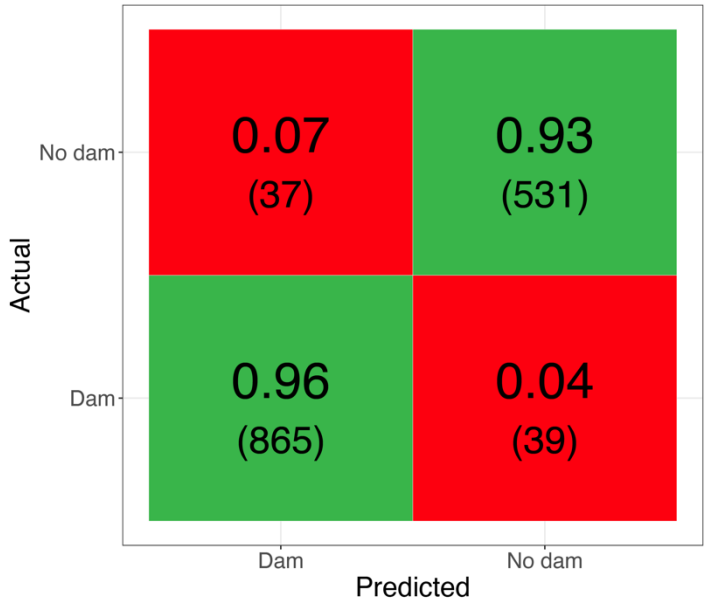


Figure S1. Confusion matrix for farm dam detection with our deep learning CNN. We used 1,472 images to estimate the performance of the classification model. Values and colours indicate the frequency of each condition (with sample size in brackets). Overall, correct predictions (green) where 1,396 (94.8%), of which 865 true positives and 531 true negatives. Wrong predictions (red) where 5.1%, of which 37 false positives (2.5%) and 39 false negatives (2.6%).

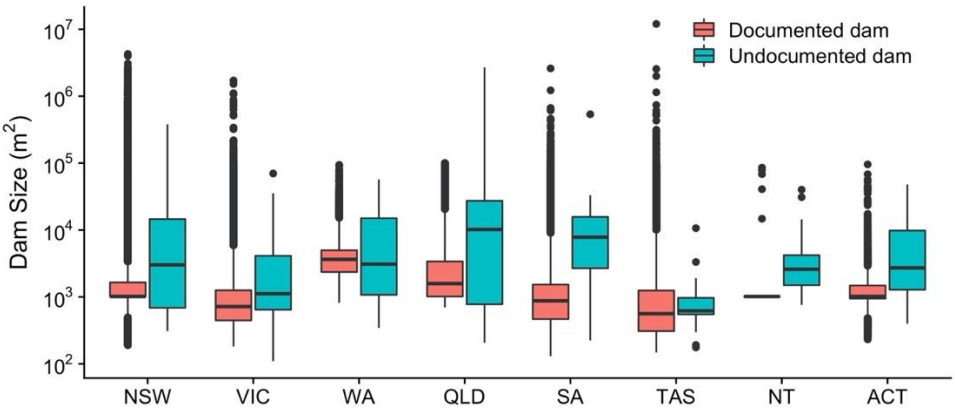
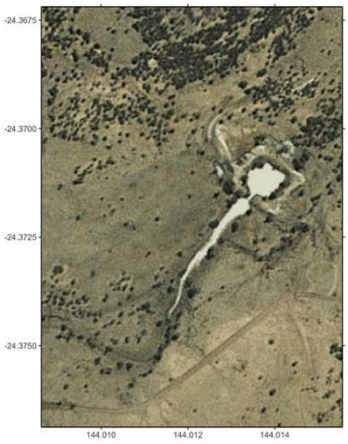


