Documentation for the hydrology-landuse modeling

Hydrology-landuse models have been developed for each of 15 communities in the Northern Basin using regression analysis. The models relate surface water diversions to the area of irrigated production across the period from 1999-2000 to 2013-14. They are based on the different types and volumes of water utilized in each community. By defining the water availability-production relationships across time, it will be possible to estimate how the recovery of water for the environment might be expected to alter farmers' production decisions.

Where communities rely on groundwater, groundwater-dependent production is calculated and deducted from the total area planted prior to the surface water-area irrigated regression analysis. In some cases, data for rainfall either prior to planting and/or during the previous irrigation season is incorporated into the regression analysis. Different approaches for modelling the hydrology-landuse models are contained in the spreadsheet 'NthBasin rain allocation ag'.

The purpose of these models is to provide estimates of the annual area of irrigated production with and without water recovery. This information provides one of the inputs for examining broader community level effects of changes in water availability. Preferred hydrology-landuse models for each community are combined into a single spreadsheet model (NBR landuse-hydrology model). The development and use of that spreadsheet model is described in this report.

Sources of data

Hydrologic modelling outputs – monthly diversion data by entitlement types was obtained from current conditions models in New South Wales and the IQQM models in Queensland. Monthly diversion data covers the period from 1 January 1998 to 30 June 2013 (Macquarie) or 30 June 2014 (Namoi, Gwydir, Barwon-Darling, Condamine-Balonne, Border Rivers).

Area irrigated – the estimates of cotton area irrigated were derived from raw data provided by Monsanto. The data represents the final hectares of green cotton grown by each farm across the period from 2002. Farm areas of production were manually ascribed to the individual community areas applying to the analysis in this project. For 1999, 2000 and 2001 planting years, estimates of the area planted were derived from a combination of the cotton Australia data, Australian Bureau of Statistics data, where the latter is available, or other primary sources such as the Border Rivers Commission annual reports.

While the area irrigated in each community is examined across the period 1999-2000 to 2013-14, the analytical approach does not seek to treat the data as a traditional time series. Instead, the maximum area of development was largely determined for each community at the start of this relatively short period. The response, in terms of the area of that land which ends up being irrigated each year, is largely a function of the water available for diversion and use on the farms. Production in this period represents short-run economic decisions based around utilising a fixed level of capital (developed land plus irrigation infrastructure). It might also be suggested production decisions take into account the prices paid for irrigated produce. Across the time period of this analysis, there is only a 35% correlation between the area irrigated and the price of cotton. This is not to say that prices received aren't important to farmers, but rather, the production decisions year-on-year are driven primarily by the amount of water available to support irrigated production.

Rainfall – rainfall data for the community areas was extracted from the Bureau of Meterorology 'Monthly Rainfall Maps' as average estimates of rainfall (in mm). The monthly rainfall maps are provided as a national grid of rainfall estimates using a grid size of 0.05 x 0.05 degree. To extrace the

estimates of monthly rainfall for each of community, the community boundaries were overlaid on the monthly rainfall maps with the data downloaded to a CSV file.

Water recovered to date – with the assistance of the Department of Agriculture and Water Resources, an analysis of all water recovery to date in the Northern Basin formed the basis for assigning water recovery to the relevant community areas. Water recovery to each community is provided on the basis of the financial year of the water recovery, the types of water entitlements recovered, the volume of recovered water and whether it is to be included in water recovery through infrastructure investment or buyback. The timing of water recovery is used to determine the timeframe used when developing the models for each community.

Additional water recovery – additional water recovery that has the potential to influence the modelling results is taken into account. Much depends on the nature and timing of that water recovery. For example, State government water recovery in the Gwydir generally preceded the Commonwealth water recovery in that catchment while the State government water recovery program in the Macquarie-Castlereagh is difficult to distinguish from the Commonwealth's buyback activities. With respect to groundwater, communities have different degrees of dependence on that resource. Groundwater is a significant component of the Namoi communities' water resources and that water recovery process has proceeded across a period of 10 years. It will conclude in 2017.

Statistical analysis of regression equations – three statistical tests are applied to indicate the level of confidence that could be placed on the hydrology-landuse models developed to support the social and economic analysis for the northern Basin review. Those tests are:

- Adjusted R^2 – which takes account of the R^2 value provided for the regression equations, the number of observations and the number of independent regressors (variables excluding any equation constant);
- t-statistic applied to each coefficient – provides an estimate of the significance of each of the coefficients in the modelled regression equations. It is derived from the ratio between each coefficient and its standard error;
- F-statistic applied to the reqression equation – used to determine whether a regression equation is a reasonable predictor of the outcomes being modelled. For all the modelled equations, the F-statistic is considerably larger than the critical level of F, indicating the reliability of the regression equations as a predictor of area planted based on water availability (diversions).

