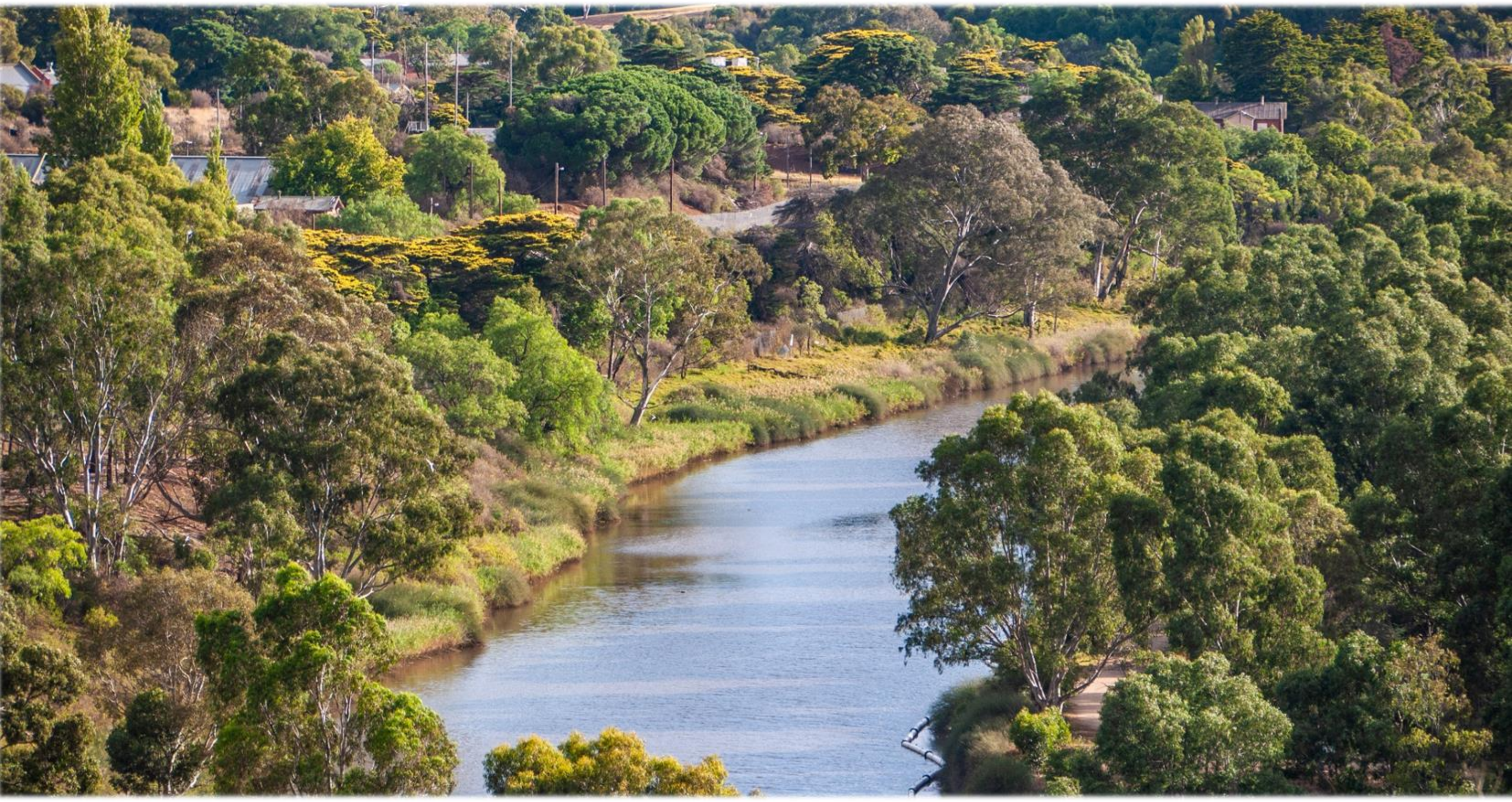

Water Resource Risks in the Maribyrnong and Moorabool Catchments

Impact of farm dams on streamflow

Version 1

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Copyright and Limitation

Contents

1. Introduction

This briefing paper has been prepared prior to a meeting with the Stakeholder Reference Group for the Water Resources Risks in the Maribyrnong and Moorabool Catchments project, which is scheduled for 9 September 2025.

The scope of the briefing paper and the scheduled meeting is:

- An overview of models used for water resources planning in the Maribyrnong and Moorabool basins (see Section 2)
- Modelling the estimated impact of farm dams and other small water bodies (see Section 3)
- Climate change projections and scenarios (see Section 4)
- Changes in the number and storage volumes of farm dams across the Maribyrnong and Moorabool catchment over time (see Section 5)
- Estimated impact of farm dams on streamflow in the Maribyrnong and Moorabool catchments, which have been assessed from the models in each catchment (see Section 6) and
- An overall summary of changes in farm dam numbers, storage volumes and estimated impact in the Maribyrnong and Moorabool catchments (see Section 7)

2. Water resources planning and modelling overview

The study areas for this project are the upper catchments of the Maribyrnong and Moorabool basins:

- Maribyrnong River catchment upstream of Keilor gauge (230200)
- Moorabool River catchment upstream of Batesford gauge (232202)

DEECA and Southern Rural Water review and update water resources plans for the basins and supply systems within their areas of responsibility. These plans are underpinned by water resources systems models. The models represent features such as catchment inflows, supply to licensed users, supply to meet environmental water needs, large dams and reservoirs and rules representing transfer of water to simulate a water resource system. Modelling in the Barwon-Moorabool and Maribyrnong systems is undertaken using the Source water resources modelling package, which is developed and supported by eWater. Source is the industry-standard software for modelling hydrology and water resources across Australia.

DEECA have developed water resources planning models, using the Source modelling package, for the Barwon-Moorabool and Maribyrnong basins. These models are used by DEECA, in consultation with stakeholders, to:

- Inform planning and development of water resources allocation policies
- Assess volumes, reliability and pattern of delivery of environmental flows
- Assess yields to bulk entitlement holders (such as Barwon Water and Melbourne Water) and the reliability of those yields
- Assess the impacts on water availability of larger scale Integrated Water Management projects in urban areas
- Assess the impacts of climate change and climate variability on these factors

A map of the subcatchments represented in the Maribyrnong Source model is shown in Figure 2-1. The Keilor streamflow gauge (230200) is at the downstream boundary of subcatchment F19, so subcatchment F20 is not included in the scope of the current project, even though it is within the extent of the water resources planning model (Source – see below) for the Maribyrnong system.

A map of the Moorabool portion of the Barwon-Moorabool Source model is shown in Figure 2-2. The Source model for the Barwon-Moorabool system includes catchments in the Barwon part of the system that are outside of the Moorabool catchment, which are not shown on Figure 2-2. Within the Barwon part of the system, part of the model and inputs were developed as part of the Ballarat Source model (for Central Highlands Water, CHW), which are labelled site 1 to 19 and shown in orange on Figure 2-2. Inputs for some Moorabool subcatchments, labelled F12 to F20 and shown in blue on Figure 2-2, were developed as part of a separate project. Inflows for CHW sites 14 to 19 are included in the Barwon Moorabool Source model but are outside of the Moorabool basin. Similarly, subcatchment F12 for inflows to Stony Creek reservoir is also outside of the Moorabool basin.