Figure S2. We manually traced the surface area of 221 unreported dams and used the median to estimate their water capacity using the calibration curve in Figure 1. Colour of the boxplot indicate documented (red, N = 1,696,321) and undocumented (green, N = 221) dams. We used the 2016 Australian Bureau of Agricultural and Resource Economics and Sciences to identify the 33 agricultural land types with the highest documented dam densities (>2 dams km^{-2}) across Australia (see section 2.2.3 in main text for details). Specifically, these land types were: *Other forest production* (code: 222), *Perennial horticulture* (340), *Tree fruits* (341), *Vine fruits* (344), *Shrub nuts, fruits and berries* (345), *Perennial flowers and bulbs* (346), *Beverage and spice crops* (347), *Grapes* (349), *Seasonal horticulture* (350), *Seasonal flowers and bulbs* (352), *Abandoned perennial horticulture* (365), *Grazing irrigated modified pastures* (420), *Irrigated shrub nuts, fruits and berries* (445), *Irrigated perennial flowers and bulbs* (446), *Irrigated seasonal vegetables and herbs* (454), *Intensive horticulture* (510), *Glasshouses* (512), *Irrigated seasonal flowers grown in glasshouses* (513), *Hydroponics* (514), *Abandoned intensive horticulture* (515), *Dairy sheds and yards* (521), *Cattle feedlots* (522), *Poultry farms* (523), *Poultry farms* (524), *Stockyards or saleyards* (528), *General purpose factory* (531), *Food processing factory* (532), *Bulk grain storage* (534), *Rural residential with agriculture* (542), *Farm buildings or infrastructure* (545), *Effluent pond* (591), *Reservoir or dam* (620), *Water storage; intensive use or farm dams* (622).


-26.940
-26.942
-26.944
-26.946
-26.948
152.550
152.552
152.554


-25.800
-25.802
-25.804
-25.806
152.670
152.672
152.674

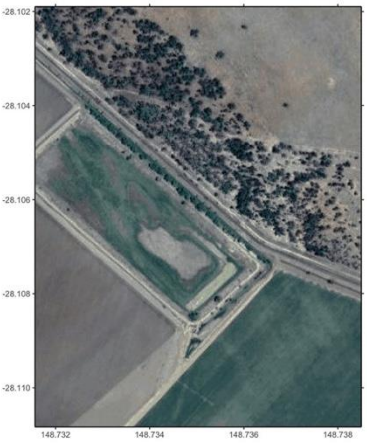

-24.3675
-24.3700
-24.3725
-24.3750
144.010
144.012
144.014

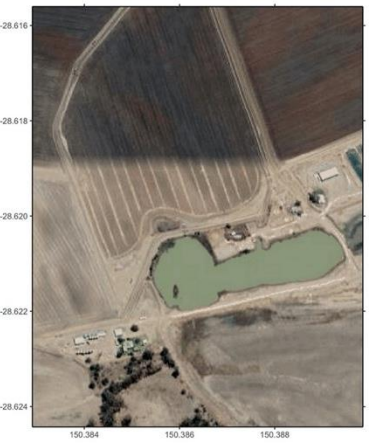

-18.0750
-18.0775
-18.0800
-18.0825
143.458
143.460
143.462
143.464


-26.8250
-26.8275
-26.8300
150.072
150.074
150.076


-27.712
-27.714
-27.716
-27.718
-27.720
153.178
153.180
153.182


-20.704
-20.706
-20.708
-20.710
-20.712
-20.714
146.300
146.302
146.304


-28.102
-28.104
-28.106
-28.108
-28.110
148.732
148.734
148.736
148.738


-28.616
-28.618
-28.620
-28.622
-28.624
150.384
150.386
150.388


-21.622
-21.624
-21.626
-21.628
-21.630
147.010
147.012
147.014


-24.722
-24.724
-24.726
-24.728
-24.730
149.342
149.344
149.346
149.348


-25.4075
-25.4100
-25.4125
-25.4150
152.748
152.750
152.752
152.754

Figure S3. Examples of farm dams identified with our deep learning CNN across Australia that were previously undocumented. In total, we analysed 124,510 RGB images (mostly from 2018 to 2019) at 0.5 m resolution and detected 5,105 farm dams. See Figure S1 for confusion matrix and model performance.

