Wungong Catchment Trial

WEC-C Modelling of forest management options for the 31 Mile Brook catchment

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REPORT
TO
THE WATER CORPORATION

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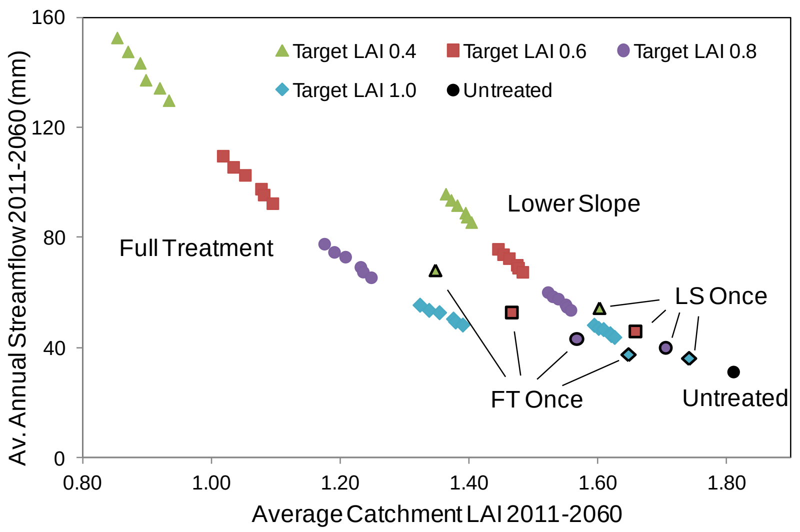

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Water & Environmental Consultants

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SUMMARY

Water & Environmental Consultants were requested by the Water Corporation to undertake a modelling study to assess the potential hydrological benefits from the management of the forest vegetation cover on a representative catchment in the jarrah forest of the south-west of WA. The requirement for the study stems from the present protracted below-average rainfall period and the effects it is having in terms of groundwater and streamflow declines in the jarrah forest. Particular emphasis in the study was placed on understanding the forest management options that will allow restoration of:

- Streamflow volumes from the catchment.
- Streamflow durations (flow-days per year) as these are known to be important for the life-cycles of various aquatic invertebrates.
- Water abundance to riparian ecosystems in the swamp and lower-slope areas of the catchment.

The study used a variety of possible management scenarios in combination with two rainfall scenarios to produce sets of possible catchment hydrological responses. The catchment modelled was 31 Mile Brook near Jarrahdale; it was chosen due to its use already in a number of forest management modelling studies and because it appears to be well suited to having its results up-scaled to the water-supply catchments within the Integrated Water-Supply Scheme. The model used was WEC-C, which is custom designed for studies of vegetation treatment and has been successfully applied to a number of catchment studies on the Darling Plateau, both within the jarrah forest and in the lower-rainfall agricultural areas to the east.

The primary findings of the study were that if a useful hydrological response is to be attained through the treatment of the forest cover, then the treatments need to be to low vegetation densities, be undertaken over most of the catchment, and have regular follow-up treatments. The treatment which seemed to most closely fit these criteria, and still probably be acceptable from aesthetics, timber production, and other non-hydrological viewpoints, was to a Leaf Area Index (LAI) of 0.6 over all except the streamzone buffer and to have follow-up treatments at a nominal nine-year rotation. An LAI of 0.6 is approximately a basal area of 9 m^2/ha. An average streamflow-increase of 36 mm/yr was predicted for this treatment in the first decade following treatment, for an assumed rainfall scenario of the rainfall for 2001 to 2010 repeated; the increase in the second decade was 70 mm/yr. There were also predicted hydrological benefits in terms of flow-days, increases of 66 and 131 days/yr for the first two decades, and predicted benefits in terms of soil-water storages and groundwater levels. While this option appears to be the preferred one, the study tabulated the results for 55 other combinations of target treatment LAIs and retreatment frequencies. These were combined with two rainfall scenarios, the 2001 to 2010 low-rainfall scenario and the 2000 to 2009 medium-rainfall scenario, to create 114 simulation cases in total. Overall, the study seems to have created a logical and realistic set of results that allow treatment options to be considered on their hydrological merits and divided into those which should be considered further and those which are unlikely to be of value.

1. INTRODUCTION

Water & Environmental Consultants (WEC) were requested by the Water Corporation of WA to undertake a hydrological study via modelling of the possible options for forest management in the 31 Mile Brook catchment on the Darling Plateau of the south-west of Western Australia (Figure 1). The 31 Mile Brook catchment is within the northern jarrah forest and the objective of the study was to determine the potential efficacy of a range of treatment options as they relate to restoring catchment hydrological processes to what they were in the 1990s and before. This objective emanates from the effects of the present below-average rainfall period that has been affecting the south-west of WA since 1969 and a desire to address the hydrological issues that are developing in the jarrah forest. Particular emphasis was placed on understanding the forest management options that will allow restoration of:

- Streamflow volumes from the catchment.
- Streamflow durations (flow-days per year) as these are known to be important for the life-cycles of various aquatic invertebrates.
- Water abundance to riparian ecosystems in the swamp and lower-slope areas of the catchment.

The 31 Mile Brook catchment was chosen for this modelling as studies by the Water Corporation (A.J. Reed, pers. comm.) have shown close relations between 31 Mile Brook streamflows and streamflows into the Darling Plateau water-supply reservoirs within the Integrated Water-Supply Scheme. Thirty-One Mile Brook is therefore a good candidate to be used in a modelling exercise where the results may be extrapolated across the jarrah forested section of the Darling Plateau.

The WEC-C model was chosen for the study as being a fully distributed-deterministic catchment model; it contains the necessary processes at the required spatial scales – plot, hillslope and sub-catchment – to usefully model detailed forest treatments and their effects. The WEC-C model has been successfully applied to a number of land-management studies in the south-west of WA (see References for full list of WEC-C related publications) and the model itself has been described by Croton & Bari (2001) and Croton & Barry (2001). An early application of the WEC-C model to the 31 Mile Brook catchment was described by Croton & Silberstein (2009).

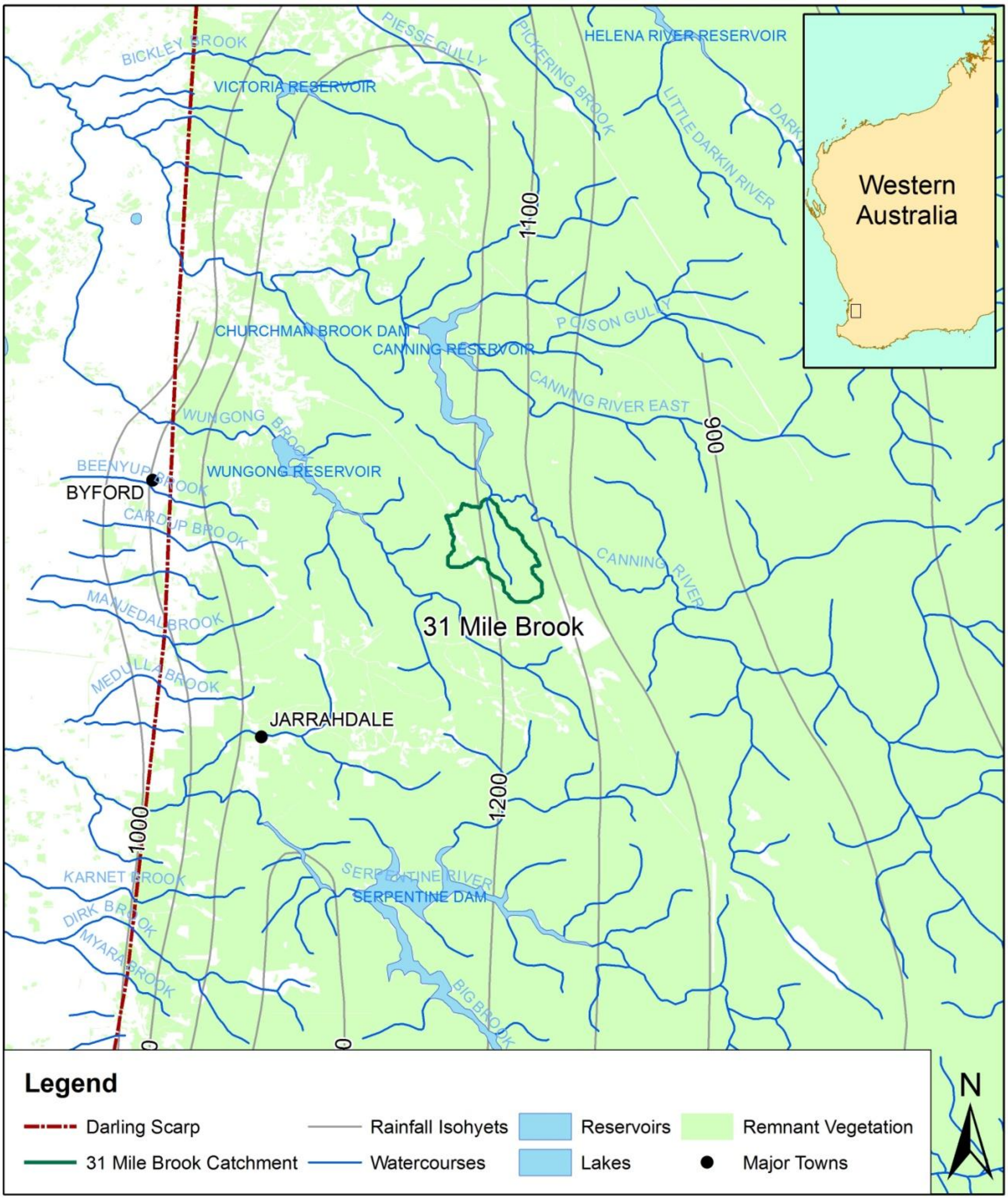

Figure 1: The location of the 31 Mile Brook catchment in the northern jarrah forest on the Darling Plateau of the south-west of Western Australia.

2. THE MODEL AND THE MODELLING SET-UP

2.1 The WEC-C Model

The Water & Environmental Consultants - Catchment (WEC-C) model belongs to the most complex category of catchment models in that it is a distributed, deterministic model of numerical form, simulating both water and solute movement within a catchment by solving the governing equations for flow and transport. Its form is especially useful in situations where the streamflow generation process is a mix of direct surface runoff, interflow, and groundwater discharge; this is the case in the jarrah forest of the Darling Plateau.

WEC-C employs a rectangular grid of uniform cell size in the lateral plane combined with a system of soil layers in the vertical, to represent the regolith (soil profile) of a catchment (Figure 2). A uniform grid was chosen for the lateral plane to simplify data input and output. For the same reason, the number of soil layers has been kept uniform across the model domain, although the thickness of any layer, or its elevation compared with the model datum, is flexible. This structure permits any soil layering and surface topography to be modelled. The top of the soil profile is defined by the soil surface while the bottom is defined by an impermeable basement surface (usually taken as the top of the parent rock). The catchment is delineated by defining as active only those cells within the catchment divide; inactive cells are impermeable and act as solid boundaries to flow within the model. All parameters are defined locally in each model cell so that all available data on catchment variability can be directly and fully incorporated into the model.

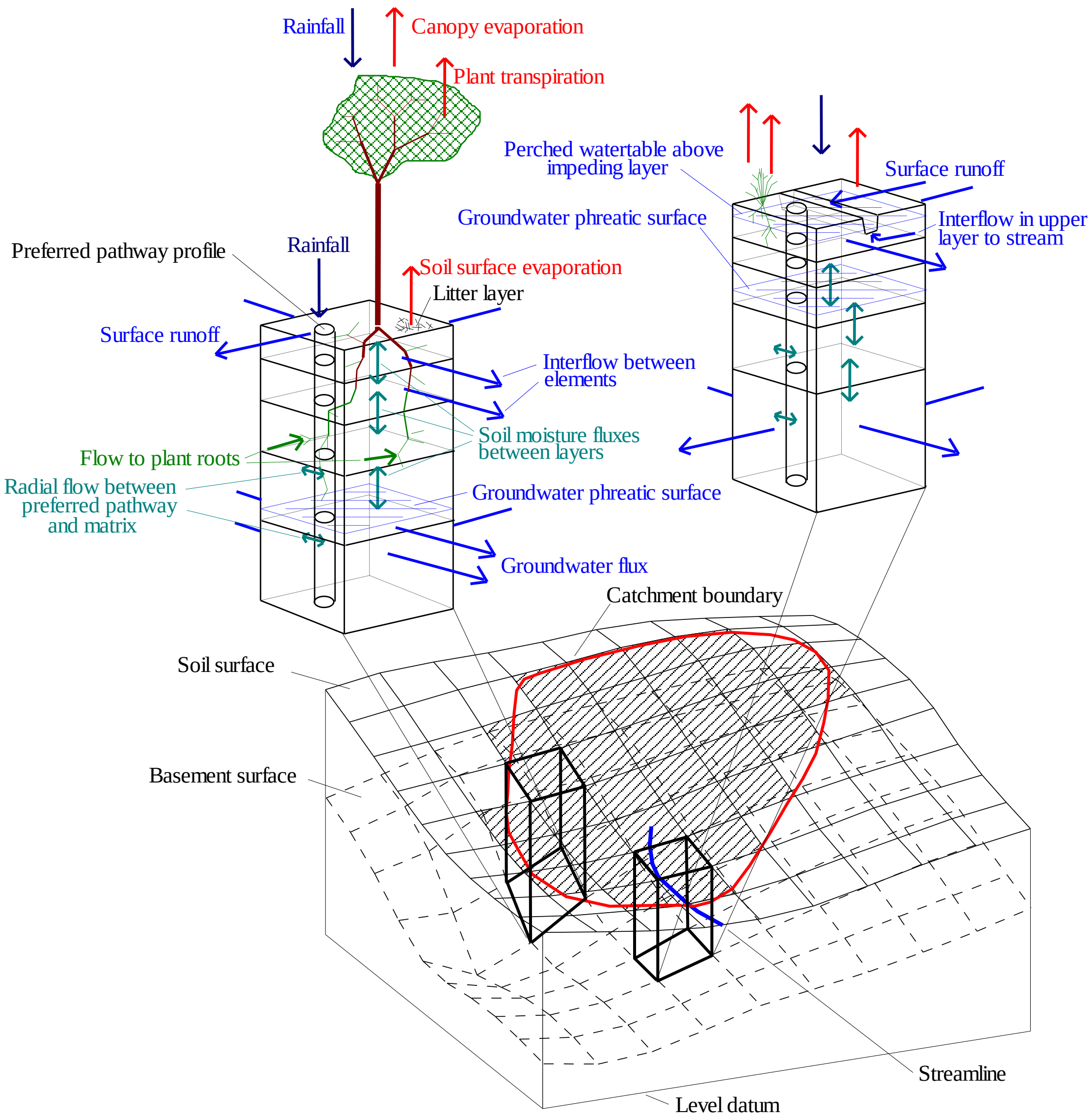

Figure 2: Schematic of the WEC-C model layout and processes modelled.