Individual community-level hydrology-landuse models (NthBasin rain allocation ag spreadsheet)

In developing the models, it is necessary they provide an estimated baseline of production from which it is possible to measure changes associated with water recovery. In some cases, the recovery of water may have occurred within the period being modelled. Under those circumstances, the individual community-level models are derived using diversion and irrigated production data up until the time of water recovery. Baseline estimates of production are then derived for the whole period using hydrology model information which represents the water expected to have been available for consumptive uses in the absence of any water recovery.

Boggabri – the preferred model is provided at cell AP17 on the 'NamoiGunBog' spreadsheet page. This model applies to the irrigated area related to surface water use, after accounting for the area of production based on groundwater. Estimates of the area produced from groundwater are developed in cell A23, with annual estimates of the area provided in cells E32 to E52. The remaining area grown using surface water is provided in cells F32 to F52.

Two sources of surface water captured in this model are the general security on-allocation and off-allocation water. The on-allocation volumes are the water diversions between 1 July and 31 March each year; off-allocation volumes represent the sum of diversions over the 12 months prior to planting. The coefficient for on-allocation water is significant at the 99.5% confidence level; the coefficient for off-allocation water is significant at the 90% confidence level. This model applies to the whole period under consideration (1999-2000 to 2013-14)

$$\text{Boggabri SW Ha} = \underset{(0.096)}{0.396}\,\text{GS on - alloc ML} + \underset{(0.735)}{1.183}\,\text{GS off - alloc ML} \qquad \text{adjusted } R^2 = 0.72$$

A comparison of the actual and modelled areas of irrigation is provided at cell AS2. The difficulties of modelling irrigated production as a function of the different types of surface water entitlements arise from the relatively small area of production and the highly variable nature in the area irrigated across the 15-year time period being examined. While the estimate of irrigated production does not pick up the peak areas planted in 1999, 2000 or 2010, the modelled function still provides a reasonable representation of the production response to water availability (based on the R^2, the F-statistic and the significance test for the explanatory variables).

Bourke – the preferred model is provided at cell BM19 on the 'Bourke' spreadsheet page. Model inputs are the area planted the previous year, rainfall between the cropping periods (April to October) and water available for production at 30 October (just prior to planting). Water available for production is a function of the water diverted during the period between 1 November the previous year to 31 October in the year of planting after taking into account additional or lesser demands for irrigation water during the previous cropping year. The water balance as an input to production for each year (Starting volume) is calculated using the table at cell Z1.

$$\text{Bourke SW Ha} = \underset{(0.005)}{0.0218}\,\text{Start Vol (ML)} + \underset{(7.94)}{24.873}\,\text{pre - crop rain (mm)} + \underset{(0.058)}{0.739}\,\text{Ha (t - 1)} +$$
$$\underset{(1,317)}{7{,}891} * 2004\,\text{Ha variable} - \underset{(1,208)}{6{,}276} * 2002/2006\,\text{Ha variable} \qquad \text{adjusted } R^2 = 0.98$$

For the Bourke analysis, the diversion data has been extracted from the Barwon-Darling current conditions model developed by the New South Wales government. Monthly diversions cover the period 1 January 1998 to 30 June 2014 and between the gauges of Warraweena and Louth. There are no high security entitlements or groundwater entitlements used by industry in this area. A comparison of the actual and modelled area of irrigation is provided at cell BI2.

As a significant volume of the water recovery for the Bourke area occurred in 2011-12, the model is developed for the period of 1999-2000 to 2012-13. Two timing variables influence the area of production in this model. The first of these relate to anomalous production decisions by irrigators in 2004, where the planting area is considerably greater than the water required to support the planting decisions as taken in each of the other years being modelled. For example, unlike the case in Wee Waa, there is no considerable increase in local rainfall in the months immediately preceding the 2004 planting decisions.

A second hectare-related variable is included for 2002 and 2006. In both years, the starting volumes of water are zero but with hectares planted in the previous year being a significant contributor to the planting decision for the current year, the model would otherwise predict a significant area being planted in these two years. The 2002/2006 variable is therefore required to address a potential over-estimation of planted area in the zero water availability years.

Collarenebri – the preferred model is provided at cell EH19 of the 'Gwydir' spreadsheet page. Model inputs are general security on allocation water, all sources of unregulated water, and an area allowance for water carried over from 1999 to support additional plantings in 2000. No high security or groundwater entitlements were available in the Collarenenbri area.

Multiple sources of diversions considered in the landuse-hydrology modelling for the Collarenebri area included allocations against:

- Barwon-Darling entitlements held between the Mogil Mogil and Tara gauges;
- Gwydir general security and floodplain harvesting water below the Gingham return flows;
- Gwydir general security and floodplain harvesting water held below the Bronte and Iffley gauges; and
- 5% of the general security and floodplain harvesting entitlements for the Moree area.