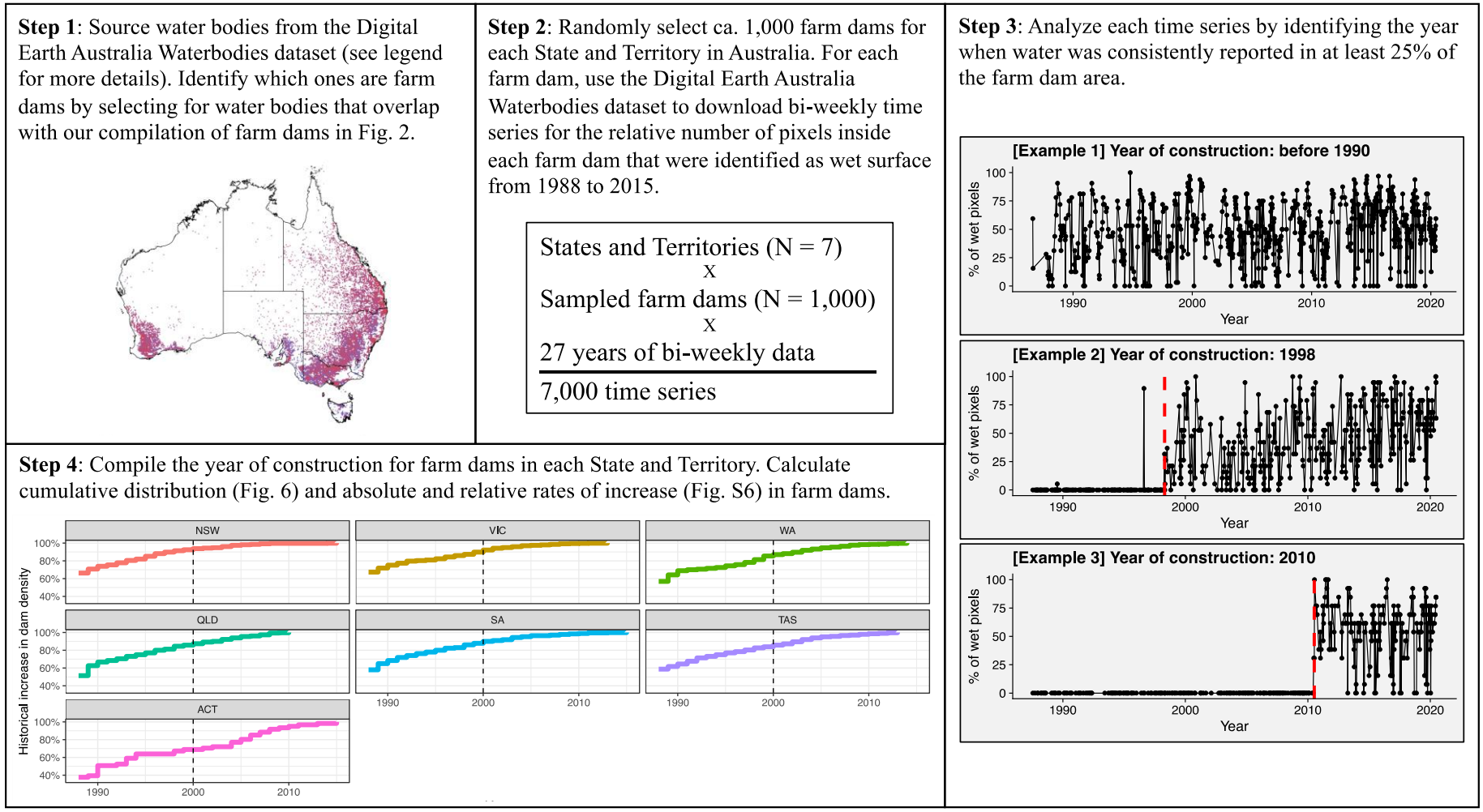


Figure S4. Step-by-step graphical explanation for the methods to calculate the absolute and relative rates in farm dam development for each State and Territory across Australia. The 28 years of bi-weekly time series of relative wet surface for each farm dam were sourced from the Digital Earth Australia Waterbodies, which is an elaboration of the Landsat-based Water Observations from Space compiling data for ca. 300,000 waterbodies across Australia. The spatial resolution is 30 m pixel size and the temporal resolution is from 1988 to 2015. Curator website for Digital Earth Australia Waterbodies: https://www.ga.gov.au/dea/products/dea-waterbodies. Curator website for Water Observations from Space: https://www.ga.gov.au/dea/products/wofs.