The WEC-C model uses operator splitting such that fluxes are sequentially computed for the vertical and lateral models. The vertical and lateral models share the same spatial framework, and the heads within the lateral models are defined directly from the soil-water potentials of the vertical models. This commonality is made possible through the explicit form of the WEC-C solvers, and allows a more direct linkage between the vertical and lateral components than is possible within models such as SHE and TOPOG which employ implicit solvers.

The explicit form of WEC-C also allows the model to fully exploit present advances in parallel processing by multi-core CPUs and CUDA processing on GPUs. While a parallel-processing version of WEC-C has not yet been completed, one is under development, and when complete will remove all limitations as to catchment size and result in simulation-times orders of magnitude less than those possible with implicit models.

An essential component of distributed modelling is the efficient management of spatial input and output data. The WEC-C model employs the CATMAGIC system, developed by Geoff Mauger formerly of the Water & Rivers Commission of WA, as its model GIS. CATMAGIC is a stand-alone system which has been specifically developed for the management, analysis and visualisation of hydrological data on a rectangular grid. It can easily exchange data with packages such as SURFER and ArcGIS.

The WEC-C model is customised for the simulation of vegetation-cover dynamics and includes all the components of evapo-transpiration (ET) as well as an efficient methodology through CATMAGIC for the input of various vegetation treatment-scenario maps. A detailed understanding and quantification of WEC-C vegetation parameters has been developed through the model's application to a wide variety of catchments in the south-west of WA. Without such a history of application it would be difficult to undertake what-if simulations like those of this study where the vegetation cover is being significantly altered. As well, the hydrology of the 31 Mile Brook catchment is undergoing continuous change due to the below-average rainfalls causing steady depletion of the soil-water storage. This hydrological non-stationarity means that the hydrological processes present during the observed streamflow record will differ from those used for the various what-if scenarios being studied, and therefore modelling employing the standard methodology of having calibration and verification periods will add little to the proof of the model as a reliable predictor for the what-if scenarios. Instead, the approach adopted in this study where a generic WEC-C parameter set has been developed by the application of the model to wide variety of catchments appears to be the only scientifically acceptable approach in the present situation.

2.2 31 Mile Brook Catchment

Figure 3 shows the layout of the 31 Mile Brook catchment. It can be seen that 31 Mile Brook is a second-order catchment with a well-defined drainage system. There is full forest cover except for a strip along the western side which is where Albany Highway passes through the catchment and where there were also some areas of pines that were logged and replanted in 2009; in the simulations these are assumed to regrow over the following ten years and to reach a Leaf Area Index (LAI) of 1.8 by 2020. Also shown in Figure 3 are the rock outcrops which naturally occur in the 31 Mile Brook catchment and elsewhere on the Darling Plateau; these have been included in the model simulation files.

The model developed for the 31 Mile Brook catchment had 50 by 50 m grid-cells, which resulted in 4,473 active cells for its catchment area of 11.2 km^2. The model was based on seven soil-layers with dual continua in each, thus giving 62,622 active cell-layer-profiles within the model with transfers of soil-water occurring between these. The soil-water parameters used were those from previous modelling of Darling Plateau catchments with this largely based on the report of Raper & Croton (1996). The Leaf Area Index (LAI) maps used in the study to define the vegetation cover are developed from Landsat MSS and Landsat 5 TM satellite data, using a method based on first converting the cells to a Normalised Difference Vegetation Index (NDVI) and then to an LAI via a relationship based on regressions between Landsat NDVIs and plot-scale ground-based LAI measurements. Where available, a historical LAI map has been developed for January of each year. For the what-if future simulations, an LAI map has been produced for January of every year.

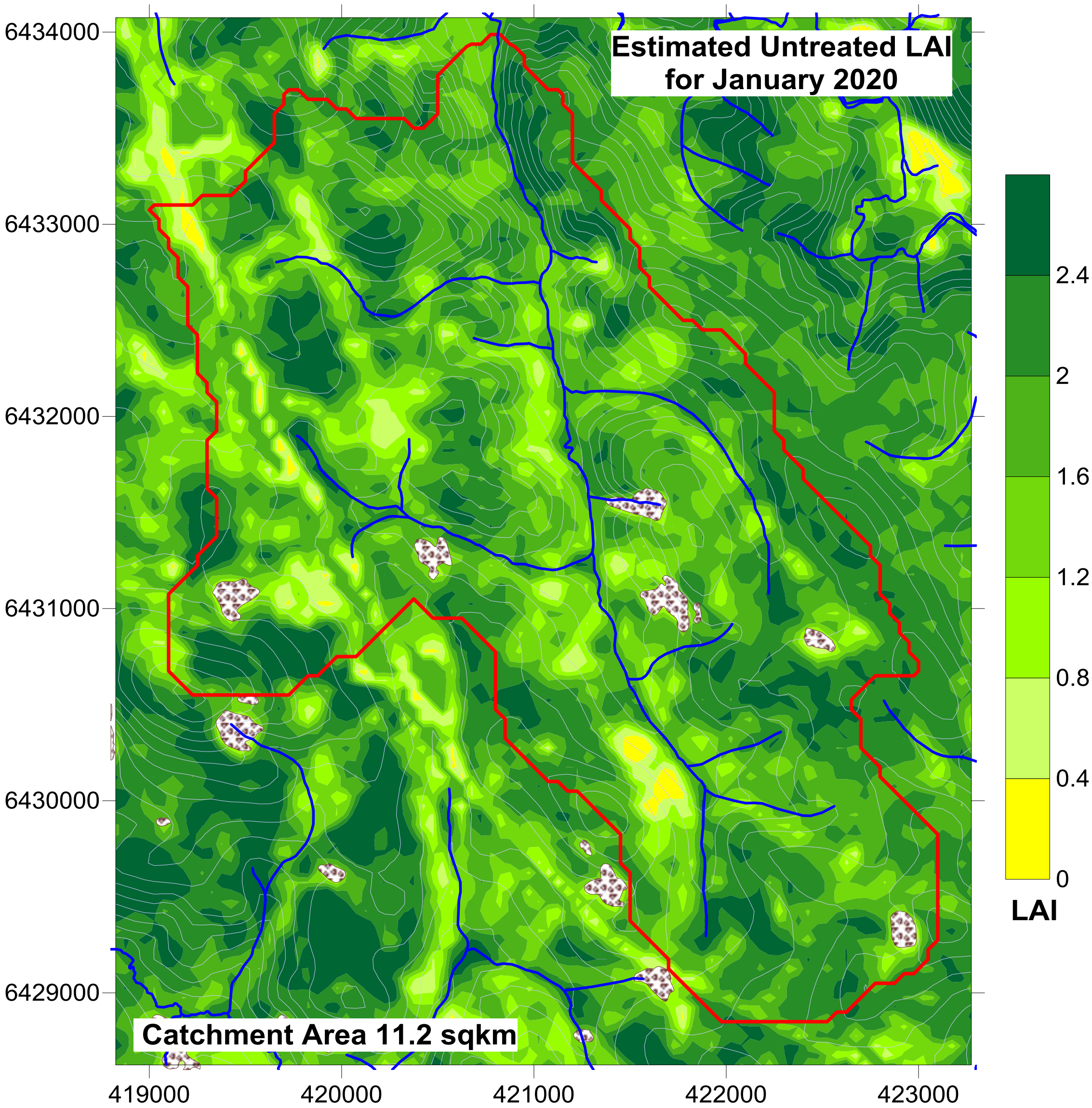

Figure 3: 31 Mile Brook catchment showing the estimated LAI (Leaf Area Index) of the forest cover in January 2020.

2.3 Forest Management Scenarios Studied

A number of forest management options were simulated as part of the study. These can be sorted by forest-treatment target Leaf Area Index (LAI), period between treatments, and area treated as follows:

1. The forest-treatment target LAIs simulated in the study were 0.4, 0.6, 0.8 and 1.0. Using the relationship between tree basal-area and LAI of 15 to 1, these correspond to basal areas of 6.0, 9.0, 12.0 and 15.0 m^2/ha.
2. Two options for the area treated were used: one where all the catchment except a stream buffer was treated, and another where only the lower-slope half of this area was treated. The stream-buffer was 12% of the catchment area, thereby

leaving 88% of the catchment being treated in the full-treatment area scenario. For the lower-slope-only treatment scenario, 44% of the catchment was treated.

3. The standard period between treatments was assumed to nine years. However, to test sensitivity to treatment frequency, treatment periods of seven, eight, 10, 11 and 12 years were also used. A once-only treatment scenario was also included.

Including the untreated case, the total number of cases studied was 4*2*7 + 1 = 57. When the two rainfall scenarios are added, see below, the total becomes 57*2 = 114. The LAIs for the treatment scenarios, and the subsequent growth curves following treatment, were all based on information supplied by Jack Bradshaw (pers. comm.)

2.4 Rainfall Scenarios

Two rainfall scenarios were studied, a low rainfall scenario based on repeating the ten years of rainfall from 2001 to 2010 five times, and a higher rainfall scenario based on 2000 to 2009 rainfall repeated five times. Figure 4 shows the two rainfall scenarios graphically.

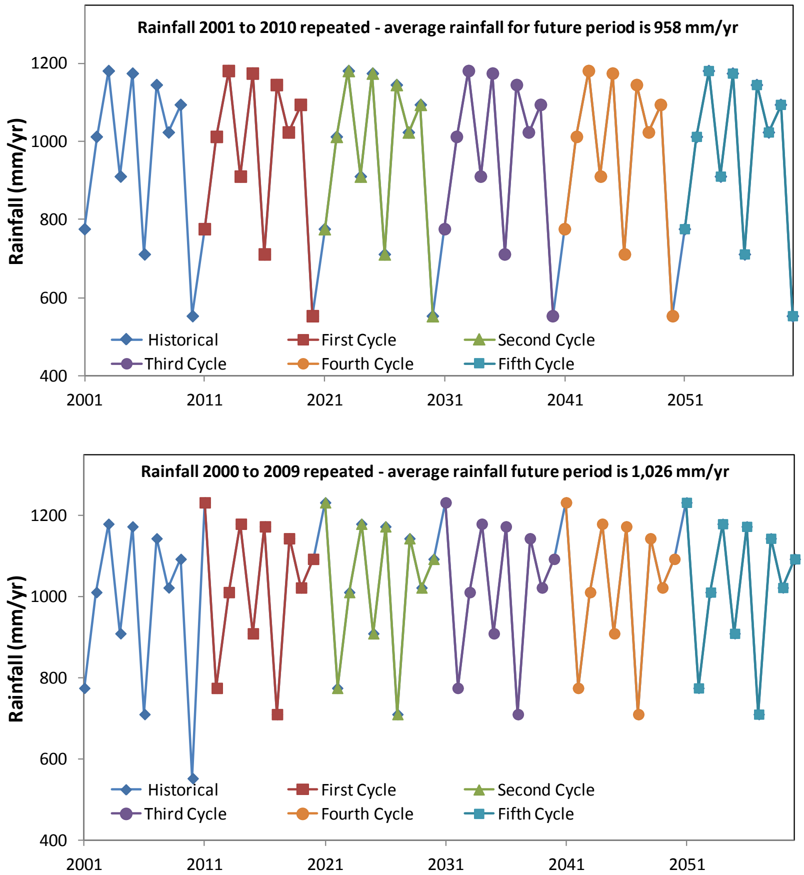

Figure 4: The two rainfall scenarios used in the modelling exercise.

It can be seen that while the difference between the two series is only the exchange of the year 2000 for that of 2010, the historical low rainfall of 2010 and the above-average rainfall of 2000 makes the difference between the two series pronounced. In terms of long-term averages, the average for all available record from the SILO Data Drill system (http://www.longpaddock.qld.gov.au/silo/), 1907 to 2010, is 1,206 mm/yr, or well above either of the rainfall series used in the simulations. However, the average for the last 20 years, 1990 to 2010, is 1,044 mm/hr, which is very close to the higher of the two series. The Water Corporation Wungong Trial (K.L. Barrett pers. comm.) has based future scenario modelling on the 2001 to 2010 rainfall pattern as it provides a best available representation of the rainfall predicted to 2030 by climate change modelling for south west Western Australia. Some predictions by climate modellers, e.g. IOCI (2010), imply an even worse future situation than that represented by the 2001 to 2010 series.

Combining all the above with the desire to keep things as simple and realistic as possible, the 2001 to 2010 rainfall scenario was considered a reasonable likely worst case, and the 2000 to 2009 rainfall scenario as representative of the recent past excluding the historical extreme event of 2010. These two rainfall scenarios form the basis of the following "what-if" modelling studies.

Although many studies in the south-west of WA use a water-year starting on 1st April and going to 31st March the following year, we define the hydrological-year as the calendar year (1st January to 31st December). This is because for small catchments like 31 Mile Brook, unseasonal rains in the period 1st January till 31st March have more effect on the commencement of flow in the coming winter than they do in adding to flow of the previous year.

3. HISTORICAL SIMULATION OF THE CATCHMENT

3.1 Historical Forest Density

Figure 5 shows the catchment average LAI by year from the start of available Landsat record in 1973. It can be seen that while there is year-to-year variation due to measurement error and management treatments such as fire, the general trend is LAIs increasing from about 1.1 in the early 1970s to about 1.7 by 2010/11. A similar trend has been observed for most Darling Plateau catchments. The drop for the last year, 2011, is almost certainly due to the historically low rainfall of 2010 causing leaf fall. For the what-if modelling in this study it was therefore decided to start with the LAIs of 2010 as the initial map rather than 2011. The presented 2011 LAIs in Figure 5 are based on a January 2011 Landsat image; the actual LAIs of 2011 should be greater once the winter rains commence.

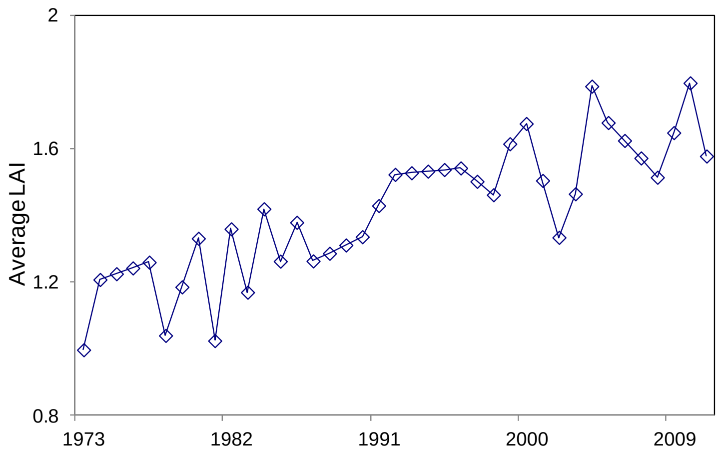

Figure 5: Catchment average LAI used in the historical simulations.

3.2 Simulation of Historical Streamflows and Soil-Water Storage

Figure 6 shows the match between observed annual streamflow and the model-simulated values for the historical record for the 31 Mile Brook catchment. There is good correspondence and, in particular, the steady downward trend in streamflow has been well captured. This downward trend is a combination of two factors: the declining rainfall during the period and the increases in vegetation as shown in Figure 5.