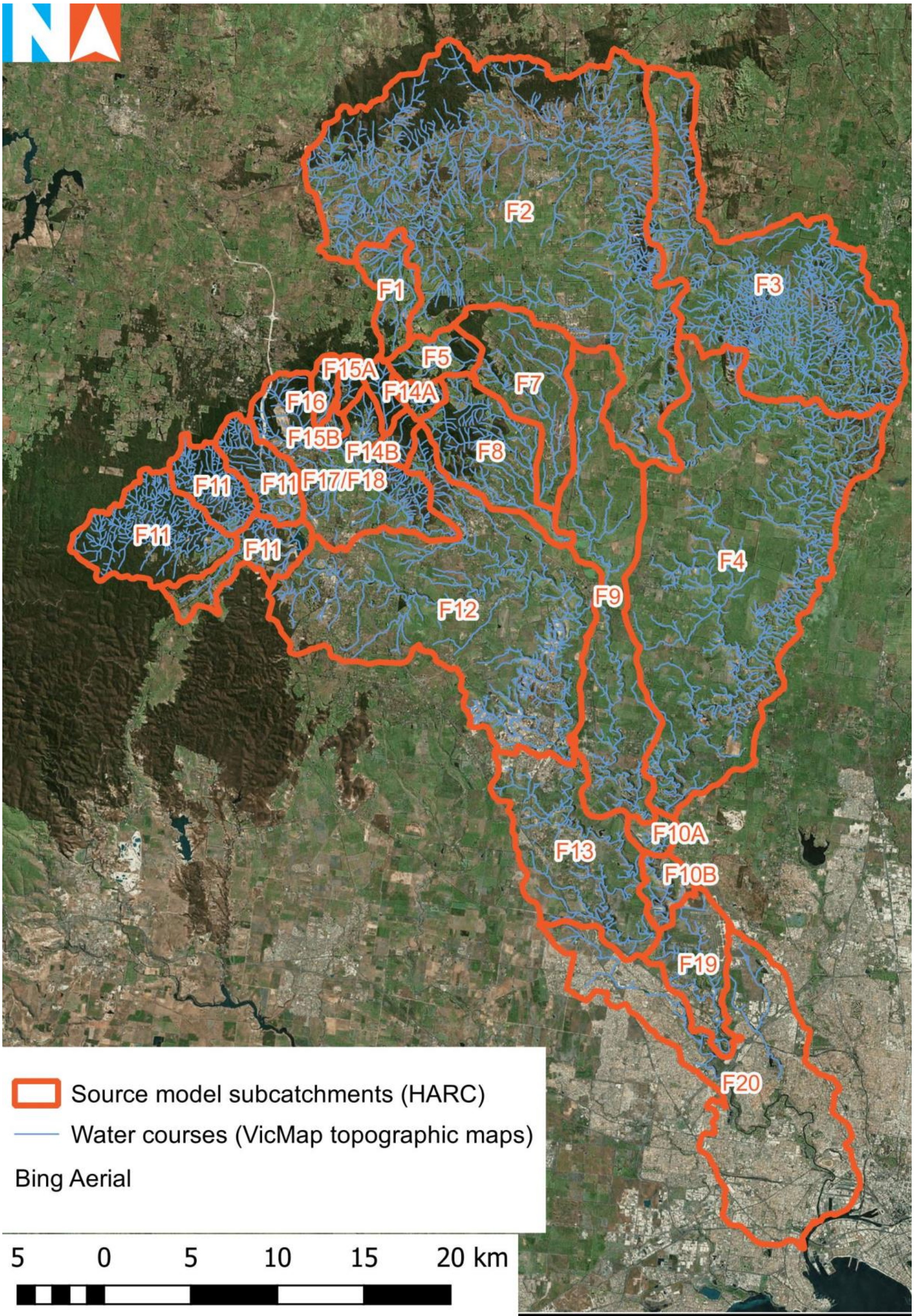

Figure 2-1 Maribyrnong subcatchment map

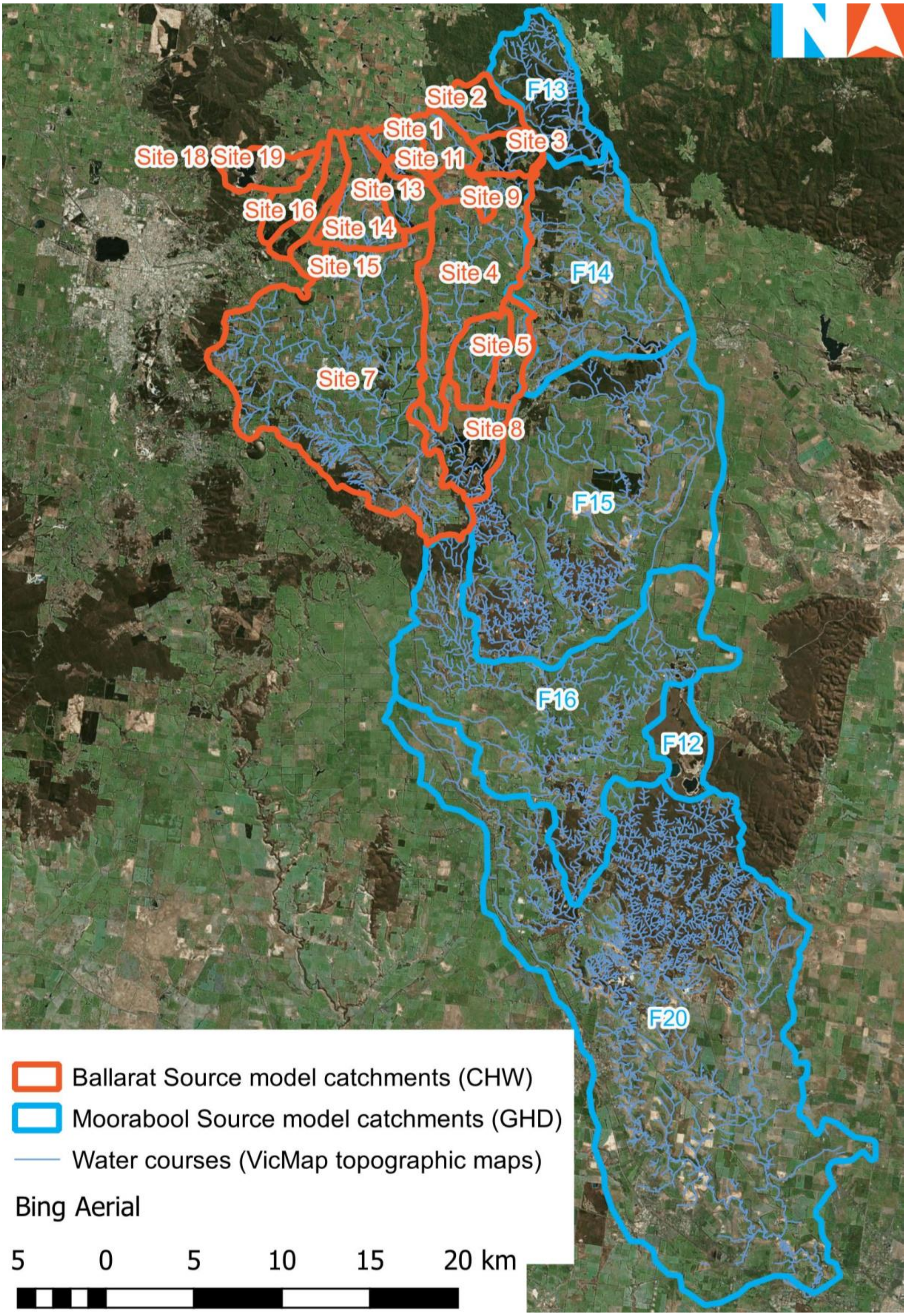

Figure 2-2 Moorabool subcatchment map

Figure 2-3 shows a schematic diagram of the Maribyrnong system Source model (DELWP and HARC, 2021; HARC, 2023a, 2023b). The level of detail represented within the model is demonstrated by the number of components of the model, such that it is difficult to read the details of any one component at this high level. The different types of nodes within the Source model are provided in the legend of Figure 2-3. The dashed connector arrows represent flows of water within the system. The Maribyrnong Source model runs on a daily timestep, representing the status of the system for every day in the period between January 1900 and June 2021.

Figure 2-4 shows a schematic diagram of the Barwon-Moorabool system Source model (SKM, 2006; HARC, 2019, 2024; DELWP and GHD, 2022; Central Highlands Water and HARC, 2023). The Barwon-Moorabool Source model runs on a daily timestep, representing the status of the system for every day in the period between January 1889 and June 2021. The dashed line in Figure 2-4 surrounds the Moorabool section of the model, which is in focus for this project.

Both Source models represent the water management rules that operate in each system, including:

- Storage curves and operating rules for large dams
- Requirements for passing flow and other releases under Bulk Entitlements
- Diversions, pumping and transfer rules
- Constraints such as the capacities of pumps, pipelines and open channels
- Restrictions of urban demands
- Restrictions on licensed irrigation and other rural demands during low flow periods

Further details on farm dam impact modelling using STEDI are discussed in Section 3.

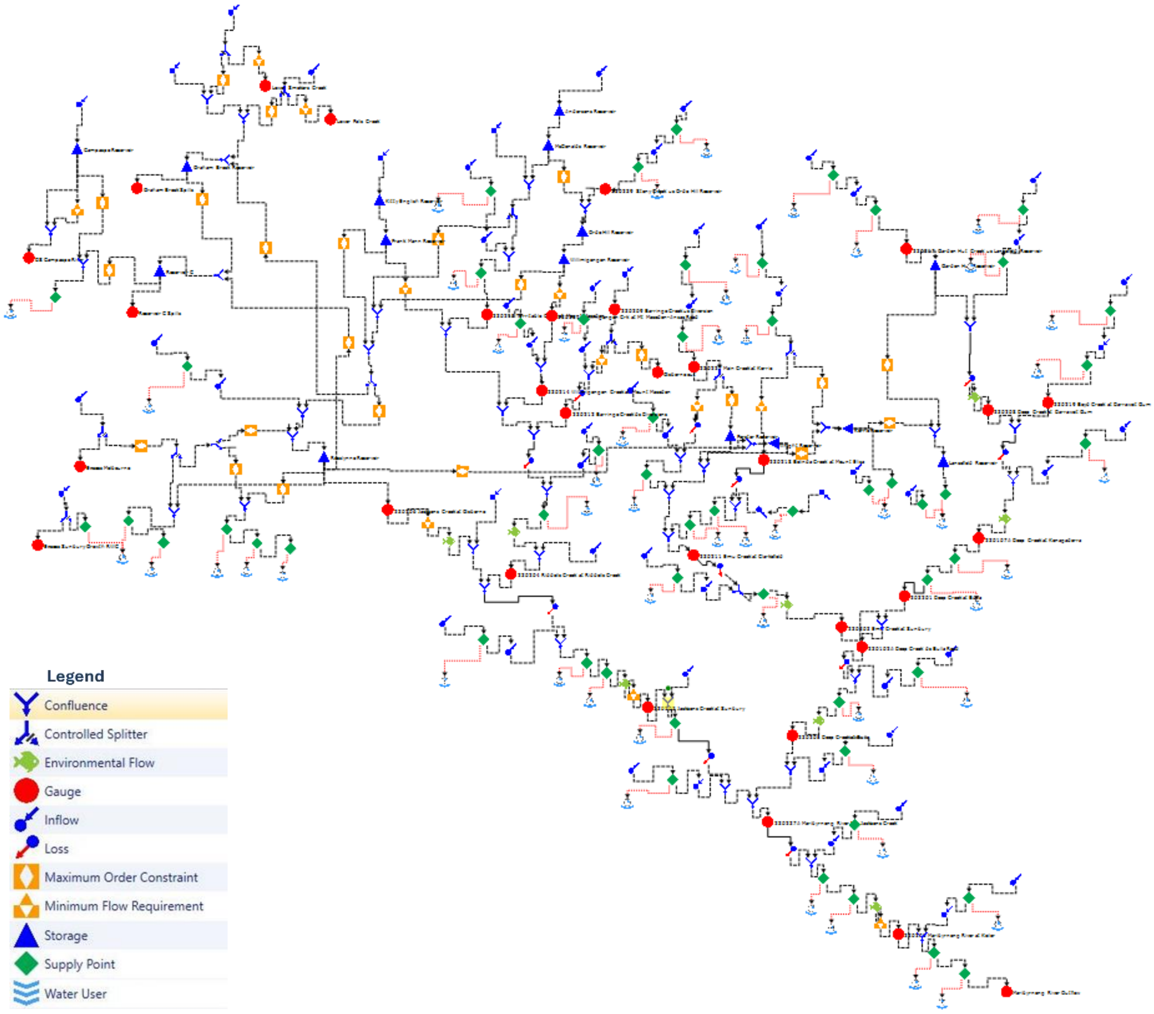

Figure 2-3 Schematic of Maribyrnong Source model

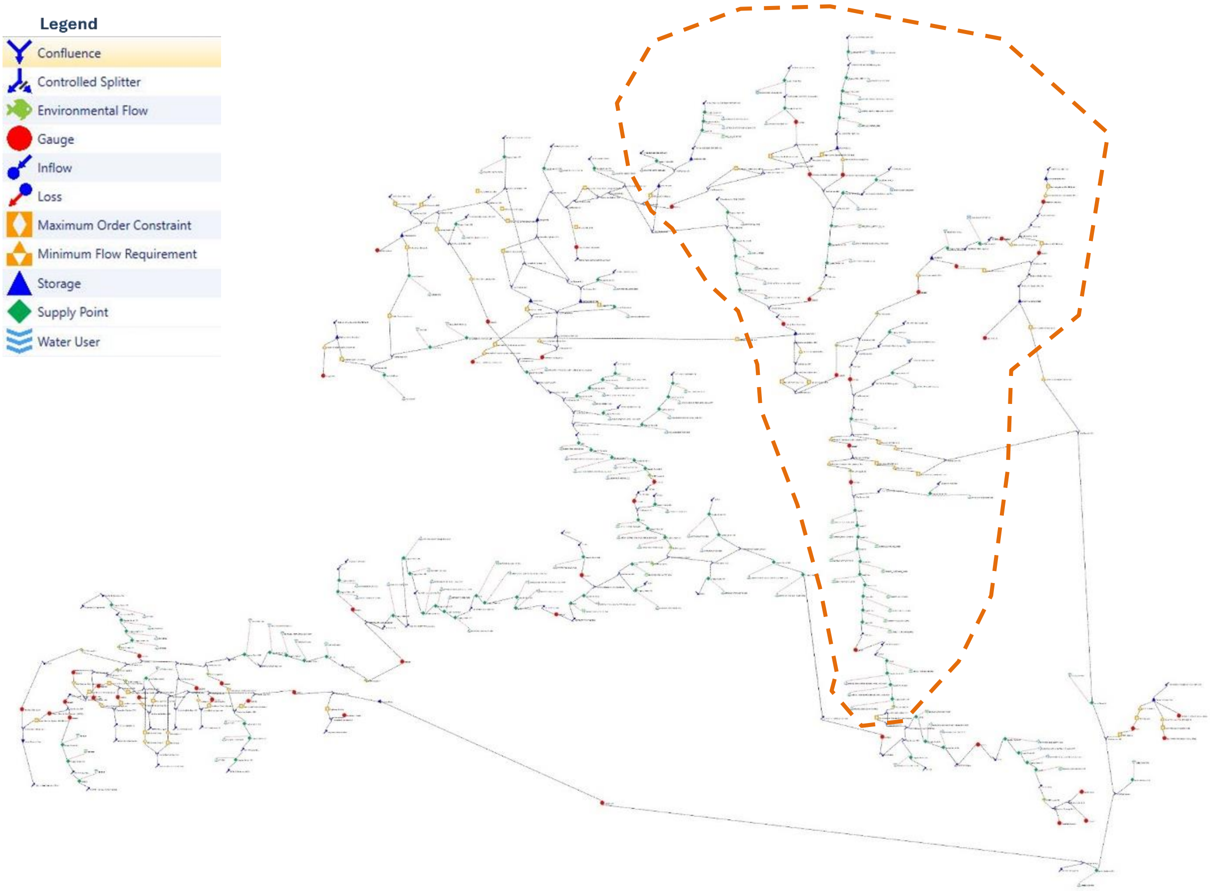

Figure 2-4 Schematic of Barwon-Moorabool Source model, with the Moorabool section enclosed within the dashed line

3. Modelling farm dams and other small water bodies

3.1 Modelling method in STEDI

The Source models for the Barwon-Moorabool and Maribyrnong systems incorporate, either explicitly or implicitly, water that is taken and used by licensed and domestic and stock (D&S) users in these systems. Water take from farm dams in each of the major subcatchments of these systems are explicitly modelled using the Spatial Tool for Estimation of Dam Impacts (STEDI) model.

STEDI is used to explicitly model farm dam impacts in 19 subcatchments of the Maribyrnong system and 16 subcatchments of the Moorabool system. STEDI is used to model current farm dam impacts and estimate the historical impact of farm dams, which has evolved over time. These are then added back to the streamflow time series that were recorded at flow gauges.

The conceptual structure of the STEDI model is shown in Figure 3-1. The water balance for each farm dam is characterised by inflows; net evaporation: the difference between evaporation from the dam surface area and rainfall directly falling on the dam; extractions from the dam to supply demands; seepage losses and spills. Spills from upstream dams may be intercepted by dams that are further downstream. Low-flow bypasses may be installed on some or all dams in a catchment, which will divert inflows up to the flow capacity of the bypass around the dam. Low flow bypasses are currently relatively uncommon in the Maribyrnong and Moorabool catchments. Farm dams in a catchment have a cumulative impact, which affects the overall hydrograph of inflows at locations further down the catchment.

Inflows to runoff dams may be contributed by surface runoff from the upstream catchment area, capture of excess runoff from irrigated areas upstream of the dam, discharge from groundwater via springs, diversion from a nearby stream, pumping from groundwater and/or spills from upstream dams. Water that may otherwise have flowed into a farm dam may also be intercepted by features in the catchment upstream of the dam, such as natural lakes, depressions or wetlands. Gauging of inflows to individual runoff dams is rare and spatial and temporal variations in the above aspects contribute uncertainty to estimates of inflows to individual dams.