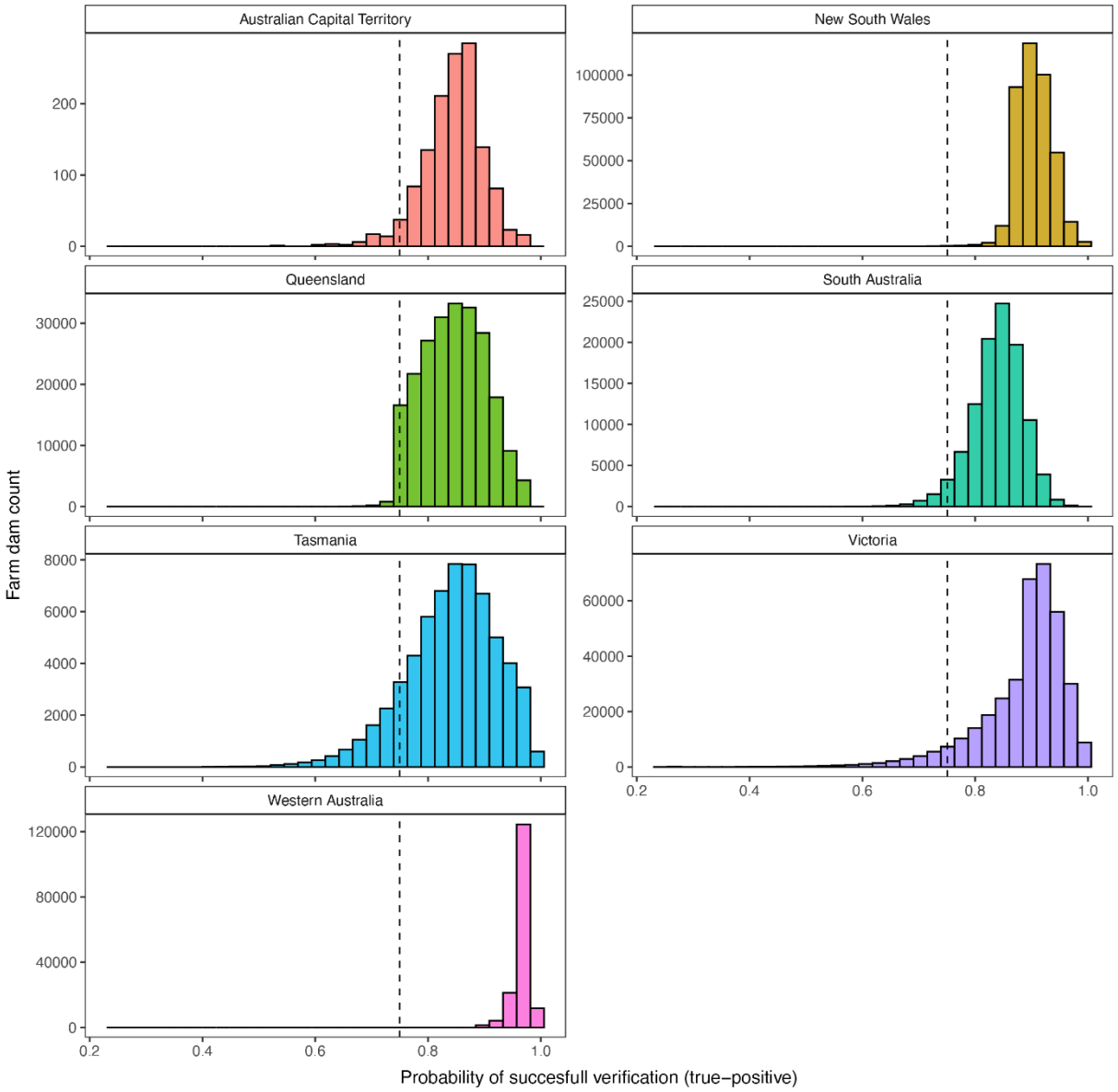


Figure S5. Predicted probability for a successful verification (true positive) for each dam in our dataset. In our analyses, we removed all entries that recorded less than 75% reliability of being a true positive (left of dashed line), which we verified to be an appropriate threshold to filter out the large majority of false positives.