Figure 7 shows the observed and predicted flow-days for the 31 Mile Brook catchment during the historical record; flow-days have been defined as those days with an average flow-rate of 0.5 L/sec or more (0.004 mm/day). While there is some over-prediction by the model, particularly in the early years, this over-prediction isn't large, and in the later years the model has closely tracked the decline in flow-days. This accurate tracking of changes in flow-days is particularly important in the contexts of stream ecology and riparian ecosystems, as it shows that the model is realistically representing the changes of the streamflow form from one which flows almost throughout the year, to a system which has streamflow only during the winter months. A key objective of the following study is to see how practical it is to restore the flow regime from its present, ephemeral form back to its previous, largely perennial form.

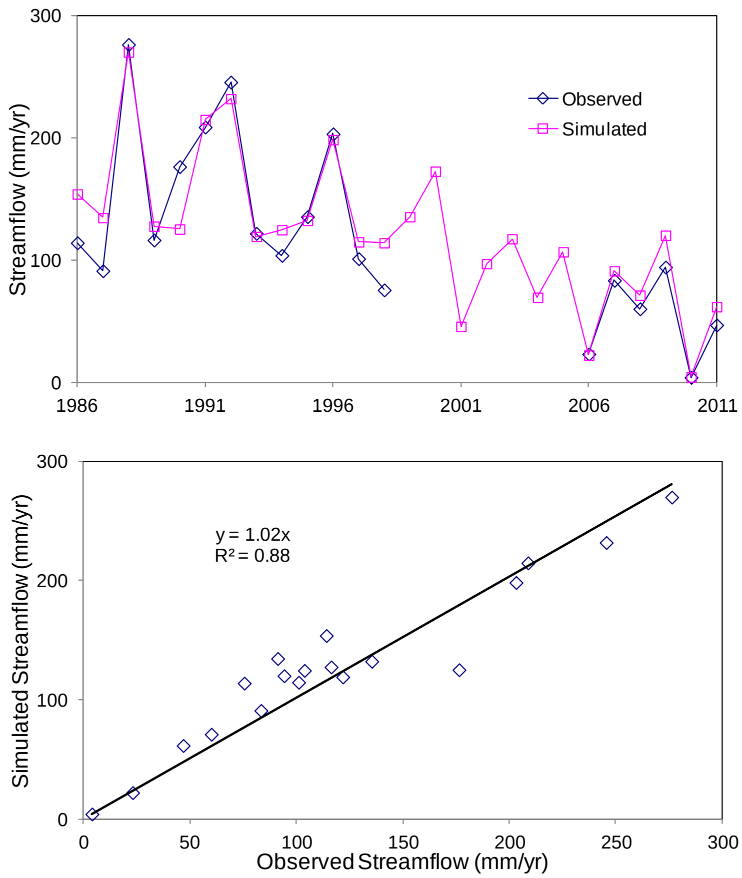

Figure 6: Comparison of observed and predicted annual streamflows for the historical simulations.

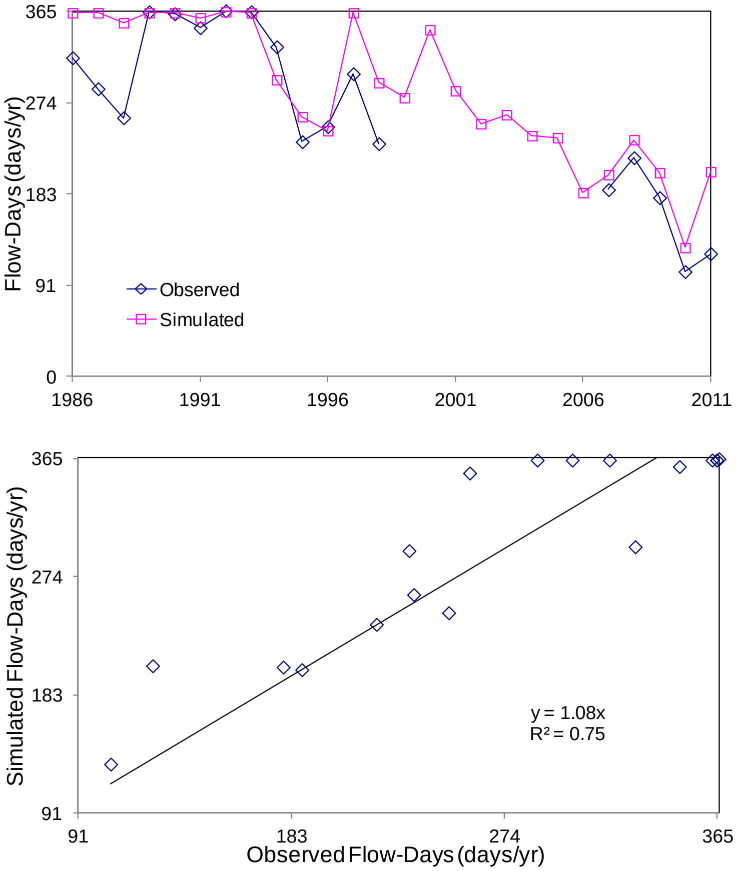

Figure 7: Comparison of observed and predicted flow-days for streamflows for the historical simulations.

As an indicator of the model's ability at the daily time-scale, Figure 8 shows daily hydrographs for observed and predicted streamflows for 31 Mile Brook. The first graph is for 1988, the highest-flow year on record; the model is matching the peak flows well, with a generally good correspondence to the interflow periods between the peaks.

The second graph is for 2006, which is the second-lowest flow year on record with 2010 being the lowest but producing so little flow it isn't practical to use in a comparison. It can be seen that the match in 2006 is generally good, though there are obvious mismatches such as the flow for the first major storm event of the year. Overall the daily-flow matches are more than acceptable and the model appears to be producing a realistic match to the streamflow processes at this time-scale.

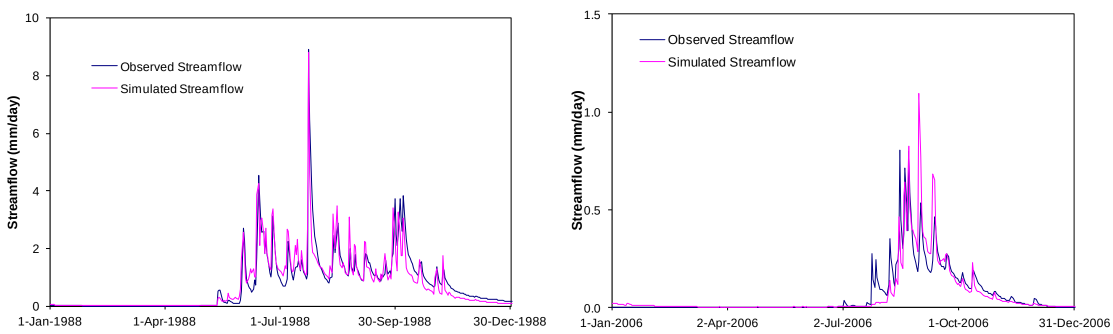

Figure 8: Comparison of observed and predicted daily-flows for streamflows for the historical simulations of the high flow year of 1988 and the low flow year of 2006.

Figure 9 shows a model output which is particularly useful in understanding the behaviour of the catchment during the period of observed streamflow record. It is the simulated change in soil-water storage of the soil profile relative to the storage on 1st January 1986. It shows a steady decline in storage from 1986 to 2009, with a marked drop at the end due to the historically low rainfall year of 2010. This decline in storage is altering the hydrology of the catchment and, in particular, making rainfall in the later period produce less runoff than rainfall in the early period. For instance, the year 1989 had 995 mm rainfall and produced 116 mm of streamflow while 2008 had 1,023 mm rainfall and produced only 60 mm of streamflow. This variation in streamflows is largely attributable to storage changes and is why the following study emphasises restoring soil-water storages, particularly in those sections of the catchment along the main streamline.

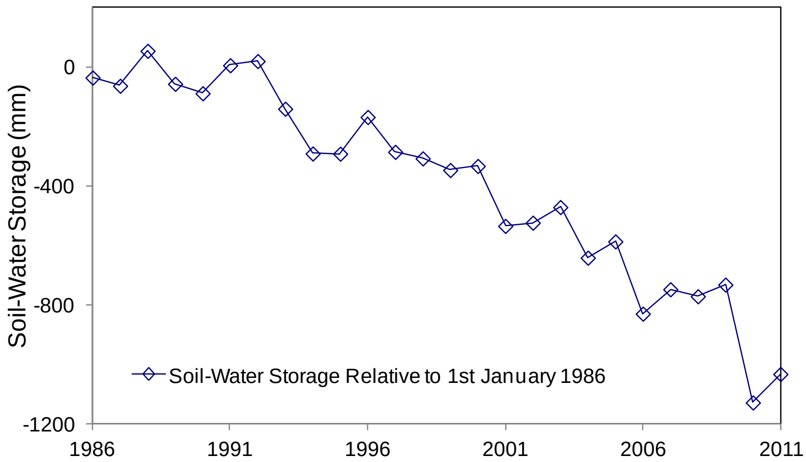

Figure 9: Simulated soil-water storage change relative to 1st January 1986, for the historical simulations.

3.3 Simulation of Historical Groundwater Levels

Following from the soil-water storage changes shown in Figure 9, WEC-C can also be used to produce maps of simulated depths to groundwater. Figure 10 shows four maps of the depths to groundwater in December 1970, 1990, 2000 and 2010. The piezometric pressures used to create these maps are for the primary aquifer in the regolith directly above the basement rock; so areas that are associated with upward fluxing of groundwater, and its possible discharge, are shown with negative depths (purple and pink colours). Those areas where the groundwater system is less essentially absent, that is dry, are shown in yellow.

The maps in Figure 10 show a marked progression from a groundwater system in 1970 that extends across much of the catchment and has large areas with negative depths, to one in 2010 that covers only about half the catchment and has little potential for discharge. The implications for both streamflow generation, and riparian ecosystems which are groundwater dependent, are painfully clear.

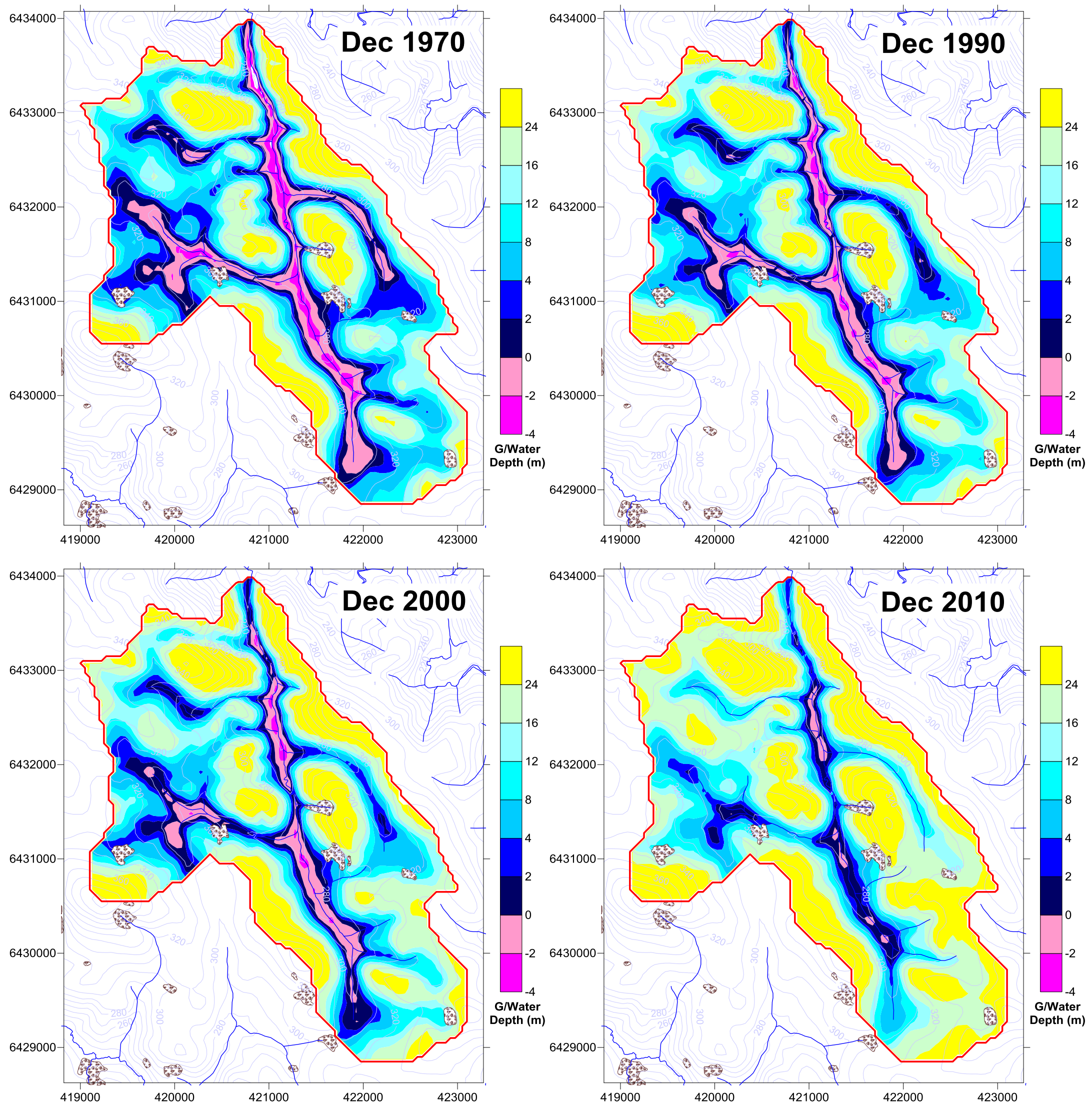

Figure 10: Simulated depth to groundwater for December 1970, 1990, 2000 and 2010.

4. RESULTS – RAINFALL SCENARIO 2001 TO 2010 REPEATED

In an attempt to make the simulation results follow a logical reporting order, we will cover the drier of the two rainfall scenarios, 2001 to 2010 repeated five times to 2060, first. We will also start with a primary simulation set, and then move to various supporting simulations such as high and lower treatment LAIs, etc. In the discussion we will cover the most important aspects of each simulation set and will leave it to the interested reader to review the tabulated information in the Appendices.

4.1 Primary Simulation Set

As discussed in Section 2.3, a number of forest management options are being simulated as part of the study. However, previous studies and discussions have resulted in a particular interest in a forest-treatment target LAI 0.6 as this is seen as providing the best likely compromise; this equates to an equivalent tree basal-area of 9.0 m^2/ha. The overstory-treatment frequency considered most likely to be applied is once every nine years, though the recovery-rate contained in this is now seen more as a target LAI development-curve than hard criteria. In particular, recent discussion has developed the concept of an adaptive management approach where the LAI recovery is monitored and compared to the target recovery curve: if the LAI varies significantly from the target then subsequent treatments could be brought forward or delayed.

The results for the primary simulations will be discussed in detail in the following sub-sections: for streamflow, both volume and flow-days; soil-water storage volume changes; and groundwater levels. The nomenclature used to describe all cases, not just the primary simulation set, is given in Appendix 1. For the primary simulation set, the cases covered and the nomenclature used is given in Table 1.

Table 1: Nomenclature for the primary simulation set.