The general security on-allocation diversions were summed for the period 1 July to 31 March each year. Unregulated diversions were summed for the Barwon-Darling and Gwydir sources across the 12 months prior to planting.

$$\text{Collarenebri SW Ha} = \underset{(0.126)}{0.5191}\,\text{GS on - alloc (ML)} + \underset{(0.0375)}{0.0775}\,\text{pre - crop rain (mm)} + \underset{(2,504)}{7{,}920} * 2000\,\text{Ha variable} \qquad \text{adjusted } R^2 = 0.92$$

As approximately two-thirds of the Collarenebri area water entitlements were recovered in 2009-10 and 2010-11, the model has been developed using area planted and diversion data for the period 1999-2000 to 2009-10. A comparison of the actual and modelled area of irrigation is provided at cell EN1.

Dirranbandi – preferred model for Dirranbandi is located at cell AT153 of the 'LwrBal' spreadsheet page. Irrigated production occurs in response to water available through water harvesting (unsupplemented) and capture of overland flows against the respective entitlements held between bifurcation B1 (slightly north of Dirranbandi) and the New South Wales- Queensland Border.

The model covers the period from 1999-2000 to 2013-14. Even though a significant volume of water had been recovered in the Dirranbandi area prior to 2013-14, farms were still producing close to the maximum area of production up to that point off the back of being able to use water held in on-farm storages. Diversion data for this modelling exercise was extracted by the Queensland government.

It was possible to represent the water harvesting across the period 12 months prior to planting each year in the model. Other factors relevant to the area planted each year were the area planted the previous year and particular decisions (a more aggressive planting decision in November 2000 as a consequence of the considerably higher-than-average rainfall around the time of planting in that year. However, it was not possible to directly represent the area planted being a function of the overland flow diversions. This appears to be a consequence of the highly variable nature of the overland flow diversion data with the 15-year period being modelled.

To capture the use of overland flow diversions in the model, they have been represented as part of a pool of water referred to as the water 'leftover' in storages following the completion of the previous irrigation seasons. The leftover water calculation starts with water available to support planting at the beginning of the previous irrigation season. That volume of water is affected by water use in that irrigation season, which may be higher or lower than expected depending upon whether there has been higher or lower than expected in-crop rainfall during the cropping season.

Where there is higher than expected in-crop rainfall during the previous, irrigation water demands will be lower than expected, leading to water being leftover from the current season. To the leftover water is added the water diverted as floodplain harvesting between 1 November and 31 October. In this case, if in-crop rainfall is lower than expected and no overland flows occur to support floodplain harvesting, the likely effect is a reduction in yield for the planted crops.

$$\text{Dirranbandi Ha} = \underset{(0.0058)}{0.0571}\,\text{Unsupp (ML)} + \underset{(0.0073)}{0.0256}\,\text{leftover (ML)} + \underset{(0.09)}{0.137}\,\text{Ha (t - 1)} + \underset{(3,594)}{13,014} * 2000\,\text{Ha variable} \qquad \text{adjusted } R^2 = 0.97$$

Standard error terms are presented below the coefficients; coefficients for the Unsupplemented diversion, leftover water and 2000 planting decision variable are significant at the 99% confidence level; coefficient for the hectares planted the previous year is significant at the 90% confidence level. A comparison of the actual and modelled area planted is provided at cell AU162. In developing the Dirranbandi model, a previous version had a significant variation between the actual and estimated area planted in 2000 (comparison provide at cell AL175). On the advice of irrigators, the larger area of actual planting that year was a consequence of the significant rainfall which fell in the area just prior to planting in October-November). On the advice of irrigators, a hectare variable was introduced to the model for 2000 to account for difference in the planting decision for that year.

Goondiwindi – the preferred model for the Goondiwindi area is located at cell DX17 on the 'Goondiw' spreadsheet page. Multiple sources of water are represented by the general security on-allocation and unregulated water in the following equation. These hydrology model inputs are described separately below.

$$\text{Goondiw Ha} = \underset{(0.067)}{0.5257}\,\text{GS Reg Vol (ML)} + \underset{(0.017)}{0.0939}\,\text{Unreg ML start} + \underset{(40.1)}{125.94}\,\text{in - crop rain t - 1 (mm)} + \underset{(10,992)}{39,328} * 2005\,\text{Ha variable} + \underset{(7,037)}{26,807} * 2001/20011\,\text{Ha variable} \qquad \text{adjusted } R^2 = 0.94$$

Standard error terms are presented below the coefficients; all coefficients are significant at the 99% confidence level. A comparison of the actual and modelled area planted is provided at cell EJ1.

Monthly diversions data for medium security, general security on-allocation, general security off-allocation and floodplain harvesting (or overland flows) were extracted from the current conditions model across the period from January 1998 to June 2014 (starting in cell R1). Parts of the Border Rivers and Gwydir catchment considered as being relevant to the Goondiwindi area include:

- Queensland Border Rivers – medium security, unsupplemented and overland flow diversions for the Macintyre Brook System down to Boomi weir, and Weir River down to Talwood;
- New South Wales Border River – general security on-allocation, off-allocation and floodplain harvesting diversions for Glenlyon Dam to Boomi Weir and for the Severn River and its tributaries down to Boomi Weir; and
- 10% of the Gwydir general security on-allocation, off-allocation and floodplain harvesting diversions from the Moree area.

