D. REVIEW AND UPDATE OF IRRIGATION AND RECHARGE INFORMATION FOR THE MORGAN TO WELLINGTON REGIONAL GROUNDWATER MODEL

REVIEW AND UPDATE OF IRRIGATION AND RECHARGE INFORMATION FOR THE MORGAN TO WELLINGTON REGIONAL GROUNDWATER MODEL

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INTRODUCTION

The purpose of this report is to collate research into the development of irrigation and the history of irrigation practices, including infrastructure rehabilitation and water usage in the Morgan to Wellington reach of the River Murray in South Australia. The research compiled in this report will assist in the estimation of historical groundwater accession in the development of the Morgan to Wellington numerical groundwater model. The estimation of accession volumes where data is incomplete is beyond the scope of this report and is noted where appropriate.

STUDY AREA

The Morgan to Wellington area is located in the Lower Murray region of South Australia. The Morgan to Wellington numerical groundwater model has been divided into 4 sub-zones for the purpose of modelling – Morgan to Lock 1, Lock 1 to Mannum, Mannum to Murray Bridge and Murray Bridge to Wellington (see Figure 1). These divisions are based on anticipated policy requirements for the model output, i.e. lower sub-zones divided at Murray Bridge due to location of major urban water off take.

The Morgan to Wellington numerical groundwater model incorporates a number of Local Action Planning Associations, including Riverland West, Mid Murray and Mannum to Wellington. The model area includes highland irrigated areas, predominately used for viticulture and horticulture and the reclaimed swamp areas, dominated by irrigated pasture for the dairy industry.

DATA METHODOLOGY AND AVAILABILITY

The methodology involved three parts: (1) Literature search; (2) contact with community and Government; and (3) analysis of crop data.

LITERATURE SEARCH

Literature was accessed on previous reports focussing on the history of irrigation development, drainage systems and infrastructure rehabilitation within the Morgan to Wellington sub-zones, including Jolly, Overton and Smitt (2003), Whittle and Philcox (1996), and Dooley, Kuys and Liddicoat (2005).

Jolly, Overton and Smitt (2003) discussed the historical growth of irrigation within the highland irrigation areas of Mypolonga, Toora and Mobilong and the impacts on the Lower River Murray and its floodplain. Whittle and Philcox (1996) conducted a feasibility study of drainage management options for the reclaimed irrigation areas, and Dooley, Kuys and Liddicoat (2005) prepared a scoping report on the Murray Bridge Highland vegetable growers for Land and Water Management Planning.

Very few reports were available for the two sub-zones of Morgan to Lock 1 and Lock 1 to Mannum, with the exception of the Mid Murray Local Action Plan (Mid Murray Local Action Planning Association, 2000) documenting some of the irrigation history of the areas between Blanchetown and Mannum.

COMMUNITY CONTACT

A number of different individuals were approached for historical records and anecdotal information on irrigation and drainage within each sub-zone of the groundwater model. Project officers from the relevant Local Action Planning groups (LAP) were contacted for records, data and for further contacts. Others contacted included irrigation consultants, Agency and Government personnel and South Australian Murray-Darling Basin Natural Resources Management Board (SAMDB NRMB) staff.

Local Action Plan (LAP) Project Officers were identified and contacted to access data on irrigation establishment and water use history with the sub-zone located within their LAP group. From these discussions, a list of other relevant people was produced and contacted for further information.

ANALYSIS OF CROP DATA

The data layer created by the Department of Environment and Heritage (DEH) to record the commencement of irrigation, referred to as the 'eras coverage', was updated through discussions with key staff (P Cole [Department of Water Land and Biodiversity Conservation] 2008, pers. comm., 2008). Dates were validated against Landsat imagery (1972, 1980, 1989, 2000). The 2008 on ground crop surveys, conducted by the South Australian Murray-Darling Basin Resource Information Centre (SAMRIC), on behalf of the SAMDBNRMB, were utilised to source irrigation that had commenced after the DEH 'eras coverage' was created. This covered the timeframe from 2003 to 2008.

LIMITATION OF DIVERTED WATER DATA

The areas of floodplain irrigation in the Mannum to Murray Bridge and Murray Bridge to Wellington sub-zones are not metered and usage is based on anecdotal evidence. While the majority of irrigation diversions in the highland areas have been metered since 1988, these records are incomplete. The rehabilitated Mypolonga highland irrigation area has been metered since 2003-04 (Murray Bridge to Wellington sub-zone).

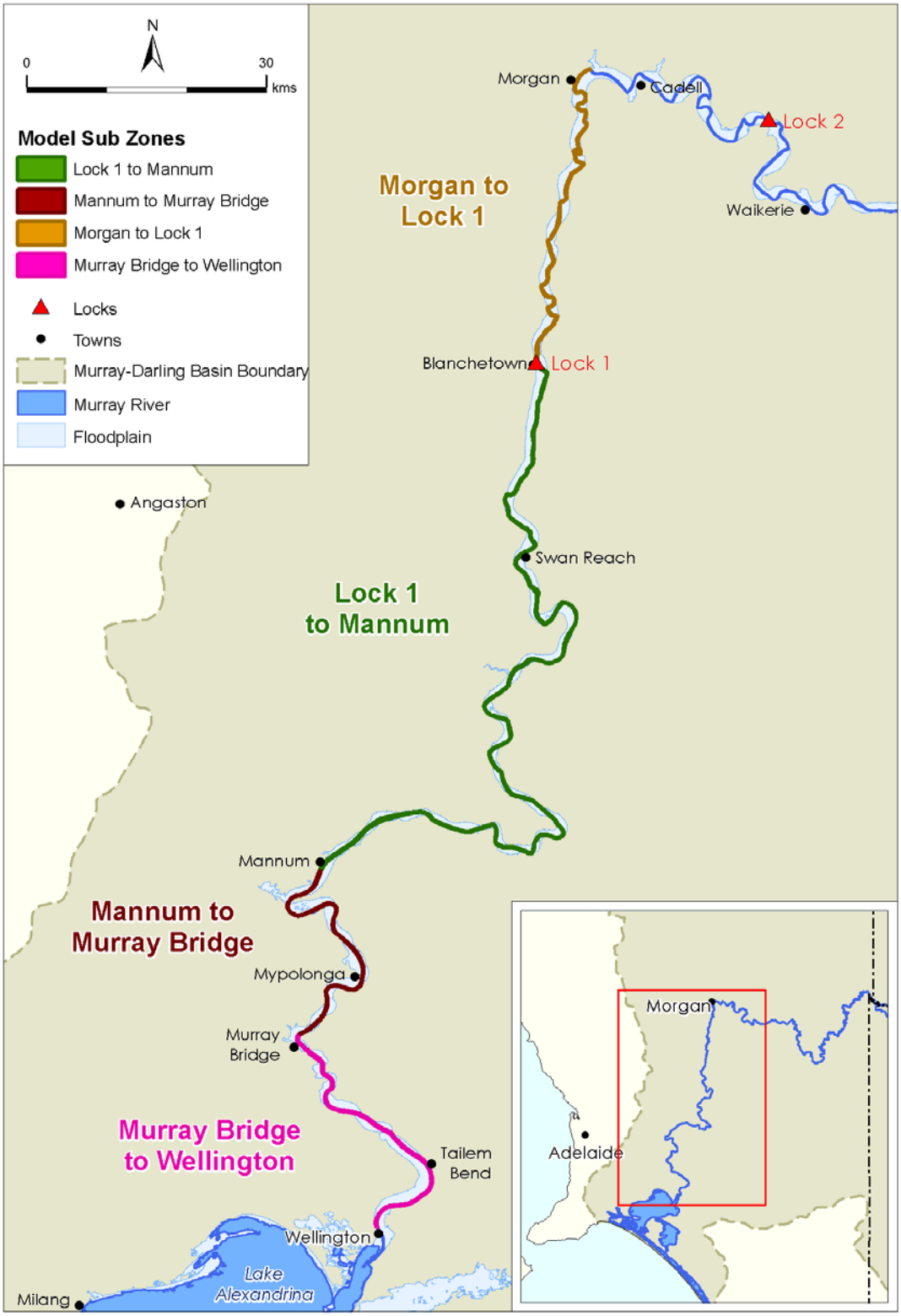
An attempt was made to calculate groundwater accessions with available meter information (see tables and graphs in appendices), however, due to incomplete meter records the calculated volumes of recharge were significantly underestimated when compared with irrigated area. An alternative method of estimating required application rates by crop type was abandoned, as the estimated rate of recharge through the root zone would propagate any errors introduced in estimating application rates. In the absence of complete and accurate information the estimated historical root zone drainage rates were adopted from the CSIRO's Floodplain Risk Methodology project (Holland et al., 2005).

PIVOT IRRIGATION

Crops irrigated by pivot systems, if growing potato crops, are traditionally irrigated for 6 months of the year, and are utilised one year in every 5-7 years. The reason for the long fallow time between potato crops is due to the high number of potential crop diseases that can survive in soil. Alternatively, legumes and vegetables crops are planted in continual rotation, with irrigation occurring for most of the year. Initial field studies by the Integrated Crop Management Services unit of the Department of Primary Industries and Resources South Australia (PIRSA) estimates that field application efficiency of pivots is approximately 70%, with 5% being lost to evaporation and 25% draining through the rootzone.

The majority of pivots in the study area are used to for potatoes, while some of the isolated pivots grow legumes and other vegetables, which are continually rotated.

Figure 1. Morgan to Wellington study area



HISTORY OF MALLEE CLEARANCE

The total area of mallee clearance is shown in Figure 2.

MORGAN TO LOCK 1

The majority of highland area is uncleared as minimal mallee clearance occurred in this area.

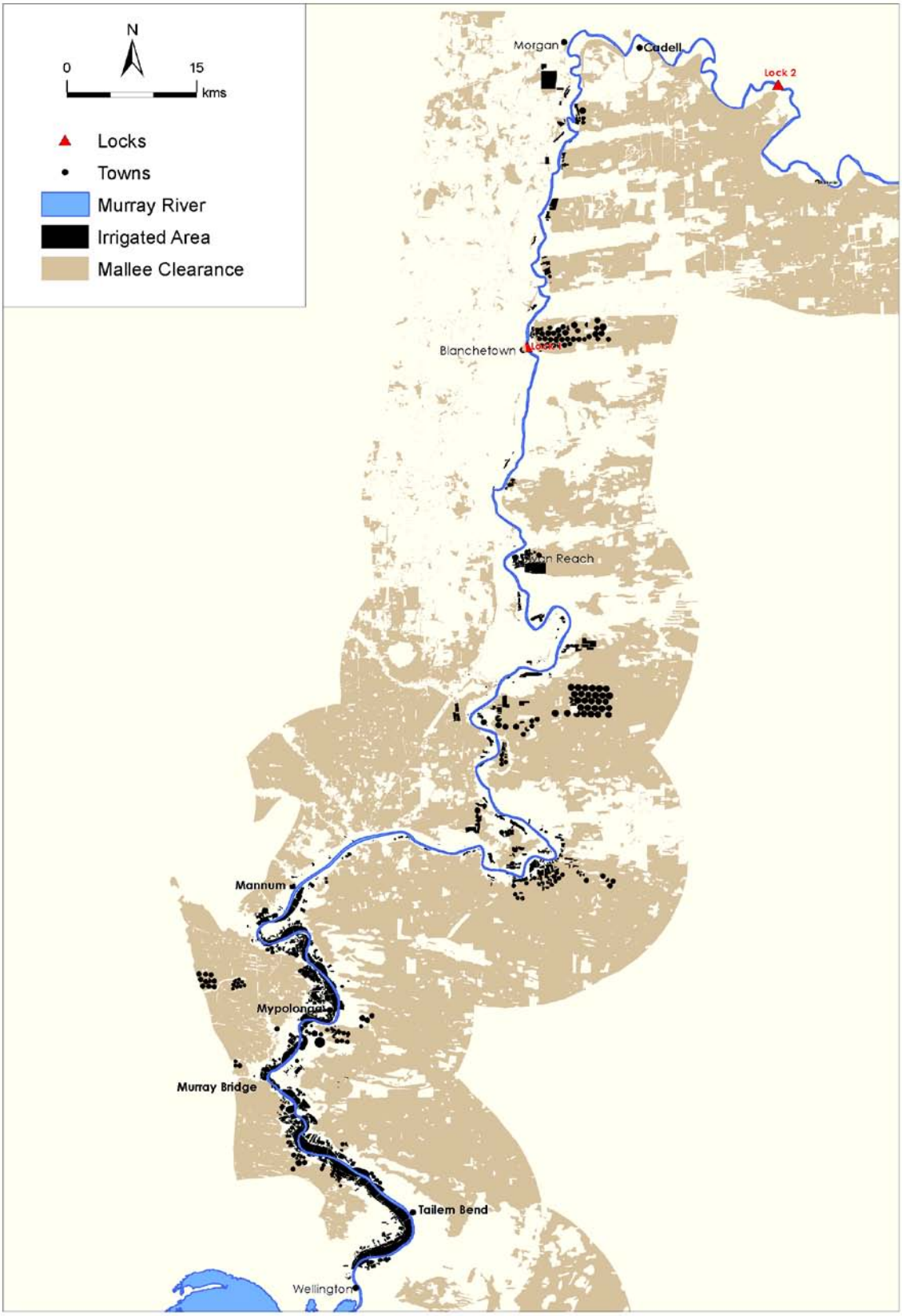
LOCK 1 TO MANNUM

While there is no mallee clearance between Blanchetown and Swan Reach, some areas between Swan Reach and Mannum have been cleared. Of the 90,000 ha of land with this region, approximately one third is remnant vegetation and only 7% riparian vegetation (Mid Murray Local Action Planning Association, 2000).

MANNUM TO MURRAY BRIDGE AND MURRAY BRIDGE TO WELLINGTON

Large areas in the highland and swamps have been cleared and modified and little of the original vegetation remains, with only 10% of wetlands still present (Mannum to Wellington Local Action Planning Committee Inc., 1999).

Figure 2. Mallee cleared area



HISTORY OF IRRIGATION DEVELOPMENT

MORGAN TO LOCK 1

Irrigation commenced in this area around the 1970s (P Cole [DWLBC], pers. comm., 2008) and was located in the highland area. Most of the irrigated vines at this time were drip irrigated, and a number of developments failed soon after planting, due to the development of perched water tables and the underlying presence of Blanchetown clay. Many areas of plantings were removed and replanted. Water was applied daily to vines at a rate of 2 – 3 ML/ha, or approximately 1000L per vine per season during the mid 1970s (D Davidson [Davidson Viticulture], pers. comm., 2008). More recently (from the 1980s), centre pivots have been used to irrigate horticultural produce within this area.

The total area of irrigation in 2007 was 2,321 hectares with areas of expansion occurring in 2000, 2003 and 2005.

The development of irrigated areas over time in the Morgan to Lock 1 sub-zone is shown in Figure 3.

LOCK 1 TO MANNUM

Irrigation commenced in this area, mostly located on the highland areas, in the 1960s, when the Greenways and Swan Reach irrigation areas commenced (Mid Murray LAP Association 2000). Figures from the SAMDBNRMB currently estimate that there are approximately 5564 hectares of irrigated horticulture in this zone, including vegetables, vines, citrus and stone fruit (SAMDB NRMB, pers. comm., emailed 1 December 2008). Some irrigated pasture for grazing exists on the floodplain.

The development of irrigated areas over time in the Lock 1 to Mannum sub-zone is shown in Figure 4.

The major irrigation systems used in this area are under canopy and drip system for citrus and drip system, overhead sprinkler and under canopy for vines.

MANNUM TO MURRAY BRIDGE AND MURRAY BRIDGE TO WELLINGTON

Irrigation developed from 1881 to 1929 following the reclamation of a number of swamps for pasture, and on the highland areas adjoining the swamps in 1914. Most of the swamp areas were reclaimed by 1945, and little further development has occurred since this time. Irrigation developed within the highland areas, with approximately 325 ha developed at Mypolonga between 1914 and 1944 and a further 414 ha developed within the highlands between 1945 and 2001 (Jolly, Overton and Smitt, 2003).