Target LAI	**Treatment Frequency** (yrs)	**Treatment Area** (%)	**Nomenclature**	**Case Description**
Untreated	-	0	Untreated	Untreated scenario
0.6	-	44	LAI 0.6 LS Once	Treated once to an LAI of 0.6 for 44% of the catchment. Treatment is on the lower slopes.
0.6	-	88	LAI 0.6 FT Once	Treated once to an LAI of 0.6 for 88% of the catchment.
0.6	9	44	LAI 0.6 LS 9yr	Treated to an LAI of 0.6 every nine years for 44% of the catchment.
0.6	9	88	LAI 0.6 FT 9yr	Treated to an LAI of 0.6 every nine years for 88% of the catchment

4.1.1 *Streamflow and Soil-Water Storage*

Figure 11 shows the annual streamflows for the cases in the primary simulation set for the rainfall scenario 2001 to 2010 repeated. It can be seen that the flows divide into essentially two groups, those for the untreated and treated-once cases, and those which are treated at a nine-year frequency. The treated at a nine-year frequency cases increase in streamflow for the following cycles compared to the decade 2011 to 2020, while the others all decline and then start to approach a steady state. Figure 12 is a difference plot of all the other cases to the untreated case. Again the difference between the two cases with a nine year treatment frequency to the other two cases that are treated once can be clearly seen. A careful study of Figure 12 will also reveal the slight differences between decades due to the treatment cycle being nine years while the rainfall cycle is ten years.

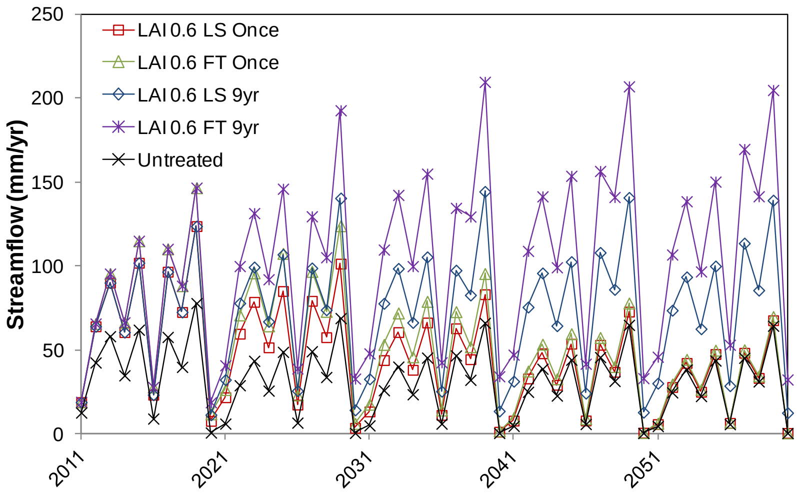

Figure 11: Annual streamflows for the cases in the primary simulation set for the rainfall scenario 2001 to 2010 repeated.

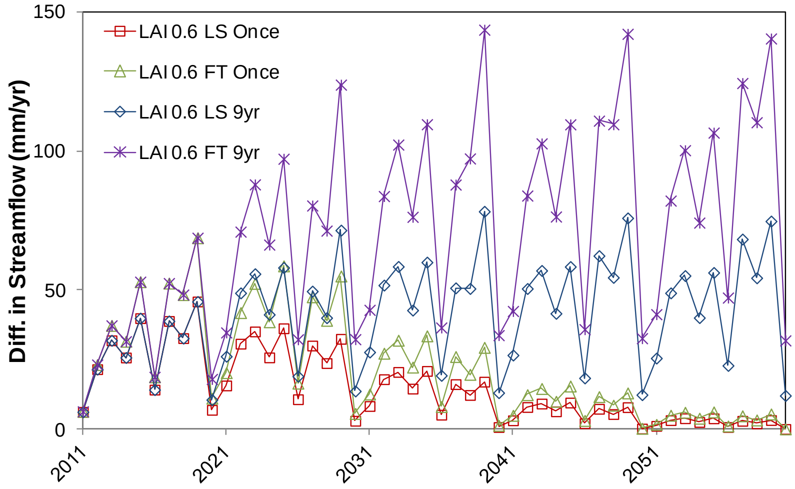

Figure 12: Difference in annual streamflows to the untreated case for the cases in the primary simulation set for the rainfall scenario 2001 to 2010 repeated.

While the above two graphs display a number of interesting annual differences between cases, they are somewhat hard to understand and draw conclusions from. To overcome this, Figure 13 shows the average streamflows by decade for the various cases for the rainfall scenario 2001 to 2010 repeated; Table 2 is the same information in tabular form. Also included on Figure 13 are the decadal averages for the historical simulations going back to the 1970s. What is most dramatic in this plot is the extent of the declines in streamflow that have already occurred: from 236 mm/yr in the 1970s, to 74 mm/yr by the decade 2001 to 2010. The streamflows for the untreated case are predicted to continue to decline under the simulated rainfall scenario: reaching 40 mm/yr in the decade 2011 to 2020, and 28 mm/yr by the decade 2051 to 2060. While there is potential in the primary-set simulations to reverse these trends by treatments to an LAI of 0.6 every nine years, it can be seen that even the full-treatment scenario is only a restoration to flows mid-way between the values observed in the decades 1990 to 2000 and 2001 to 2010; it isn't a return to the streamflows of the 1970s, 1980s or 1990s. The lower-slope only treatment every nine years essentially maintains streamflows at the level of the 2001 to 2010 decade. For the once-only treatments, they of course give essentially the same response for the 2011 to 2020 decade as the treatment every nine year scenarios, but after that they start to decline and essentially rejoin the untreated scenario by the 2041 to 2050 decade.

Figure 14 is a plot of the difference in decadal streamflows between those for the treated cases compared to the untreated case. These again clearly show the marked difference between the treated every nine years cases and the treated once cases. They also show some interesting effects in terms of response size and delay. For instance, the streamflow responses for the lower-slope only treatments are 75% of the response of the full-treatment case for the decade 2011 to 2020; this is despite the area treated being half (44% compared to 88%). This difference in response is due to the lower-slope treatments having the area being treated at a lesser average distance from the streamzone and therefore in a better position to create a response. However, this difference in response tends to decline with the decades and by 2051 to 2060 the streamflow ratio between treatments for the treatments every nine years is down to 53%. It is also interesting to note that the time taken to achieve a full response to treatment is long and it is only by the last three decades that stability is being reached for the treatment every nine years scenarios.

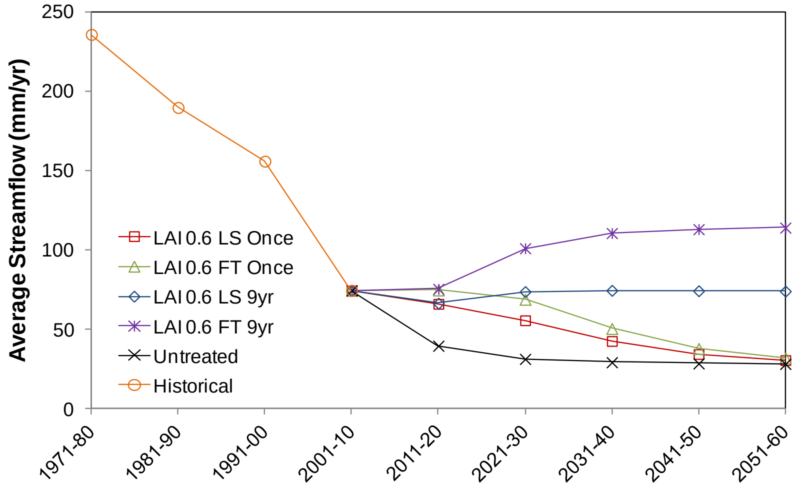

Figure 13: Decadal streamflows for the cases in the primary simulation set for the rainfall scenario 2001 to 2010 repeated. Also included are simulated historical flows.

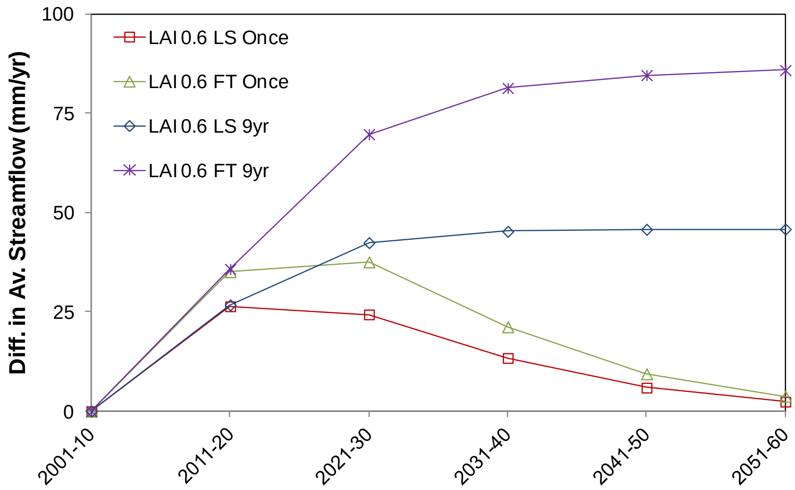

Figure 14: Difference in decadal streamflows to the untreated case for the cases in the primary simulation set for the rainfall scenario 2001 to 2010 repeated.

Table 2: Decadal averages of simulated streamflow for the primary simulation set cases for the rainfall scenario 2001 to 2010 repeated.

	Avg. Flow in Period (mm/yr)				
Case	2011-20	2021-30	**2031-40**	**2041-50**	**2051-60**
Untreated	39.6	31.2	29.2	28.4	28.1
LAI 0.6 LS Once	66.0	55.6	42.5	34.3	30.5
LAI 0.6 FT Once	74.7	68.8	50.4	37.8	31.9
LAI 0.6 LS 9yr	66.3	73.7	74.4	74.2	73.9
LAI 0.6 FT 9yr	75.3	101.0	110.5	113.0	114.0

Figure 15 shows the average flow-days per year by decade for all the primary cases for the rainfall scenario 2001 to 2010 repeated; Table 3 shows the same data tabulated. Like the streamflow volumes, there has been a marked decline in flow-days per year from the 1970s to the 2000s with expected further declines for the untreated case reaching 154 days by 2041 to 2050.

It is interesting to note that the flow-days for the full-treatment every nine years case have returned by the 2031 to 2040 decade to almost equal to those of the 1990s (311 vs. 320 flow-days – 97%), while Figure 13 showed that the streamflow volume was just under three-quarters (110 vs. 156 mm/yr – 71%). This difference in flow-days vs. streamflow volume appears to relate to differences in the catchment hydrology of the simulated treated-catchment compared to the simulated historical untreated-catchment. In particular there is a greater contribution of groundwater for the treated scenario leading to an increased duration of flows into spring and summer. This has positive implications for stream and riparian zone ecology as this ecology normally depends on the continuation of streamflows into spring and summer.

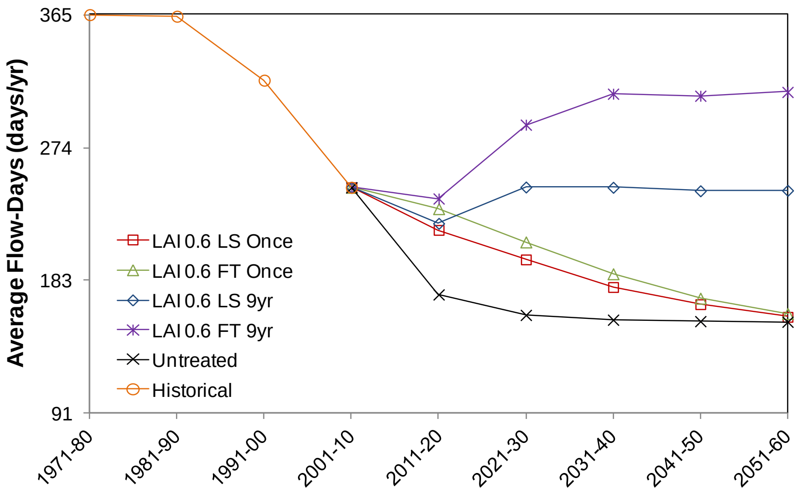

Figure 15: Decadal average flow-days for the cases in the primary simulation set for the rainfall scenario 2001 to 2010 repeated.

Table 3: Decadal average flow-days of simulated streamflow for the primary simulation set cases for the rainfall scenario 2001 to 2010 repeated.

	Avg. Flow-Days in Period (days/yr)				
Case	2011-20	2021-30	**2031-40**	**2041-50**	**2051-60**
Untreated	173	159	155	154	154
LAI 0.6 LS Once	217	197	178	166	157
LAI 0.6 FT Once	232	209	187	170	160
LAI 0.6 LS 9yr	222	247	247	244	244
LAI 0.6 FT 9yr	239	290	311	310	312

The last graph in this section, Figure 16, shows the simulated soil-water storage for the catchment relative to 1st January 1970. It can be seen that the untreated case undergoes a steady decline until 2040 after which it flattens out and does not significantly decline further. For the full-treatment every nine years case, there is a steady increase to 2040, after which it flattens out and does not significantly increase further; this stabilisation occurs at a level about equal to the historical year 2000 value. As expected, the once-only treatment cases initially track slightly below the treatment every nine years cases and then steadily decline until they almost rejoin the untreated line by 2060. The lower-slope only treated every nine years case is interesting in just how accurately it maintains storages equal to the 2010 level.

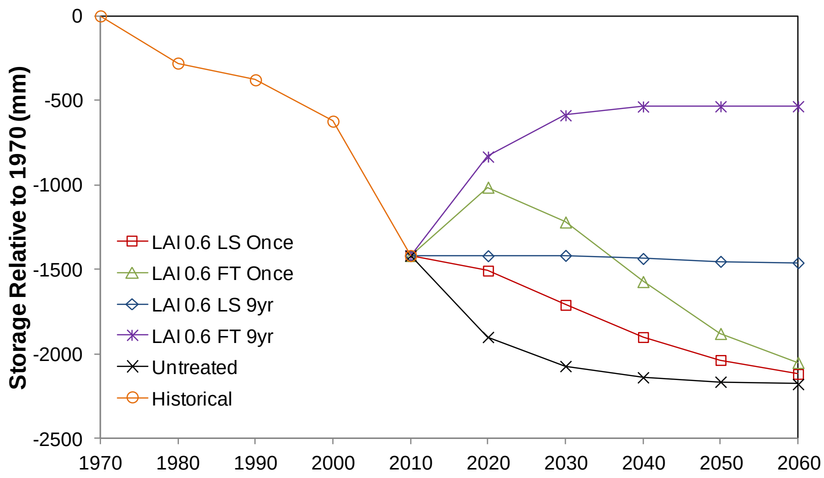

Figure 16: Soil-water storage difference relative to 1st January 1970 for the cases in the primary simulation set for the rainfall scenario 2001 to 2010 repeated.

4.1.2 Groundwater

In the preceding section we reviewed the differences in streamflow behaviour between the cases in the primary simulation set. In this section we will look at the groundwater responses in terms of depth-to-water below the soil surface. These simulation results have already been presented for the historical period 1970 to 2010 in Figure 10. It was noted already that large historical changes have already taken place for the groundwater system: it has moved from a system with extensive areas of the valley-floors along both the main stream-channel and the major side-channels, with the groundwater intersecting the surface in the 1970s to 1990s; to one by 2010 with limited areas of intersection along the valley-floor of the main stream-channel.