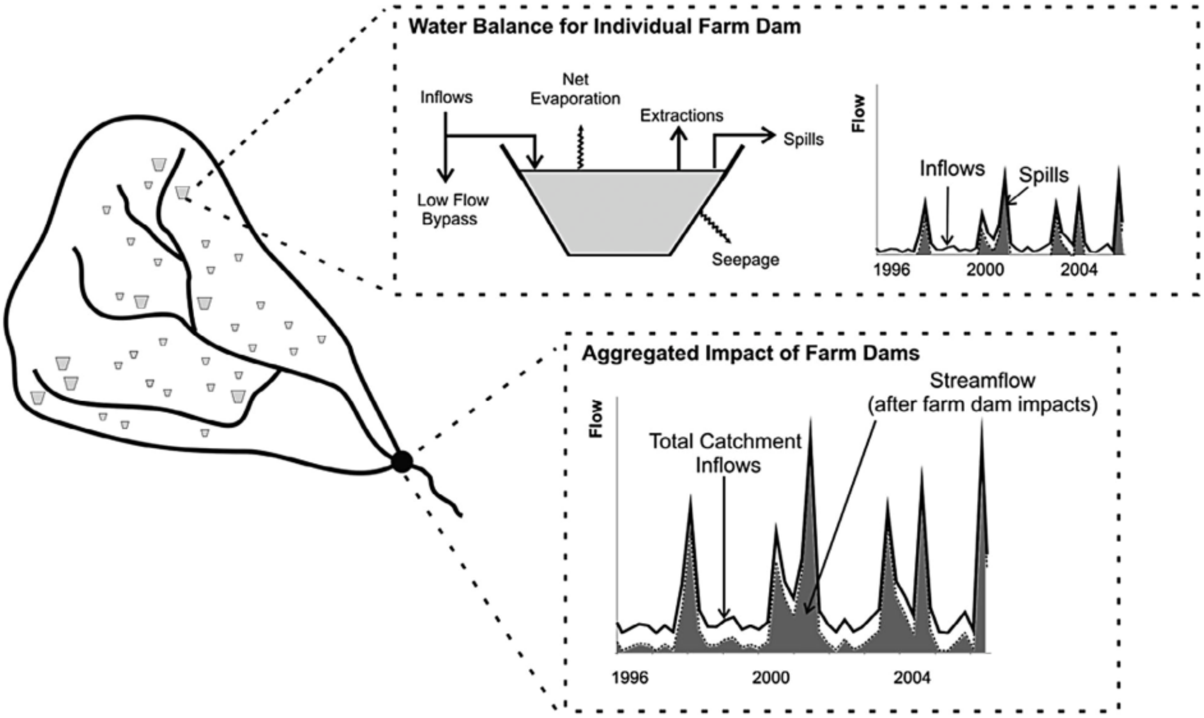

Figure 3-1 Conceptual representation of farm dam impacts in the STEDI model (from Fowler et al., 2016)

3.2 Limitations of farm dam impact modelling

The following discussion provides an overview of the main limitations and sources of uncertainty in surface water interception models for farm dams.

Identification, location classification and extent of runoff dams – Modelling runoff dam impact requires an understanding of the number, location and extent (catchment area and surface area) of runoff dams. The spatial data analysis used for this purpose is influenced by the resolution and quality of the spatial imagery and data used, the period or periods for which data is available, the method of identification, the catchment conditions at the time of data acquisition, and the quality of any regulatory or other water body data available to support identification and classification.

Historical change in the number of dams – Modelling requires assumptions to be made about which of the dams were present over the period that was concurrent with modelled or gauged streamflow data for the catchment. There is often some uncertainty about the trajectory of runoff dam development over time, and this contributes uncertainty to how the model would scale impacts from historical periods, when there may have been fewer dams and with lower aggregate storage volume, to current and forecast future numbers and storage volumes of dams.

Runoff dam inflow – Uncertainties in spatial and temporal variations of inflow to runoff dams are influenced by catchment characteristics, including soils, vegetation cover, land use, agricultural practices, hydrogeology of underlying aquifers and stream networks. Uncertainty in the estimation of inflow has been reduced, at a catchment level, by calibrating a catchment model to gauged streamflows at several locations within the Maribyrnong and Moorabool catchments. However, a component of uncertainty will remain around the inflow to each dam, due to spatial and temporal variations in surface runoff and other inflows to each dam.

Spatial and temporal variation of rainfall and evapotranspiration within a catchment – Uncertainties in spatial and temporal variations of rainfall and evapotranspiration within a catchment contribute to uncertainties in spatial and temporal variations of inflow to runoff dams

Demands and usage – Demand and usage is not metered from D&S farm dams and from almost all other small water bodies in Victoria. The typical annual volume of usage and pattern of demand, across the year, is therefore estimated as a proportion of the estimated storage volume in the STEDI model. Demand is likely to vary significantly between dams and from year to year for each dam.

Storage volume – A contributor to uncertainty in the impact of runoff dams is the uncertainty in the volumetric storage capacity of each dam, as accurate survey data is rarely available for runoff dams and their storage volumes must therefore be estimated from their surface area.

Volume stored – Uncertainty in estimating the volume stored in each farm contributes to uncertainty in usage and net evaporation losses. It will also contribute to uncertainty in the estimation of inflow if the runoff dam storage volume is used as a predictor of the area of the upstream contributing catchment.

Net evaporation – Uncertainty in net evaporation from dams is typically viewed as a relatively small component of the overall uncertainty. This is because (a) direct rainfall on the surface area of the dams counterbalances much of the evaporation losses and (b) the total surface area of all runoff dams in a catchment is a small proportion of the overall catchment area.

Seepage losses – Seepage losses from runoff dams are difficult to estimate and often ignored in models of runoff dam impacts.

Groundwater flows / Ingress – While typically assumed to be negligible due to the use of clay, plastic or geo-textile liners, inflow from groundwater can impact the overall water balance of runoff dams, i.e., the volume stored and, therefore, influences the uncertainty outlined above.

Losses and hydrologic connection: seepage rates from dams and each dam's location in the landscape can contribute significantly, in some cases, to take by runoff dams. It is difficult to generalise dam characteristics across a region and levels of hydrologic connection to downstream waterways may vary significantly between dams in a catchment. . The modelling assumes that all of the modelled impact at each individual dam translates directly to an impact on flows in the waterway, but in many cases, particularly during dry times, the level of hydrologic connection will be significantly less than 100%.

Spatial resolution of flow regimes from Source models - Source models are focussed on assessing flow regimes and environmental water deliveries for the major streams in each system, which generally run from downstream of the major reservoirs. Spatial and temporal variations in water takes across the catchments may present different levels of risk to in-stream flows and environmental values in the tributary streams that are not explicitly represented in the Source models.

Climate change projections - There are large variations in projected mean annual rainfall and runoff between climate change projection scenarios. The low projection scenarios show projected increases in rainfall and runoff for the Maribyrnong and Moorabool basins, whilst the high projection scenarios project decreases in runoff of up to 45% to 55% by 2065 under the high climate change projection for RCP8.5. The proposed 2065 RCP 4.5 medium scenario allows provides for a reasonable assessment of the sensitivity of how the influence of farm dams might be modulated by projected climate change.

Changes in catchment response after the Millennium drought –. In some catchments, runoff decreased more than expected for the given amount of rainfall during and after the Millennium Drought, as shown in Figure 3-2. The reductions in runoff generation are widespread across central and Western Victoria and are observed in unimpacted catchments where flow conditions are not impacted by farm dam growth, changes in land use, extractions or other flow regulation. About one-third of the Victorian catchments studied are still in this drought-like state, including catchments in the upper Maribyrnong and other catchments in the vicinity of this study.

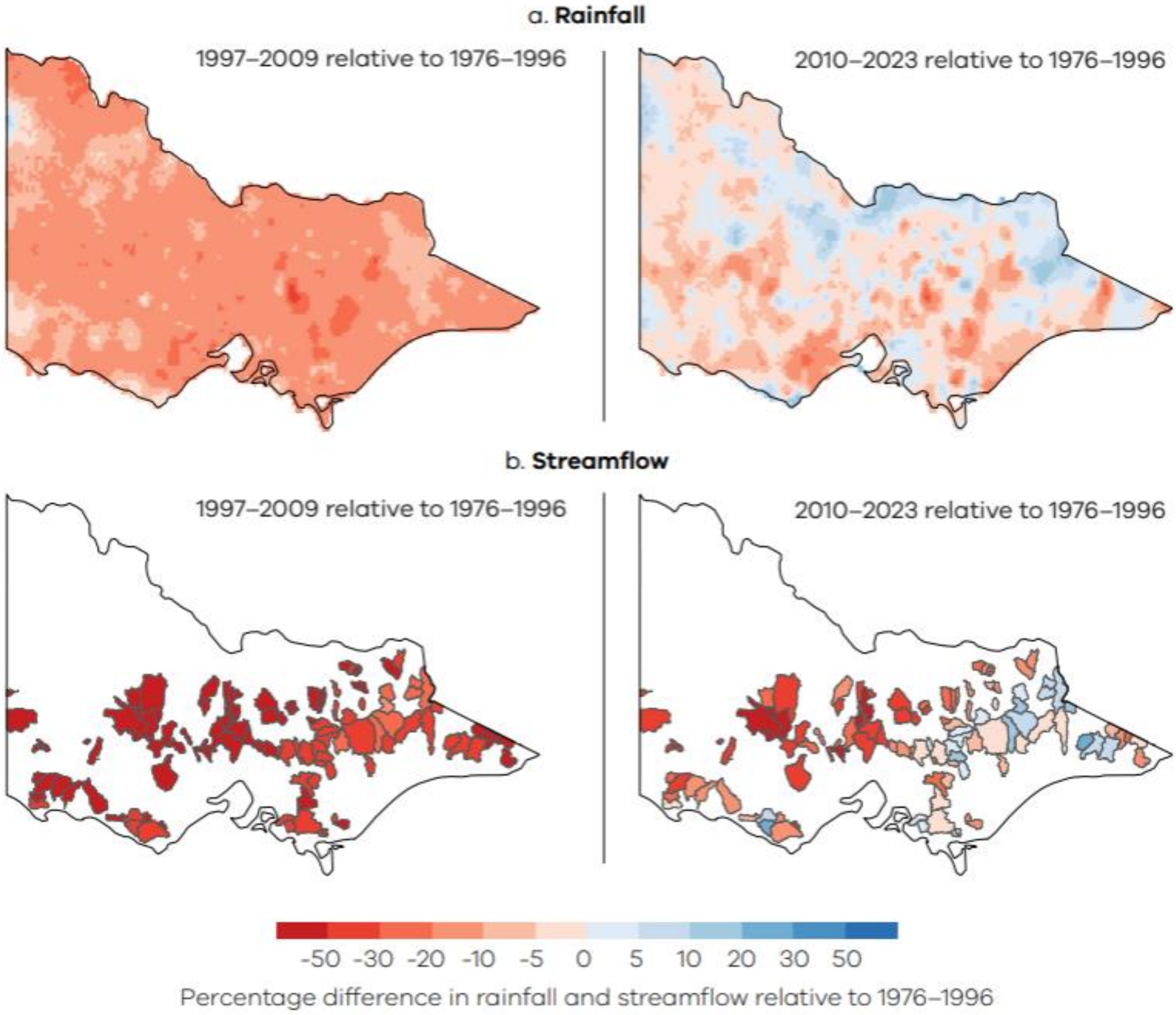

Figure 3-2 Percentage change in observed mean rainfall (a) and mean streamflow (b) in 1997–2009 during the Millennium Drought (left column) and in 2010–2023 after the drought (right column) relative to 1976–96 (pre-drought). Blue colours represent increased rainfall and streamflow, while red colours represent a reduction. (Source: CSIRO)

3.3 Improvement of previous STEDI models in the Maribyrnong and Moorabool basins

STEDI models apply data on the maximum surface area of water bodies in the catchment captured from aerial photography or satellite imagery, to estimate the maximum storage volume of each farm dam. There are uncertainties in estimating the volume of each water body and in being sure about which water bodies are farm dams and which are other water bodies, such as natural wetlands or wastewater treatment ponds. The STEDI models also make assumptions about the demand that is extracted from each farm dam for use in each year (normally as a function of each dam's estimated storage volume), the catchment area upstream of each farm dam (which influences the volume of inflow that each dam captures), rainfall on and evaporation from the surface area of each dam and the spatial connectivity of dam impacts in each subcatchment.

The existing Maribyrnong and Moorabool Source models available to inform this current study previously included STEDI models to represent the small catchment dams in each subcatchment. That is, there are 19 existing STEDI models for catchments in the Maribyrnong system and 16 existing STEDI models for subcatchments in the Moorabool system. All of these models were “level 1” STEDI models, which made relatively simple assumptions about the spatial arrangement and catchment areas of each individual farm dams. The previous level 1 STEDI models ignored the spatial connectivity of farm dams in each subcatchment (i.e. ignoring the fact that dams are often in chains along a stream, where one farm dam may fill and then water spilling from that dam, along with local inflows, would be captured by dams that are further downstream along the chain) and that the local catchment area draining to each farm dam is a simple linear function of the storage volume of the dam (i.e. the upstream catchment area for each dam is not known; instead it is assumed that farm dams with larger volumes collect runoff from a larger upstream area).

Level 2 STEDI models were set up for every subcatchment in the Maribyrnong and Moorabool basin. These level 2 STEDI models explicitly represented the catchment draining to every water body in the catchment. The level 2 STEDI models demand factors by water body type as shown in Table 3-1. Note that all water bodies lose water via evaporation but gain water via direct rainfall on their surface. The previous level 1 STEDI models also assumed that the mean annual usage from each D&S farm dam was 50% of the estimated dam storage volume and that mean annual usage from each irrigation farm dam was 84% of the estimated dam storage volume.

Table 3-1 Proposed demand factors for water bodies in level 2 STEDI models

Water body type	Ratio of mean annual demand to storage volume
Licensed irrigation dams	0.84
Domestic and stock unlicensed dams	0.5
Quarry pits	0
Natural pools and wetlands	0
Aesthetic lakes	0
Wastewater treatment lagoons	0 (and no external catchment inflows or overflows)

3.4 Data on farm dams and water bodies

The key Victorian statewide data source is the *Farm Dams Boundaries* data set[1]. Although it is dated 2019, the mapping for the Maribyrnong and Moorabool catchments was completed using imagery captured in 2009 -2010. The attributes of the dataset were updated in 2018 to improve interpretation and usability. The data set includes licensed and unlicensed dams, mapped via manual interpretation with polygon boundaries to represent the extent of each dam when full. Attribution includes a flag for farm dams and runoff dams, date of source aerial imagery and licensing status, surface area and calculated volume (where the volume is estimated by applying the equation from Fowler et al., 2016).