In 2005 there were 27 reclaimed irrigation areas, with approximately 5 200 hectares irrigated for pasture for dairy and cattle, and 1 700 hectares of highland, with 780 hectares of this as irrigated horticulture, including citrus and stone fruit (Environment Protection Authority, 2005). Not included in this are an increasing number of glasshouses being used to produce horticultural crops on the highland. The number of individual irrigators in the reclaimed areas has reduced in the last few years, as irrigators leave the industry due to the economic constraints of the current drought, . Recent figures from the South Australian Murray-Darling Basin Natural Resources Management

Board suggest there are approximately 9000 irrigated hectares (including Environmental Land Management Allocation (ELMA) only irrigation) used within this sub-zone (SAMDBNRMB, pers. comm., emailed 1 December 2008).

As the Lower Murray Reclaimed Irrigation Areas were unmetered prior to rehabilitation of these swamps, there is not an accurate historical record of water use before meters were installed. It has been estimated that in 2002, the amount of water diverted for irrigation exceeded 173 GL per year, due to inefficient irrigation practices and outdated infrastructure. This was approximately 70% in excess of allocations for this area (DWLBC, 2003). At the start of rehabilitation, the water entitlement on the 5 200 ha of reclaimed swamp was 13.8 ML/ha, plus the ELMA of 4.2 ML/ha, with a total of 18 ML/ha and 72 000 GL as the maximum entitlement. The actual water use was approximately 25 ML/ha, and irrigators were potentially extracting up to 150 000 GL, as there was no metering to keep a check on extractions (G Copley [DWLBC], pers. comm., 16 December 2008).

The development of irrigated areas over time in the Mannum to Murray Bridge sub-zone and Murray to Wellington sub-zone are shown in Figure 5.

The major irrigation systems used in the highland areas of these zones are under canopy, overhead sprinklers and drip system for citrus and drip system, under canopy and overhead sprinkler for vines. Flood irrigation is mostly used on the pastures on the reclaimed irrigation areas.

Figure 3. Irrigation development areas over time in the Morgan to Lock 1 sub-zone

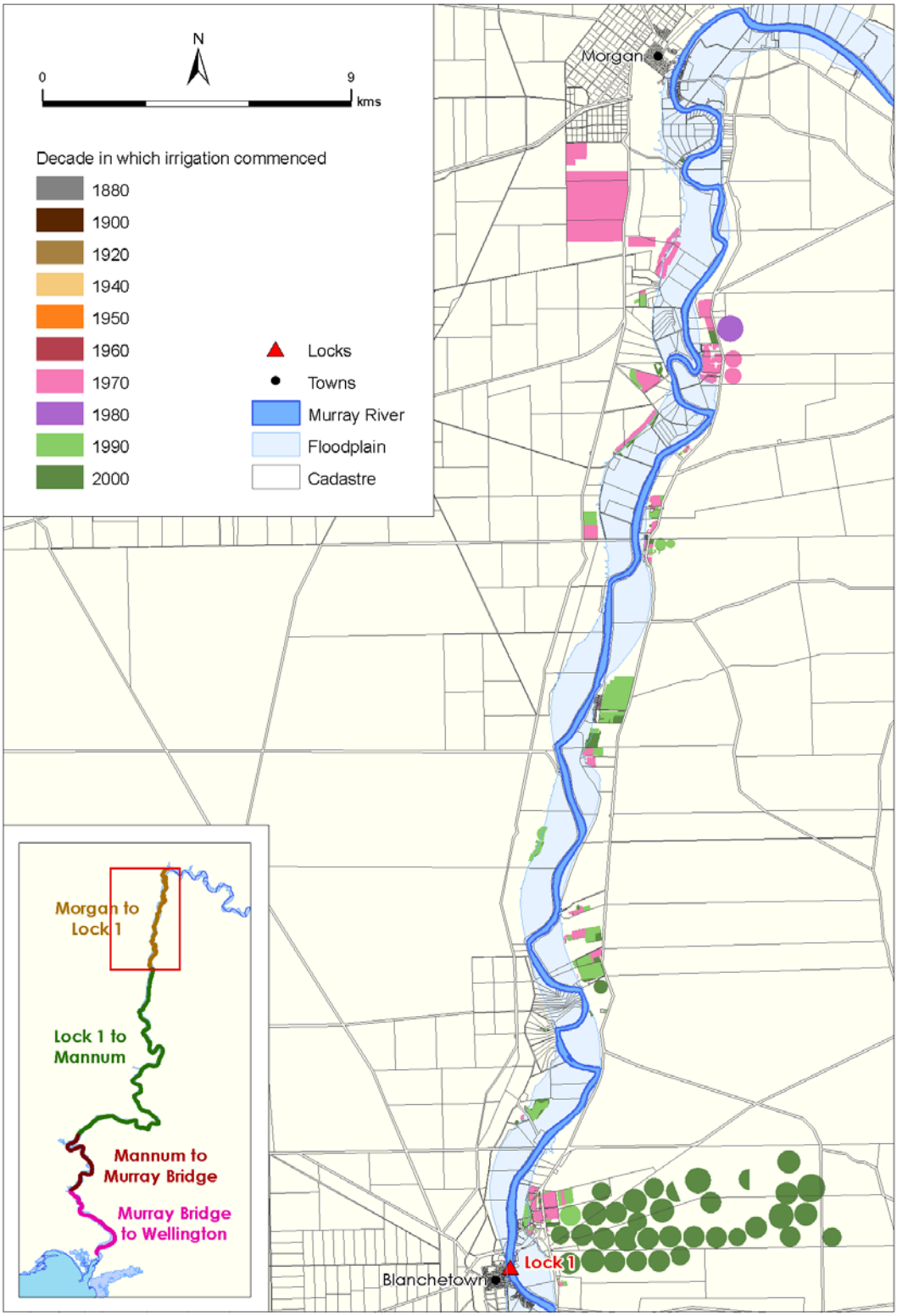


Figure 4. Irrigation development areas over time in the Lock 1 to Mannum sub-zone

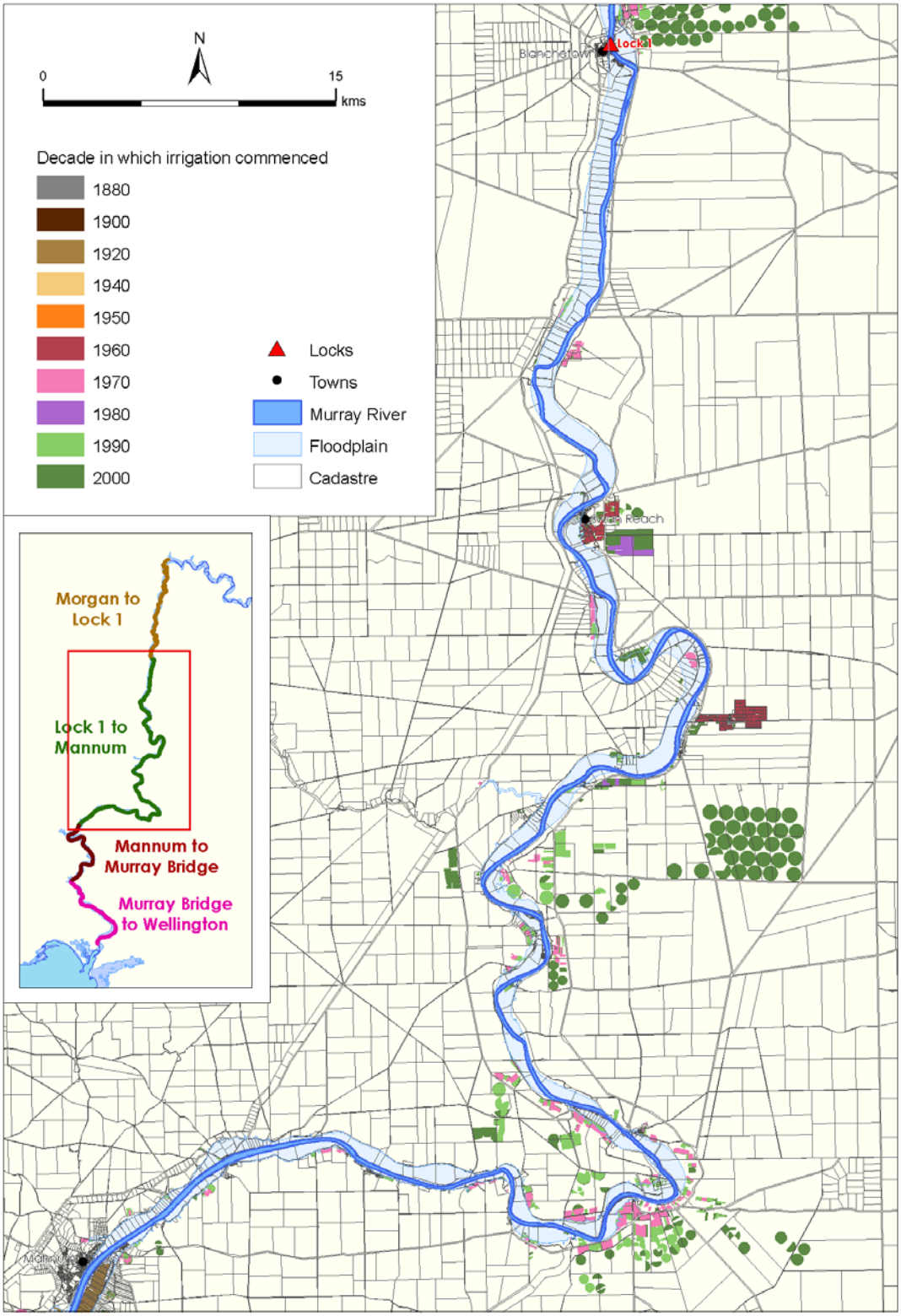
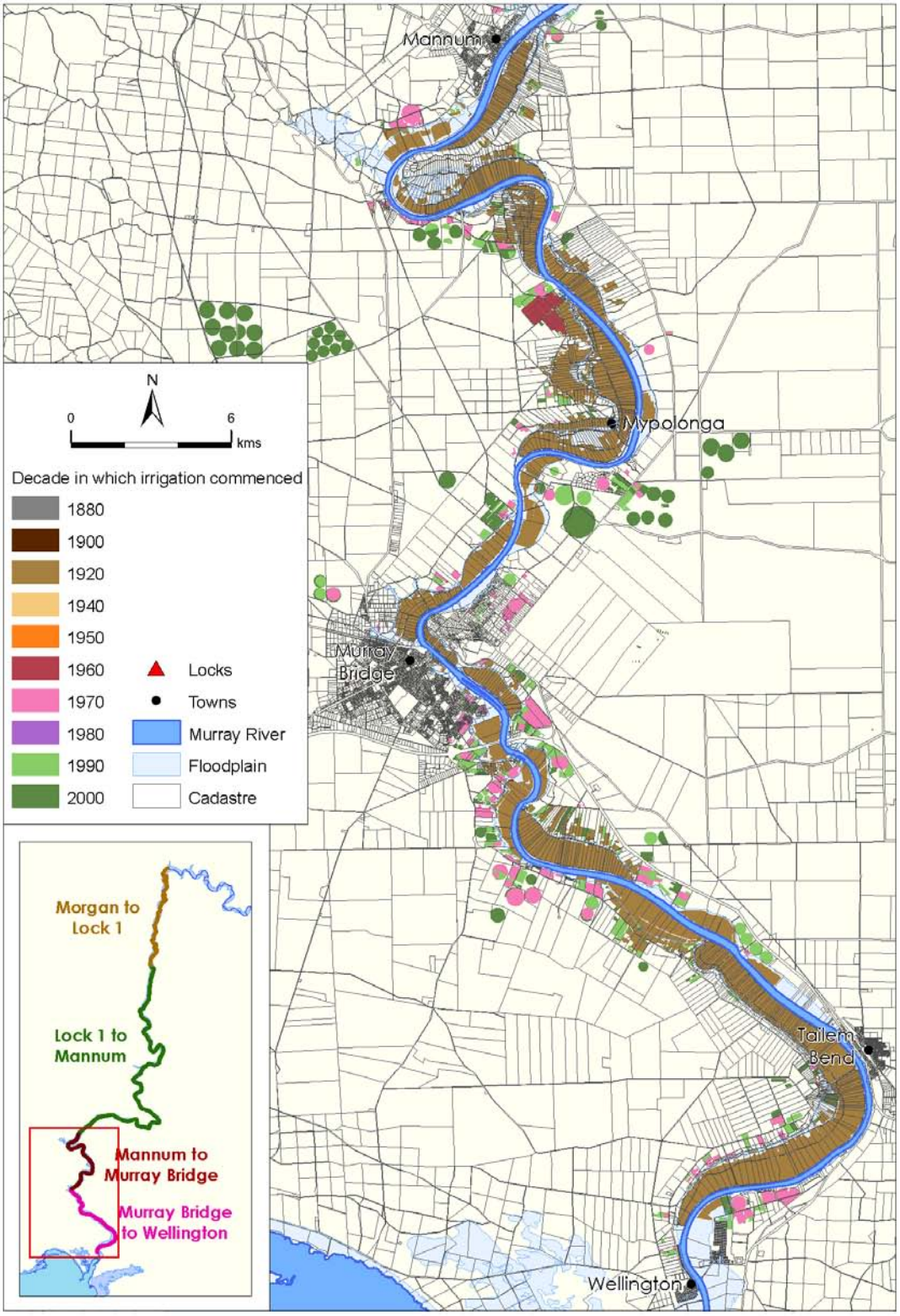


Figure 5. Irrigation development areas over time in the Mannum to Murray Bridge and Murray Bridge to Wellington sub-zones



DRAINAGE HISTORY

MORGAN TO LOCK 1

There are no drainage systems in the highland of the Morgan to Lock 1 sub-zone.

LOCK 1 TO MANNUM

A gravity pipe system was developed south of Swan Reach in the early 1960s and expanded in 1997 as shown in Figure 6. No other drainage systems were developed in the highland of the Lock 1 to Mannum sub-zone.

MANNUM TO MURRAY BRIDGE AND MURRAY BRIDGE TO WELLINGTON

Approximately 80 000 ML of drainage water was disposed annually into the River Murray from the highland and reclaimed irrigation areas (Lower Murray Irrigation, 2006), with drainage on the reclaimed swamps in 1996 of 20ML/ha for the Government areas and 7ML/ha on private swamps (Whittle and Philcox, 1996). Drainage channels have existed from early times, diverting drainage water back into the River, or utilising it as irrigation for parts of the highland. Very little maintenance was undertaken on the drainage systems over the years, and much of the infrastructure was in poor condition. The original irrigation and drainage systems were designed to follow the natural characteristics of the land and not necessarily for efficient use. The levee banks, and later the barrages, were built to reclaim the swamps and maintain the swamps at 1.0 to 1.5 metres below the river level. They allowed the water to be gravity-fed for irrigation through infrastructure, including sluices and syphons. Traditional irrigation practice used a rotation of 21 days, applying up to 8" of water at once, so that the soil was waterlogged for the first seven days, fine for the next seven and too dry for the next seven until water was applied again. This was an inefficient way to water and poor drainage practice (Lower Murray Irrigation Action Group and CSIRO Land and Water, 1999).

Irrigation has been used on the highland areas, and in many cases it utilised the water in the drains left after flood irrigation of the reclaimed areas. This process, while enabling water to be recycled and re-used from the reclaimed areas, was seen as generally inefficient, as it encouraged excess water use on the reclaimed areas and left large amount of water in the drains for long periods, causing water tables to rise.

Some efficiencies were undertaken during the 1990s, including laser levelling to reduce the amount of water required to flood irrigate a property. As an incentive, extra waterings were provided to those who carried out laser levelling.

There is some concern regarding urban storm water runoff entering the drainage systems of the reclaimed irrigation areas and adding to the associated costs of removal to individual irrigators. Burdett is the main reclaimed area that is adversely affected by stormwater runoff, as it is the nearest to the urbanised area. The Rural City of Murray Bridge has included these concerns in their recent Stormwater Management Plan (Tonkin Engineering, 2007), with a strategy to separate urban drainage runoff from irrigated land drainage to

> 'ensure that development in upstream areas does not result in irrigators receiving and being responsible for the treatment and disposal of an urban drainage water volume that is above and beyond that which could reasonably be expected' (Tonkin Engineering, 2007).

The location of drainage channels in the Mannum to Murray Bridge and Murray Bridge to Wellington sub-zones are shown in Figures 7 and 8.