To start the process of assessment of possible future groundwater regimes, Figure 17 shows the depth-to-water for December 2020, 2030, 2040 and 2060 for the untreated case for the rainfall scenario 2001 to 2010 repeated. It can be seen that the simulated groundwater levels have continued to decline compared with simulated historical; by December 2020 there is only one small area on the main streamline where the groundwater still has a negative depth-to-water, that is a potential area of groundwater discharge, and by December 2030 even this has disappeared. From 2030 on there is really little change in groundwater depths and the groundwater system appears to have entropied to a new state that differs markedly from the historical situation.

Note that the simulated future state of the groundwater is highly dependent on the assumed rainfall, 2001 to 2010 repeated in this scenario. Later we will review the groundwater situation for the 2000 to 2009 repeated scenario and show that it is significantly different.

Figure 18 shows the depth-to-water for the rainfall scenario 2001 to 2010 repeated for December 2020, 2030, 2040 and 2060 for the lower-slope only treated-once case (LAI 0.6 LS Once). It can be seen that these groundwater depths are different from the untreated case for 2020 and 2030; in particular, there are now positive groundwater heads (negative depths-to-water) along sections of the main stream-channel. However, by 2040 these gains are largely lost and by 2060 there is little difference between this case and the untreated case. This process of initial gains followed by a period of gradual loss is of course a direct result of this being only a single treatment followed by a period when the LAI steadily recovers to pre-treatment levels.

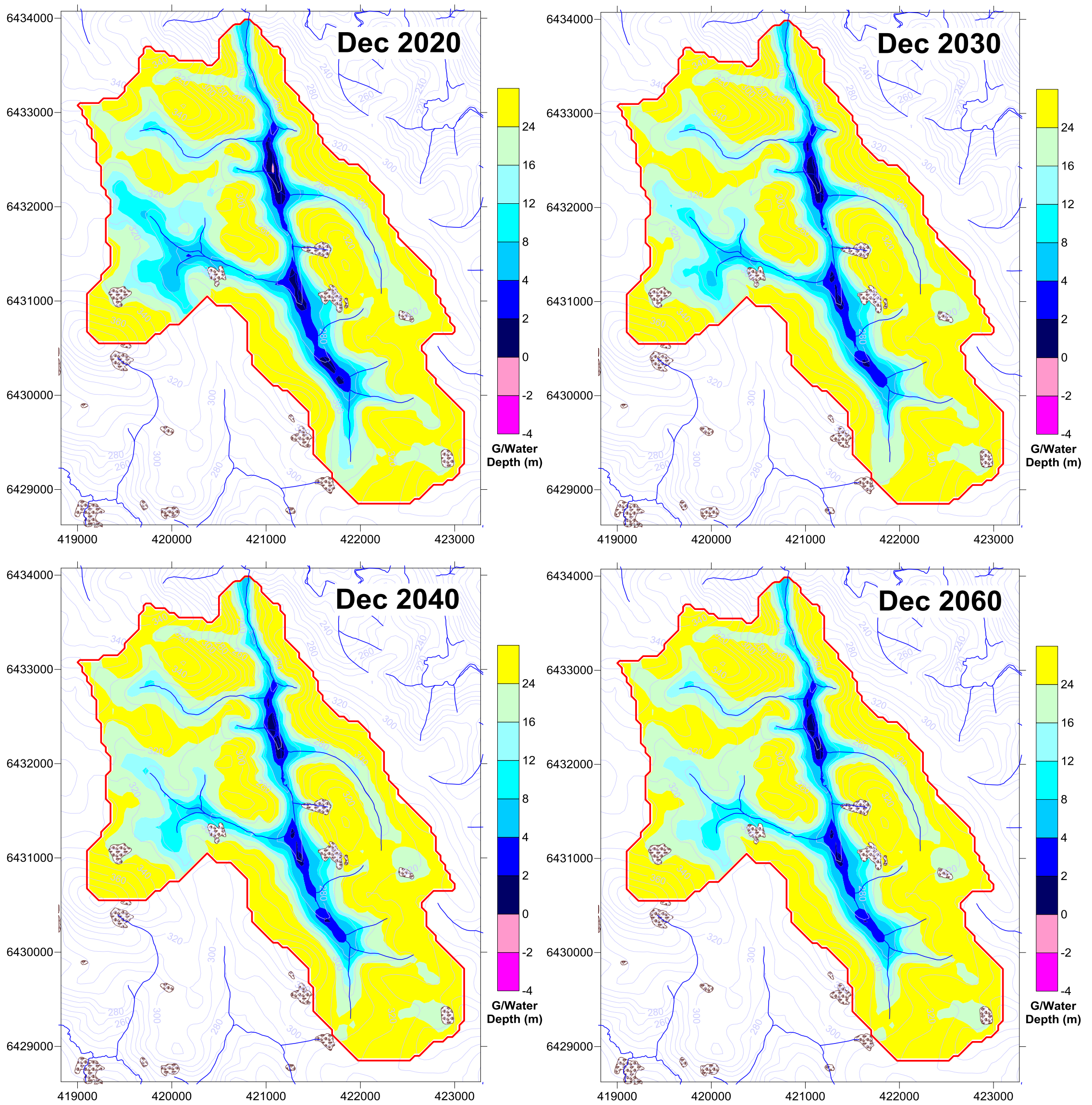

Figure 17: Simulated depth to groundwater for December 2020, 2030, 2040 and 2060 for the untreated case for the rainfall scenario 2001 to 2010 repeated.

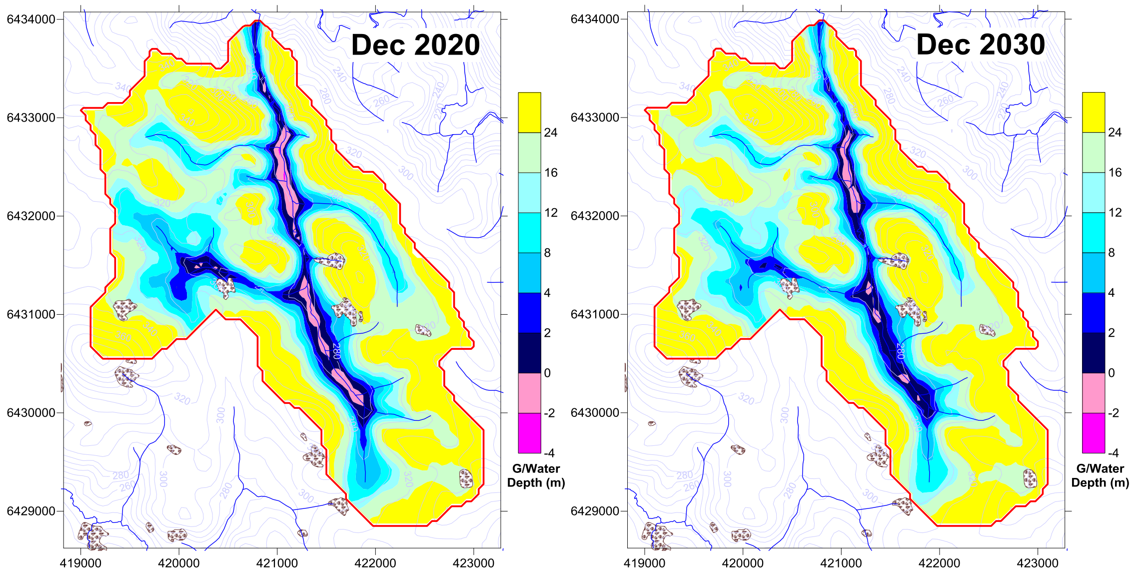

Figure 18 cont'd.

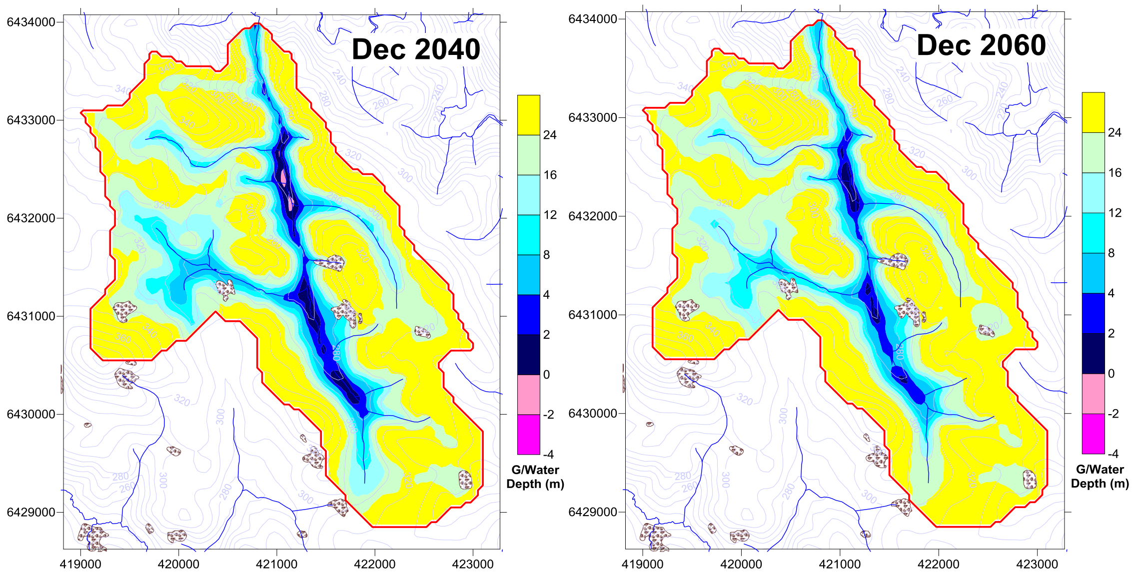

Figure 18: Simulated depth to groundwater for December 2020, 2030, 2040 and 2060 for the lower-slope only treated once case (LAI 0.6 LS Once) for the rainfall scenario 2001 to 2010 repeated.

Figure 19 shows the depth-to-water for the rainfall scenario 2001 to 2010 repeated for December 2020, 2030, 2040 and 2060 for the full-treatment but once only case (LAI 0.6 FT Once). Like the LAI 0.6 LS Once case, these plots differ from the untreated case with positive groundwater heads (negative depths-to-water) along significant sections of the main stream-channel for 2020 and 2030. There is also for this case a significant elevation of groundwaters in the large side-valley on the western side with positive heads for the valley-head area. However, by 2040 any differences between this case and the LAI 0.6 LS Once case have been completely lost and both follow a similar trajectory to 2060.

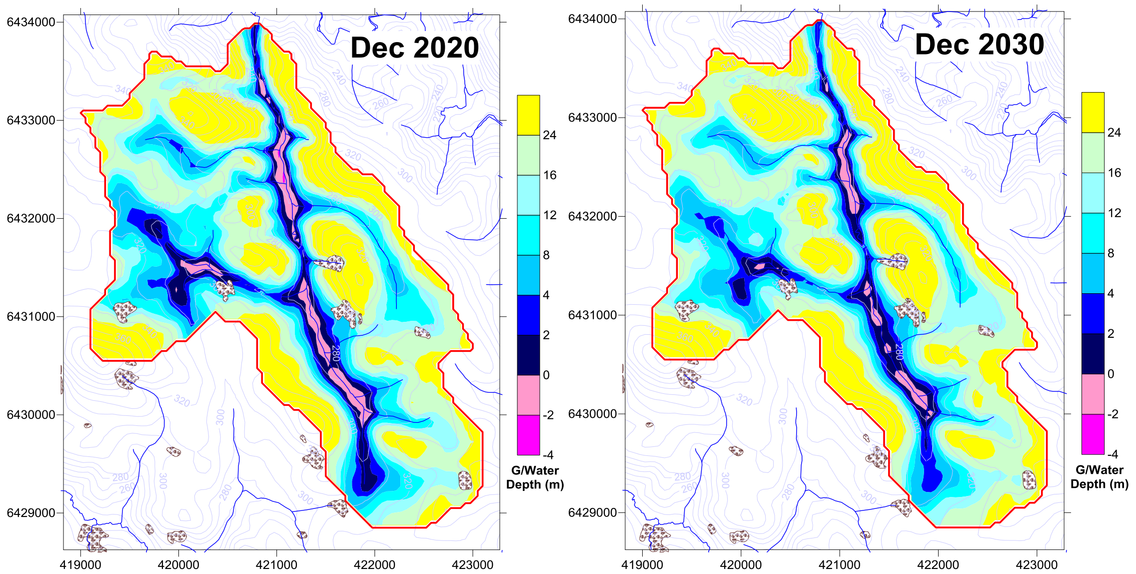

Figure 19 cont'd.

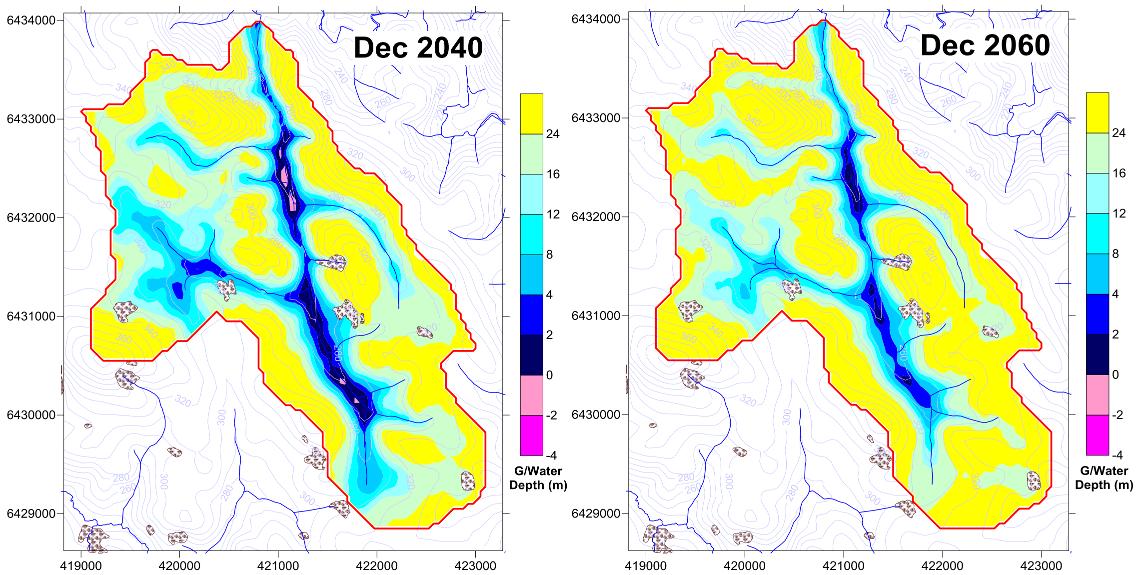

Figure 19: Simulated depth to groundwater for December 2020, 2030, 2040 and 2060 for the full-treatment but once only case (LAI 0.6 FT Once) for the rainfall scenario 2001 to 2010 repeated.