The medium security and general security on-allocation diversions are summed across the period from 1 July to 30 November to provide the Regulated diversion volume in the equation above. The unregulated water input is developed from a water balance estimate presented in the table at cell AP1. That is, a final planted area decision is made around 1 November each year. It takes into account the total volume of water available. Irrigation water applied might then be higher or lower,

depending upon whether the in-crop rainfall is below or above average, respectively. If additional water is required, it leads to additional water being used out of the unregulated diversions being harvested for the following season. Conversely, if rainfall is above average, additional water will be held in the on-farm storages to support plantings in the following year. The net sum of that analysis provides an estimate of unregulated water availability for that next year.

The 2005 area variable represents the relatively high commitment to planting a relatively large area that year. However, there was a significant difference in the planting decisions based around water available along the Weir River and limited water available on the main river stem. Further significant variations to the planting decisions occurred in 2001 and 2011. Further examination is required to understand why the area planted in those two years was greater than might otherwise be indicated by the volume of irrigation water available.

The Goondiwindi model applies to the diversion, production and rainfall data for the period 1999-2000 to 2013-14.

Gunnedah – for the Gunnedah area, the hydrology model recognizes only a small volume of surface water entitlements and subsequently small diversion of surface water each year. The estimates of surface water diversions against available on-allocation and off-allocation entitlements are provided in cells BY54 to BZ69 of the 'NamoiGunBog' spreadsheet page.

As indicated from groundwater use (in cells BG54 to BL70) the majority of irrigated production appears to be a function of access to groundwater in the Gunnedah area. Across the 15 years examined in the modelling, it is estimated that groundwater could have supported the estimated area of production in all but 3 years – 1999, 2010 and 2011. For those three years, it is possible that water not currently present in the current conditions hydrology model might contribute to the production outcomes. For example, water derived from floodplain harvesting in the high rainfall years.

Moree – the preferred model for surface water irrigated area, after allowing for the area grown in response to high security surface water and groundwater availability, is located at cell M145 on the Gwydir spreadsheet page. Surface-water based production, after accounting for groundwater and high security entitlement use, is a function of general security on-allocation water and the combined availability of off-allocation diversions and floodplain harvesting.

$$\underset{}{\text{Moree SW Ha}} = \underset{(0.0822)}{0.8244}\,\text{GS on - alloc ML} + \underset{(0.0238)}{0.4142}\,\text{unreg ML} - \underset{(4.443)}{16{,}886} * 2003\,\text{Ha variable}$$

$$\text{adjusted } R^2 = 0.98$$

Standard error terms are presented below the coefficients; all coefficients are significant at the 99.5% confidence level. A comparison of the actual and modelled area of irrigation is provided at cell V129.

Monthly diversions data for high security, general security on-allocation, general security off-allocation and floodplain harvesting were extracted from the current conditions model developed by the NSW government across the period from January 1998 to June 2014 (starting in cell A144). Data for groundwater use in the Moree area for 2003-04 to 2013-14 is provided in cells B83 to B93. An estimate of groundwater use for the period 1999-2000 to 2002-03 was used to inform the estimate of area derived from groundwater.

Moree area general security (on-allocation, off-allocation) and floodplain harvesting diversion data was derived from the total Gwydir diversions by first removing Gwydir diversion data for other locations:

- Downstream of Garah Point on Gil Gil Creek to the point where the Gingham return flows enter Gil Gil Creek is water used in the Mungindi area; and
- Gwydir diversions downstream of the Gingham return flows, the Mehi at Bronte and the Moomin at Iffley are all associated with the Collarenebri area.

Out of the remaining general security and floodplain harvesting diversions, it is estimated that 80% is used in the Moree community area. For the remaining 20%, it is assumed 10% is associated with production in the Goondiwindi area, 5% with production in the Collarenebri area and 5% with production for the Narrabri area.

For the unregulated water use, the diversions are aggregated for the 12 months prior to planting (1 November the previous year to 31 October in the year of planting); the GS on-allocation water represents the sum of GS on-allocation diversions between 1 July and 30 November in the year of planting. For Moree, the majority of the water recovered through buyback occurred in 2009-10. The regression equation has been developed using the 12 years of data across the period from 1999-00 to 2010-11. The reason for extending the modelling period to 2010-11 is based on the assumption water allocations held in accounts at the time entitlements were sold to the Commonwealth would remain available for use in the year following the entitlement sales.

To account for the use of high security water, high security water diversion are extracted for the period from 1 July to 31 March. Estimates of production from high security diversions are provided in cells E97 to E111. It is assumed that 9ML of water is applied to each hectare of cotton, although the area of cotton grown with high security water is affected by the deviation in rainfall from the average in the three months prior to planting.