To identify changes in farm dams (decommissioned & newly established) post-2009, Digital Earth Australia (DEA) Water Observation From Space (WOFS) data set was utilised. Dams that consistently

[1] State Government of Victoria, Department of Energy, Environment and Climate Action. Farm Dam Boundaries

lacked water in recent observations were flagged for potential removal. Additional water bodies appearing in the dataset after 2009 were identified, as these could be newly constructed water bodies or water bodies that were missed when the DELWP (2012) dataset was compiled. Each identified change was subjected to review through comparing historical and recent aerial imagery. The volume of these newly constructed dams was estimated using the same methodology as that used in the stakeholder provided datasets (Fowler *et al.*, 2016).

Based on the metadata, the WOFS data was collected on 31 December 2023 and published on 7 March 2024 Geoscience Australia DEA data hub. The currency of the satellite imagery from Google Earth covering the study area as:

- **Maribyrnong Catchment –** captured between September 2023 to February 2024.
- **Moorabool Catchment –** captured between January and February 2024.

Stakeholder provided farm dam information was incorporated into this study. Cross-checking with the recent satellite imagery was performed to confirm the existence and current status of the farm dams reported by stakeholders. Collectively, these additions significantly enhanced the comprehensiveness of this study, ensuring that developments after the publication of the DELWP (2012) dataset were accurately captured. The updated dataset provided a more contemporary foundation for analysing the impact of farm dams on water resources within the catchments.

4. Modelling scenarios

The Source and STEDI models in the Barwon-Moorabool and Maribyrnong systems have been calibrated to recorded streamflow and climate data over the full historical period of record.

In accordance with the *Guidelines for assessing the impact of climate change on water availability in Victoria* (Department of Environment Land Water and Planning, 2020), the representation of current conditions uses data on inflows and climate for the full historical period but with data recorded prior to 1975 adjusted to be statistically equivalent to data from the post-1975 period.

The proposed scenarios are as follows:

- **2009 / 2010 level of development scenario:** updating the farm dam impacts in the baseline scenario models with farm dam impacts derived using the upgraded Level 2 STEDI models and water body inputs from the DELWP (2012) data set.
- **Unimpacted by farm dams scenario:** current Source models (from Baseline scenario) but with all farm dam impacts set to zero.
- **2025 level of development scenario:** updating the farm dam impacts from the 2009/2010 level of development scenario with farm dam impacts derived from the Level 2 STEDI models with current (2025) spatial data on water bodies.
- **2025 level of development with projected climate change scenario:** as for the previous scenario (using current spatial data on water bodies) but with all climate and inflow data re-scaled to represent the 2065 RCP 4.5 Medium sensitivity climate change projections (see Table 4-1).

Table 4-1 Projected changes in mean annual rainfall and inflows for 2065 Representative Concentration Pathway 4.5 W/m^2 (RCP 4.5) Medium climate change sensitivity scenario, relative to mid-point of post-1975 period (DELWP, 2020)

Projection	Maribyrnong mean annual rainfall	Moorabool mean annual rainfall	Maribyrnong mean annual streamflow	Moorabool mean annual streamflow
2065 RCP4.5Medium	-3.3%	-3.2%	-9.7%	-7.1%

All model scenarios included the same assumptions for current large dams and water infrastructure, current licensed entitlements and demands and current operational and environmental flow rules.

5. Number and storage volume of farm dams

5.1 Maribyrnong catchment

Table 5-1 lists the total number of water bodies, by type, in the Maribyrnong catchment for the 2009 and 2025 level of development. Domestic and stock farm dams constitute by far the largest proportion of water bodies in the Maribyrnong catchment. There was an increase of 2% in the total number of domestic and stock farm dams in the Maribyrnong between 2009 and 2025.

Table 5-1 Number of water bodies in the Maribyrnong catchment by type for 2009 and 2025 level of development

Type of water body	2009 Level of farm dam development	2025 Level of farm dam development	Change between 2009 and 2025	% Change between 2009 and 2025
Domestic and stock farm dam	6,774	6,938	164	2%
Licensed irrigation farm dam	106	109	3	3%
Golf course irrigation dam	6	7	1	17%
Subtotal: Rural farm dams	**6,886**	**7,054**	**168**	**2%**
Quarry pit	11	15	4	36%
Natural lakes and wetlands	58	57	-1	-2%
Public aesthetic lakes and other water bodies	16	13	-3	-19%
Wastewater treatment plant and recycled water plant lagoons	2	2	0	0%
Total: water bodies modelled in STEDI	**6,973**	**7,141**	**168**	**2%**

The storage capacity (V in ML), of each water body was estimated from their surface area (S in m²) from the equation provided in (Fowler et al., 2015):

$$V = 0.00001042\ S^{1.3213}$$

Storage volumes were calculated for each subcatchment in the Maribyrnong for the 2009 and 2025 levels of development by calculating the volumes for each water body that was present in the spatial data at that time and then aggregating the total volumes by subcatchment. Table 5-4 shows the total storage volume of farm dams for the 2009 and 2025 levels of development in the Maribyrnong catchment. The increases in storage volume of domestic and stock and licensed irrigation farm dams and irrigation lakes on golf courses increased by 16% over the 16 year period. The estimated storage volume of rural farm dams increased by 16%, which was considerably larger than the 2% increase in the number of rural farm dams. This difference was due to the enlargement of the surface area of existing farm dams, which increased the estimated total storage volume.

There were also changes over the 2009 to 2025 period in the numbers and volumes of other water bodies, which include quarry pits, natural lakes and wetlands and aesthetic lakes on public land, such as parks. Whilst these other water bodies are represented in the STEDI models (see Section 6), their numbers and volumes are considerably lower than rural farm dams and it is the rural farm dams that have the largest influence on changes in impact on streamflow.

Table 5-2 Storage volume of water bodies in the Maribyrnong catchment by type for 2009 and 2025 level of development

Type of water body	2009 Level of farm dam development (ML)	2025 Level of farm dam development (ML)	Change between 2009 and 2025 (ML)	% Change between 2009 and 2025
Domestic and stock farm dam	11,657	12,453	796	7%
Licensed irrigation farm dam	516	1,592	1,077	209%
Golf course irrigation dam	26	47	21	79%
Subtotal: Rural farm dams	**12,199**	**14,092**	**1,893**	**16%**
Quarry pit	28	60	32	115%
Natural lakes and wetlands	221	221	0	0%
Public aesthetic lakes and other water bodies	155	156	1	1%

There is considerable spatial variation in the numbers, volume and estimated impact of farm dams across the Maribyrnong basin.

Figure 5-1 shows that most of the increase in storage volume between 2009 and 2025 occurred in 4 of the 21 subcatchments in the Maribyrnong basin, albeit that those are 4 of the larger subcatchments by area.

5.2 Moorabool catchment

Table 5-3 shows that the number of farm dams has increased in the Moorabool catchment by 4% between 2010 and 2025. Domestic and stock farm dams constitute by far the largest proportion of water bodies in the Moorabool catchment.

Table 5-3 Number of water bodies in the Moorabool catchment by type for 2010 and 2025 level of development

Type of water body	2010 Level of farm dam development	2025 Level of farm dam development	Change between 2010 and 2025	% Change between 2010 and 2025
Domestic and stock farm dam	5,749	5,996	247	4%
Licensed irrigation farm dam	294	298	4	1%
Golf course irrigation dam	0	0	0	0%
Subtotal: Rural farm dams	**6,043**	**6,294**	**251**	**4%**
Quarry pit	33	60	27	82%
Natural lakes and wetlands	19	18	-1	-5%
Public aesthetic lakes and other water bodies	15	16	1	7%
Wastewater treatment plant and recycled water plant lagoons	11	11	0	0%
Total: water bodies modelled in STEDI	**6,121**	**6,399**	**278**	**5%**
Dams operated by water corporations	8	8	0	0%

The storage capacity (V in ML), of each water body was estimated from their surface area (S in m²) from the equation provided in (Fowler et al., 2015):

$$V = 0.00001042\ S^{1.3213}$$

Storage volumes were calculated for each subcatchment in the Maribyrnong for the 2009 and 2025 levels of development by calculating the volumes for each water body that was present in the spatial data at that time and then aggregating the total volumes by subcatchment.

Table 5-4 shows that the total storage volume of farm dams has increased in the Moorabool catchment by 20% between 2010 and 2025. There was an increase over this period in domestic and stock dams and licensed irrigation farm dams. The estimated storage volume of rural farm dams increased by 20%, which was considerably larger than the 4% increase in the number of rural farm dams. This difference was due to the enlargement of the surface area of existing farm dams, which increased the estimated total storage volume.

There were also changes over the 2010 to 2025 period in the numbers and volumes of other water bodies, which include quarry pits, natural lakes and wetlands and aesthetic lakes on public land, such as parks. Whilst these other water bodies are represented in the STEDI models (see Section 6), their numbers and volumes are considerably lower than rural farm dams and it is the rural farm dams that have the largest influence on changes in estimated impact on streamflow.

Table 5-4 Storage volume of water bodies in the Moorabool catchment by type for 2010 and 2025 level of development

Type of water body	2010 Level of farm dam development (ML)	2025 Level of farm dam development (ML)	Change between 2010 and 2025 (ML)	% Change between 2010 and 2025
Domestic and stock farm dam	14,880	18,059	3,179	21%
Licensed irrigation farm dam	2,177	2,458	282	13%
Golf course irrigation dam	0	0	0	0%
Subtotal: Rural farm dams	**17,057**	**20,517**	**3,460**	**20%**
Quarry pit	40	372	331	824%
Natural lakes and wetlands	93	86	-7	-8%
Public aesthetic lakes and other water bodies	4	26	22	518%

Spatial variation in the numbers, volume and estimated impact of farm dams across the Moorabool basin is considerable and probably more marked than spatial variation in these characteristics across the Maribyrnong basin.

Figure 5-2 shows that most of the increase in storage volume between 2010 and 2025 occurred in 2 of the 16 subcatchments in the Moorabool basin, albeit that those are 2 of the larger subcatchments by area (the Lal Lal Creek subcatchment and the mid-Moorabool River between Morrisons and Sheaoaks Diversion Weir).

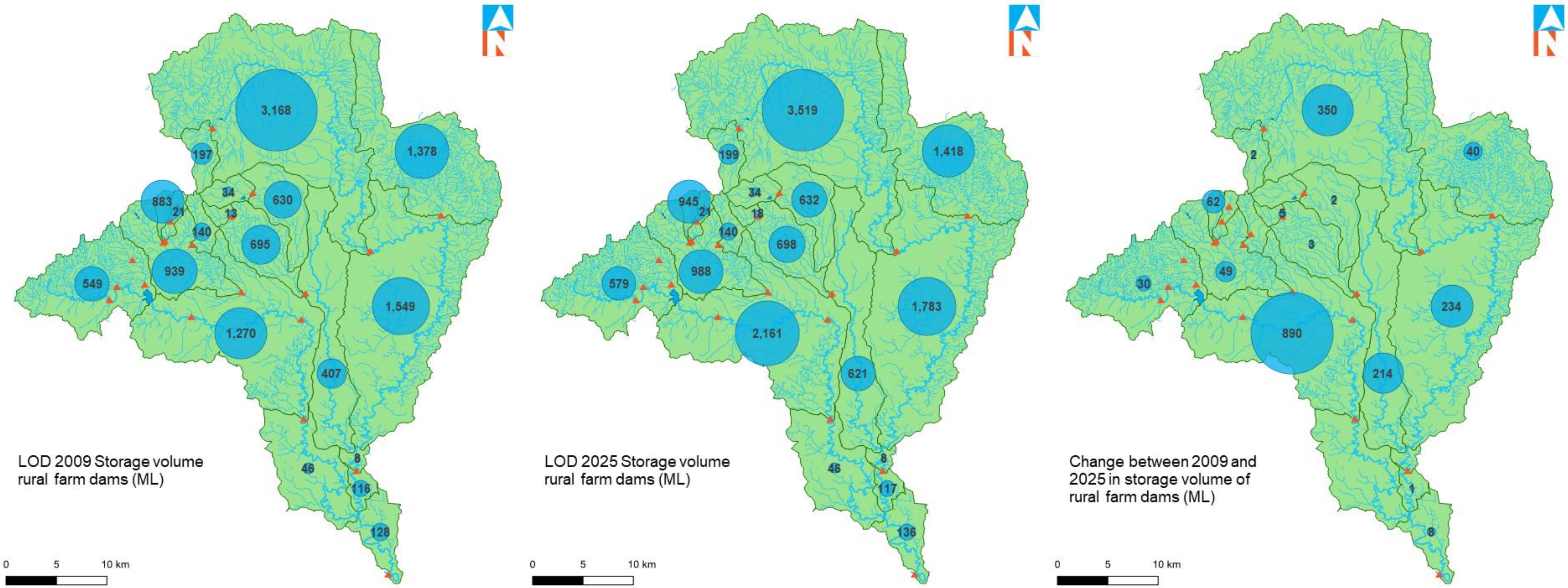

Figure 5-1 Storage volume of farm dams in subcatchments of the Maribyrnong: (left) 2010 farm dams; (centre) 2025 farm dams; (right) change in storage volume between 2010 and 2025 level of development