Figure 6. Irrigation drainage channels in the Lock 1 to Mannum sub-zone

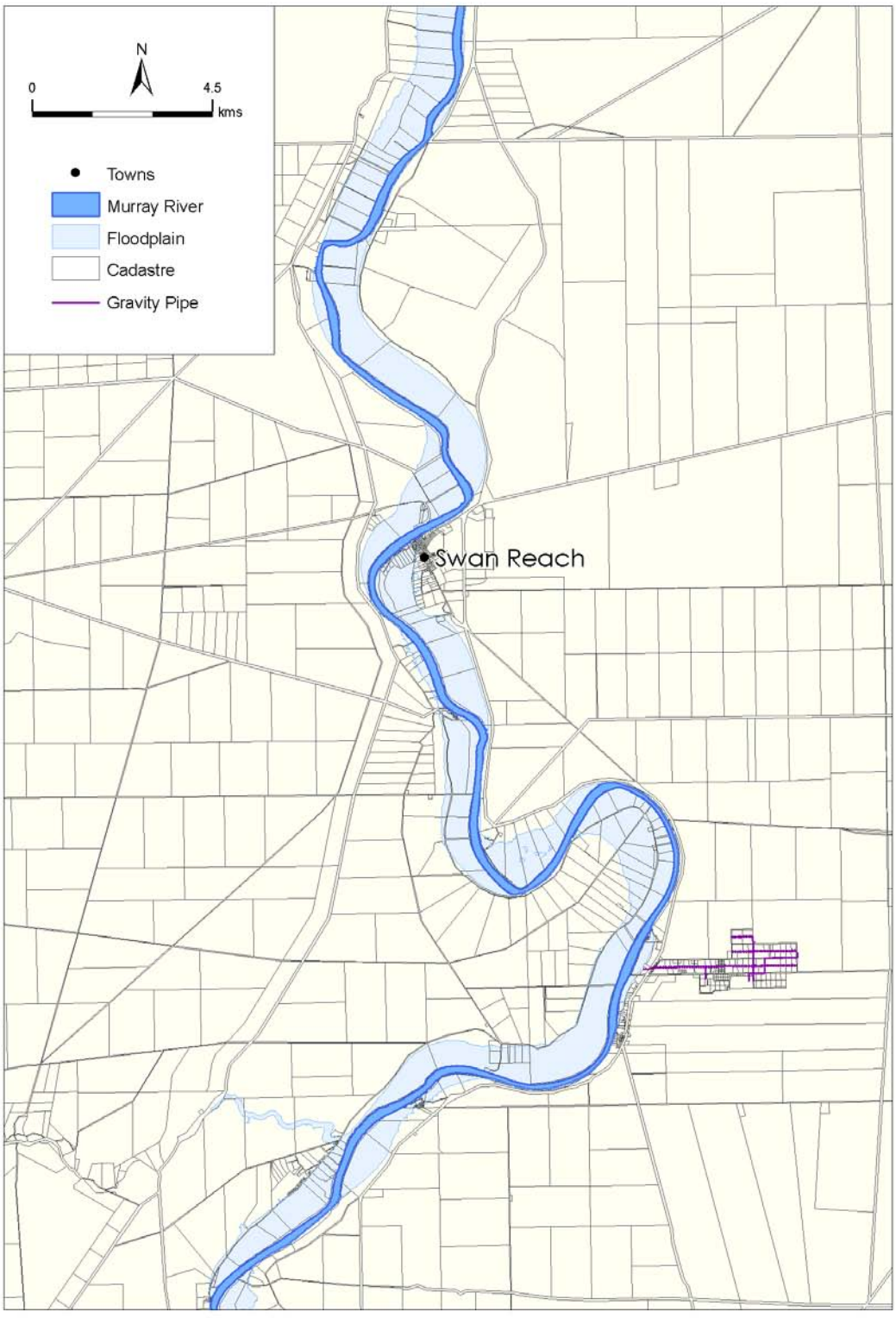


Figure 7. Irrigation drainage channels in the Mannum to Murray Bridge sub-zone

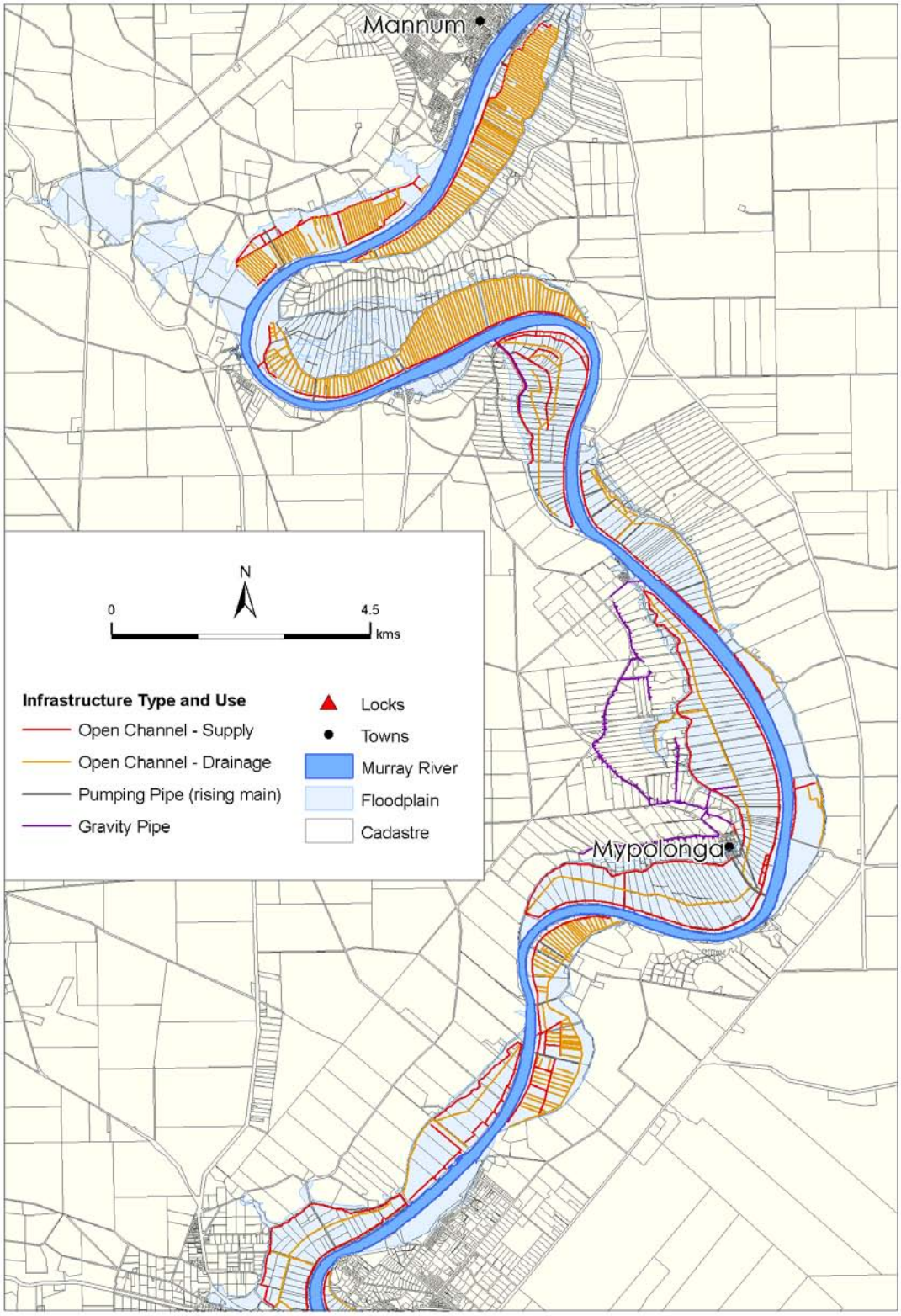
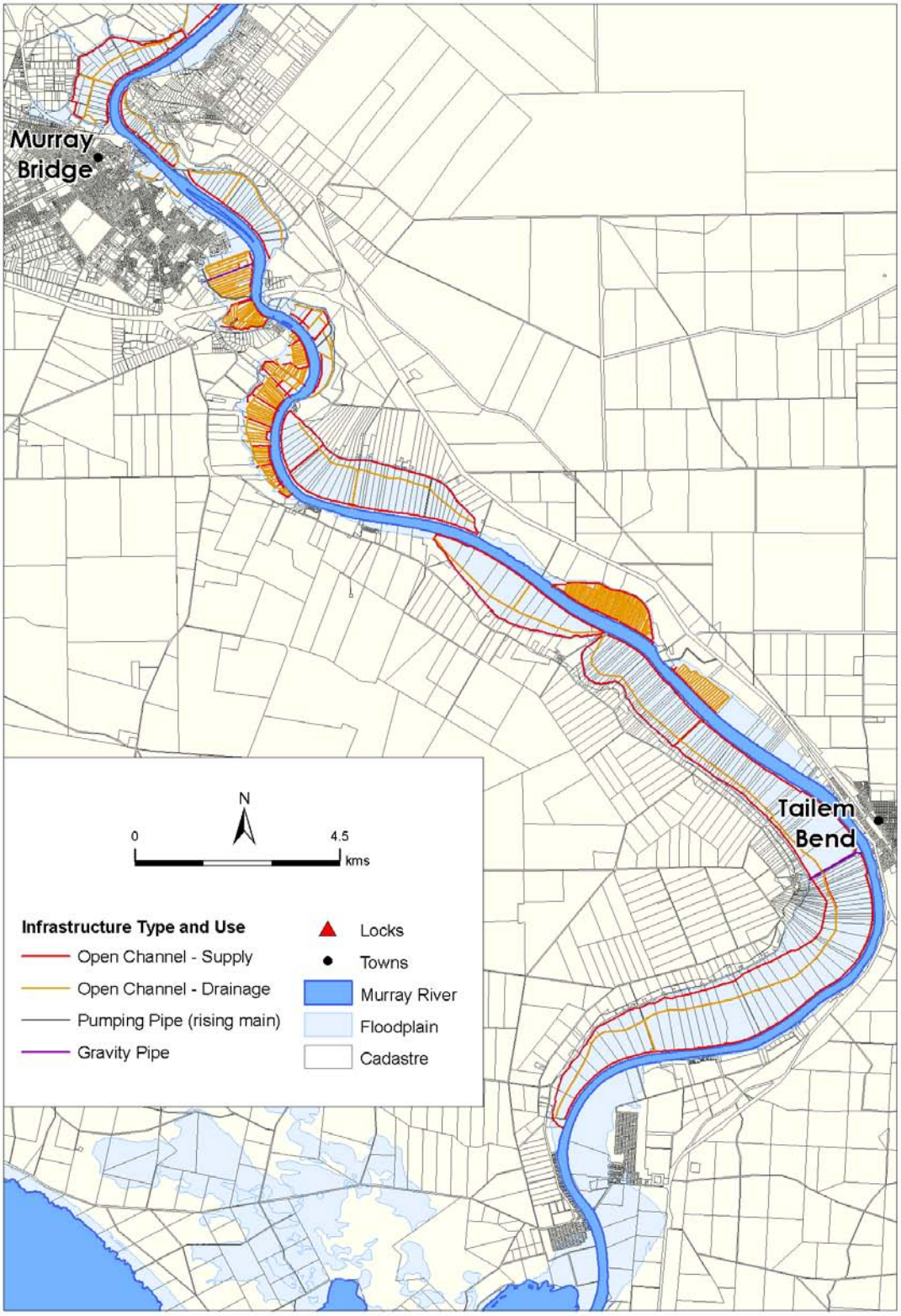


Figure 8. Irrigation drainage channels in the Murray Bridge to Wellington sub-zone



INFRASTRUCTURE REHABILITATION HISTORY

MORGAN TO LOCK 1

No infrastructure rehabilitation has occurred within the Morgan to Lock 1 sub-zone.

LOCK 1 TO MANNUM

No infrastructure rehabilitation has occurred in the highland within the Lock 1 to Mannum sub-zone.

MANNUM TO MURRAY BRIDGE AND MURRAY BRIDGE TO WELLINGTON

Rehabilitation and Restructure of the Government Highland Irrigation areas in South Australia commenced in 1992, and ran for seven years to 1999. It involved improved on-farm management practices, replacing irrigation channels and gates with pressurised pipes and metered outlets and the transfer of control of the areas from State Government to self-management. Contributions to the total cost was split between the Commonwealth Government, State Government and regional irrigators at a ratio of 40:40:20, respectively and the key irrigation districts rehabilitated were Cobdogla, Moorook, Cadell and Mypolonga (Kirk, Miles and Ralph 1999). Land suitability for irrigation was also assessed, and blocks unsuited were retired from irrigation, withcompensation provided to the owner.

Rehabilitation of the highland area of Mypolonga was completed in 1997/98, with ten hectares retired through the land suitability assessment process (Kirk, Miles and Ralph 1999).

For the Lower Murray Reclaimed Areas, the Land and Water Management Program, initiated in 1996 – 2001 by the Lower Murray Irrigation Action Group (Lower Murray Irrigation, 2006), enabled large numbers of irrigators to implement rehabilitation work on their properties to meet best management practice. The works carried out included laser levelling of paddocks, channel upgrades and fitting of demonstration meters to gauge water diversions. In the late 1990s a report was commissioned into a proposed restructure and rehabilitation of the reclaimed swamp areas, to investigate issues such as the cost to the community from pollution returned to the River Murray from the irrigation schemes, the costs and benefits to farmers of rehabilitating and privatising these schemes, and the impact of installing meters at swamp inlets. This later led to a trial undertaken on the Cowirra reclaimed swamp. This trial incorporated a rehabilitation of infrastructure and use of irrigation efficiencies, and demonstrated that total water use could be reduced, runoff/drainage could be decreased, the water table lowered and that better quality pasture could be produced under this regime, through deeper rooted vegetation. During this trial the volume of water used on the irrigation bays was reduced from 1.2 ML/ha to 0.7 ML/ha, showing that rehabilitation of infrastructure and irrigation efficiencies could reduce water use (Environment Protection Authority, 2005).

In June 2001, the Government approved a four-stage reform strategy to achieve the objectives of reducing the effects of drainage, improving water use efficiency and transforming Government responsibility in the irrigation areas to irrigators. From this a comprehensive reform package to rehabilitate and restructure the reclaimed areas was initiated in 2003. It also included handing over ownership of the Government areas to irrigators, with financial assistance provided to irrigators to carry out the necessary rehabilitation to their infrastructure, sell their land to other irrigators or retire their land from irrigation. The rehabilitation work included mandatory installation

of water meters, digging drains to intercept surface irrigation runoff (toe drains) and putting in re-use pumps and systems. The restructure and rehabilitation program for the Lower Murray Reclaimed Irrigation Areas is expected to have a lifespan of 25 years.

Following applications for the restructure packages, around 1 200 ha of land was retired from irrigation, and 602.69 ha was sold to other irrigators to continue using the land for irrigation, leaving 4,047 ha of land being irrigated (G Copley [DWLBC], pers. comm., 16 December 2008).