Groundwater-based production estimated in cells C97 to C111 is derived from the estimate of groundwater use (cells B97 to B111) each year and allowing for 9ML of water application per hectare planted, with the area modified by the deviation in in-crop rainfall from the average in-crop rainfall across the period from 1999 to 2014.

An additional production-decision parameter has been included to account for the variation in hectares of irrigated cotton planted in 2003 (following the 2002-03 drought). Further investigation is required to understand a key production-based decision particular to determining the area planted in 2003.

Mungindi – the preferred model is located at cell EE18 of the 'Mungindi' spreadsheet page. Irrigated production in this area is a function of water source from the Border Rivers, Gwydir and Barwon-Darling systems.

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$$\text{Mungindi Ha} = \underset{(0.0985)}{0.3244}\,\text{GS - on all (ML)} + \underset{(0.005)}{0.0583}\,\text{Unreg stored 1 Nov (ML)} + \underset{(9.56)}{41.49}\,\text{in - crop rain (mm) (t - 1)} + \underset{(1,860)}{10{,}283} * 2001, 2005\,\text{Ha var} \quad \text{adjusted } R^2 = 0.98$$

Coefficients for the equation variables are significant at the 99.5% confidence level. A comparison of the actual area planted and modelled estimate of area planted is provided at cell EM2.

Diversion data was extracted from three current conditions model for the period 1 January 1998 to 30 June 2014. Diversions for the Mungindi area are sourced from the Border Rivers catchment between Boomi weir and Mungindi, between Talwood and Mungindi on the Weir River, and for Callandoon Creek; Gwydir diversions between Garah Point and the Gingham return flows on Gil Gil Creek; Barwon-Darling diversions between the Mungindi Weir and Mogil Mogil.

The regulated flows relating to the area of production for the Gwydir and New South Wales Border River are the diversions between 1 July and 30 November in the year of planting. All of the unregulated flows are represented as the diversions held in storage on 1 November each year. The estimated volume of unregulated water available for production are determined by calculating a water balance (starting in cell CF1) which takes into account water held in storage on 1 November the previous year, the area planted at time t-1, the in-crop rainfall and demands for irrigation across the summer of the previous year, and whether some of the diversions during the previous cropping period were required to water that crop.

The modelled equation applies to the 15-year period. No groundwater is used for irrigated production in this community area.

Narrabri – the preferred model for Narrabri surface water irrigated area, after allowing for the area grown in response to groundwater, is located at cell DS18 on the 'NamoiBlNarr' spreadsheet page. Surface-water based production is a derived mostly from the Namoi water resource with some contribution from Gwydir water, represented as general security on-allocation and off-allocation diversions plus floodplain harvesting. The off-allocation diversions and floodplain harvesting are group together as unregulated diversions. In this model.

$$\text{Narrabri SW Ha} = \underset{(0.0929)}{0.2973}\,\text{GS on - alloc ML} + \underset{(0.1825)}{0.9619}\,\text{unreg ML} \qquad \text{adjusted } R^2 = 0.89$$

Standard error terms are presented below the coefficients; all coefficients are significant at the 99.5% confidence level. A comparison of the actual and modelled area of irrigation is provided at cell DQ34.

Monthly diversions data for general security on-allocation, general security off-allocation and floodplain harvesting were extracted from the current conditions model developed by the NSW government for the Namoi and Gwydir. Data was used from the period from July 1998 to June 2014 (starting in cell CR1). Data for groundwater use in the Narrabri area for 2006-07 to 2013-14 is provided in cells DN10 to DN17. In this area, a minimum of approximately 1,000 hectares is irrigated from groundwater. From that minimum, the area irrigated from groundwater increases up to a maximum of around 3,500 hectares. The equation relating the area irrigated from groundwater and surface water allocations are provided at cells DO20 and DN23. From this information, an estimate of area of irrigated production based on groundwater use for the period 1999-2000 to 2013-14 is provided in cells DP3 to DP17.

For Narrabri, the surface water general security and floodplain harvesting diversions are those between Boggabri and Mollee. Additional diversions represent 5% of the Gwydir general security and floodplain harvesting water.

For the unregulated water use, the diversions are aggregated for the 12 months prior up to the end of November in the year of planting; the general security on-allocation water represents the sum of diversions between 1 July and 31 March for the year of planting. The surface water model relating diversions and area irrigated applies to the full 15-year period (1999-00 to 2013-14).

Narromine – the preferred model is located at cell EG84 of the 'War-Nar-Tra' spreadsheet page. Irrigated production in this area is a function of groundwater, high security water, and general security on-allocation and off-allocation water in the Warren area. Production from general security water follows a more rules-based approach in the Macquarie communities than occurs in other locations. That is, while the area of production is influenced by variations in general security allocations, the industry seeks to utilize its developed area whenever it is possible to do so. As such, the planting decisions of landholders appear to follow a rule where if the allocations are above 70% for two years in a row, they will grow a 'core' area of irrigated crop. The core area will be moderated by variations in the allocations (and the water diverted).