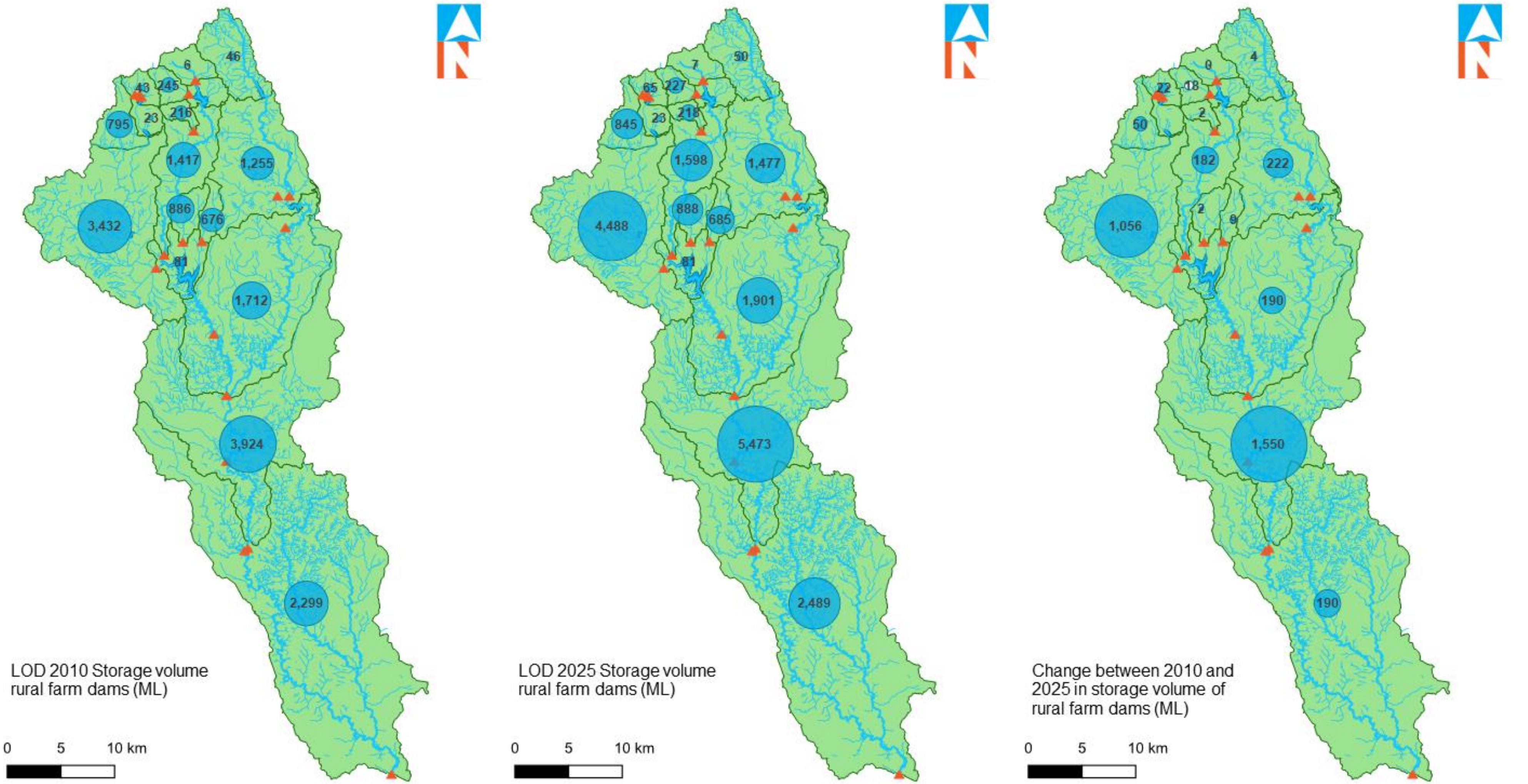

Figure 5-2 Storage volume of farm dams in subcatchments of the Moorabool: (left) 2010 farm dams; (centre) 2025 farm dams; (right) change in storage volume between 2010 and 2025 level of development

6. Estimated impact of farm dams on streamflow

There is spatial variation in the number, volume and density of farm dams and other water bodies across both the Maribyrnong and Moorabool catchments. There are also spatial variations in generation of runoff across the Maribyrnong and Moorabool catchments and these spatial variations in runoff generation and farm dam arrangement interact to produce spatial variations in the estimated impact of farm dams on streamflow. The estimated impact of farm dams also varies from year to year, in accordance with year to year variations in rainfall, evapotranspiration and runoff across each of the catchments. Uncertainties in modelling of farm dam impacts are discussed further in Section 3.2.

This section presents results for the Maribyrnong and then the Moorabool basins. Results were produced from the STEDI models for each of the subcatchments in each basin, with runs undertaken for the 2009/2010 and 2025 level of farm dam development scenarios and for a 2025 level of farm dam development with projected climate change scenario. For each catchment, results are addressed firstly for temporal (year to year variations) in estimated farm dam impact, then for spatial variations in estimated farm dam impact and finally a summary of overall estimated farm dam impact is provided.

6.1 Temporal variation in estimated farm dam impact across the Maribyrnong

Figure 6-1 and Figure 6-2 show an annual time series of the estimated impact of water bodies in the Maribyrnong catchment for the 2009 and 2025 level of development scenarios, respectively. In both scenarios, quarries, natural water bodies and public recreational aesthetic lakes make minimal contribution to the overall take of small water bodies. In both the 2009 and 2025 level of development scenarios, most of the estimated impact is due to domestic and stock dams, with a smaller contribution in total from licensed farm dams.

Figure 6-1 and Figure 6-2 also demonstrate the considerable year to year variability in the estimated impact of farm dams on flows in the Maribyrnong catchment. For example, estimated farm dam impacts in the water year starting July 2010 were the largest of any year that was modelled, as farm dams refilled during this wet La Niña year that followed the Millennium Drought (1997-2009). The estimated farm dam impacts were low in the 2001, 2002, 2005, 2006, 2007, 2008 and 2009 water years which were all dry years in the Millennium Drought. Inflows to many farm dams were low during these years, so many dams would have been at or near empty and this would have reduced their overall take.

The volume of farm dams is larger for the 2025 than the 2009 level of farm dam development scenario, which increases the volume of take in each year, which can be seen by comparing the orange with the blue lines in Figure 6-3. With projected climate change, the total estimated impact of farm dams in the Maribyrnong is projected to further increase, as demonstrated by the grey line sitting above the orange line in Figure 6-3. The estimated impact of the current (2025) farm dams will therefore increase on the whole across the Maribyrnong catchment due to the projected influence of climate change, as farm dams capture a larger proportion of flow, even if there is no further change in the number or volume of farm dams from the current level of development.

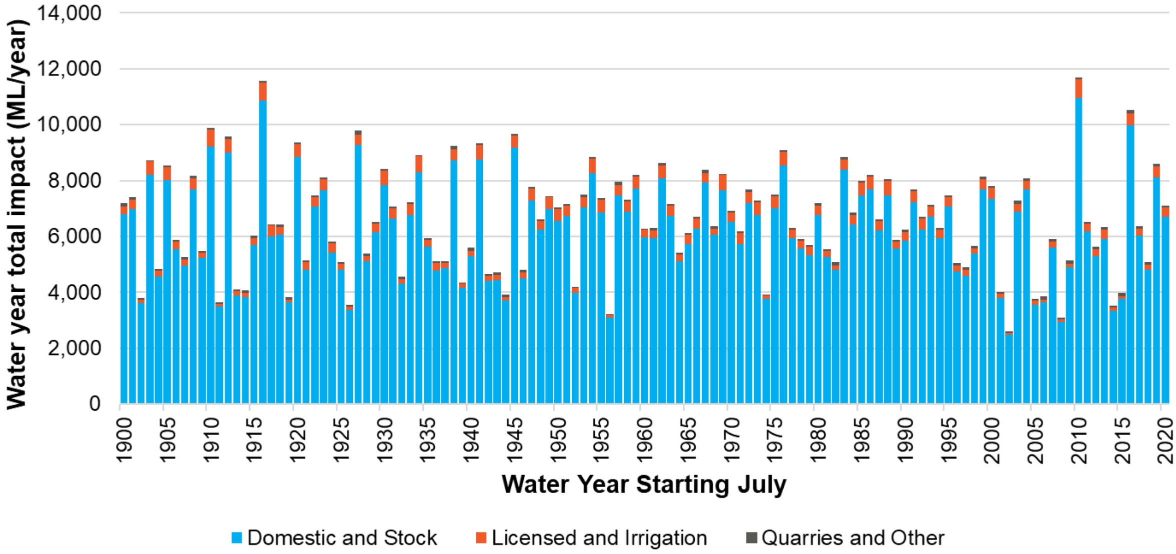

Figure 6-1 Annual estimated impact of farm dams and other small water bodies in the Maribyrnong catchment for 2009 level of farm dam development (DELWP 2012 data set)

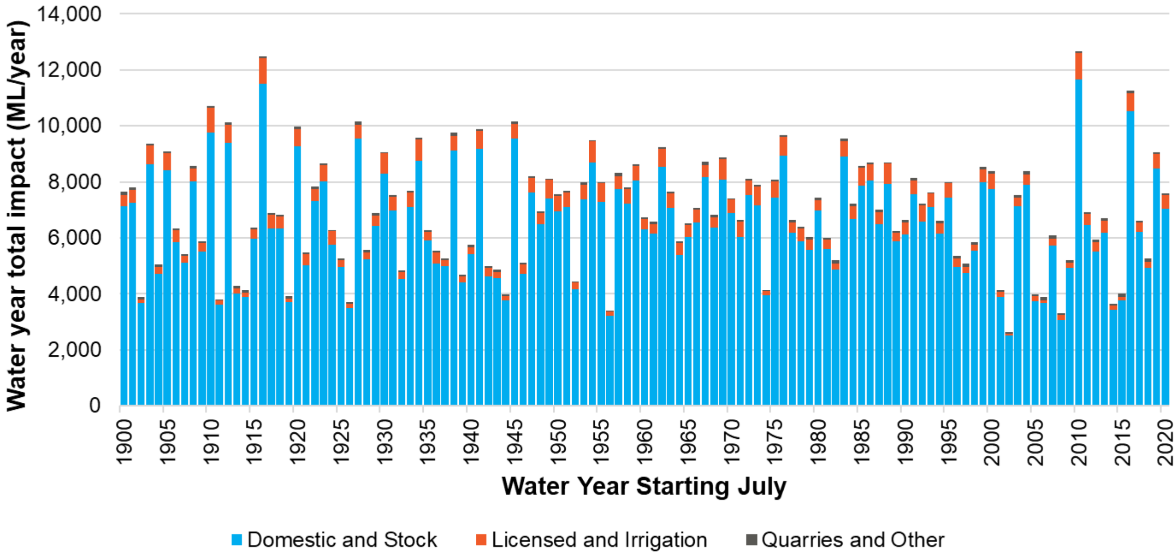

Figure 6-2 Annual estimated impact of farm dams and other small water bodies in the Maribyrnong catchment for 2025 level of farm dam development (updated data set)

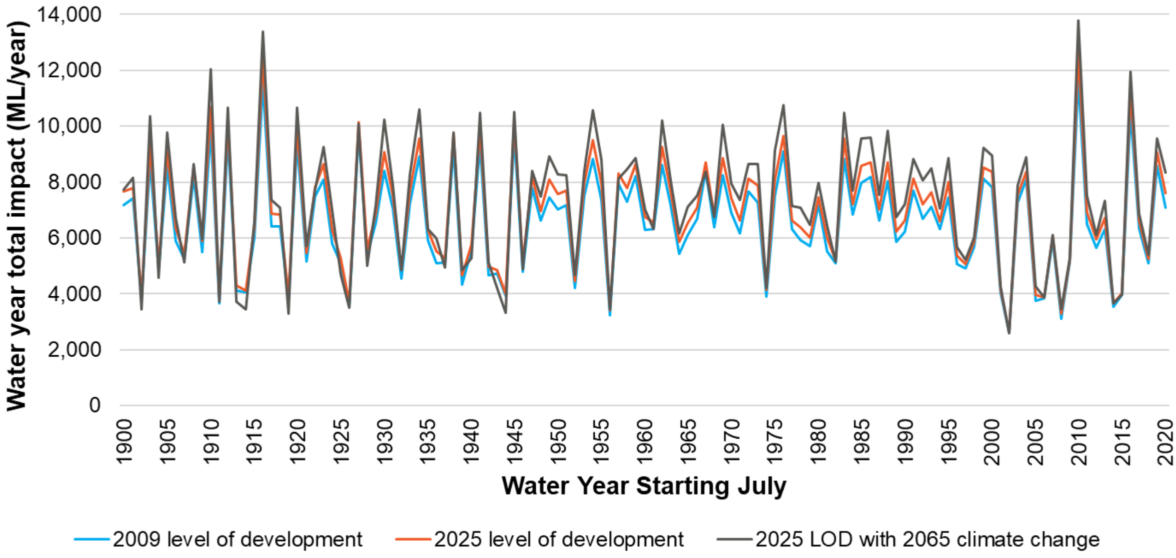

Figure 6-3 Comparison of annual estimated impact of farm dams in the Maribyrnong catchment between 2009 and 2025 levels of development and 2025 level of development with climate change projection for 2065 Medium RCP 4.5

6.2 Spatial variation in farm dam estimated impact across the Maribyrnong

Figure 6-4 shows the mean annual estimated impact by subcatchment area for the 2009, 2025 and 2025 with projected climate change scenarios. The largest mean annual estimated impact by volume generally occur in the largest subcatchments.