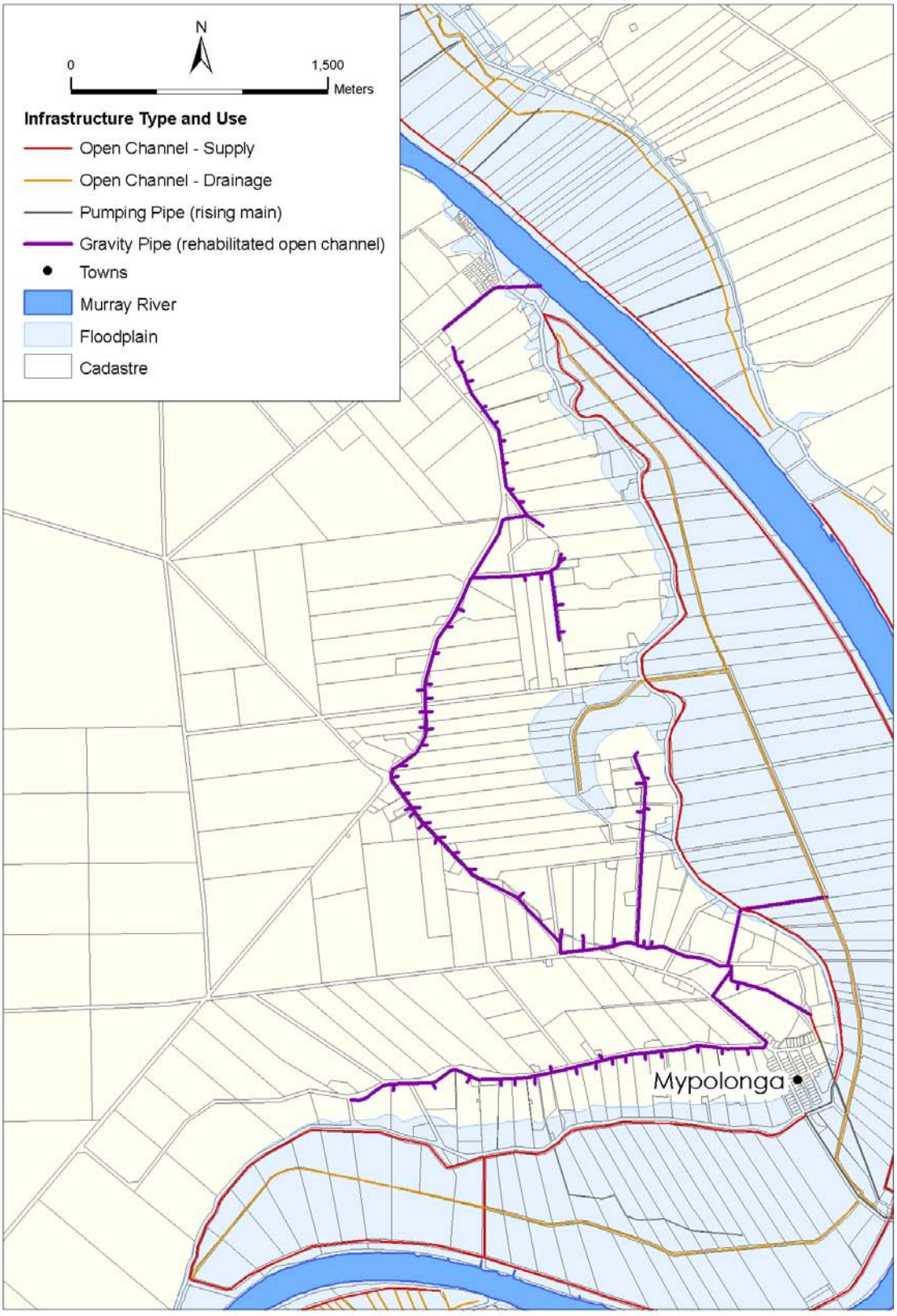
Another aspect of rehabilitation of the reclaimed areas was an allocation of water available to specific irrigators to be used to minimise the effects of rising saline groundwater. This is known as the Environmental Land Management Allocation (ELMA) and it was necessary as the land within the reclaimed area is low-lying (below the level of the River Murray) and saline regional groundwater discharges within this zone (Lower Murray Reclaimed Areas Irrigation Management Zone). In 2002 the 22.2 GL ELMA was incorporated into the Water Allocation Plan (WAP) for the River Murray Prescribed Watercourse.

The Water Allocation Plan for the River Murray Prescribed Watercourse provides for an allocation of up to 67.3 GL for irrigation for the Lower Murray Reclaimed Areas Irrigation Management Zone (LMRA IMZ), which can be allocated at a rate not greater than 13.92 ML/ha. Prior to metering, the estimated use was approximately 25 ML/ha. With rehabilitation of the reclaimed areas (and before the drought), the average water application is estimated to have been reduced to 10 ML/ha, plus the 4.2 ML/ha ELMA, for a total of around 15 ML/ha. The savings from the reduction in hectares and water use that apply over 4 047 ha at 15 ML/ha is 60.7 GL, plus the removal of approximately 1 200 ha from production after 2001/02, at an application rate of 25 ML/ha (exclusive of ELMA) at 30 GL, makes an estimated saving of 90 GL (G Copley [DWLBC], pers. comm.,).

Each reclaimed area has undergone rehabilitation and restructure to replace irrigation infrastructure first installed in 1903 - 08, starting with Woods Point Private Irrigation District in May 2005. Restructure and conversion of all the districts to private trusts has continued, with the current program having a life span of 25 years.

The location of rehabilitated infrastructure at Mypolonga is shown in Figure 9.

Figure 9. Rehabilitated irrigation infrastructure in the Murray Bridge to Wellington sub-zone



RECHARGE RATES AND ZONES - MALLEE CLEARANCE

Groundwater recharge in the Morgan to Wellington numerical groundwater model incorporates recharge to the water table from dryland (mallee) clearing and/or irrigation development incorporating the time lag for recharge (flux) to reach the water table.

Dryland recharge rates for mallee cleared areas have been supplied by DEH and are based on studies by DWLBC and CSIRO during development of the SIMPACT/SIMRAT models. The recharge rate prior to clearing is estimated to be 0.1 mm/yr.

The combined timelag and recharge rates for mallee clearance are displayed in Table 1.

Table 1. Summary of mallee recharge zones for the study area

Mean Recharge (m) by Year	Recharge Zone (drainage zone combined with timelag)																				
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
11	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0016	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
21	0.0000	0.0006	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0028	0.0006	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
31	0.0000	0.0006	0.0004	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0029	0.0025	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
41	0.0000	0.0006	0.0006	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0029	0.0036	0.0007	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
51	0.0001	0.0006	0.0007	0.0004	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0029	0.0039	0.0023	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
61	0.0001	0.0006	0.0007	0.0005	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0029	0.0039	0.0035	0.0008	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
71	0.0001	0.0006	0.0007	0.0006	0.0004	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0029	0.0039	0.0039	0.0022	0.0004	0.0000	0.0000	0.0000	0.0000	0.0000
81	0.0001	0.0006	0.0007	0.0006	0.0005	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0029	0.0039	0.0039	0.0032	0.0012	0.0001	0.0000	0.0000	0.0000	0.0000
91	0.0001	0.0006	0.0007	0.0006	0.0006	0.0004	0.0001	0.0000	0.0000	0.0000	0.0000	0.0029	0.0039	0.0039	0.0037	0.0023	0.0004	0.0000	0.0000	0.0000	0.0000
101	0.0001	0.0006	0.0007	0.0006	0.0006	0.0005	0.0002	0.0000	0.0000	0.0000	0.0000	0.0029	0.0039	0.0039	0.0038	0.0031	0.0011	0.0002	0.0000	0.0000	0.0000
111	0.0002	0.0006	0.0007	0.0006	0.0006	0.0006	0.0003	0.0001	0.0000	0.0000	0.0000	0.0029	0.0039	0.0039	0.0038	0.0035	0.0020	0.0006	0.0001	0.0000	0.0000
121	0.0002	0.0006	0.0007	0.0006	0.0006	0.0006	0.0004	0.0001	0.0000	0.0000	0.0000	0.0029	0.0039	0.0039	0.0038	0.0036	0.0028	0.0013	0.0003	0.0000	0.0000
131	0.0002	0.0006	0.0007	0.0006	0.0006	0.0006	0.0005	0.0002	0.0001	0.0000	0.0000	0.0029	0.0039	0.0039	0.0038	0.0037	0.0033	0.0020	0.0007	0.0002	0.0000
141	0.0004	0.0006	0.0007	0.0006	0.0006	0.0006	0.0005	0.0003	0.0001	0.0000	0.0000	0.0029	0.0039	0.0039	0.0038	0.0037	0.0036	0.0027	0.0012	0.0004	0.0000
151	0.0006	0.0006	0.0007	0.0006	0.0006	0.0006	0.0005	0.0003	0.0002	0.0001	0.0000	0.0029	0.0039	0.0039	0.0038	0.0037	0.0037	0.0031	0.0018	0.0009	0.0000
161	0.0008	0.0006	0.0007	0.0006	0.0006	0.0006	0.0005	0.0004	0.0003	0.0001	0.0000	0.0029	0.0039	0.0039	0.0038	0.0037	0.0038	0.0033	0.0024	0.0015	0.0000
171	0.0012	0.0006	0.0007	0.0006	0.0006	0.0006	0.0005	0.0004	0.0003	0.0002	0.0000	0.0029	0.0039	0.0039	0.0038	0.0037	0.0038	0.0035	0.0027	0.0021	0.0000
181	0.0016	0.0006	0.0007	0.0006	0.0006	0.0006	0.0005	0.0004	0.0003	0.0002	0.0000	0.0029	0.0039	0.0039	0.0038	0.0037	0.0038	0.0035	0.0030	0.0026	0.0001
191	0.0020	0.0006	0.0007	0.0006	0.0006	0.0006	0.0005	0.0004	0.0003	0.0003	0.0000	0.0029	0.0039	0.0039	0.0038	0.0037	0.0038	0.0035	0.0031	0.0030	0.0001
201	0.0025	0.0006	0.0007	0.0006	0.0006	0.0006	0.0005	0.0004	0.0003	0.0003	0.0000	0.0029	0.0039	0.0039	0.0038	0.0037	0.0038	0.0036	0.0032	0.0033	0.0001

Table 1. Summary of mallee recharge zones for the study area (cont)

Mean Recharge (m) by Year	Recharge Zone (drainage zone combined with timelag)																			
	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
11	0.0031	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0047	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
21	0.0069	0.0005	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0276	0.0023	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
31	0.0074	0.0041	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0287	0.0139	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
41	0.0074	0.0060	0.0011	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0287	0.0200	0.0028	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
51	0.0074	0.0063	0.0037	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0287	0.0208	0.0097	0.0005	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
61	0.0074	0.0063	0.0057	0.0015	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0287	0.0209	0.0147	0.0035	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000
71	0.0074	0.0063	0.0063	0.0038	0.0005	0.0000	0.0000	0.0000	0.0000	0.0000	0.0287	0.0209	0.0162	0.0090	0.0010	0.0000	0.0000	0.0000	0.0000	0.0000
81	0.0074	0.0063	0.0065	0.0057	0.0020	0.0002	0.0000	0.0000	0.0000	0.0000	0.0287	0.0209	0.0165	0.0134	0.0038	0.0004	0.0000	0.0000	0.0000	0.0000
91	0.0074	0.0063	0.0065	0.0065	0.0042	0.0011	0.0001	0.0000	0.0000	0.0000	0.0287	0.0209	0.0165	0.0154	0.0079	0.0019	0.0001	0.0000	0.0000	0.0000
101	0.0074	0.0063	0.0065	0.0067	0.0062	0.0028	0.0004	0.0000	0.0000	0.0000	0.0287	0.0209	0.0165	0.0159	0.0114	0.0048	0.0007	0.0001	0.0000	0.0000
111	0.0074	0.0063	0.0065	0.0068	0.0072	0.0047	0.0013	0.0002	0.0000	0.0000	0.0287	0.0209	0.0165	0.0160	0.0133	0.0081	0.0023	0.0003	0.0000	0.0000
121	0.0074	0.0063	0.0065	0.0068	0.0077	0.0063	0.0028	0.0006	0.0001	0.0000	0.0287	0.0209	0.0165	0.0161	0.0140	0.0107	0.0048	0.0011	0.0002	0.0000
131	0.0074	0.0063	0.0065	0.0068	0.0078	0.0072	0.0044	0.0015	0.0003	0.0000	0.0287	0.0209	0.0165	0.0161	0.0143	0.0123	0.0076	0.0027	0.0006	0.0000
141	0.0074	0.0063	0.0065	0.0068	0.0079	0.0076	0.0058	0.0028	0.0009	0.0000	0.0287	0.0209	0.0165	0.0161	0.0143	0.0130	0.0101	0.0050	0.0016	0.0002
151	0.0074	0.0063	0.0065	0.0068	0.0079	0.0078	0.0067	0.0041	0.0017	0.0001	0.0287	0.0209	0.0165	0.0161	0.0143	0.0133	0.0117	0.0074	0.0032	0.0004
161	0.0074	0.0063	0.0065	0.0068	0.0079	0.0079	0.0073	0.0053	0.0029	0.0002	0.0287	0.0209	0.0165	0.0161	0.0143	0.0134	0.0127	0.0096	0.0053	0.0010
171	0.0074	0.0063	0.0065	0.0068	0.0079	0.0079	0.0075	0.0061	0.0041	0.0004	0.0287	0.0209	0.0165	0.0161	0.0143	0.0134	0.0132	0.0111	0.0074	0.0018
181	0.0074	0.0063	0.0065	0.0068	0.0079	0.0079	0.0076	0.0066	0.0051	0.0007	0.0287	0.0209	0.0165	0.0161	0.0143	0.0134	0.0134	0.0121	0.0094	0.0029
191	0.0074	0.0063	0.0065	0.0068	0.0079	0.0079	0.0077	0.0069	0.0060	0.0011	0.0287	0.0209	0.0165	0.0161	0.0143	0.0134	0.0135	0.0127	0.0109	0.0042
201	0.0074	0.0063	0.0065	0.0068	0.0079	0.0079	0.0077	0.0071	0.0065	0.0015	0.0287	0.0209	0.0165	0.0161	0.0143	0.0134	0.0135	0.0130	0.0119	0.0055

RECHARGE RATES - IRRIGATION

An attempt was made to calculate groundwater accessions with available meter information but was abandoned when the analysis showed that calculated volumes of recharge were significantly underestimated when compared with irrigated area (see tables and graphs in appendices). An alternate method of estimating required application rates by crop type was abandoned, as the estimated rate of recharge through the root zone would propagate any errors introduced in estimating application rates. In the absence of complete and accurate information the estimated historical root zone drainage rates from the CSIRO's Floodplain Risk Methodology project (Holland et al., 2005) were adopted (Table 2).

Table 2. Root zone drainage rates applied depending on when the action started. These rates are kept constant for the duration of the analysis (CSIRO, 2005)

Era of Action	Long Term Drainage Rates
1880s – 1970s irrigation	300 mm yr^{-1} with reduction to 160 mm yr^{-1} after 1970
1980s irrigation	160 mm yr^{-1}
1990s - 2000s irrigation	120 mm yr^{-1}
1920 mallee clearance	1 – 16 mm yr^{-1} spatially varying

LAG TIME – MALLEE CLEARANCE AND IRRIGATION

The lag time for drainage water to reach the water table is dependent on several factors including drainage rate through the root zone, the depth to the groundwater and the thickness of the Blanchetown clay. The time lags on recharge rates were also applied to cleared dryland areas, using recharge rates estimated by DEH using the SIMPACTII model. The results are displayed in Figures 10 to 15.