Where allocations are below 70% for two years in a row or more, the area irrigated is a function of the allocation percentages (and diversions against the irrigation entitlements). When water availability rose above 70% for two years in a row post the drought, the core area of production for the Narromine community had been reduced by around one third (from 9,600 hectares to approximately 6,000 hectares). In the modelled equation for Warren, Core Ha 1 refers to the core area before the drought and water recovery; Core Ha 2 refers to the core area post 2010-11.

$$\text{Narromine GS SW Ha} = \underset{(0.006)}{0.021}\,\text{GS on, off all (ML)} + \underset{(755)}{9{,}601} * \text{Core Ha 1} + \underset{(947)}{5{,}978} * \text{Core Ha 2}$$

$$\text{adjusted } R^2 = 0.97$$

Coefficients for the general security diversions, Core Ha 1 and Core Ha 2 are significant at the 99.5% confidence level. A comparison of the actual area planted and modelled estimate of area planted is provided at cell EN69. Diversions for the Narromine community area are extracted from the Macquarie River between Dubbo and the Narromine weir, and includes water used in the Narromine irrigation scheme.

Surface water diversion data was obtained from the Macquarie current conditions model. Monthly diversion data covers the period 1 July 1998 to 30 June 2013. In each year, the area planted from high security and general security surface water is related to the diversions between 1 July and 31 March. In other areas, general security off-allocation water is represented as the water diverted and stored by irrigators in the 12 months prior to planting. However, in the Macquarie community areas, the relatively small volume of on-farm storage capacity is consistent with farmers taking and using the off-allocation water as it becomes available.

Prior to modelling the area of irrigated production associated with the general security diversions, it was necessary to account for irrigated production derived from groundwater and high security surface water. Estimates of the groundwater-based production are provided in cells EM2 to EM16. The estimates of irrigated area derived from high security surface water are presented in cells EO2 to EO16. The remaining area relevant to general security surface water is in cells ES2 to ES16.

The modelled equation applies to the whole period, noting significant water recovery occurred prior to and since 2010-11. The difference in the 'core area' coefficients represents the effects of both a reduction in water entitlements held by irrigators and a response to the risk (uncertainty) of there being less water available in the temporary water market following the recovery of water for the environment.

St George – the preferred model for the St George community area is located at cell AE57 of the 'LwrBal' spreadsheet page. Surface-water based production is a function of supplemented water supplied from Beardmore Dam to the St George irrigation district, water harvesting and overland flows. Numerous attempts were made to represent the supplemented and water harvesting

diversions as individual sets of entitlements. However, the coefficient on the supplemented water was not significant in all cases. For this modelling, the unsupplemented and water harvesting entitlements are bundled together. In effect, the model then applies the same coefficient to both types of water entitlement.

$$\text{St George Ha} = \underset{(0.01)}{0.0403}\,\text{Supp, Unsupp ML} + \underset{(0.13)}{0.3095}\,\text{Area (t - 1)} + \underset{(0.018)}{0.0239}\,\text{Leftover ML (t} - 1)$$

$$\underset{(2,573)}{-6{,}916} * 2002{,}06{,}08\,\text{Ha variable} \qquad \text{adjusted } R^2 = 0.95$$

Standard error terms are presented below the coefficients; the coefficient for supplemented plus unsupplemented water is significant at the 99.5% confidence level; coefficients for the other variables are significant at the 95% confidence level. A comparison of the actual and modelled area of irrigation is provided at cell AN42.

Monthly diversions data for the supplemented, unsupplemented and overland flow diversions were extracted from the IQQM model developed by the Queensland government across the period from January 1998 to June 2014 (starting in cell P4). Supplemented water diversions are assumed to be taken from 1 July in the year of planting through to 30 June the following year. For the unregulated water use, the water harvesting (unsupplemented) and overland flow diversions are aggregated for the 12 months prior to planting (1 November). It was not possible to derive a regression equations where overland flow diversions were included as a specific parameter. As an alternative, a water balance which included the overland flows was estimated for each year. The water balance took into account the water available from the previous year (leftover water) then took into account the area planted, the in-crop rainfall and crop water needs and diversions during the cropping period to estimate the volume of water "leftover" (held in on-farm storages) for the following year. the previous year to 31 October in the year of planting); the GS on-allocation water represents the sum of GS on-allocation diversions between 1 July and 30 November in the year of planting. For Moree, the majority of the water recovered through buyback occurred in 2009-10.

For the St George community area, most of the water recovered through purchase occurred after 2012. As such, the regression equation has been developed using the 14 years of data across the period from 1999-00 to 2012-13.

An additional production-decision parameter has been included to account for the variation in hectares of irrigated cotton planted in 2002, 2006 and 2008. Further investigation is required to understand the differences in the production-based decision processes which lead to a smaller area of cotton being planted than is otherwise suggested by the availability of supplemented, unsupplemented and overland flow diversions.