Figure 6-5 shows the mean annual estimated impact divided by the area of each subcatchment, which allows more useful comparison of spatial variations in farm dam impact across the Maribyrnong catchment. The pattern of spatial variation in estimated impact is similar between the three scenarios but the estimated impact generally increase between the 2009 and 2025 levels of development and then increase again with the climate change projection. For the 2025 level of development, the mean annual estimated impact are between 6.9 and 8.1 ML/year/km² in the Deep and Garden Hut Creek upstream of Bolinda, Boyd Creek, Main Creek, Bolinda Creek and Riddells Creek subcatchments. Mean annual estimated impact are generally less than 4.5 ML/year/km² in the remaining subcatchments (i.e upstream of Rosslynne Reservoir, Emu Creek, Jacksons Creek, Deep Creek downstream of Bolinda and Boyd Creek and the Maribyrnong River).

Figure 6-6 shows the spatial variation in mean annual estimated impact as a percentage of the mean annual inflow in each subcatchment of the Maribyrnong. The same catchments that have a large mean annual impact per unit catchment area (Deep and Garden Hut Creek upstream of Bolinda, Boyd Creek, Main Creek, Bolinda Creek and Riddells Creek) also have farm dam takes of between 11% and 24% of inflows before farm dam impacts for the 2025 level of development. Farm dam takes are less than 8% of inflows across most of the remaining subcatchments of the Maribyrnong. Figure 6-6 shows that percentage takes increase between the 2009 and 2025 levels of development and are projected to increase again with climate change for the 2065 medium RCP 4.5 projection.

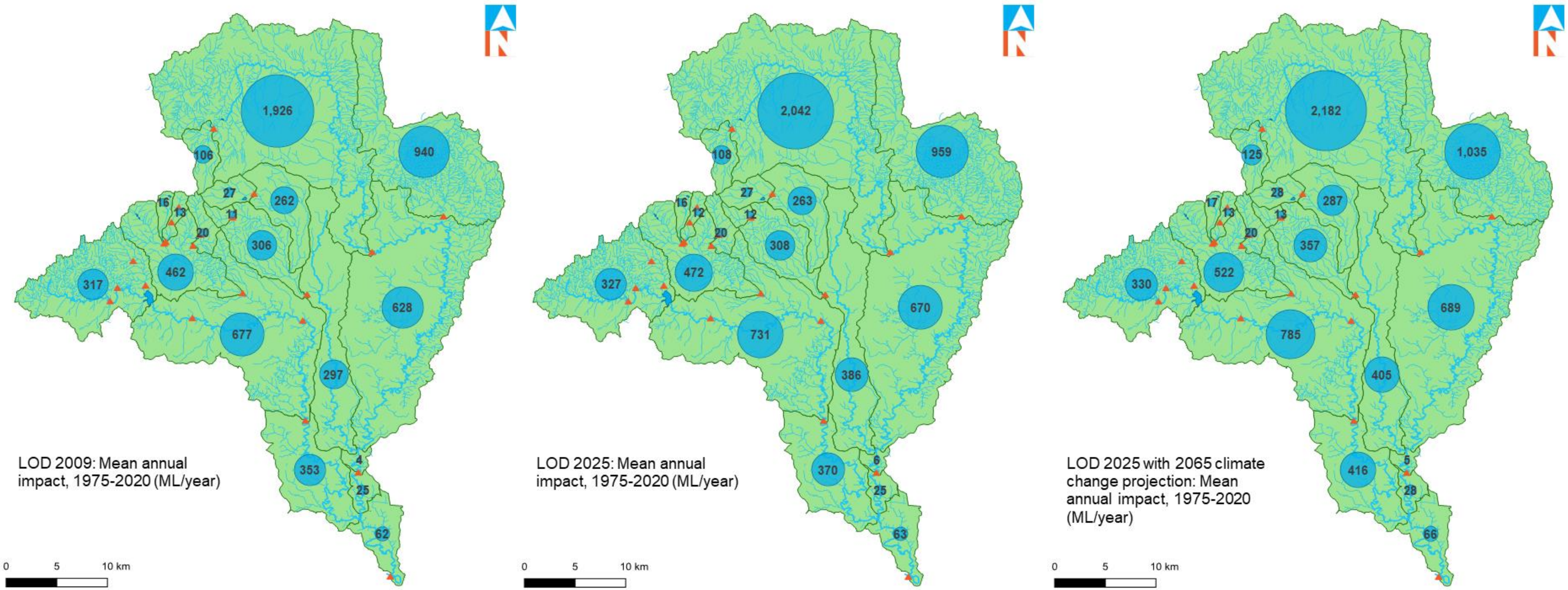

Figure 6-4 Mean annual estimated impact of farm dams in subcatchments of the Maribyrnong (all assessed across 1975-2020 period): (left) 2009 farm dams; (centre) 2025 farm dams; (right) 2025 farm dams with projected climate change for 2065 medium RCP4.5 projection

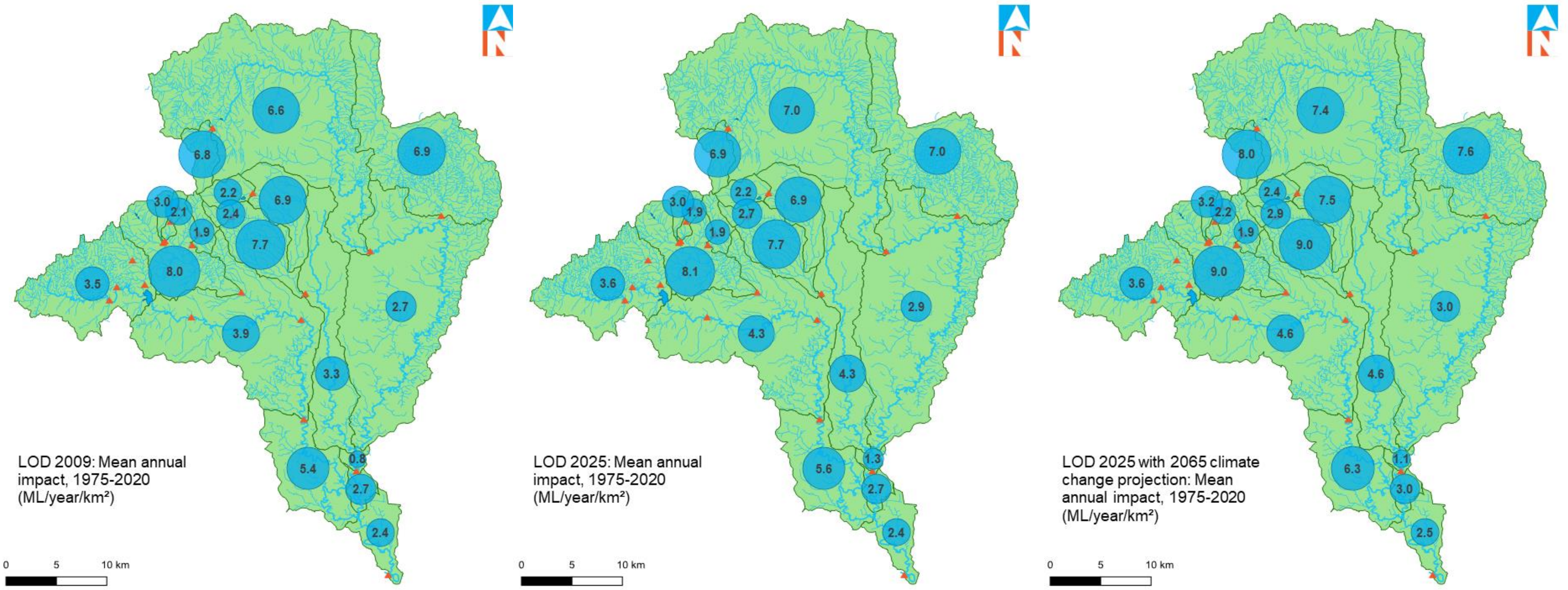

Figure 6-5 Mean annual estimated impact of farm dams per unit area in subcatchments of the Maribyrnong (all assessed across 1975-2020 period): (left) 2009 farm dams; (centre) 2025 farm dams; (right) 2025 farm dams with projected climate change for 2065 medium RCP4.5 projection

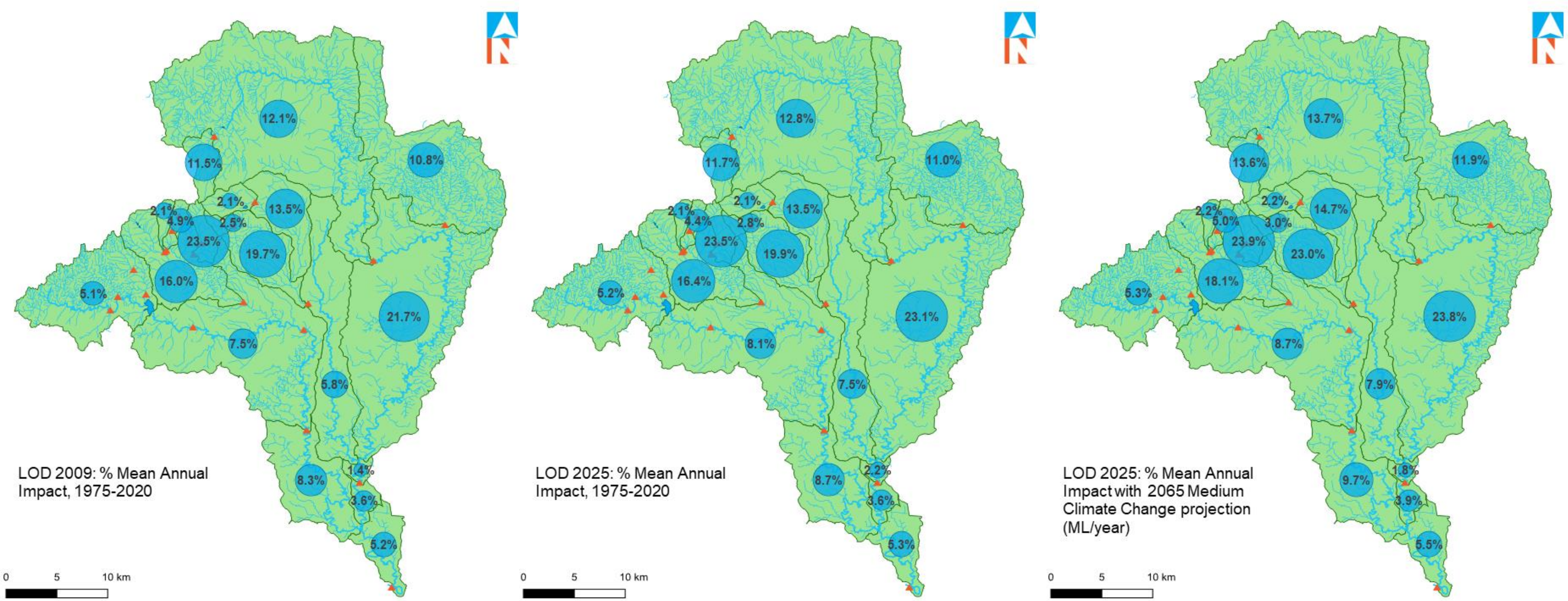

Figure 6-6 Mean annual estimated impact of farm dams as a proportion of no farm dams inflow in subcatchments of the Maribyrnong (all assessed across 1975-2020 period): (left) 2009 farm dams; (centre) 2025 farm dams; (right) 2025 farm dams with projected climate change for 2065 medium RCP4.5 projection

6.3 Temporal variation in farm dam estimated impact in the Moorabool

Figure 6-7 and Figure 6-8 show an annual time series of the estimated impact of water bodies in the Moorabool catchment for the 2010 and 2025 level of development scenarios, respectively. In both scenarios, quarries, natural water bodies and public recreational aesthetic lakes make minimal contribution to the overall take of small water bodies. In both the 2010 and 2025 level of development scenarios, most of the estimated impact is due to domestic and stock dams, with a smaller contribution in total from licensed farm dams.

Figure 6-7 and Figure 6-8 also demonstrate the considerable year to year variability in the estimated impact of farm dams on flows in the Moorabool catchment. For example, farm dam impacts in the water year starting July 2010 were the largest of any year that was modelled, as farm dams refilled during this wet La Niña year that followed the Millennium Drought (1997-2009). The total volume of estimated farm dam impact was low in the 2001, 2002, 2005, 2006, 2007, 2008 and 2009 water years, which were all dry years in the Millennium Drought. Inflows to many farm dams were low during these years, so many dams would have been at or near empty and this would have reduced their overall take.

The volume of farm dams is larger for the 2025 than the 2010 level of farm dam development scenario, which increases the volume of take in each year, which can be seen by comparing the orange with the blue lines in Figure 6-9.