Figure 10. Timelag in mallee cleared areas in the Morgan to Lock 1 sub-zone

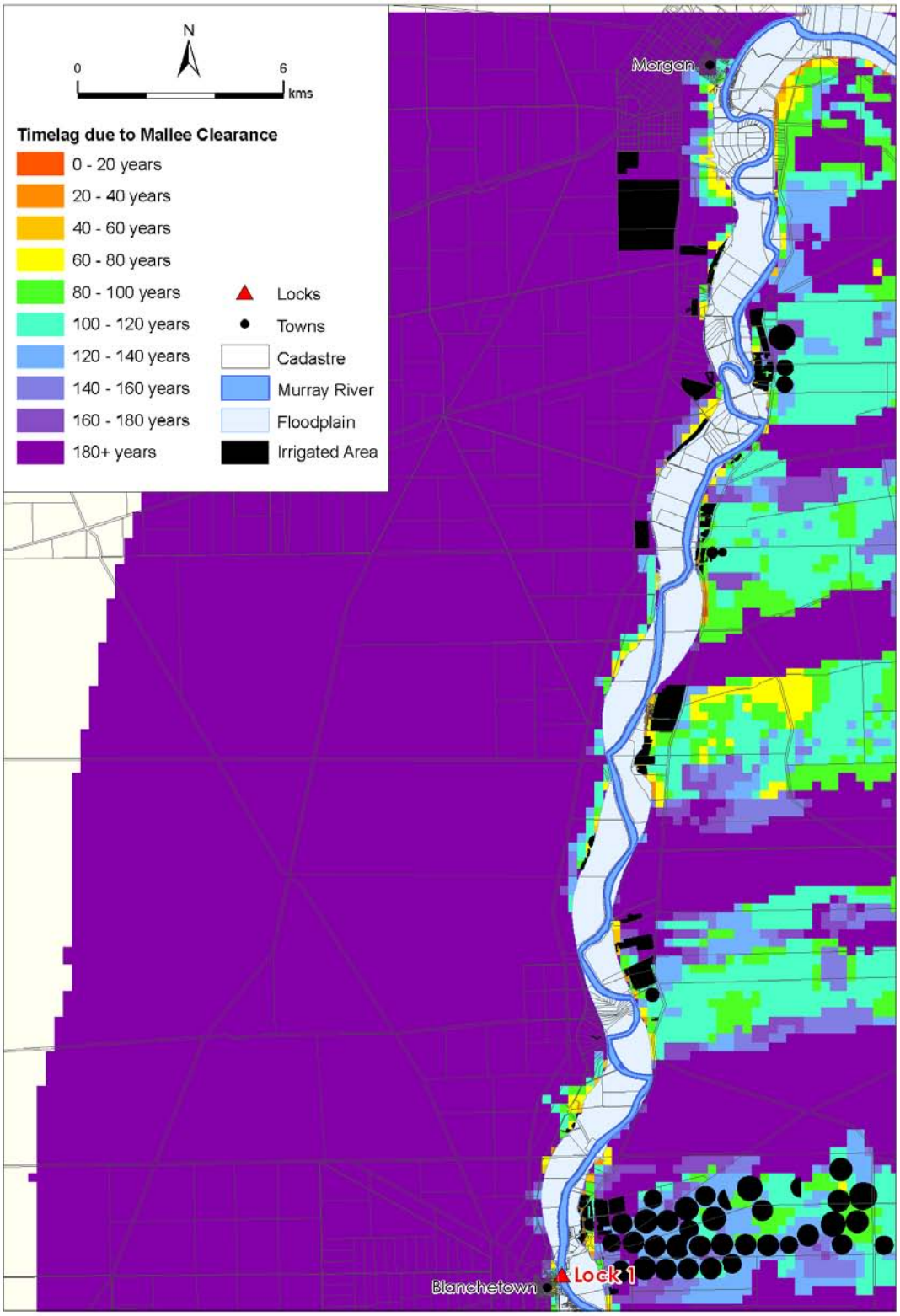


Figure 11. Timelag in irrigation areas in the Morgan to Lock 1 sub-zone

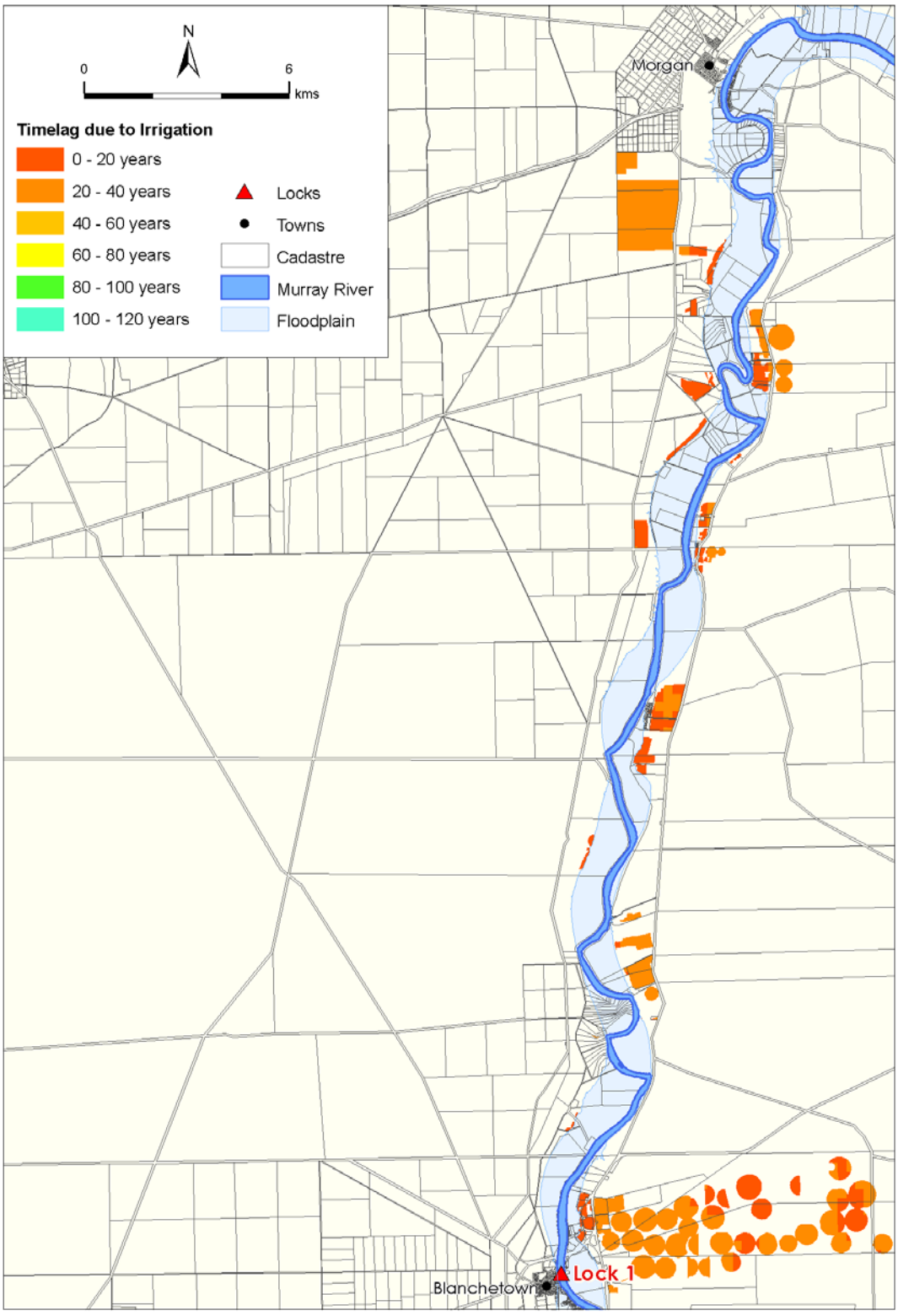


Figure 12. Timelag in mallee cleared areas in the Lock 1 to Mannum sub-zone

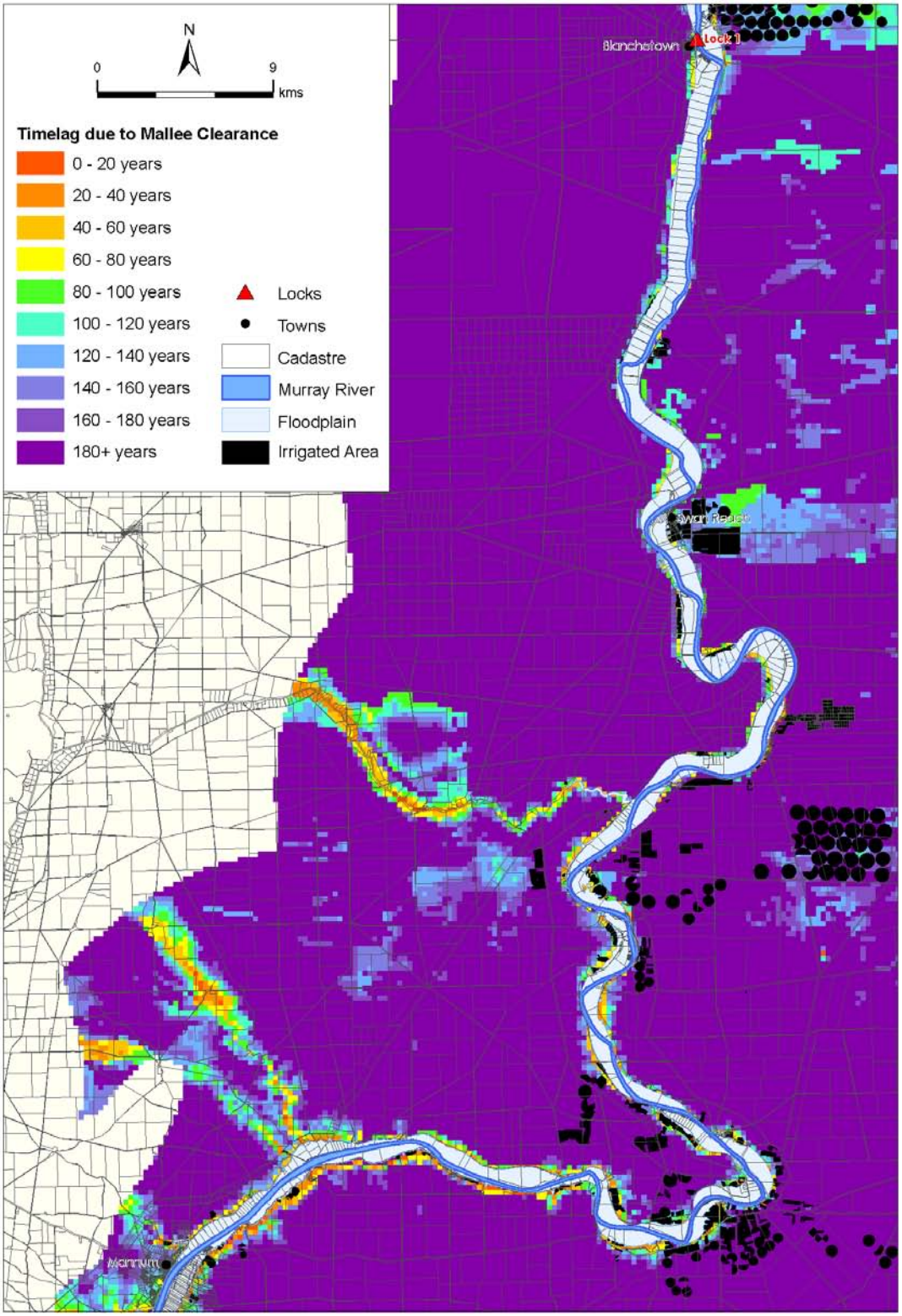


Figure 13. Timelag in irrigation areas in the Lock 1 to Mannum sub-zone

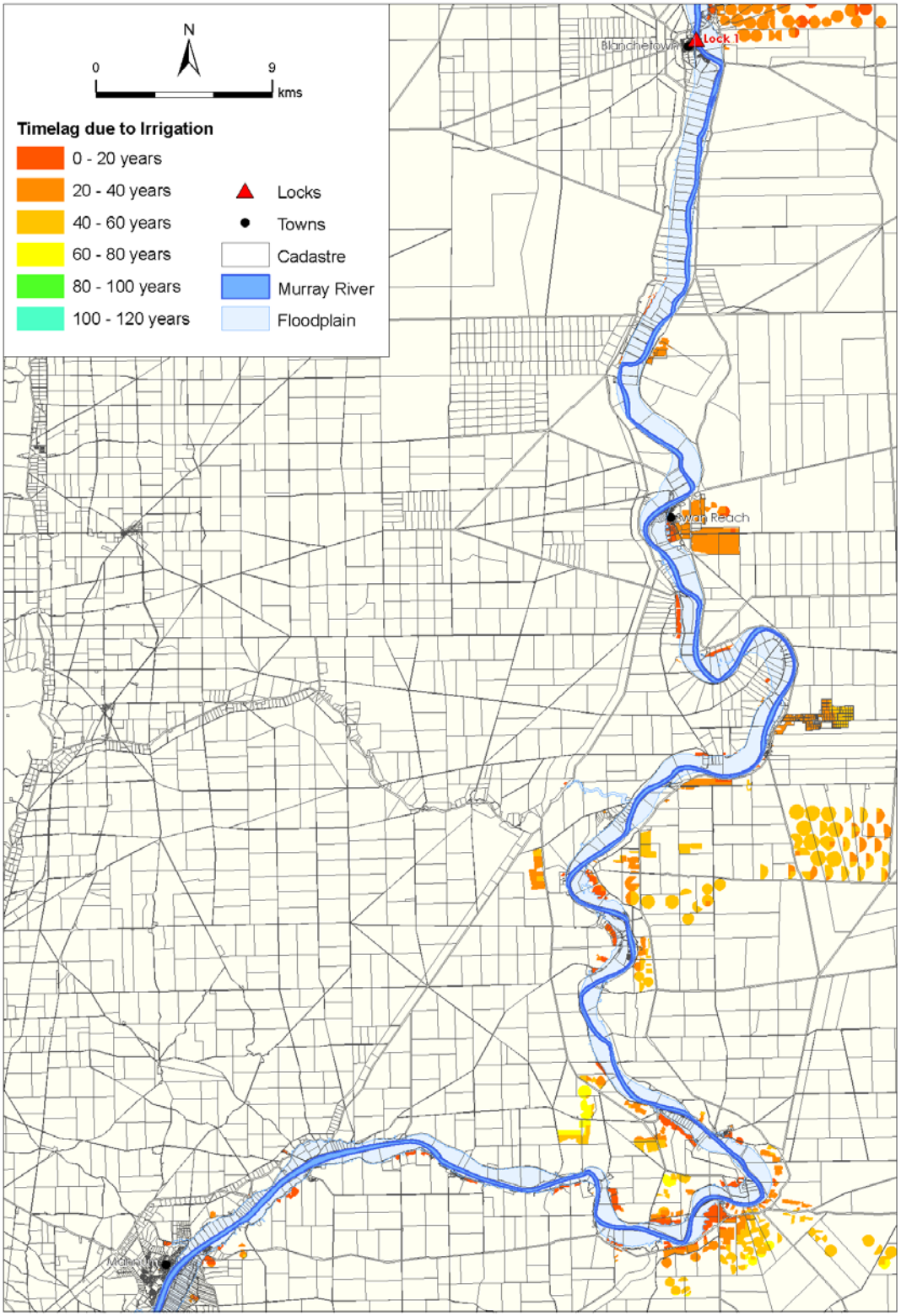


Figure 14. Timelag in mallee cleared areas in the Mannum to Murray Bridge and Murray Bridge to Wellington sub-zones