Figure 20 shows the depth-to-water for the rainfall scenario 2001 to 2010 repeated for December 2020, 2030, 2040 and 2060 for the LAI 0.6 LS 9yr case, that is the lower-slope only treatment to an LAI of 0.6 every nine years. Like the once-only treatment cases, the plots for this case have positive groundwater heads (negative depths-to-water) along significant sections of the main stream-channel for 2020 and 2030. However, due to the follow-up treatments these benefits persist till simulation end. As well, the groundwater depths for this lower-slope only treatment case, are closer to the depths seen in the full-treatment once-only case than they are to those of the lower-slope once-only treatment case; this includes a significant elevation of groundwaters in the large side-valley on the western side with positive heads for the valley-head area. Comparing with the historical maps in Figure 10, the groundwater depth plots for this case are between those for 2000 and 2010.

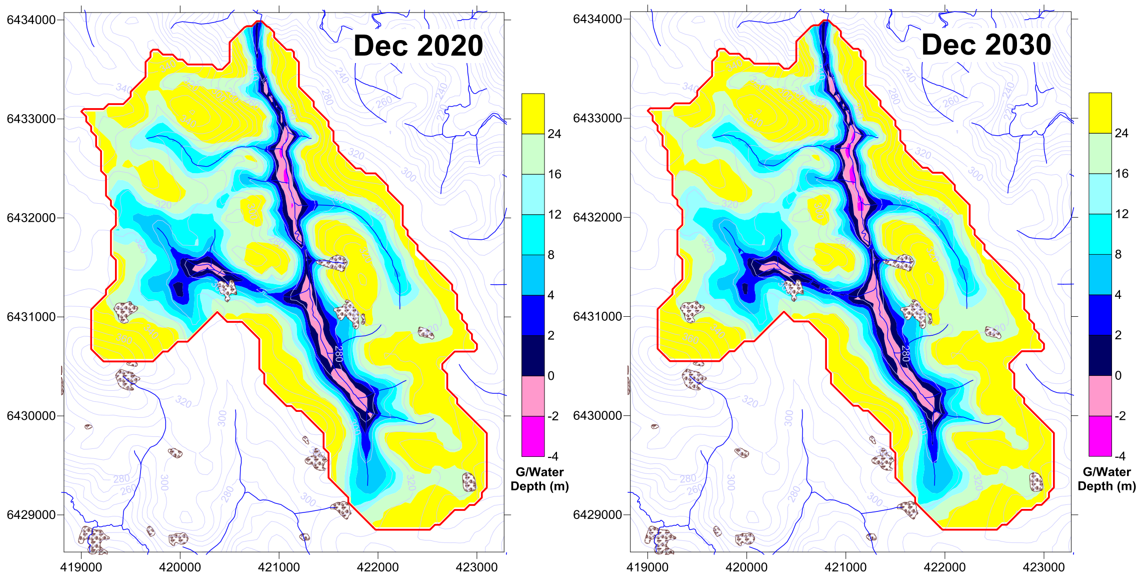

Figure 20 cont'd.

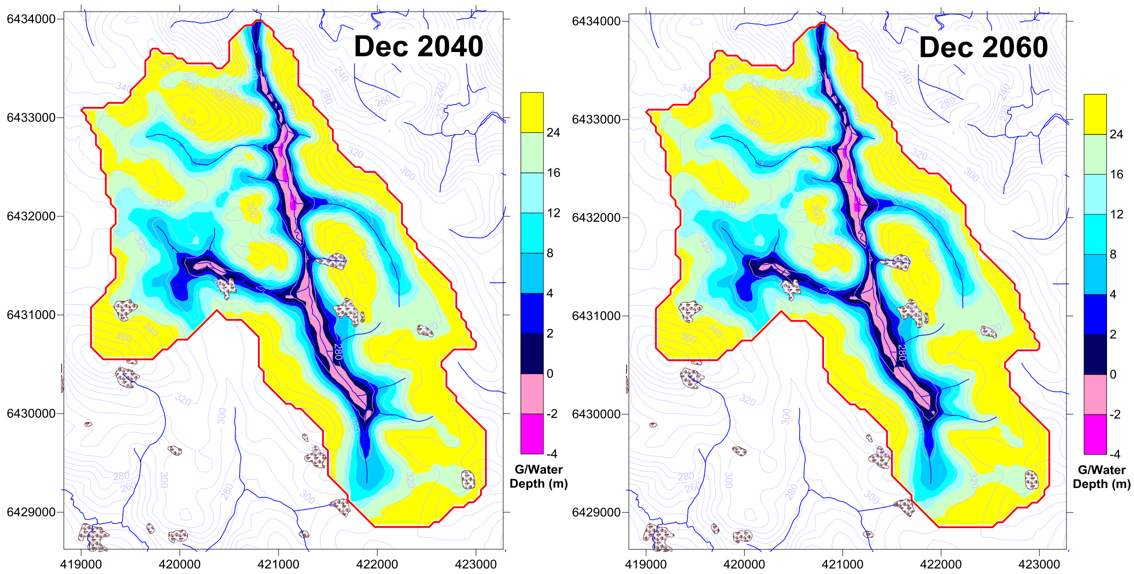

Figure 20: Simulated depth to groundwater for December 2020, 2030, 2040 and 2060 for the LAI 0.6 LS 9yr case for the rainfall scenario 2001 to 2010 repeated.

Figure 21 shows the depth-to-water for the rainfall scenario 2001 to 2010 repeated for December 2020, 2030, 2040 and 2060 for the LAI 0.6 FT 9yr case, which is the full-treatment to an LAI of 0.6 every nine years. These plots are similar to those in Figure 20, but display the obvious benefit of having 88% rather than 44% of the catchment area treated. In terms of a historical comparison, the plots from 2030 on are very close in form to that for the year 2000.

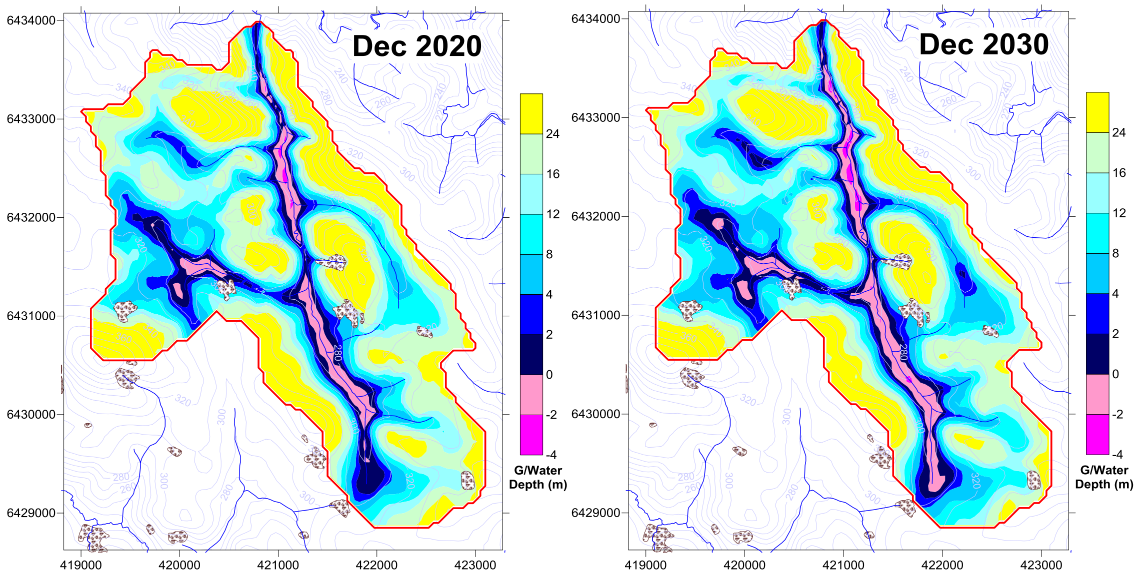

Figure 21 cont'd.

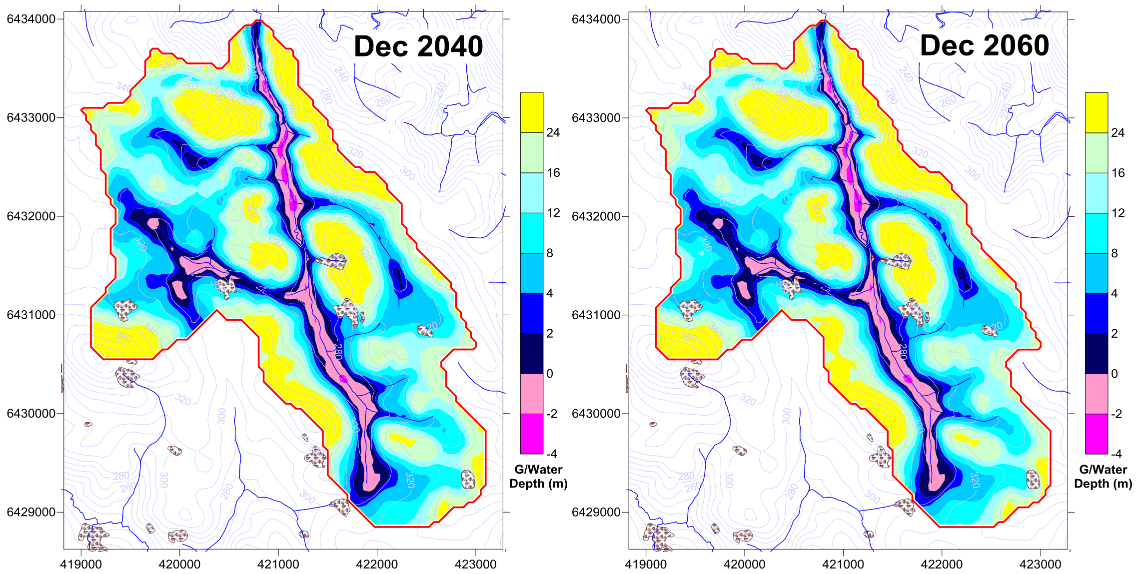

Figure 21: Simulated depth to groundwater for December 2020, 2030, 2040 and 2060 for the LAI 0.6 FT 9yr case for the rainfall scenario 2001 to 2010 repeated.

4.2 Effects of Varying the Treatment Frequency

In the preceding section, a treatment frequency of once every nine years was used for the presented simulations that included retreatment. In this section we will look at the effects of altering the retreatment frequency. To keep things simple, we will only look in this section at the cases for full-treatment (that is 88% of the catchment area) to an LAI of 0.6; the reader is referred to the Appendices for tabulated results of other cases. Figure 22 shows a plot of the decadal streamflow for retreatments from seven to 12 years. What is probably most interesting about Figure 22 is how close the treatment simulations are to each other and how distant they become from the untreated case. For the 2051 to 2060 decade, the average flow for the 12 year cycle was 99 mm/yr and that for the seven year cycle was 121 mm/yr, a range of 22 mm/yr, while the untreated average flow was 28 mm/yr, or 71 mm/yr less than the 12 year cycle flow.

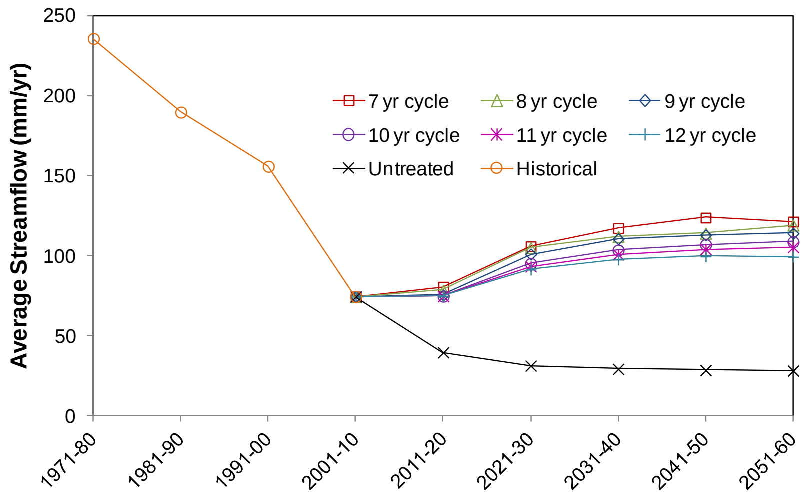

Figure 22: Decadal average streamflows for the full-treatment cases to an LAI of 0.6 with retreatments every seven to 12 years for the rainfall scenario 2001 to 2010 repeated. Also included are simulated historical flows.

Figure 23 shows the same treatments as Figure 22 except that average flow-days are now plotted in place of streamflows. Again the complete separation between the treated cases and the untreated case is evident. For the last decade, all the treatments fall in the range 284 to 323 flow-days, while the untreated average is 154 flow-days. Figure 24 shows the soil-water storage difference relative to 1st January 1970 for the same treatment cases as Figure 22 and 23. It can be seen that like the other two figures, all the treatments clump together and are well above the untreated case. Figure 24 contains what may initially seem a some-what puzzling effect due to it being a report every decade of the soil-water storage on the 1st January while a set of treatments are occurring that have cycles between seven and 12 years. The net result is that on the reporting day it is possible for the storage of some of the longer treatment cycles to be above those for shorter treatment cycles.

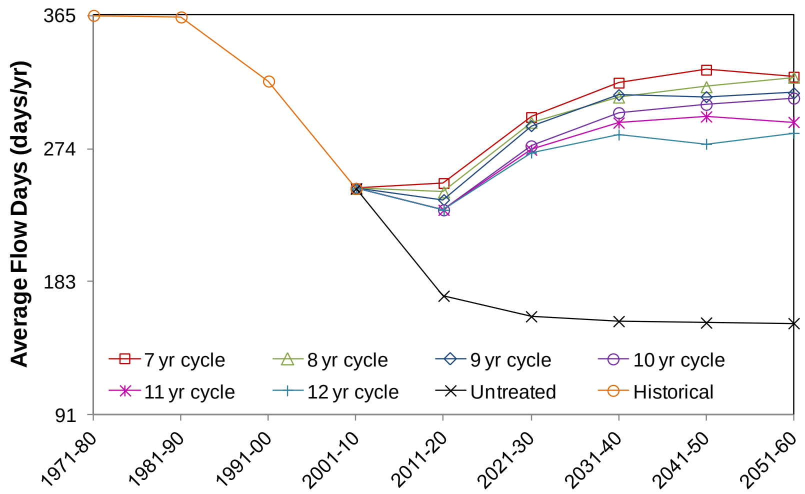

Figure 23: Decadal average flow-days for the full-treatment cases to an LAI of 0.6 with retreatments every seven to 12 years for the rainfall scenario 2001 to 2010 repeated. Also included are simulated historical flow-days.