The combined estimated impact of projected climate change and farm dams in the Moorabool catchment is somewhat more complicated than it is in the Maribyrnong catchment. As will be discussed below, some subcatchments in the Moorabool already have a very high density of farm dam development. When the existing number and volume of farm dams is high, the reduction in inflows projected with climate change reduces the total volume taken by those farm dams in dry years, as the dams run dry more often. Projected take under dryer climate conditions will be less due to the reduction in overall water availability but will make up a greater portion of the total volume.

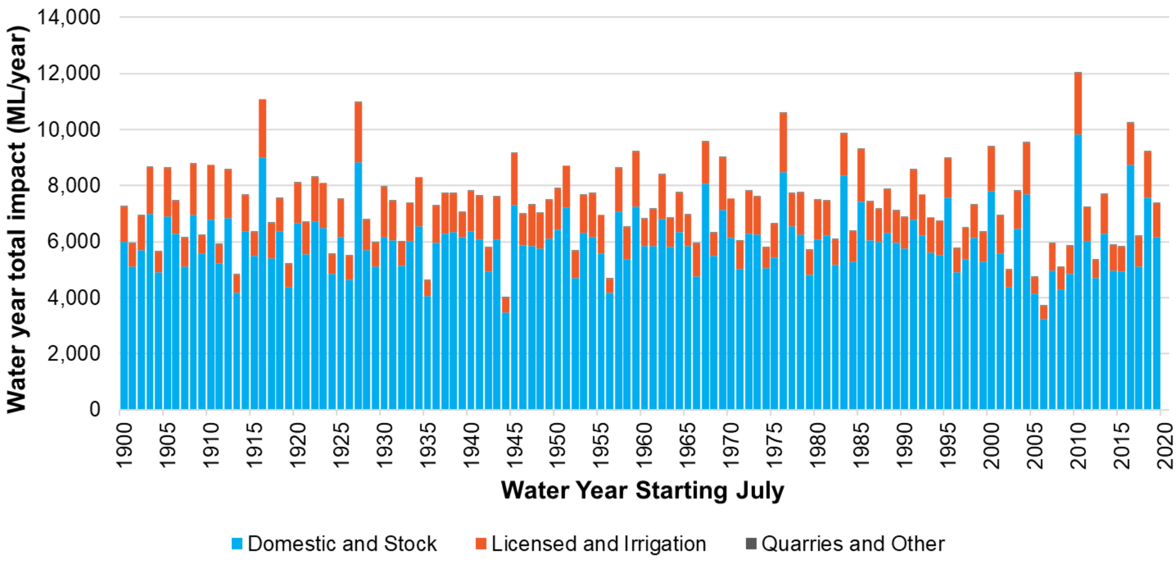

Figure 6-7 Annual estimated impact of farm dams and other small water bodies in the Moorabool catchment for 2010 level of farm dam development (DELWP 2012 data set)

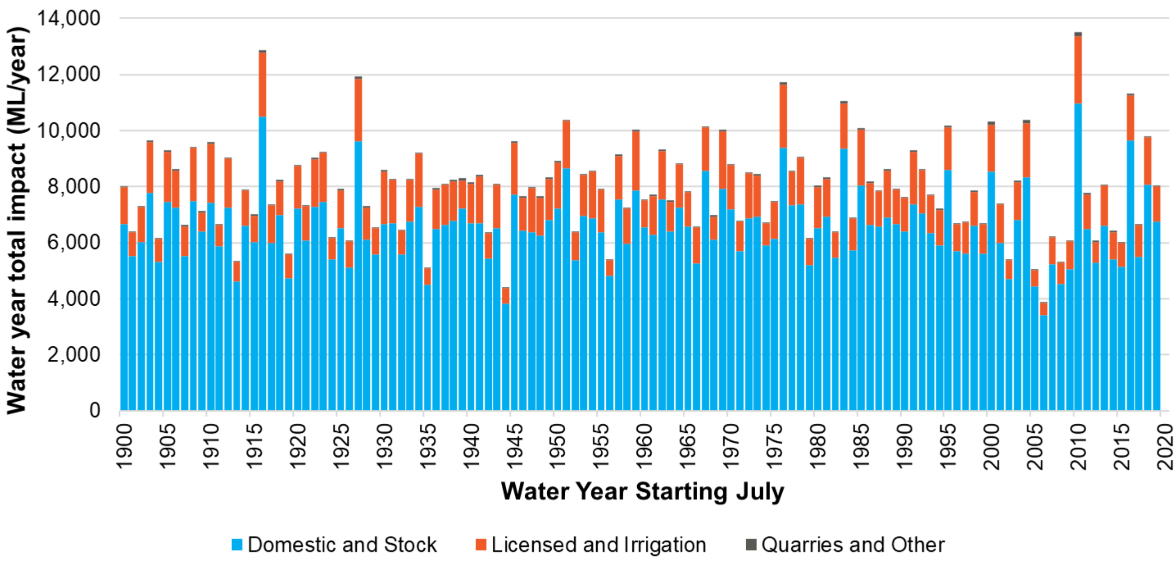

Figure 6-8 Annual estimated impact of farm dams and other small water bodies in the Moorabool catchment for 2025 level of farm dam development (updated data set)

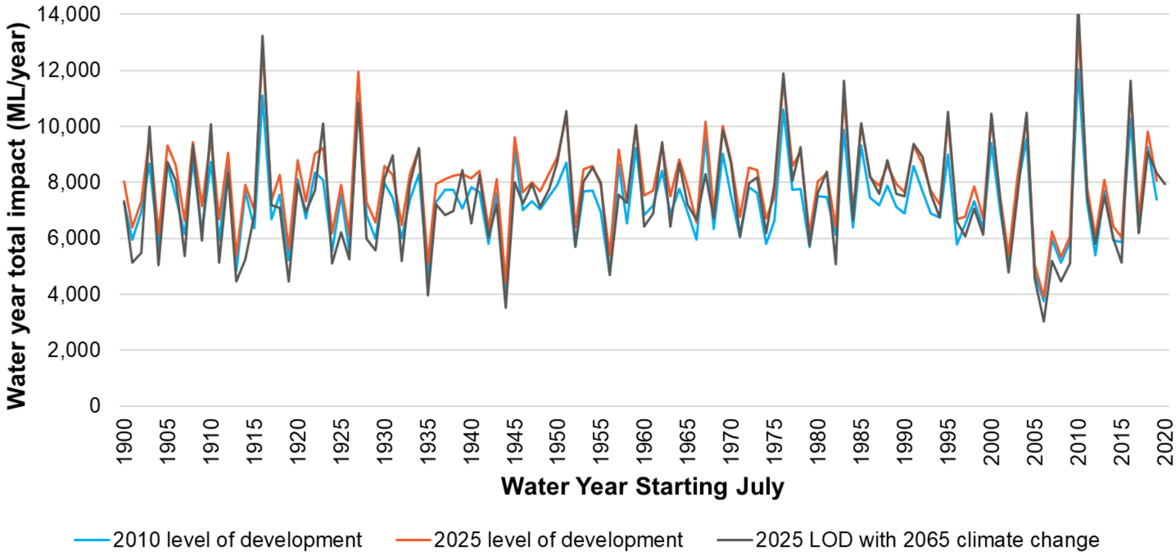

Figure 6-9 Comparison of annual estimated impact of farm dams in the Moorabool catchment between 2010 and 2025 levels of development and 2025 level of development with climate change projection for 2065 Medium RCP 4.5

6.4 Spatial variation in farm dam estimated impact across the Moorabool

Figure 6-10 shows the mean annual estimated impact by subcatchment area for the 2010, 2025 and 2025 with projected climate change scenarios in the Moorabool catchment. The largest mean annual estimated impact by volume generally occur in the largest subcatchments.

Two subcatchments of the Moorabool, Black Creek and Woollen Creek, already have some of the highest densities of farm dam development and mean annual impact in Victoria. Figure 6-11 shows that the estimated takes in these two subcatchments were 37.8 ML/yr/km² for Black Creek and 42.7 ML/yr/km² for Woollen Creek of mean annual inflows under the 2025 level of development scenario, which were both slightly larger than for the 2010 level of development. Estimated farm dam impacts also exceeded 12 ML/year/km² in 6 other subcatchments of the Moorabool: Whiskey Creek (23.96 ML/year/km² in 2025 level of development), Devils Creek (14.1 ML/year/km²), Moorabool River West Branch between Moorabool Reservoir and Bungal Dam (14.7 ML/year/km²), Geddes Creek upstream of White Swan Channel (23.1 ML/year/km²), Lal Lal Creek (12.6 ML/year/km² in 2025 level of development) and the Geddes Creek upstream of White Swan Channel (23.1 ML/year/km²).

Figure 6-12 shows that there are several subcatchments in the north of the basin where estimated farm dam impacts were less than 2% of mean annual inflows for 2010 and 2025 levels of development and impacts are projected to remain below 2% with projected climate change. Climate change is projected to increase the estimated impact of farm dams to more than 10% of mean annual inflows in several subcatchments, with the mean annual impact projected to reach almost 40% in the Black Creek subcatchment and more than 50% in the Woollen Creek catchment. Whilst there has been minimal growth in the volume of farm dams between 2010 and 2025 in both subcatchments (see Figure 5-2), climate change will reduce inflows which will substantially increase the estimated impact from the existing farm dams. In the subcatchments with the largest increases in total farm dam volume between 2010 and 2025 the combined estimated impact of farm dam growth (2010 to 2025) and projected climate change to 2065 will increase farm dam impacts from 9.7% to 12.6% of inflows in the Lal Lal Creek subcatchment and from 11.8% to 16% of inflows in the mid-Moorabool River between Morrisons and Sheaoaks Diversion Weir.

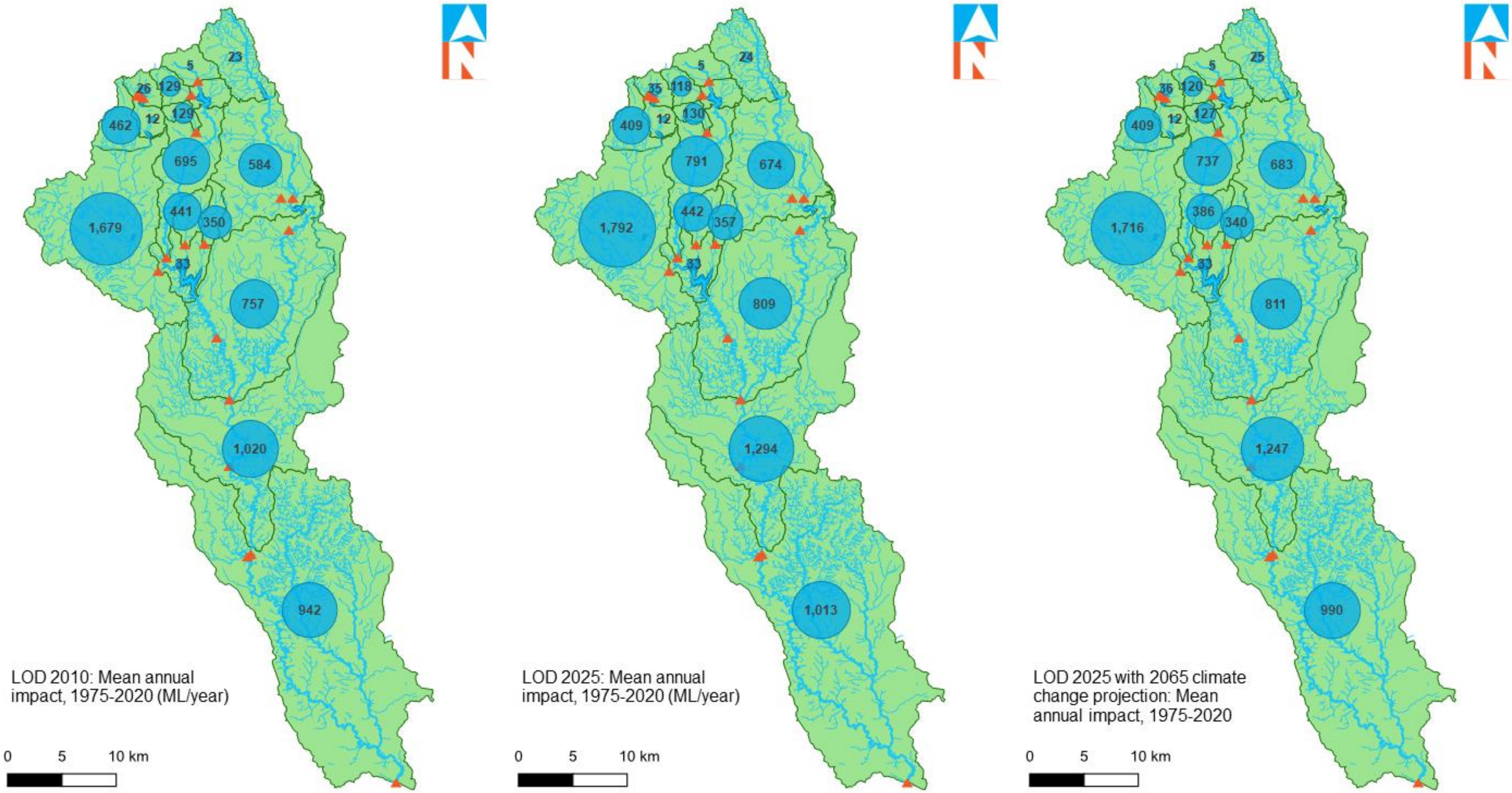

Figure 6-10 Mean annual estimated impact of farm dams in subcatchments of the Moorabool (all assessed across 1975-2020 period): (left) 2010 farm dams; (centre) 2025 farm dams; (right) 2025 farm dams with projected climate change for 2065 medium RCP4.5 projection