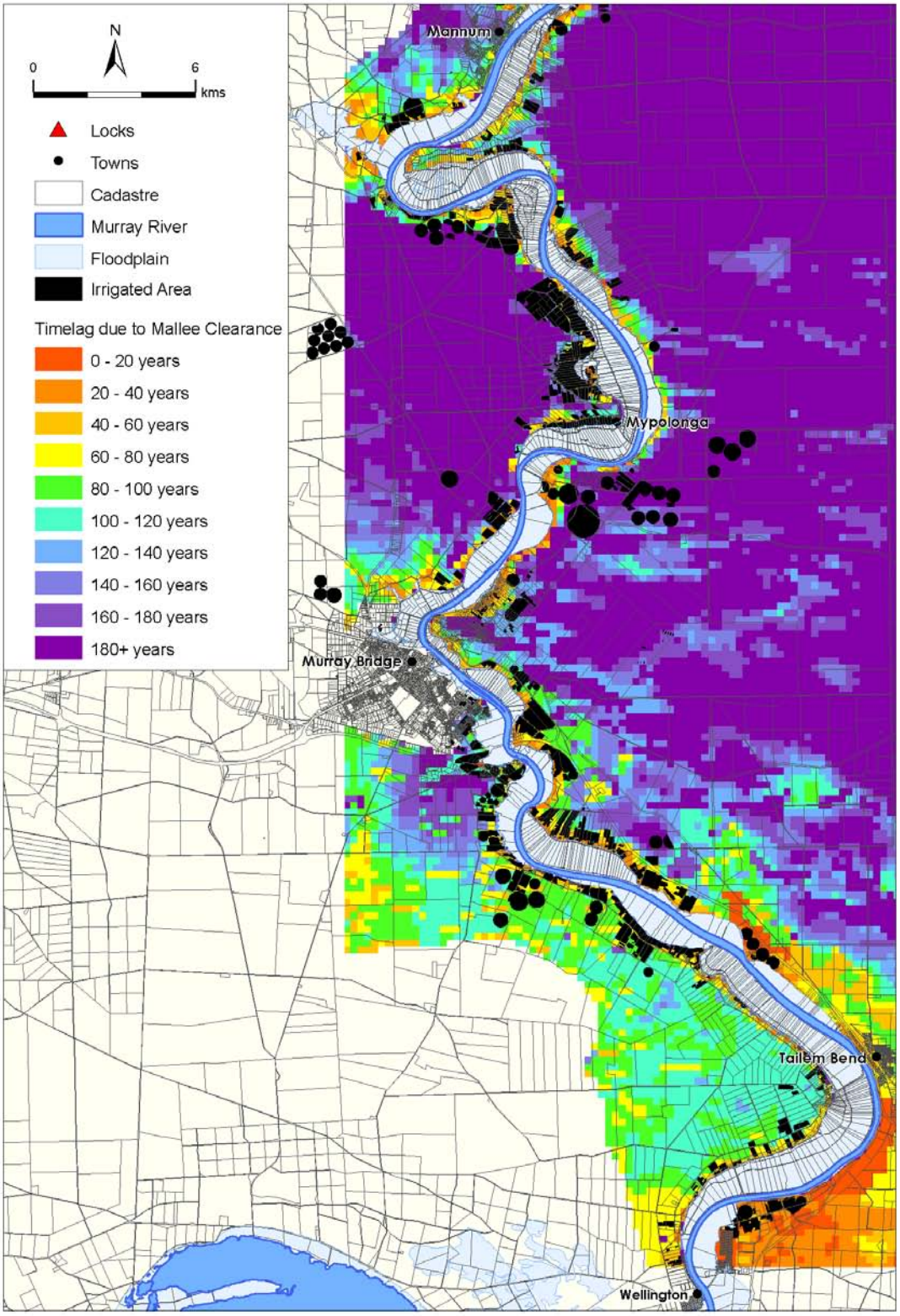
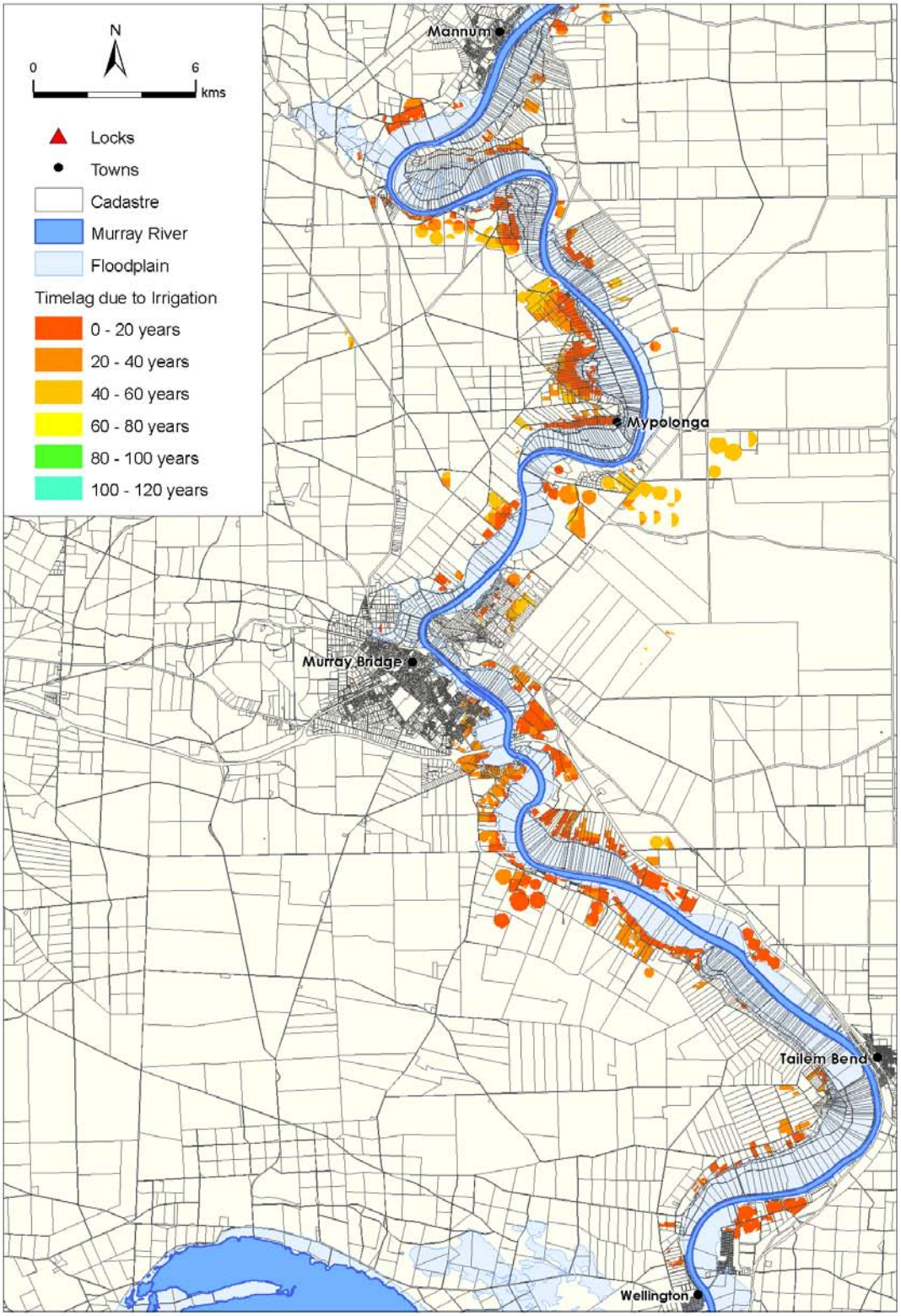


Figure 15. Timelag in irrigation areas in the Mannum to Murray Bridge and Murray Bridge to Wellington sub-zones



RECHARGE ZONES FOR MALLEE CLEARANCE

The recharge zones for mallee cleared areas are generated by combining the surface drainage rate, classified into 4 categories (see Table 3) and the timelag generated by DEH's SIMRAT mallee clearance run, classified into 10 categories (see Table 4). The result is a category with 40 classes, representing the combined recharge rate and timelag for the model area (Table 5)

Table 3. Drainage rate categories

Drain_zone
1. < 1mm
2. 1 - 5mm
3. 5 - 10mm
4. > 10mm

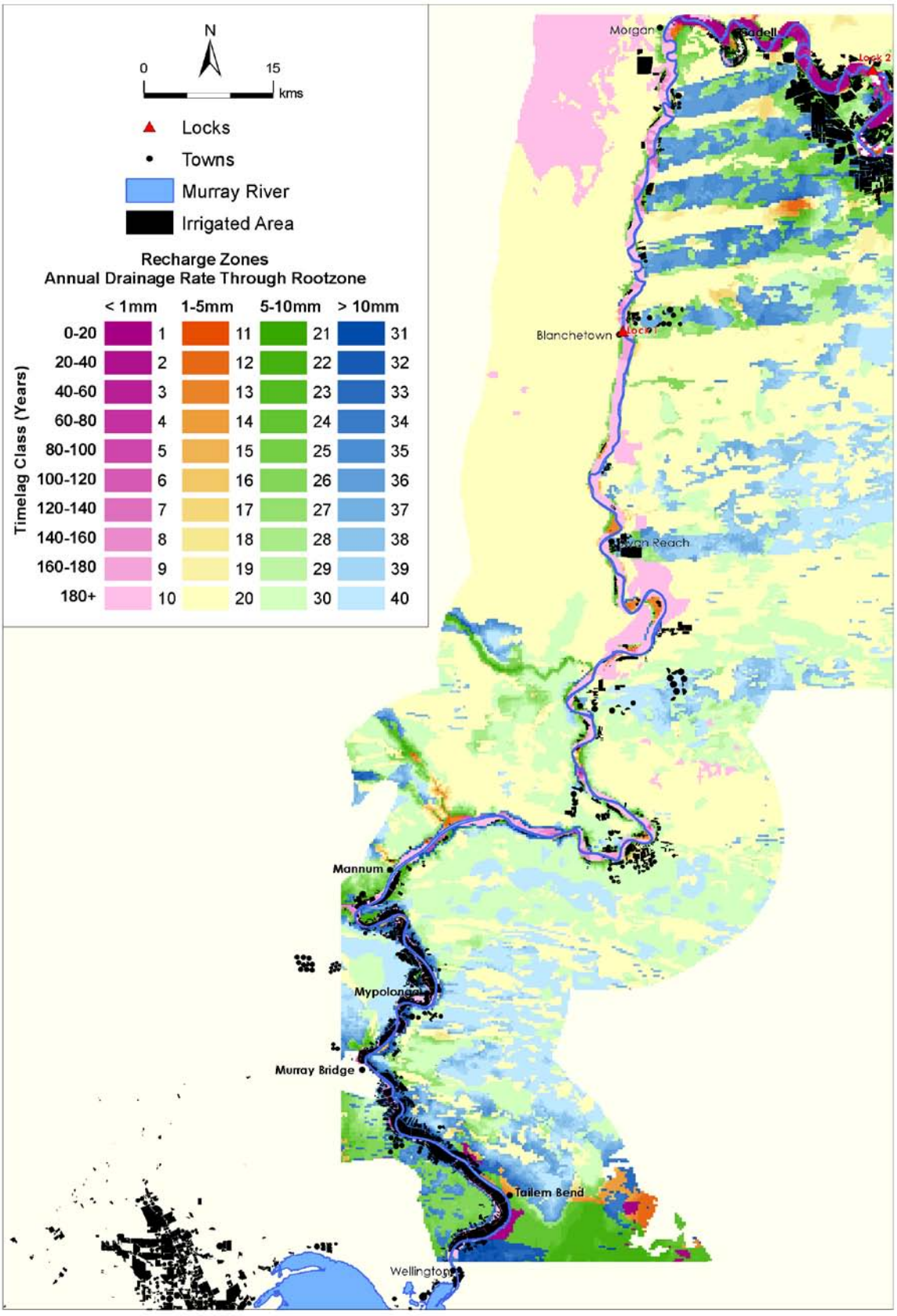
Table 4. Timelag categories

Timelag_zone
1. 0 – 20
2. 20 – 40
3. 40 – 60
4. 60 – 80
5. 80 – 100
6. 100 – 120
7. 120 – 140
8. 140 – 160
9. 160 – 180
10. 180 +

Table 5. Recharge zone categories

Class	Drain_zone	Timelag_zone
1	1	1
2	1	2
3	1	3
4	1	4
5	1	5
6	1	6
7	1	7
8	1	8
9	1	9
10	1	10
11	2	1
12	2	2
13	2	3
14	2	4
15	2	5
16	2	6
17	2	7
18	2	8
19	2	9
20	2	10
21	3	1
22	3	2
23	3	3
24	3	4
25	3	5
26	3	6
27	3	7
28	3	8
29	3	9
30	3	10
31	4	1
32	4	2
33	4	3
34	4	4
35	4	5
36	4	6
37	4	7
38	4	8
39	4	9
40	4	10

Figure 16. Recharge zones due to mallee clearance in the Mannum to Wellington sub-zones



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APPENDIX ARECHARGE RATE TABLES

Table A1. Summary of recharge rates for the Morgan to Lock 1 sub-zone

Morgan to Lock 1								
Year	Irrigated Area	Irrigation Application *			Rainfall (Blanchetown)	Total Recharge to Surface (Irrigation + Rainfall)	Root Zone Drainage	Total Recharge to Water Table (Irrigation + Rainfall)
	Hectares	Pumped Volume ML/yr	ML/Ha /yr	mm/yr	mm/yr	mm/yr	%	mm/yr
1970	760.6				240	240	15	36
1971	760.6				285	285	15	43
1972	760.6				194	194	15	29
1973	760.6				569	569	15	85
1974	760.6				583	583	15	87
1975	760.6				279	279	15	42
1976	760.6				245	245	15	37
1977	760.6				203	203	15	31
1978	760.6				310	310	15	46
1979	760.6				411	411	15	62
1980	806.9				261	261	15	39
1981	806.9				236	236	15	35
1982	806.9				142	142	15	21
1983	806.9				320	320	15	48
1984	806.9				234	234	15	35
1985	806.9				238	238	15	36
1986	806.9				302	302	15	45
1987	806.9				295	295	15	44
1988	806.9	9850	12.2	1221	284	1505	15	226
1989	806.9	9850	12.2	1221	352	1573	15	236
1990	806.9	9850	12.2	1221	248	1469	15	220
1991	806.9	9850	12.2	1221	243	1464	15	220
1992	806.9	9850	12.2	1221	517	1738	15	261
1993	806.9	9850	12.2	1221	356	1576	15	236
1994	806.9	9850	12.2	1221	159	1380	15	207
1995	934.8	3690	3.9	395	396	790	15	119
1996	934.8	3690	3.9	395	357	752	15	113
1997	1096.5	3690	3.4	337	298	635	15	95
1998	1096.5	3690	3.4	337	344	681	15	102
1999	1150.5	3690	3.2	321	285	605	15	91
2000	1498.8	3462	2.3	231	299	530	15	79
2001	1552.3	3462	2.2	223	297	520	15	78
2002	1552.3	3462	2.2	223	133	356	15	53
2003	1823.7	3462	1.9	190	292	482	15	72
2004	1838.8	3462	1.9	188	215	403	15	60
2005	2321.4	6807	2.9	293	298	591	15	89
2006	2321.4	6807	2.9	293	193	486	15	73
2007	2321.4	6807	2.9	293	326	619	15	93

* NOTE: volume for irrigation diversion available from 1988 but incomplete

Rainfall text in red denotes a year with incomplete records.

Table A2. Summary of recharge rates for the Lock 1 to Mannum sub-zone

Lock 1 to Mannum								
Year	Irrigated Area	Irrigation Application *			Rainfall (Swan Reach)	Total Recharge to Surface (Irrigation + Rainfall)	Root Zone Drainage	Total Recharge to Water Table (Irrigation + Rainfall)
	Hectares	Pumped Volume ML/yr	ML/Ha /yr	mm/yr	mm/yr	mm/yr	%	mm/yr
1960	382.0				331.7			
1961	382.0				300.8			
1962	382.0				235.9			
1963	382.0				297.0			
1964	382.0				360.6			
1965	382.0				195.4			
1966	382.0				276.9			
1967	382.0				102.8			
1968	382.0				251.2			
1969	382.0				341.1			
1970	1228.5				252.8			
1971	1228.5				264.2			
1972	1228.5				186.4			
1973	1228.5				549.1			
1974	1228.5				534.8			
1975	1228.5				239.0			
1976	1228.5				225.6			
1977	1228.5				151.0			
1978	1228.5				266.0			
1979	1228.5				390.2			
1980	1358.9				236.0			
1981	1358.9				207.2			
1982	1358.9				131.0			
1983	1358.9				322.7			
1984	1358.9				242.8			
1985	1358.9				229.2			
1986	1358.9				263.4			
1987	1358.9				305.6			
1988	1358.9	20955	15.4	1542.1	275.4	1817.5	15	1817.6
1989	1368.1	20955	15.3	1531.7	337.9	1869.6	15	1869.7
1990	1368.1	20955	15.3	1531.7	219.6	1751.3	15	1751.4
1991	1368.1	20955	15.3	1531.7	255.9	1787.6	15	1787.7
1992	1368.1	20955	15.3	1531.7	515.8	2047.5	15	2047.6
1993	1368.1	20955	15.3	1531.7	259.6	1791.3	15	1791.4
1994	1368.1	20955	15.3	1531.7	158.4	1690.1	15	1690.2
1995	2136.3	8633	4.0	404.1	323.7	727.8	15	728.0
1996	2136.3	8633	4.0	404.1	263.7	667.8	15	668.0
1997	2573.7	8633	3.4	335.4	260.8	596.2	15	596.4
1998	2573.7	8633	3.4	335.4	292.1	627.5	15	627.7
1999	2715.8	8633	3.2	317.9	255.2	573.1	15	573.2
2000	2944.7	5133	1.7	174.3	290.9	465.2	15	465.4
2001	3290.4	5133	1.6	156.0	295.3	451.3	15	451.4
2002	3328.0	5133	1.5	154.2	121.0	275.2	15	275.4
2003	4174.5	5133	1.2	123.0	331.9	454.9	15	455.0
2004	4252.1	5133	1.2	120.7	244.4	365.1	15	365.3
2005	4285.5	28753	6.7	670.9	314.3	985.2	15	985.4
2006	5749.4	28753	5.0	500.1	164.3	664.4	15	664.6
2007	5757.5	28753	5.0	499.4	285.0	784.4	15	784.6

* NOTE: volume for irrigation diversion available from 1988 but incomplete

Rainfall text in red denotes a year with incomplete records.