Trangie – the preferred model is located at cell CG84 of the 'War-Nar-Tra' spreadsheet page. While irrigated production in this area is a function of groundwater and general security on-allocation and off-allocation water, production from surface water follows a more rules-based approach in the Macquarie communities than occurs in other locations. That is, while the area of production is influenced by variations in general security allocations, the industry seeks to utilize its developed area whenever it is possible to do so. As such, the planting decisions of landholders appear to follow a rule where if the allocations are above 70% for two years in a row, they will grow a 'core' area of irrigated crop. The core area will be moderated by variations in allocations (and the water diverted).

Where allocations are below 70% for two years in a row or more, the area irrigated from surface water is a function of the allocation percentages (and diversions against the irrigation entitlements).

When water availability rose above 70% for two years in a row post the drought, the core area of production for the Trangie community was reduced (by around 10%). In the modelled equation for Trangie, Core Ha 1 refers to the core area before the drought and water recovery; Core Ha 2 refers to the core area post 2010-11.

$$\text{Trangie SW Ha} = \underset{(0.005)}{0.0136}\,\text{GS on, off all (ML)} + \underset{(702)}{6{,}916} * \text{Core Ha 1} + \underset{(1{,}007)}{6{,}316} * \text{Core Ha 2}$$

$$\text{adjusted } R^2 = 0.95$$

Coefficients for the general security diversions, Core Ha 1 and Core Ha 2 are significant at least at the 99% confidence level. A comparison of the actual area planted and modelled estimate of area planted is provided at cell CN71. Diversions for the Trangie community area are extracted between the Narromine and Gin Gin weirs and include water used in the Trangie-Nevertire and Nevertire irrigation schemes.

Some groundwater is available to support production in the Trangie community area. The estimates of groundwater use and groundwater-based irrigated production are provided in cells CS24 to CS40. Estimates of groundwater production are subtracted from the total area of production to provide the area of irrigation derived from surface water.

Diversion data was obtained from the Macquarie current conditions model. Diversion data was extracted for the period 1 July 1998 to 30 June 2013. In each year, the area planted is related to the general security on-allocation and off-allocation diversions between 1 July and 31 March. In other areas, the off-allocation water is represented as the water diverted and stored by irrigators in the 12 months prior to planting. However, in the Macquarie community areas, the relatively small volume of on-farm storage capacity is consistent with farmers taking and using the off-allocation water as it becomes available.

The modelled equation for the use of surface water applies to the whole period, noting significant water recovery occurred prior to 2010-11. The small difference in the 'core area' coefficients represents the effects of both a reduction in water entitlements held by irrigators and a response to the benefits of the infrastructure investment. That is, the infrastructure upgrades are likely to support a more frequent use of water within the Trangie area irrigation schemes than was possible prior to the upgrading of the system.

Walgett – the preferred model for irrigated area is located at cell HF21 on the NamoiBlNarr spreadsheet page. Surface-water based productionis a function of general security on-allocation water and off-allocation water plus floodplain harvesting in the Namoi and unregulated diversions in the Barwon-Darling.

$$\text{Walgett Ha} = \underset{(0.039)}{0.1986}\,\text{GS on - alloc ML} + \underset{(0.0143)}{0.0224}\,\text{unreg ML} + \underset{(2.05)}{5.28}\,\text{pre - plant rain (mm)}$$

$$+ \underset{(505)}{1{,}920} * 2000, 11, 13\,\text{Ha variable} \qquad \text{adjusted } R^2 = 0.93$$

Standard error terms are presented below the coefficients; the general security on-allocation and 2000, 2011, 2013 Ha variables are significant 99.5% confidence level; the pre-planting rainfall variable is significant at the 95% confidence level; the coefficient on the unregulated water is significant at the 75% confidence level. A comparison of the actual and modelled area of irrigation is provided at cell HD1.

Monthly diversions data for general security on-allocation and unregulated diversions were extracted from the current conditions model developed by the NSW government for the Barwon-Darling and Namoi catchments. Hydrology data used was from the period July 1998 to June 2014 (starting in cell FH1). Barwon-Darling diversions related to production in Walgett are those between Tara and Boorooma. Namoi diversions are those between Bugilbone and Walgett.

For the unregulated water use, the diversions are aggregated for the 12 months prior to the final planting date (1 November the previous year to 31 October in the year of planting); the GS on-allocation water represents the sum of GS on-allocation diversions between 1 July and 31 March for in the year of planting. The Walgett model was developed using hydrology and irrigated production data for the period 1999-2000 to 2013-14.

Warren – the preferred model is located at cell BB38 of the 'War-Nar-Tra' spreadsheet page. While irrigated production is a function of general security on-allocation and off-allocation water in the Warren area, production follows a more rules-based approach in the Macquarie communities than occurs in other locations. That is, while the area of production is influenced by variations in general security allocations, the industry seeks to utilize its developed area whenever it is possible to do so. As such, the planting decisions of landholders appear to follow a rule where if the allocations are above 70% for two years in a row, they will grow a 'core' area of irrigated crop. The core area will be moderated by variations in the allocations (and the water diverted).