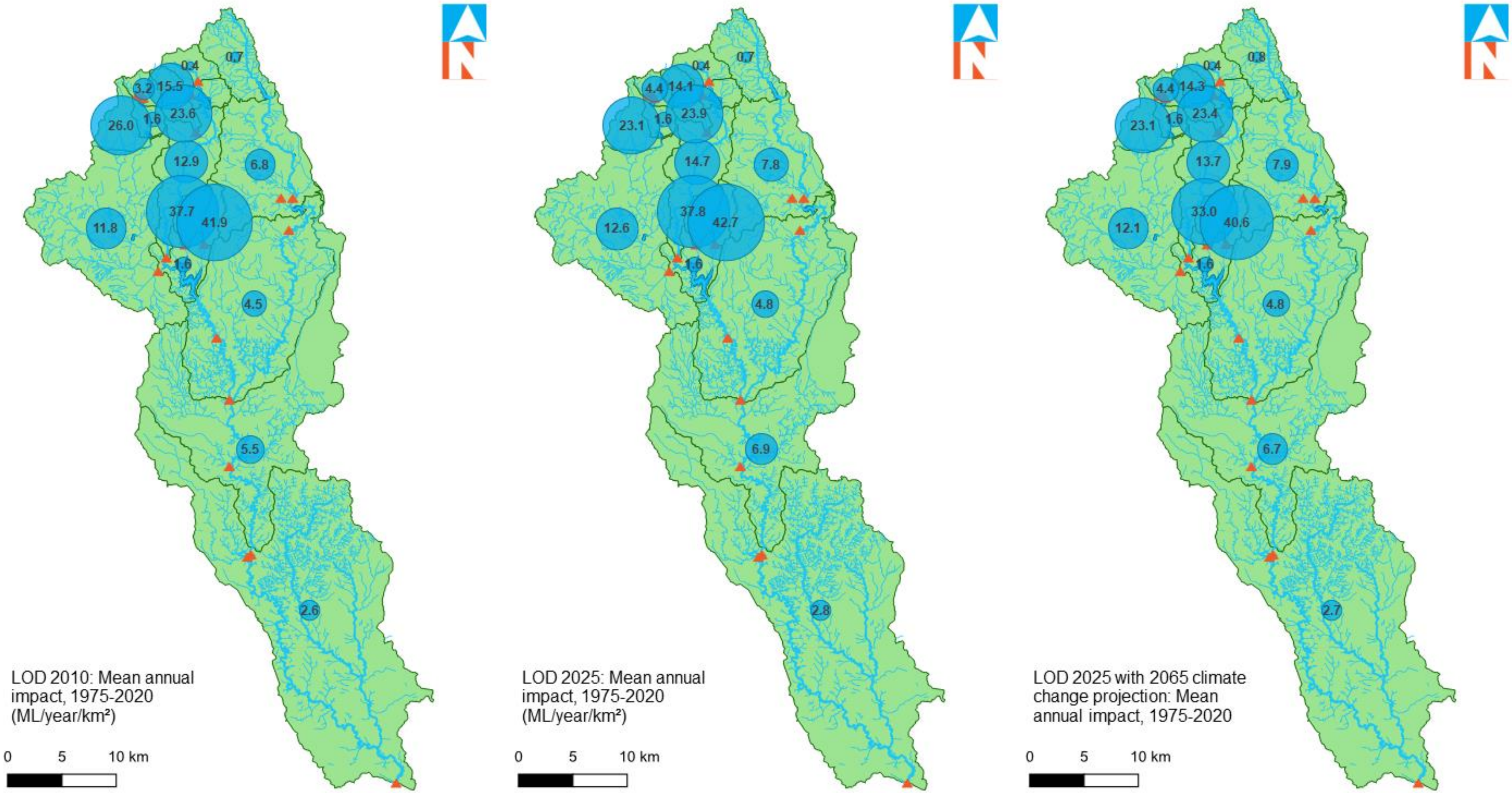

Figure 6-11 Mean annual estimated impact of farm dams per unit area in subcatchments of the Moorabool (all assessed across 1975-2020 period): (left) 2010 farm dams; (centre) 2025 farm dams; (right) 2025 farm dams with projected climate change for 2065 medium RCP4.5 projection

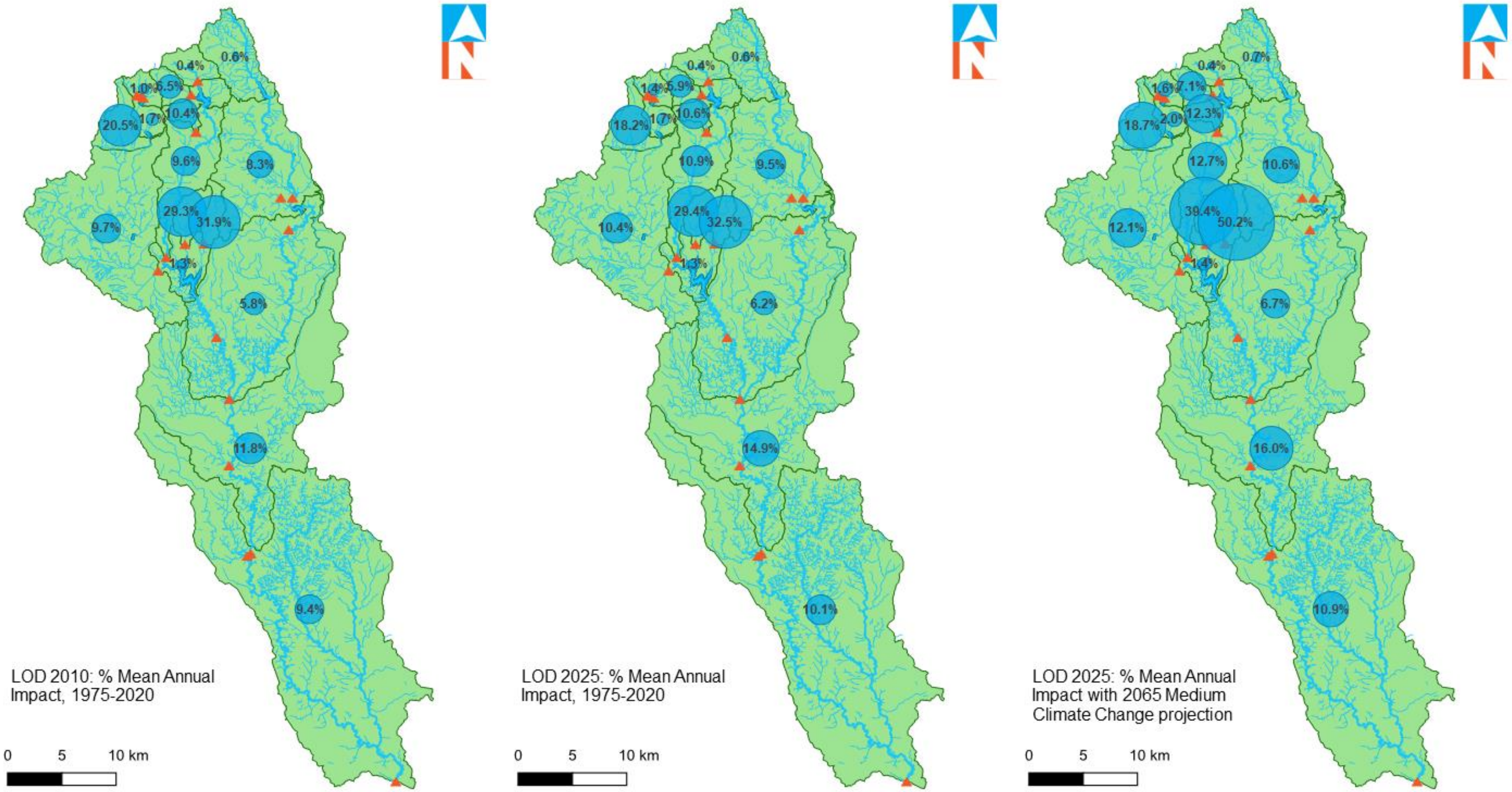

Figure 6-12 Mean annual estimated impact of farm dams as a proportion of no farm dams inflow in subcatchments of the Moorabool (all assessed across 1975-2020 period): (left) 2010 farm dams; (centre) 2025 farm dams; (right) 2025 farm dams with projected climate change for 2065 medium RCP4.5 projection

7. Summary of farm dam volumes and estimated impacts

7.1 Summary of estimated farm dam impacts in the Maribyrnong

Table 7-1 summarises the statistics of farm dam numbers, volume and estimated mean annual impact across the Maribyrnong catchment between 2009 and 2025 levels of development. There has been a 2% increase in the number of rural farm dams between 2009 and 2025, with the current number of farm dams at just over 7,000 dams. Over that 16 year period, there was a 16% increase in the estimated total storage volume of those rural farm dams, with the current total storage volume currently at just over 14,000 ML. The estimated mean annual impact of those farm dams has increased by 6% between the 2009 and 2025 levels of development. Whilst some farm dams have increased in storage volume over the 16 year period, the overall estimated impact of those farm dams is limited by overall inflows. A farm dam may increase in storage volume but the take from that dam may only increase in very wet years, when there are sufficient inflows to fill the dam. Increasing storage volumes in some farm dams within a catchment may also decrease spills and inflows to other farm dams that are downstream of them and constrain the increase in mean annual take at the subcatchment level.

Table 7-1 Comparisons of number, storage volume and estimated mean annual impact of farm dams in the Maribyrnong catchment between 2009 and 2025 level of development

Statistic	2009 Level of farm dam development	2025 Level of farm dam development	Change between 2009 and 2025	% Change between 2009 and 2025
Number of rural farm dams	6,886	7,054	168	2%
Storage volume of rural farm dams (ML)	12,199	14,092	1,893	16%
Estimated mean annual impact of farm dams (ML/year)	6,539	6,904	365	6%
Mean annual impact as proportion of unimpacted inflows	10.1%	10.7%	0.6%	6%

The increase in the number and volume of farm dams between 2009 and 2025 level of development has increased the mean annual take across the Maribyrnong catchment from 10.1% to 10.7% of mean annual inflows (see Table 7-1 and Table 7-2). Even without any further change in farm dams, with climate change mean annual farm dam impacts are projected to increase by a further 500 ML by 2065, to 11.5% of mean annual inflows (see Table 7-2).

Table 7-2 Comparisons of estimated mean annual impact of farm dams in the Maribyrnong catchment between 2009 and 2025 level of development and 2025 level of development with projected climate change

Statistic	2009 Level of farm dam development	2025 Level of farm dam development	2025 Level of farm dam development with projected climate change (2065 Medium RCP 4.5)	Change due to projected climate change
Estimated mean annual impact of farm dams (ML/year)	6,539	6,904	7,414	509
Mean annual impact as proportion of unimpacted inflows	10.1%	10.7%	11.5%	7%

7.2 Summary of estimated farm dam impacts in the Moorabool

Table 7-3 summarises the statistics of farm dam numbers, volume and estimated mean annual impact across the Moorabool catchment between 2010 and 2025 levels of development. There are almost 6,300 rural farm dams in the Moorabool basin (as at 2025), an increase in number of 4% since the 2010 level of development. The total storage capacity of rural farm dams has increased in the Moorabool basin by 20% since 2010 and is now approximately 20,500 ML. The estimated mean annual impact of those farm dams has increased by 9% between the 2010 and 2025 levels of development. Whilst some farm dams have increased in storage volume over the 15 year period, the overall estimated impact of those farm dams is limited by overall inflows, particularly in dry years and in parts of the catchment with already high densities of farm dam development. At the 2025 level of farm dam development, the estimated impact is currently 9.6% of mean annual inflows.

Table 7-3 Comparisons of number, storage volume and estimated mean annual impact of farm dams in the Moorabool catchment between 2010 and 2025 level of development

Statistic	2010 Level of farm dam development	2025 Level of farm dam development	Change between 2010 and 2025	% Change between 2010 and 2025
Number of rural farm dams	6,043	6,294	251	4%
Storage volume of rural farm dams (ML)	17,057	20,517	3,460	20%
Estimated mean annual impact of farm dams (ML/year)	7,287	7,939	652	9%
Mean annual impact as proportion of unimpacted inflows	8.8%	9.6%	0.8%	9%

Table 7-4 shows that the overall density of farm dams and projected reductions in inflow under climate change are such that the estimated volume of mean annual impact is projected to reduce slightly by 2065 due to reductions in runoff volume. However, the take is projected to increase from 9.6% to 10.6% of mean annual inflows under the 2065 medium RCP 4.5 climate change projection because the total volume of inflows are projected to decline in the Moorabool catchment.

Table 7-4 Comparisons of estimated mean annual impact of farm dams in the Moorabool catchment between 2010 and 2025 level of development and 2025 level of development with projected climate change

Statistic	2010 Level of farm dam development	2025 Level of farm dam development	2025 Level of farm dam development with projected climate change (2065 Medium RCP 4.5)	Change due to projected climate change
Estimated mean annual impact of farm dams (ML/year)	7,287	7,939	7,678	-262
Mean annual impact as proportion of unimpacted inflows	8.8%	9.6%	10.6%	11%

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