Table A3. Summary of recharge rates for the Mannum to Murray Bridge (Highland) sub-zone

Mannum to Murray Bridge (Highland)								
Year	Irrigated Area	Irrigation Application *			Rainfall	Total Recharge to Surface (Irrigation + Rainfall)	Root Zone Drainage	Total Recharge to Water Table (Irrigation + Rainfall)
	Hectares	Pumped Volume ML/yr	ML/Ha/yr	mm/yr	mm/yr	mm/yr	%	mm/yr
1920	549.5				348.1			
1921	549.5				426.9			
1922	549.5				324.1			
1923	549.5				290.5			
1924	549.5				315.6			
1925	549.5				292.7			
1926	549.5				260.8			
1927	549.5				227.6			
1928	549.5				255.1			
1929	549.5				245.2			
1930	549.5				266.2			
1931	549.5				238.8			
1932	549.5				381.1			
1933	549.5				233.8			
1934	549.5				271.5			
1935	549.5				306.3			
1936	549.5				325.6			
1937	549.5				368.9			
1938	549.5				193.4			
1939	549.5				308.9			
1940	549.5				167.4			
1941	549.5				499.5			
1942	549.5				387.0			
1943	549.5				230.1			
1944	549.5				155.2			
1945	549.5				259.8			
1946	549.5				516.9			
1947	549.5				379.4			
1948	549.5				277.5			
1949	549.5				281.5			
1950	549.5				289.8			
1951	549.5				333.7			
1952	549.5				274.1			
1953	549.5				273.4			
1954	549.5				239.3			
1955	549.5				407.9			
1956	549.5				260.2			
1957	549.5				138.4			
1958	549.5				288.3			
1959	549.5				261.4			
1960	683.9				324.1			
1961	683.9				239.8			

* NOTE: volume for irrigation diversion available from 1988 but incomplete

Rainfall text in red denotes a year with incomplete records.

Table A3. Summary of recharge rates for the Mannum to Murray Bridge (Highland) sub-zone (cont)

Mannum to Murray Bridge (Highland)								
Year	Irrigated Area	Irrigation Application *			Rainfall	Total Recharge to Surface (Irrigation + Rainfall)	Root Zone Drainage	Total Recharge to Water Table (Irrigation + Rainfall)
	Hectares	Pumped Volume ML/yr	ML/Ha/yr	mm/yr	mm/yr	mm/yr	%	mm/yr
1962	683.9				252.8			
1963	683.9				339.1			
1964	683.9				326.0			
1965	683.9				212.8			
1966	683.9				249.3			
1967	683.9				121.3			
1968	683.9				288.4			
1969	683.9				391.5			
1970	1006.6				290.6			
1971	1006.6				276.0			
1972	1006.6				199.0			
1973	1006.6				387.3			
1974	1006.6				534.4			
1975	1006.6				276.5			
1976	1006.6				235.6			
1977	1006.6				212.4			
1978	1006.6				289.8			
1979	1006.6				385.8			
1980	1006.6				311.2			
1981	1006.6				248.0			
1982	1006.6				168.4			
1983	1006.6				458.8			
1984	1006.6				332.4			
1985	1006.6				300.4			
1986	1006.6				277.0			
1987	1006.6				327.1			
1988	1006.6	9075	9.0	901.55	314.2	1215.7	15	182.4
1989	1006.6	9075	9.0	901.55	336.6	1238.1	15	185.7
1990	1006.6	9075	9.0	901.55	285.1	1186.6	15	178.0
1991	1006.6	9075	9.0	901.55	245.4	1146.9	15	172.0
1992	1006.6	9075	9.0	901.55	557.6	1459.1	15	218.9
1993	1006.6	9075	9.0	901.55	277.8	1179.3	15	176.9
1994	1006.6	9075	9.0	901.55	187.8	1089.3	15	163.4
1995	1145.5	918	0.8	80.14	313.6	393.7	15	59.1
1996	1145.5	918	0.8	80.14	312.3	392.4	15	58.9
1997	1264.1	918	0.7	72.621	333.0	405.6	15	60.8
1998	1264.1	918	0.7	72.621	268.8	341.4	15	51.2
1999	1358	918	0.7	67.599	244.7	312.3	15	46.8
2000	1358	823	0.6	60.604	163.7	224.3	15	33.6
2001	1429.2	823	0.6	57.585	239.8	297.4	15	44.6
2002	1429.2	823	0.6	57.585	166.6	224.2	15	33.6
2003	1585.8	823	0.5	51.898	88.6	140.5	15	21.1
2004	1585.8	823	0.5	51.898	182.4	234.3	15	35.1
2005	1868.1	6616	3.5	354.16	326.2	680.4	15	102.1
2006	2467.9	6616	2.7	268.08	172.8	440.9	15	66.1
2007	2472.7	6616	2.7	267.56	256.8	524.4	15	78.7

* NOTE: volume for irrigation diversion available from 1988 but incomplete

Rainfall text in red denotes a year with incomplete records.

Table A4. Summary of recharge rates for the Mannum to Murray Bridge (Floodplain) sub-zone

Mannum to Murray Bridge (Floodplain)								
Year	Irrigated Area	Irrigation Application *			Rainfall	Total Recharge to Surface (Irrigation + Rainfall)	Root Zone Drainage	Total Recharge to Water Table (Irrigation + Rainfall)
	Hectares	Pumped Volume ML/yr	ML/Ha /yr	mm/yr	mm/yr	mm/yr	%	mm/yr
1929	2,228.1				245.2			
1930	2,228.1				266.2			
1931	2,228.1				238.8			
1932	2,228.1				381.1			
1933	2,228.1				233.8			
1934	2,228.1				271.5			
1935	2,228.1				306.3			
1936	2,228.1				325.6			
1937	2,228.1				368.9			
1938	2,228.1				193.4			
1939	2,228.1				308.9			
1940	2,228.1				167.4			
1941	2,228.1				499.5			
1942	2,228.1				387.0			
1943	2,228.1				230.1			
1944	2,228.1				155.2			
1945	2,228.1				259.8			
1946	2,228.1				516.9			
1947	2,228.1				379.4			
1948	2,228.1				277.5			
1949	2,228.1				281.5			
1950	2,228.1				289.8			
1951	2,228.1				333.7			
1952	2,228.1				274.1			
1953	2,228.1				273.4			
1954	2,228.1				239.3			
1955	2,228.1				407.9			
1956	2,228.1				260.2			
1957	2,228.1				138.4			
1958	2,228.1				288.3			
1959	2,228.1				261.4			
1960	2,228.1				324.1			
1961	2,228.1				239.8			
1962	2,228.1				252.8			
1963	2,228.1				339.1			
1964	2,228.1				326.0			
1965	2,228.1				212.8			
1966	2,228.1				249.3			

* NOTE: volume for irrigation diversion not available for floodplain

Rainfall text in red denotes a year with incomplete records.

Table A4. Summary of recharge rates for the Mannum to Murray Bridge (Floodplain) sub-zone (cont)

Mannum to Murray Bridge (Floodplain)								
Year	Irrigated Area	Irrigation Application *			Rainfall	Total Recharge to Surface (Irrigation + Rainfall)	Root Zone Drainage	Total Recharge to Water Table (Irrigation + Rainfall)
	Hectares	Pumped Volume ML/yr	ML/Ha /yr	mm/yr	mm/yr	mm/yr	%	mm/yr
1967	2,228.1				121.3			
1968	2,228.1				288.4			
1969	2,228.1				391.5			
1970	2,228.1				290.6			
1971	2,228.1				276.0			
1972	2,228.1				199.0			
1973	2,228.1				387.3			
1974	2,228.1				534.4			
1975	2,228.1				276.5			
1976	2,228.1				235.6			
1977	2,228.1				212.4			
1978	2,228.1				289.8			
1979	2,228.1				385.8			
1980	2,228.1				311.2			
1981	2,228.1				248.0			
1982	2,228.1				168.4			
1983	2,228.1				458.8			
1984	2,228.1				332.4			
1985	2,228.1				300.4			
1986	2,228.1				277.0			
1987	2,228.1				327.1			
1988	2,228.1		0.0	0.0	314.2	314.2	15	47.1
1989	2,228.1		0.0	0.0	336.6	336.6	15	50.5
1990	2,228.1		0.0	0.0	285.1	285.1	15	42.8
1991	2,228.1		0.0	0.0	245.4	245.4	15	36.8
1992	2,228.1		0.0	0.0	557.6	557.6	15	83.6
1993	2,228.1		0.0	0.0	277.8	277.8	15	41.7
1994	2,228.1		0.0	0.0	187.8	187.8	15	28.2
1995	2,228.1		0.0	0.0	313.6	313.6	15	47.0
1996	2,228.1		0.0	0.0	312.3	312.3	15	46.8
1997	2,228.1		0.0	0.0	333.0	333.0	15	50.0
1998	2,228.1		0.0	0.0	268.8	268.8	15	40.3
1999	2,228.1		0.0	0.0	244.7	244.7	15	36.7
2000	2,228.1		0.0	0.0	163.7	163.7	15	24.6
2001	2,228.1		0.0	0.0	239.8	239.8	15	36.0
2002	2,228.1		0.0	0.0	166.6	166.6	15	25.0
2003	2,228.1		0.0	0.0	88.6	88.6	15	13.3
2004	2,228.1		0.0	0.0	182.4	182.4	15	27.4
2005	2,228.1		0.0	0.0	326.2	326.2	15	48.9
2006	2,228.1		0.0	0.0	172.8	172.8	15	25.9
2007	2,228.1		0.0	0.0	256.8	256.8	15	38.5

* NOTE: volume for irrigation diversion not available for floodplain

Rainfall text in red denotes a year with incomplete records.

Table A5. Summary of recharge rates for the Murray Bridge to Wellington (Highland) sub-zone

Murray Bridge to Wellington (Highland)								
Year	Irrigated Area	Irrigation Application *			Rainfall	Total Recharge to Surface (Irrigation + Rainfall)	Root Zone Drainage	Total Recharge to Water Table (Irrigation + Rainfall)
	Highland	Pumped Volume ML/yr	ML/Ha/yr	mm/yr	mm/yr	mm/yr	%	mm/yr
1920	305.5				308.7			
1921	305.5				437.9			
1922	305.5				368.3			
1923	305.5				388.8			
1924	305.5				406.7			
1925	305.5				350.5			
1926	305.5				275.8			
1927	305.5				256.0			
1928	305.5				335.7			
1929	305.5				267.9			
1930	305.5				252.6			
1931	305.5				252.0			
1932	305.5				404.8			
1933	305.5				239.9			
1934	305.5				291.4			
1935	305.5				310.4			
1936	305.5				369.8			
1937	305.5				296.9			
1938	305.5				211.1			
1939	305.5				354.3			
1940	305.5				228.4			
1941	305.5				514.2			
1942	305.5				443.5			
1943	305.5				299.4			
1944	305.5				184.4			
1945	305.5				376.2			
1946	305.5				534.6			
1947	305.5				417.6			
1948	305.5				326.8			
1949	305.5				262.5			
1950	305.5				273.0			
1951	305.5				375.2			
1952	305.5				368.5			
1953	305.5				292.7			
1954	305.5				288.3			
1955	305.5				530.1			
1956	305.5				305.9			
1957	305.5				186.5			
1958	305.5				337.9			
1959	305.5				259.8			
1960	305.5				404.9			

* NOTE: volume for irrigation diversion available from 1988 but incomplete
The rehabilitated Mypolonga Highland Irrigation District metered from 2003-04.

Rainfall text in red denotes a year with incomplete records.

Table A5. Summary of recharge rates for the Murray Bridge to Wellington (Highland) sub-zone (cont)

Murray Bridge to Wellington (Highland)								
Year	Irrigated Area	Irrigation Application *			Rainfall	Total Recharge to Surface (Irrigation + Rainfall)	Root Zone Drainage	Total Recharge to Water Table (Irrigation + Rainfall)
	Highland	Pumped Volume ML/yr	ML/Ha/yr	mm/yr	mm/yr	mm/yr	%	mm/yr
1961	305.5				277.5			
1962	305.5				315.3			
1963	305.5				422.4			
1964	305.5				390.0			
1965	305.5				253.3			
1966	305.5				332.9			
1967	305.5				136.4			
1968	305.5				382.1			
1969	305.5				435.4			
1970	949.5				380.8			
1971	949.5				313.1			
1972	949.5				284.8			
1973	949.5				446.1			
1974	949.5				675.4			
1975	949.5				340.9			
1976	949.5				275.6			
1977	949.5				302.6			
1978	949.5				368.3			
1979	949.5				389.4			
1980	949.5				326.3			
1981	949.5				338.2			
1982	949.5				196.2			
1983	949.5				490.2			
1984	949.5				360.0			
1985	949.5				381.8			
1986	949.5				362.0			
1987	949.5				383.6			
1988	949.5	704	0.7	74.1	329.3	403.4	15	60.5
1989	949.5	704	0.7	74.1	365.6	439.7	15	66.0
1990	949.5	704	0.7	74.1	342.0	416.1	15	62.4
1991	949.5	704	0.7	74.1	323.0	397.1	15	59.6
1992	949.5	704	0.7	74.1	621.9	696.0	15	104.4
1993	949.5	704	0.7	74.1	349.1	423.2	15	63.5
1994	949.5	704	0.7	74.1	256.6	330.7	15	49.6
1995	1247.3	752	0.6	60.3	320.6	380.9	15	57.1
1996	1247.3	752	0.6	60.3	*364.4*	424.7	15	63.7
1997	1423.2	752	0.5	52.8	378.1	430.9	15	64.6
1998	1423.2	752	0.5	52.8	350.0	402.8	15	60.4
1999	1553.9	752	0.5	48.4	318.1	366.5	15	55.0
2000	1553.9	1040	0.7	66.9	434.7	501.6	15	75.2
2001	1632.5	1040	0.6	63.7	368.0	431.7	15	64.8
2002	1632.5	1040	0.6	63.7	*269.6*	333.3	15	50.0
2003	1779.7	1040	0.6	58.4	402.7	461.1	15	69.2
2004	1779.7	1040	0.6	58.4	375.4	433.8	15	65.1
2005	1811	3872	2.1	213.8	498.7	712.5	15	106.9
2006	1879.8	3872	2.1	206.0	241.2	447.2	15	67.1
2007	1879.8	3872	2.1	206.0	328.5	534.5	15	80.2

* NOTE: volume for irrigation diversion available from 1988 but incomplete
The rehabilitated Mypolonga Highland Irrigation District metered from 2003-04.

Rainfall text in red denotes a year with incomplete records.

Table A6. Summary of recharge rates for the Murray Bridge to Wellington (Floodplain) sub-zone

Murray Bridge to Wellington (Floodplain)								
Year	Irrigated Area	Irrigation Application *			Rainfall	Total Recharge to Surface (Irrigation + Rainfall)	Root Zone Drainage	Total Recharge to Water Table (Irrigation + Rainfall)
	Hectares	Pumped Volume ML/yr	ML/Ha/yr	mm/yr	mm/yr	mm/yr	%	mm/yr
1929	3,110.5				267.9			
1930	3,110.5				252.6			
1931	3,110.5				252.0			
1932	3,110.5				404.8			
1933	3,110.5				239.9			
1934	3,110.5				291.4			
1935	3,110.5				310.4			
1936	3,110.5				369.8			
1937	3,110.5				296.9			
1938	3,110.5				211.1			
1939	3,110.5				354.3			
1940	3,110.5				228.4			
1941	3,110.5				514.2			
1942	3,110.5				443.5			
1943	3,110.5				299.4			
1944	3,110.5				184.4			
1945	3,110.5				376.2			
1946	3,110.5				534.6			
1947	3,110.5				417.6			
1948	3,110.5				326.8			
1949	3,110.5				262.5			
1950	3,110.5				273.0			
1951	3,110.5				375.2			
1952	3,110.5				368.5			
1953	3,110.5				292.7			
1954	3,110.5				288.3			
1955	3,110.5				530.1			
1956	3,110.5				305.9			
1957	3,110.5				186.5			
1958	3,110.5				337.9			
1959	3,110.5				259.8			
1960	3,110.5				404.9			
1961	3,110.5				277.5			
1962	3,110.5				315.3			
1963	3,110.5				422.4			
1964	3,110.5				390.0			
1965	3,110.5				253.3			
1966	3,110.5				332.9			
1967	3,110.5				136.4			

* NOTE: volume for irrigation diversion not available for floodplain

Rainfall text in red denotes a year with incomplete records.