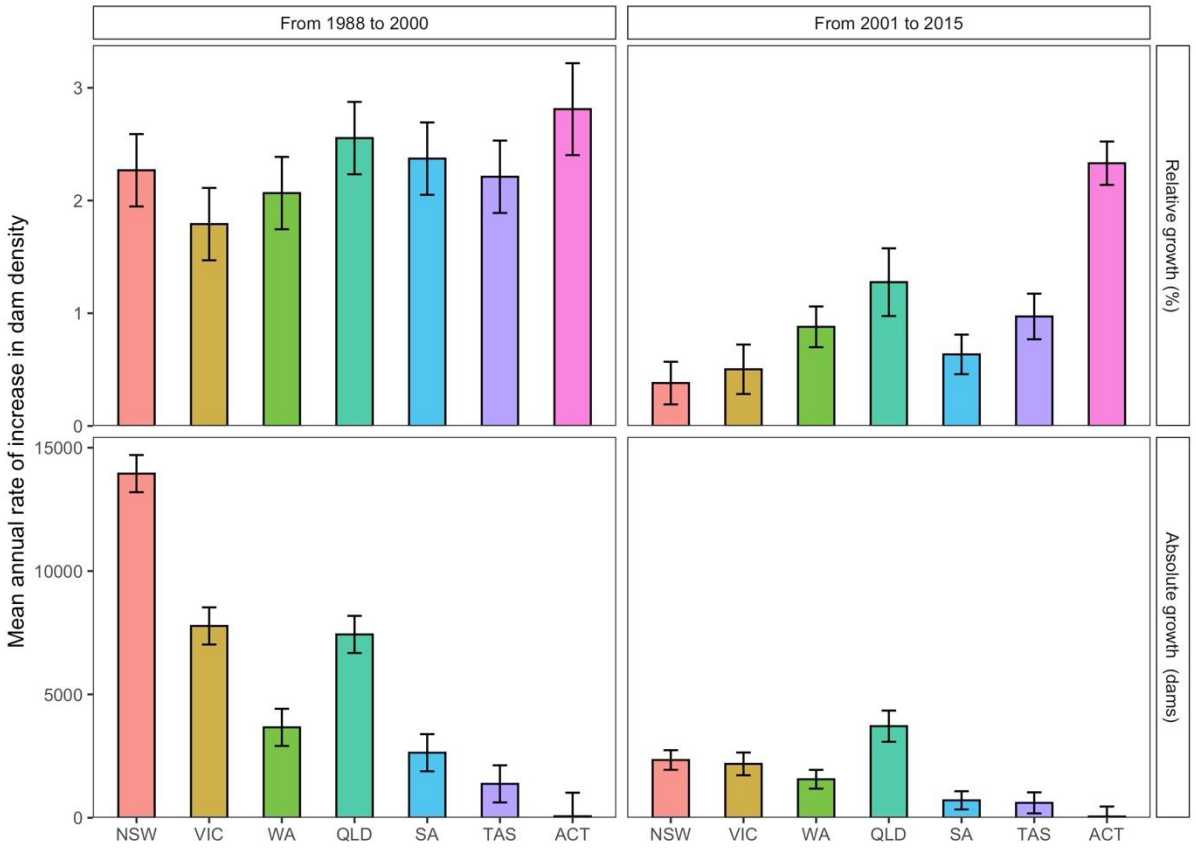


Figure S6. Estimated rates of annual increase in dam densities between the years 1988 and 2015 in each State and Territory of Australia. All rates were calculated based on the trajectories in Figure 6. Relative growth shows the percentage increase in dams per year, whereas the absolute growth shows the number of new dams built each year. Vertical facets divide the annual rates between the earlier period of faster growth (from 1988 to 2000) and the more recent years of slower growth (from 2001 to 2015). Error bars indicate the 95% confidence intervals of each mean. There were too few data to calculate historical rate for dams in the Northern Territory.

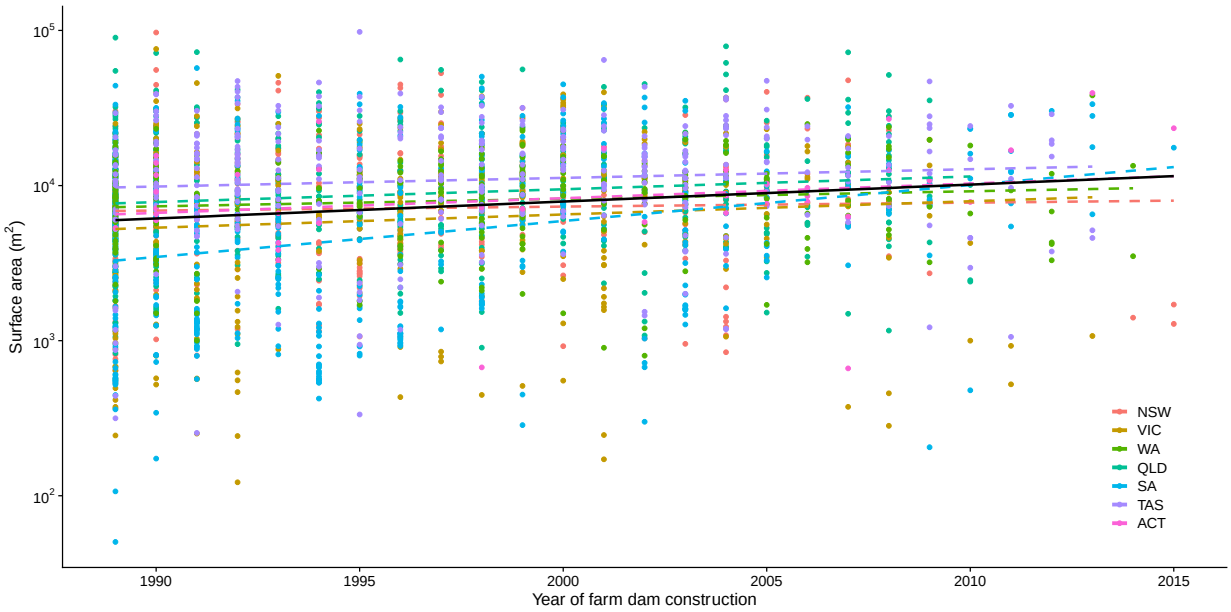


Figure S7. Historical trends in the size of constructed farm dams for each State and Territory. Each dot is a farm dam, with the colour indicating the State or Territory. Black continuous line (±95% C.I.) represents the overall trend, whereas coloured dashed lines show trends for each region. We found a significant increase in surface area over time across all regions (positive slope; $F_{1, 2435} = 33.68$, $p < 0.001$). This means that farm dams built in 2015 are on average 50.7% larger than those built in 1988. Using our area-volume relationship (Figure 1), we calculated that this increase in surface area corresponds to a 66% increase in water capacity from 1988 to 2015. Finally, the rate of increase in surface area over time was consistent across regions (i.e., no significant interaction between categorical [region] and continues [year of construction] variables; $F_{6, 2435} = 1.8065$, $p = 0.094$).