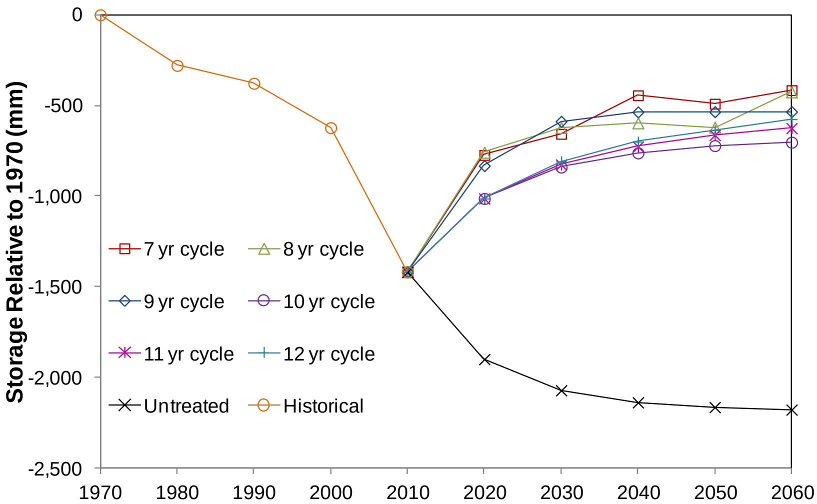

Figure 24: Soil-water storage difference relative to 1st January 1970 for the full-treatment cases to an LAI of 0.6 with retreatments every seven to 12 years for the rainfall scenario 2001 to 2010 repeated.

As discussed previously, the treatment frequencies presented here are now considered more as target LAI development-curves than hard criteria. In particular, recent discussion has developed the concept of an adaptive management approach where the LAI recovery is monitored and compared to a target recovery curve; if the LAI varies significantly from the target then subsequent treatments could be brought forward or delayed. The key finding from the data presented in Figures 22 to 24 is that providing the LAI recovery is following the expected development curve, then there isn't much in streamflow volumes, flow-days or soil-water storages to be gained or lost by bringing forward or delaying retreatments, so there is a fair degree of flexibility in future management scheduling.

4.3 Effects of Varying the Treatment LAI

In the preceding section the effects of varying treatment frequency was considered. This section is concerned with assessing the effects of varying the target LAI. The values selected for study were 0.4, 0.6, 0.8 and 1.0. As mentioned previously, using the relationship between tree basal-area and LAI of 15 to 1, these correspond to basal areas of 6.0, 9.0, 12.0 and 15.0 m^2/ha. The treatments presented are for full-treatment, which is 88% of the catchment, with retreatment every nine years; the reader is referred to the Appendices for other cases. Figure 25 shows the decadal average streamflows and Figure 26 shows the decadal average flow-days.

As expected, Figures 25 and 26 show a strong dependence between LAI and streamflow both in terms of volume and flow-days. What may not be obvious from Figures 25 and 26 is that there is a non-linear relationship between LAI and streamflow; this is shown by Figure 27 which is a plot of the average streamflow in the last decade, 2051 to 2060, vs. average catchment LAI for the various treatments shown in Figures 25 and 26. While the polynomial regression shown is slightly incorrect in that it just dips below the untreated value at an LAI of about 1.7, it nevertheless clearly shows how strong this non-linear relationship is and how important it is to maintain low LAIs if a response in streamflow is required.

Figure 28 shows the soil-water storage difference relative to 1st January 1970 for the same LAI treatment cases as Figure 25 and 26. Like Figures 25 and 26, there is a considerable range in the responses; the treatment to an LAI of 1.0 results in maintenance of the 2010 storage levels, while that for a treatment LAI of 0.4 exceeds the 1980 storage level.

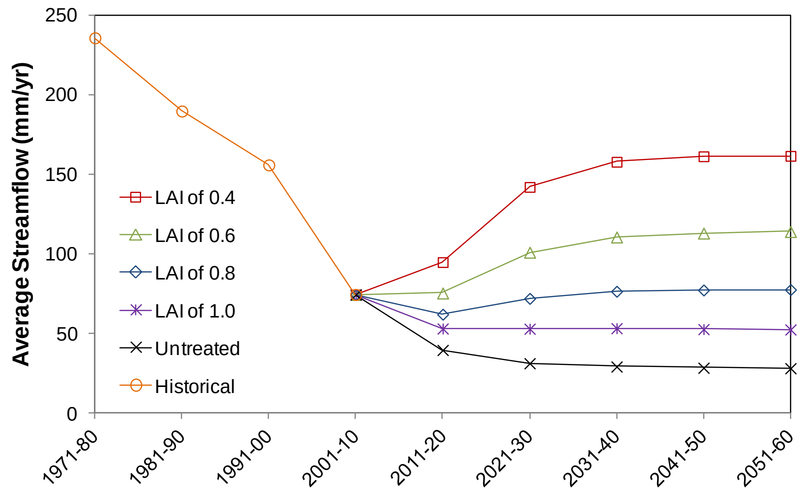

Figure 25: Decadal average streamflows for the full-treatment cases to LAIs of 0.4, 0.6, 0.8 and 1.0 with retreatments every nine years for the rainfall scenario 2001 to 2010 repeated. Also included are simulated historical flows.

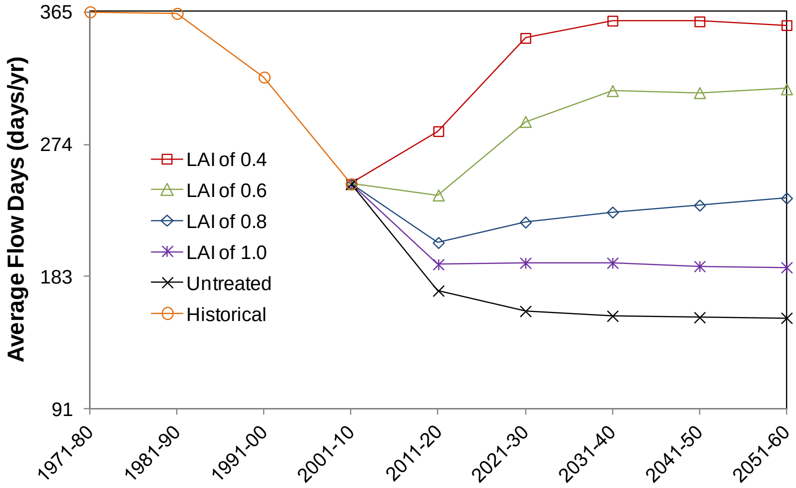

Figure 26: Decadal average flow-days for the full-treatment cases to LAIs of 0.4, 0.6, 0.8 and 1.0 with retreatments every nine years for the rainfall scenario 2001 to 2010 repeated. Also included are simulated historical flow-days.

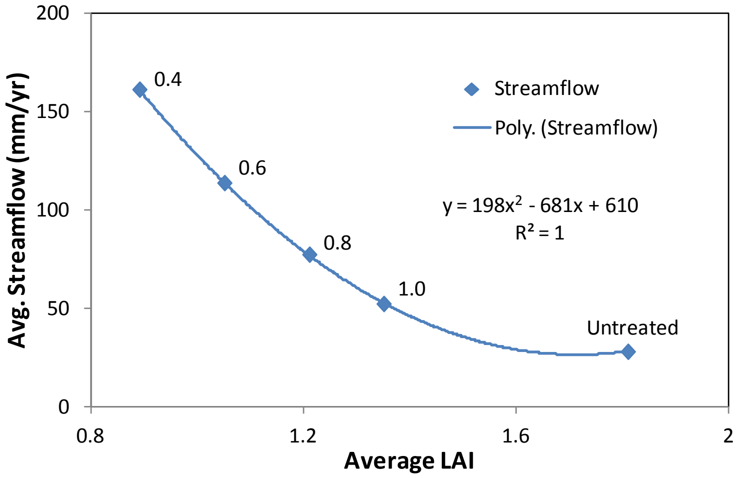

Figure 27: Average catchment LAI for the treatments shown in Figure 25 vs. decadal average streamflows for 2051 to 2060. The target treatment LAIs are shown as labels on the data points.

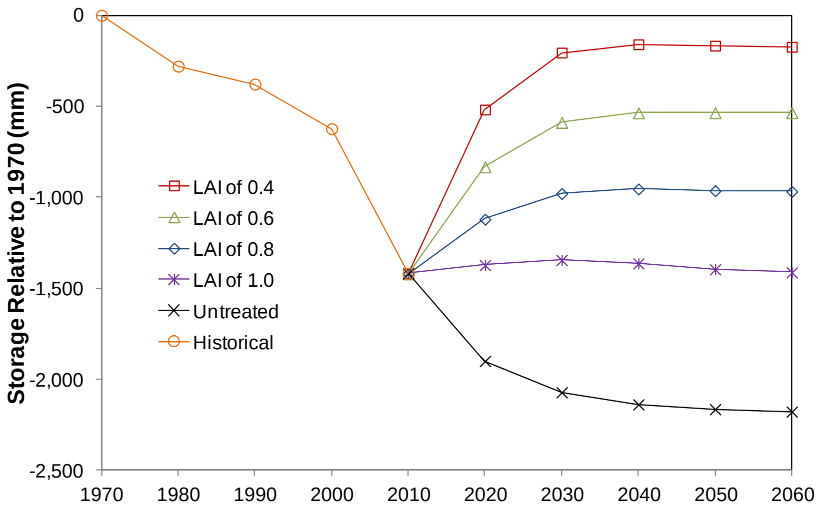

Figure 28: Soil-water storage difference relative to 1st January 1970 for the treatments shown in Figure 25.

It should also be noted in assessing the figures above that the cost of the more intensive treatments is only incremental compared to a treatment to an LAI of 1.0. This is because the pre-treatment LAI is about 1.8, so a reduction to 1.0 means the removal of 0.8 of an LAI while a reduction to 0.6 is only the removal of 50% more, which is an LAI of 1.2. Given that a significant percentage of the cost of a treatment is associated with fixed overheads, then the cost difference between these two treatments is likely to be of order 20%, while the flow increase in the last decade compared to untreated is 87% for one and 306% for the other. Therefore, the cost effectiveness is always in favour of going to the lowest practical treatment LAI. However, other issues enter the debate at very low treatment LAIs and it is likely that treating to an LAI of 0.4 will be eliminated from further consideration for reasons not related to hydrology and costs.

5. RESULTS – RAINFALL SCENARIO 2000 TO 2009 REPEATED

In Section 4 we outlined the results for the rainfall scenario using the rainfall from the years 2001 to 2010 repeated five times to create a rainfall input for the simulation of the period 2011 to 2060. We will now present the results using the rainfall scenario based on the rainfall from the years 2000 to 2009 repeated five times. We will concentrate on the primary simulation set, and where appropriate relate the results for these simulations back to those for the rainfall scenario 2001 to 2010 repeated five times. In the discussion, we will cover the most important aspects of the simulations and will leave it to the interested reader to review the tabulated information in the Appendices. For the primary simulation set, the nomenclature was already given in Table 1.

5.1 Primary Simulation Set – Streamflow and Soil-Water Storage

Figure 29 shows the decadal average streamflows for the cases in the primary simulation set for the rainfall scenario 2000 to 2009 repeated, and Table 4 is a tabulation of this data. Included on Figure 29 are the decadal averages for the simulations going back to the 1970s. As seen in Figure 13, what is most dramatic in this plot is the extent of the declines in streamflow that have already occurred, from 236 mm/yr in the 1970s, to 74 mm/yr by the decade 2001 to 2010. Unlike in Figure 13, the streamflows for the untreated case are predicted to stabilise under the 2000 to 2009 rainfall scenario reaching 52 mm/yr in the decade 2011 to 2020, and 50 mm/yr by the decade 2051 to 2060. Figure 30 is a plot of the difference in decadal streamflows between those for the treated cases compared to the untreated case. There are strong similarities between the treatment responses seen in Figures 29 and 30 and those already presented for the 2001 to 2010 rainfall in Figures 13 and 14. The essential difference is that the 2000 to 2009 rainfall plots have higher streamflows for all cases.

Table 4: Decadal averages of simulated streamflow for the primary simulation set cases for the rainfall scenario 2000 to 2009 repeated.

	Avg. Flow in Period (mm/yr)				
Case	2011-20	2021-30	**2031-40**	**2041-50**	**2051-60**
Untreated	52.1	51.6	50.8	50.4	50.4
LAI 0.6 LS Once	82.8	82.7	69.5	59.2	53.8
LAI 0.6 FT Once	94.6	105.5	85.1	66.9	56.9
LAI 0.6 LS 9yr	84.6	104.4	107.2	107.6	108.3
LAI 0.6 FT 9yr	97.4	145.2	158.9	163.0	164.7

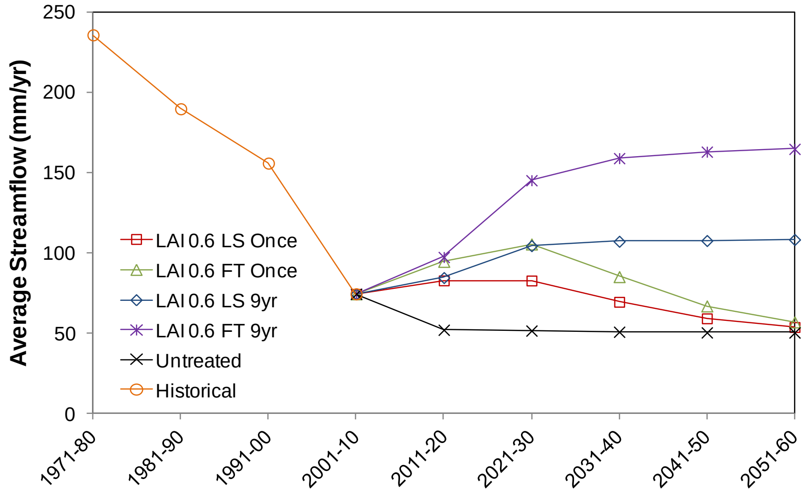

Figure 29: Decadal streamflows for the cases in the primary simulation set for the rainfall scenario 2000 to 2009 repeated. Also included are the simulated historical flows.

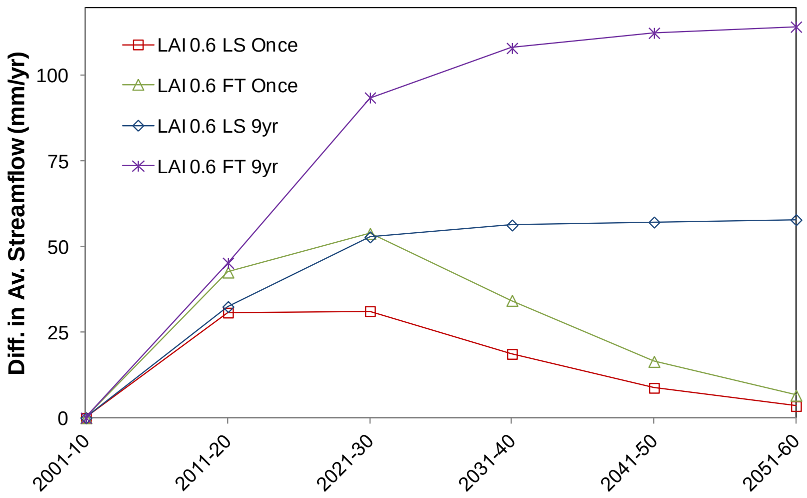

Figure 30: Difference in decadal streamflows to the untreated case for the cases in the primary simulation set for the rainfall scenario 2000 to 2009 repeated.