Where allocations are below 70% for two years in a row or more, the area irrigated is then just a function of the allocation percentages (and diversions against the irrigation entitlements). Recovery of water for the environment was pursued through separate Commonwealth and State processes operating at the same time. As such, when water availability rose above 70% for two years in a row post the drought, the core area of production for the Warren community had reduced considerably. In the modelled equation for Warren, Core Ha 1 refers to the core area before the drought and water recovery; Core Ha 2 refers to the core area post 2010-11.

$$\text{Warren Ha} = \underset{(0.009)}{0.308}\,\text{GS - on (ML)} + \underset{(0.087)}{0.1461}\,\text{GS - off (ML)} + \underset{(1,707)}{20,883} * \text{Core Ha 1}$$

$$+ \underset{(2,450)}{12,259} * \text{Core Ha 2} \qquad \text{adjusted } R^2 = 0.97$$

Coefficients for the general security on-allocation diversions, Core Ha 1 and Core Ha 2 are significant at the 99.5% confidence level; the coefficient for the general security off-allocation diversions is significant at the 90% confidence level. A comparison of the actual area planted and modelled estimate of area planted is provided at cell BF23. The Warren community area includes diversions to the Tenandra and Marthaguy irrigation schemes.

Diversion data was extracted from the Macquarie current conditions model. Diversion data was extracted for the period 1 July 1998 to 30 June 2013. Diversions for the Warren community represent those downstream of the gauge at Gin Gin. For each year, the area planted is related to the general security on-allocation and off-allocation diversions between 1 July and 31 March. In other areas, the off-allocation water is represented as the water diverted and stored by irrigators in the 12 months prior to planting. However, in the Macquarie community area, the relatively small volume of on-farm storage capacity is consistent with farmers taking and using the off-allocation as it becomes available.

The modelled equation applies to the whole period, noting significant water recovery occurred prior to 2010-11. The difference in the 'core area' coefficients represents the effects of both a reduction

in water entitlements held by irrigators and a response to the risk (uncertainty) of there being less water available in the temporary water market following the recovery of water for the environment.

Wee Waa – the preferred model for the surface water irrigated area, after allowing for the area grown in response to groundwater, is located at cell BT18 on the NamoiBlNarr spreadsheet page. Surface-water based production, after accounting for groundwater use, is a function of general security on-allocation water and the combined availability of off-allocation diversions and floodplain harvesting.

$$\text{Wee Waa SW Ha} = \underset{(0.0426)}{0.2835}\,\text{on - alloc ML} + \underset{(0.1433)}{1.0879}\,\text{off - alloc ML} + \underset{(0.0653)}{0.1923}\,\text{floodplain harvest ML}$$

$$+\underset{(5,564)}{16{,}490} * 2004\,\text{Ha variable} \qquad \text{adjusted } R^2 = 0.95$$

Standard error terms are presented below the coefficients; all coefficients are significant at least at the 99% confidence level. A comparison of the actual and modelled area of irrigation is provided at cell BT27. Monthly diversions data for general security on-allocation, general security off-allocation and floodplain harvesting were extracted from the current conditions model developed by the NSW government for the Namoi. The hydrology data used is from the period of July 1998 to June 2014 (starting in cell Y1).

Data for groundwater use in the Wee Waa area for 2006-07 to 2013-14 is provided in cells AQ10 to AQ17. The inverse relationship between groundwater use and total area of irrigated production in the Namoi area is indicated in the graph at cell AL18. This area irrigated is also a function of the allocations against the general security on-allocation entitlements. The estimate of groundwater-based irrigated area is provided in cells AU3 to AU17.

To estimate the area of irrigated production from groundwater in the Wee Waa area, the first step was to identify the potential maximum and minimum areas of groundwater-based irrigation. From the available data on area irrigated and allocation percentages, it is assumed the groundwater irrigation area varies between 2,000 hectares with a general security allocation of 100% up to 8,000 hectares with a general security allocation of 5%. Using the data in cells AL35 to AM39, it is estimated that the area of groundwater-based irrigation production increases above 2,000 hectares by 63 hectares for each 1% decrease in the allocation percentage on 1 November each year.

Surface water diversions for the Wee Waa area include the diversions between Mollee and Bugilbone plus diversions from Pian Creek. For the unregulated water use (general security off-allocation and floodplain harvesting), the diversions are aggregated for the 12 months prior to planting (1 November the previous year to 31 October in the year of planting); the GS on-allocation water represents the sum of GS on-allocation diversions between 1 July and 30 November in the year of planting.

The period covered by the model is from 1999-2000 to 2013-14. A hectare-variable is included in this model for 2004. It indicates a change in planting decisions for that year which were influenced by the high rainfall in the October-early November period which led to an increase in the planted area beyond what might otherwise be expected based on the volume of water diverted. In this case, some planting was delayed following the rains, being finished in the second half of November.