Table S1. Summary table for the datasets on farm dams used in this study. For all maps, we inspected all large dams (>10^5 m^2 in surface area) and removed those with circularity (calculated as $4 \times Area \times [\pi \times Perimeter^2]^{-1}$) above 0.5 – which resulted an effective way to filter out dams with natural origins (i.e., jiggered borders, complex and irregular shapes). Sample size indicate the number of dams.

Curator	Spatial Coverage	Temp. Coverage	Spatial Accuracy	Sample Size	Data Type	Filters	Notes	Access Date	Source
Geoscience Australia	Australia	Start: 2001-01-01 End: ongoing updates	10–30 m	627,299	Polygons	FEATURETYP = "Farm Dam Area" OR "Flood Irrigation Storage" OR "Settling Pond"	Removed entries whose name contained "(creek)|(river)|(hole)|(billabong)|(gully)|(swamp)|(river)|(lake)|(waterhole)|(salt)"	22 May 2020	Curator website https://ecat.ga.gov.au/geonetwork/srv/eng/catalog.search#/metadata/83134
Geoscience Australia	Australia	Start: 2001-01-01 End: ongoing updates	10–30 m	307,082	Points	FEATURETYP = "Dam"	Size taken as the minimum reported polygon size (Area 625m^2, Perim. 93m)	22 May 2020	Curator website https://ecat.ga.gov.au/geonetwork/srv/eng/catalog.search#/metadata/83132
Dept. of Environment, Land, Water & Planning of the Victorian Government	Victoria	Start: 2005-01-01 End: 2012-02-17	5 m	357,763	Polygons	FEAT_TYPE = "Rural Storage" OR "Rural Licensed Storage" OR "Rural Irrigation Storage" OR "Industrial Storage" OR "Flood Irrigation Storage" OR "Settling Ponds" OR "Settling Pond"	NA	5 Jun 2020	Curator website https://discover.data.vic.gov.au/dataset/farm-dam-boundaries
Dept. of Environment, Land, Water & Planning of the Victorian Government	Victoria	Start: 2005-01-01 End: 2012-02-17	5 m	71,635	Points	FEAT_TYPE = "Rural Storage" OR "Rural Licensed Storage" OR "Rural Irrigation Storage" OR "Industrial Storage" OR "Flood Irrigation Storage" OR "Settling Ponds" OR "Settling Pond"	Area reported in the data. Perimeter calculated assuming circular shape.	5 June 2020	Curator website https://discover.data.vic.gov.au/dataset/farm-dam-points

Dept. of Primary Industries and Regional Development	Western Australia	Start: 2018-01-01 End: 2019-02-17	5 m	162,785	Polygons	NA	NA	25 Sept 2020	https://catalogue.data.wa.gov.au/dataset/farm-dams-of-the-south-west-agricultural-region-of-wa
Dept. of Primary Industries, Parks, Water and Environment	Tasmania	Start: 2001-09-28 End: ongoing updates	NA	61,897	Polygons	HYDARTY2 = "Natural or dammed freshwa" OR "Water tank" OR "Sewage pond" OR "Tailings pond"	Data compiled from all municipalities. We used the 2016 Australian Land Use and Management Classification map (https://www.agriculture.gov.au/abares/aclump/land-use/alum-classification) to retain only dams in agricultural and urbanized areas.	11 June 2020	Curator website http://list-data.thelist.tas.gov.au/opendata/index.html#LIST_Hydrographic_Areas
Dept. for Environment and Water	South Australia	Start: 2011-12-12 End: ongoing updates	NA	105,361	Polygons	AHGFFType = 31 (i.e., “dams”)		10 June 2020	Private comm.
Environment & Planning Directorate	Australian Capital Territory	From: 1995-01-01 End: 2014-08-18	NA	853	Polygons	WATER_BODY = "DAM" OR "POND"		11 June 2020	Curator website https://actmapi-actgov.opendata.arcgis.com/datasets/act-water-features-polygons