Table A6. Summary of recharge rates for the Murray Bridge to Wellington (Floodplain) sub-zone (cont)

Murray Bridge to Wellington (Floodplain)								
Year	Irrigated Area	Irrigation Application *			Rainfall	Total Recharge to Surface (Irrigation + Rainfall)	Root Zone Drainage	Total Recharge to Water Table (Irrigation + Rainfall)
	Hectares	Pumped Volume ML/yr	ML/Ha/yr	mm/yr	mm/yr	mm/yr	%	mm/yr
1968	3,110.5				382.1			
1969	3,110.5				435.4			
1970	3,110.5				380.8			
1971	3,110.5				313.1			
1972	3,110.5				284.8			
1973	3,110.5				446.1			
1974	3,110.5				675.4			
1975	3,110.5				340.9			
1976	3,110.5				275.6			
1977	3,110.5				302.6			
1978	3,110.5				368.3			
1979	3,110.5				389.4			
1980	3,110.5				326.3			
1981	3,110.5				338.2			
1982	3,110.5				196.2			
1983	3,110.5				490.2			
1984	3,110.5				360.0			
1985	3,110.5				381.8			
1986	3,110.5				362.0			
1987	3,110.5				383.6			
1988	3,110.5		0.0	0.0	329.3	329.3	15	49.4
1989	3,110.5		0.0	0.0	365.6	365.6	15	54.8
1990	3,110.5		0.0	0.0	342.0	342.0	15	51.3
1991	3,110.5		0.0	0.0	323.0	323.0	15	48.5
1992	3,110.5		0.0	0.0	621.9	621.9	15	93.3
1993	3,110.5		0.0	0.0	349.1	349.1	15	52.4
1994	3,110.5		0.0	0.0	256.6	256.6	15	38.5
1995	3,110.5		0.0	0.0	320.6	320.6	15	48.1
1996	3,110.5		0.0	0.0	364.4	364.4	15	54.7
1997	3,110.6		0.0	0.0	378.1	378.1	15	56.7
1998	3,110.6		0.0	0.0	350.0	350.0	15	52.5
1999	3,110.6		0.0	0.0	318.1	318.1	15	47.7
2000	3,110.6		0.0	0.0	434.7	434.7	15	65.2
2001	3,110.7		0.0	0.0	368.0	368.0	15	55.2
2002	3,110.6		0.0	0.0	269.6	269.6	15	40.4
2003	3,110.7		0.0	0.0	402.7	402.7	15	60.4
2004	3,110.7		0.0	0.0	375.4	375.4	15	56.3
2005	3,130.7		0.0	0.0	498.7	498.7	15	74.8
2006	3,130.7		0.0	0.0	241.2	241.2	15	36.2
2007	3,144.6		0.0	0.0	328.5	328.5	15	49.3

* NOTE: volume for irrigation diversion not available for floodplain

Rainfall text in red denotes a year with incomplete records.

APPENDIX BRECHARGE RATE GRAPHS

Figure B1. Summary of recharge rates and irrigated area in the Morgan to Lock 1 sub-zone

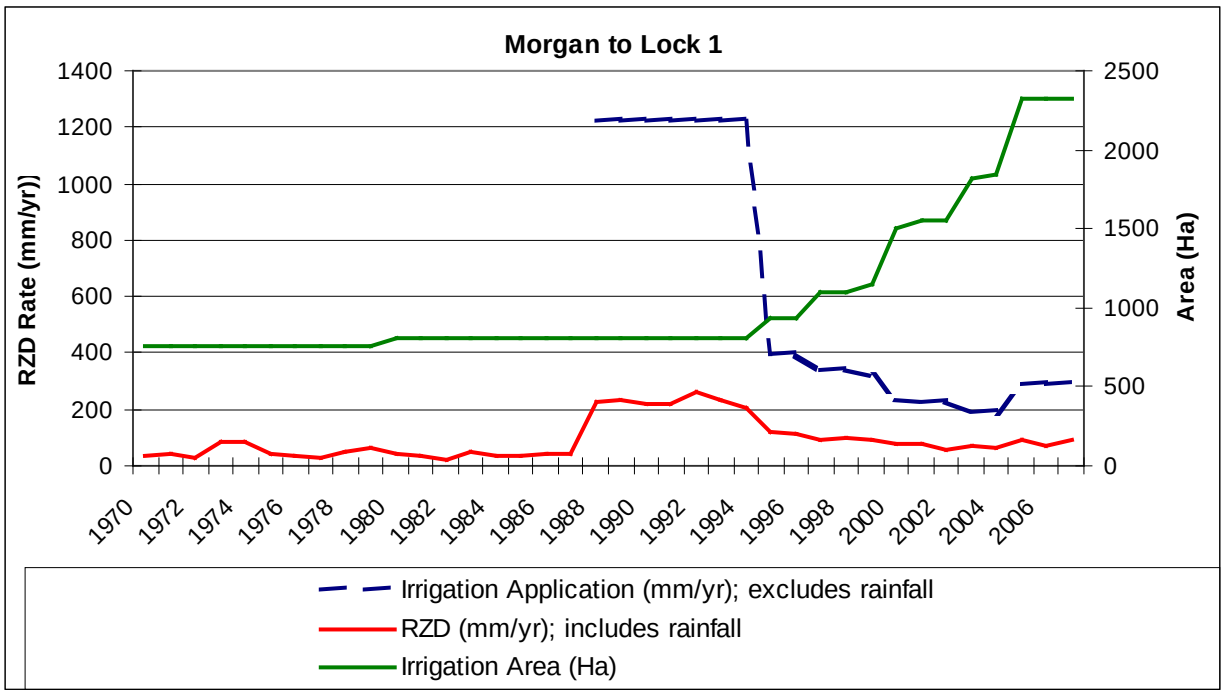

Figure B2. Summary of recharge rates and irrigated area in the Lock 1 to Mannum sub-zone

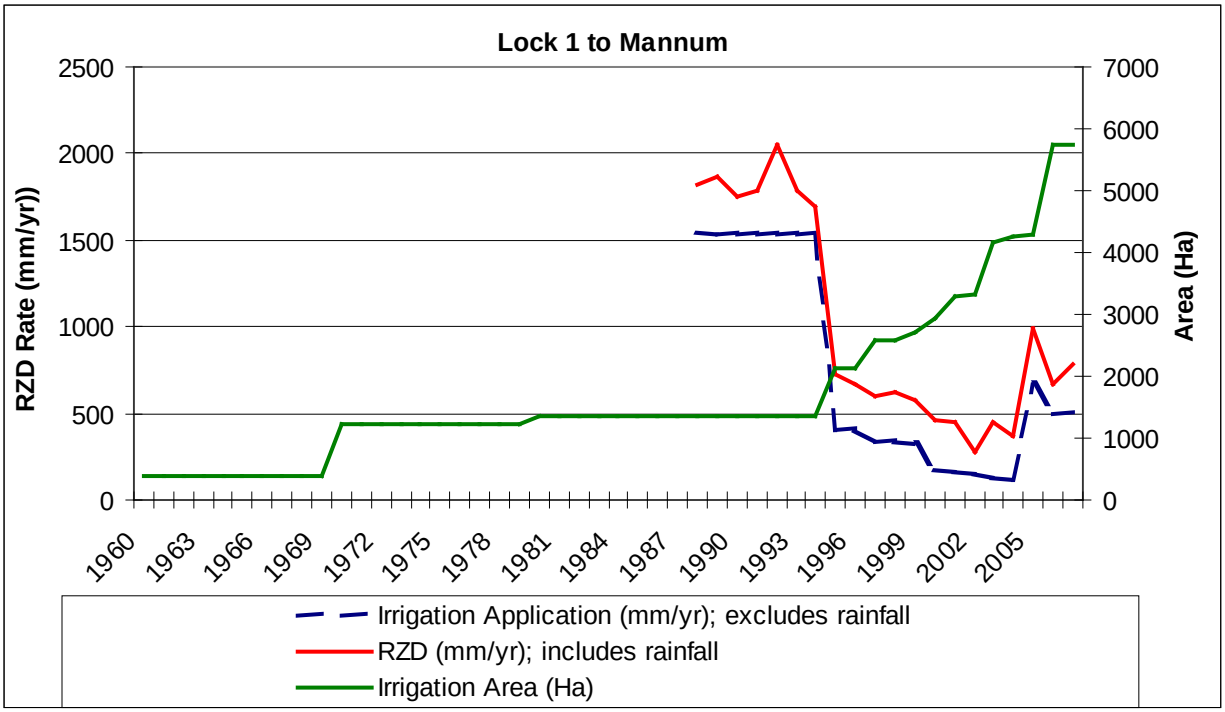

Figure B3. Summary of recharge rates and irrigated area in the Mannum to Murray Bridge (Highland) sub-zone

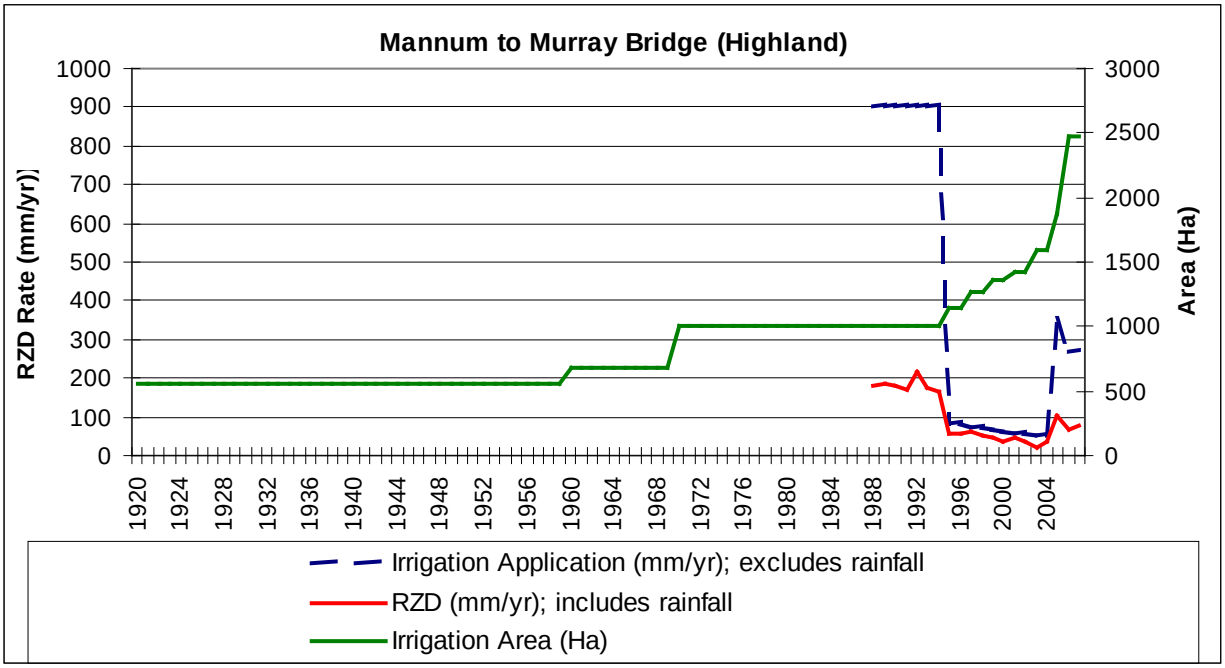

Figure B4. Summary of recharge rates and irrigated area in the Mannum to Murray Bridge (Floodplain) sub-zone

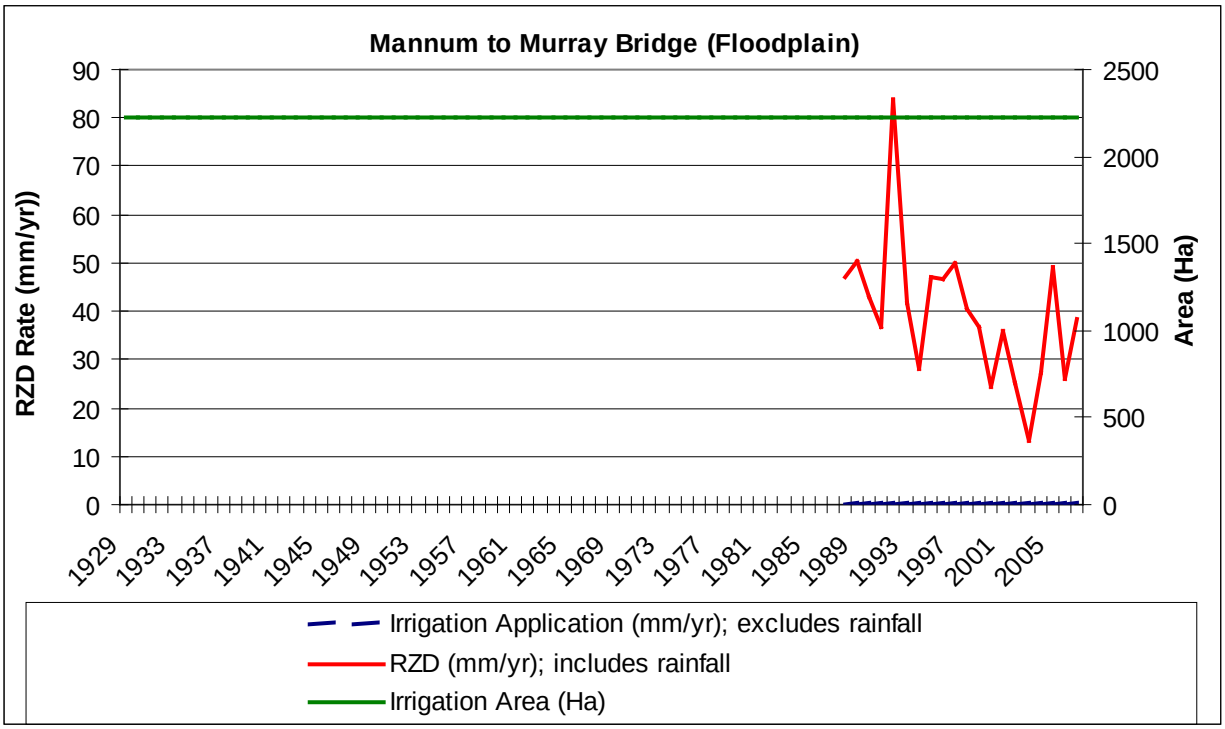

Figure B5. Summary of recharge rates and irrigated area in the Murray Bridge to Wellington (Highland) sub-zone

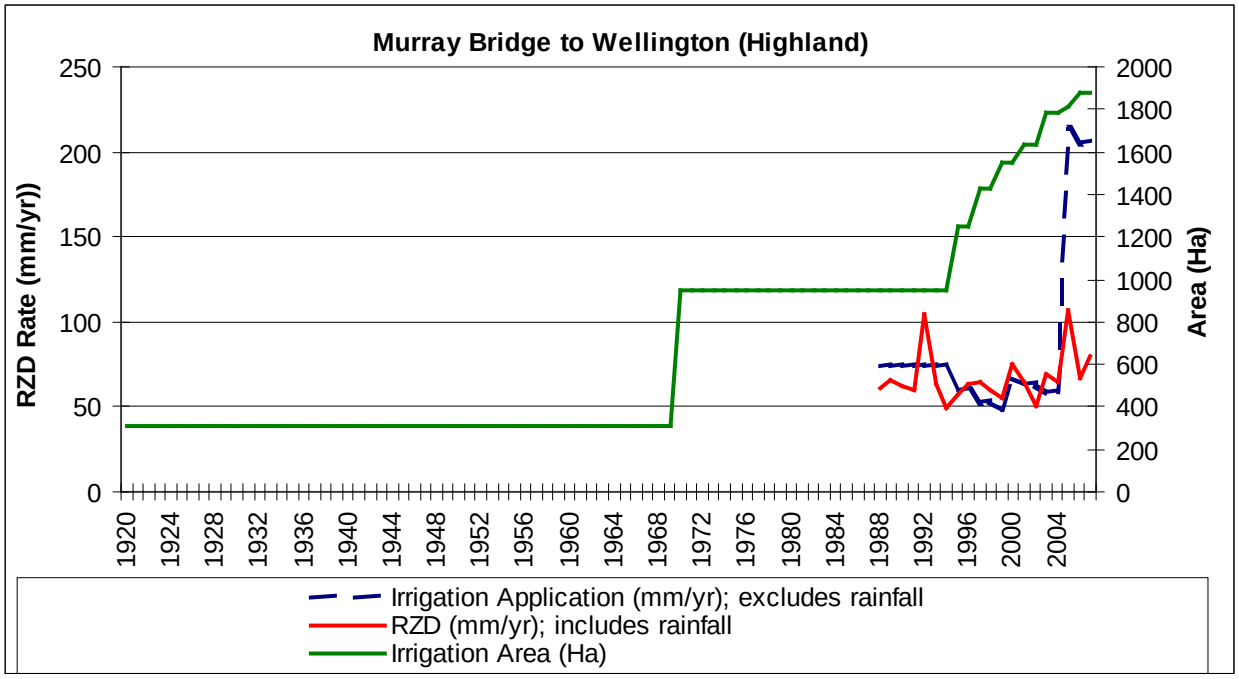

Figure B6. Summary of recharge rates and irrigated area in the Murray Bridge to Wellington (Floodplain) sub-zone