Figure 31 shows the average flow-days per year by decade for all the primary cases for the rainfall scenario 2000 to 2009 repeated; Table 5 shows the same data tabulated. Like Figure 29 for streamflow, it can be seen that the untreated case immediately reaches stability in the decade 2011-20 and the flow-days remain essentially constant for the balance of the simulation. The full-treatment every nine years case (LAI 0.6 FT 9yr) increases in flow-days until it is almost at perennial levels, that is the average just falls short of 365 days per year. As was observed for the 2001 to 2010 rainfall scenario, there is a greater relative recovery in flow-days than there is in streamflow volume. As already mentioned, this difference in flow-days vs. streamflow volume appears to relate to differences in the catchment hydrology of the simulated treated-catchment compared to the historical untreated catchment; in particular there is a greater contribution of groundwater for the treated scenario leading to an increase of the duration of flows into spring and summer.

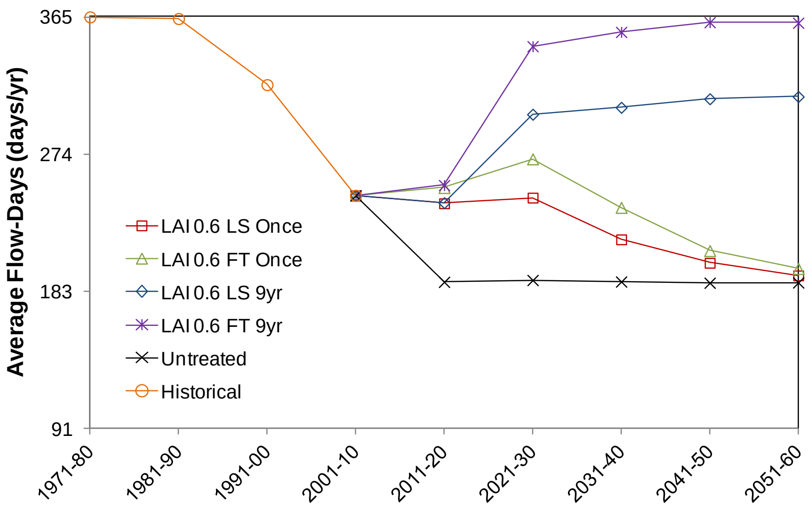

Figure 31: Decadal flow-days for the cases in the primary simulation set for the rainfall scenario 2000 to 2009 repeated. Also included are the simulated historical flow-days.

Table 5: Decadal average flow-days of simulated streamflow for the primary simulation set cases for the rainfall scenario 2000 to 2009 repeated.

	Avg. Flow-Days in Period (days/yr)				
Case	2011-20	2021-30	**2031-40**	**2041-50**	**2051-60**
Untreated	189	190	189	188	189
LAI 0.6 LS Once	241	245	217	202	193
LAI 0.6 FT Once	252	271	239	210	198
LAI 0.6 LS 9yr	242	301	305	311	312
LAI 0.6 FT 9yr	253	346	355	362	361

The last graph in this section, Figure 32, shows the simulated soil-water storage for the catchment relative to 1st January 1970. It can be seen that the untreated case undergoes a rapid decline in the historical period 2000 to 2010, due mainly to the low rainfall year of 2010, but once we enter the predictive period, 2011 to 2060, significant further declines cease. For all the treated cases there is an increase in storage from 2010 to 2020, whereas in Figure 16 for the 2001 to 2010 rainfall scenario, there was a further decline for the lower-slope once-only treatment (LAI 0.6 LS Once). Following 2020 there is a rapid divergence of storages with the full-treatment every nine years case (LAI 0.6 FT 9yr) rising to close to the historical 1970 storage level while the lower-slope only every nine-years case stabilises midway between the historical 2000 and 2010 storage levels. Both of the treatment once-only cases steadily decline towards the untreated trace. Again it is interesting to note how storages recover to higher relative levels than the streamflow volumes do. This too seems to indicate differences in catchment hydrological behaviour.

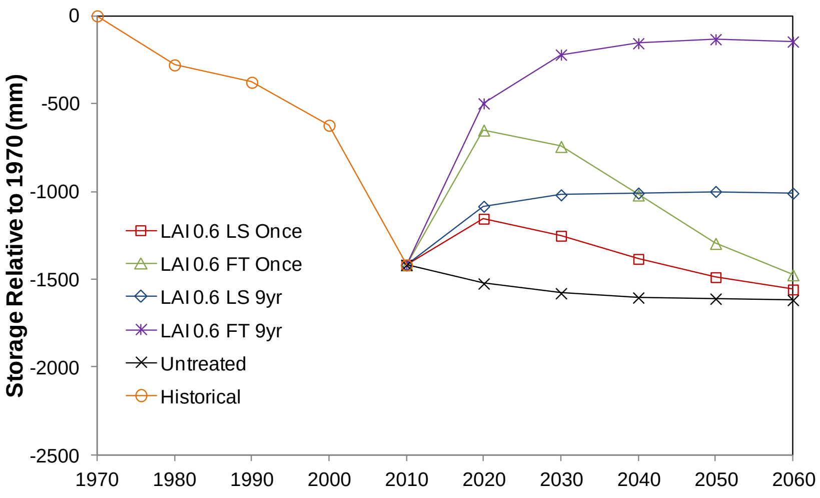

Figure 32: Soil-water storage difference relative to 1st January 1970 for the cases in the primary simulation set for the rainfall scenario 2000 to 2009 repeated.

5.2 Primary Simulation Set – Groundwater

In the preceding section we reviewed the differences in streamflow behaviour between the cases for the rainfall scenario 2000 to 2009 repeated. In this section we will look at the groundwater responses in terms of depth-to-water below the soil surface. These simulation results have already been presented for the historical period 1970 to 2010 in Figure 10 and those for the rainfall scenario 2001 to 2010 repeated were presented in Figures 17 to 21. It was noted previously that large historical changes have already taken place in the groundwater system. It has moved from a system with extensive areas in the valley-floors along both the main stream-channel and the major side-channels with the groundwater intersecting the surface in the 1970s, 1980s and 1990s, to one by 2010 with just limited areas of intersection along the valley-floor of the main stream-channel.

To start the process of assessment of possible future groundwater regimes under the rainfall scenario 2000 to 2009 repeated, Figure 33 shows the depth-to-water for December 2020, 2030, 2040 and 2060 for the untreated case. The stability in terms of soil-water storage for the untreated case shown in Figure 32 is reproduced in Figure 33 for the groundwater system; there is little difference between the four groundwater-depth plots presented. When these are also compared with the 2010 plot in Figure 10, it can be seen that the simulated groundwater levels have changed little since then. It is also interesting to note that this new stability is at a level where there are still areas on the main channel where the groundwater level is above the soil surface, implying groundwater discharge would continue.

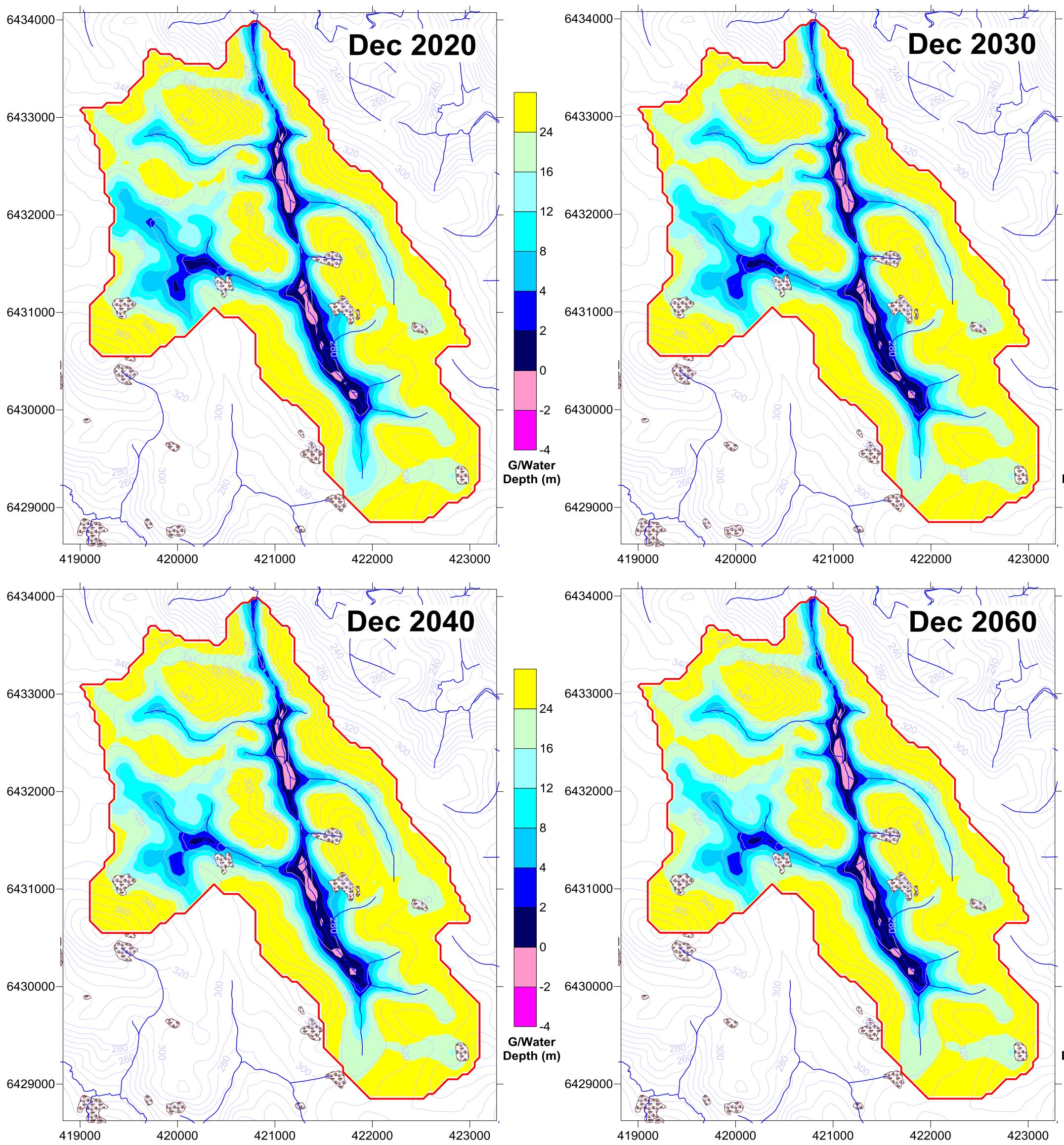

Figure 33: Simulated depth to groundwater for December 2020, 2030, 2040 and 2060 for the untreated case for the rainfall scenario 2000 to 2009 repeated.

Figure 34 shows the depth-to-water for the rainfall scenario 2000 to 2009 repeated for December 2020, 2030, 2040 and 2060 for the lower-slope only treated once case (LAI 0.6 LS Once). It can be seen that significant areas of the valley-floor, both along the main channel and in the major tributary on the western side, have the groundwater intersecting the surface in 2020 and there are still elevated levels in 2030 compared to the untreated case. Figure 35 shows the depth-to-water for the rainfall scenario 2000 to 2009 repeated for December 2020, 2030, 2040 and 2060 for the full-treatment but once only case (LAI 0.6 FT Once). The groundwater for this case in 2020 is very similar to the historical levels of 2000 with this including the groundwater being at or close to the surface in a number of the secondary valleys. As in Figure 34, significant responses are persisting until 2040.

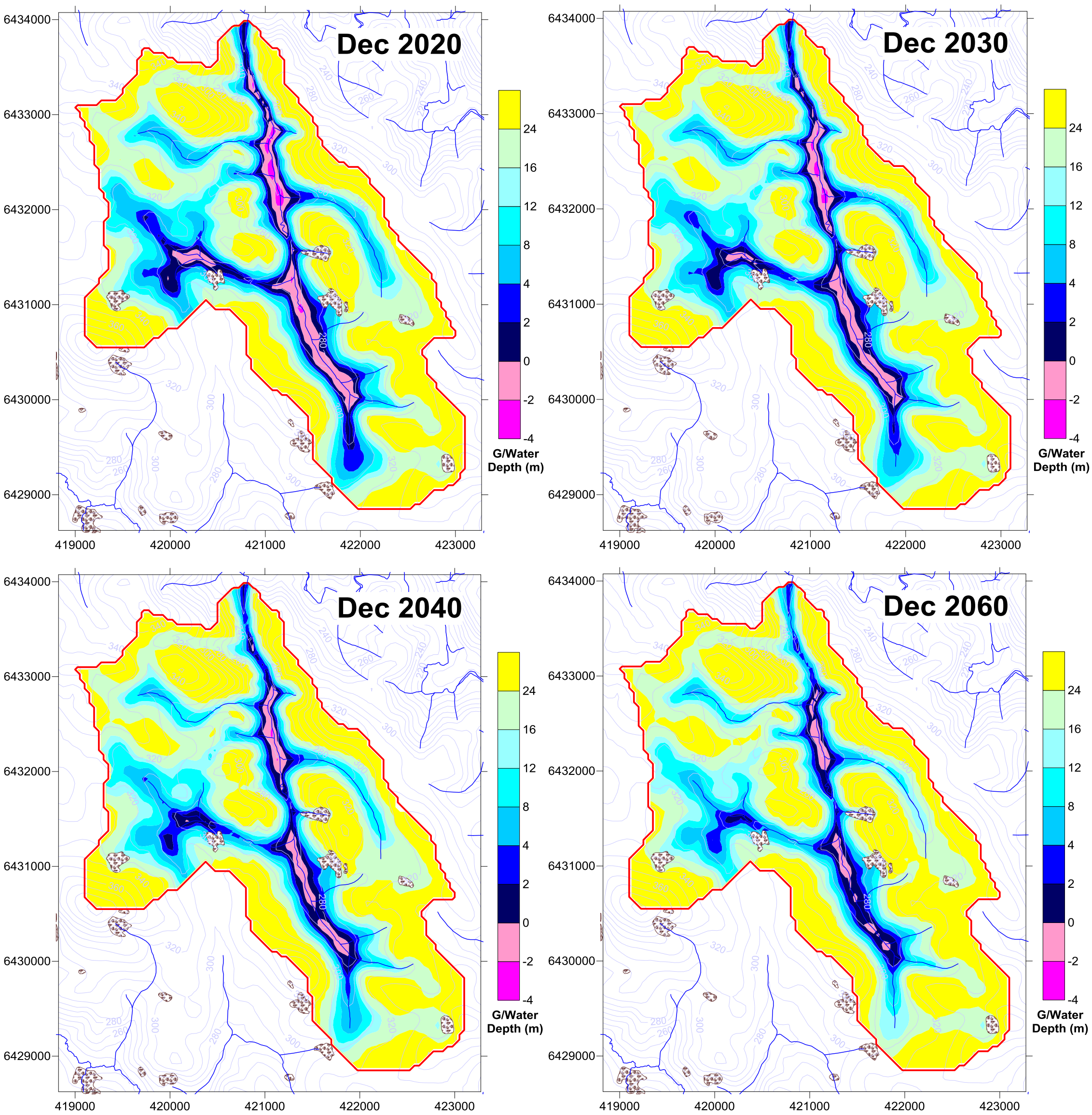

Figure 34: Simulated depth to groundwater for December 2020, 2030, 2040 and 2060 for the lower-slope only treated once case (LAI 0.6 LS Once) for the rainfall scenario 2000 to 2009 repeated.

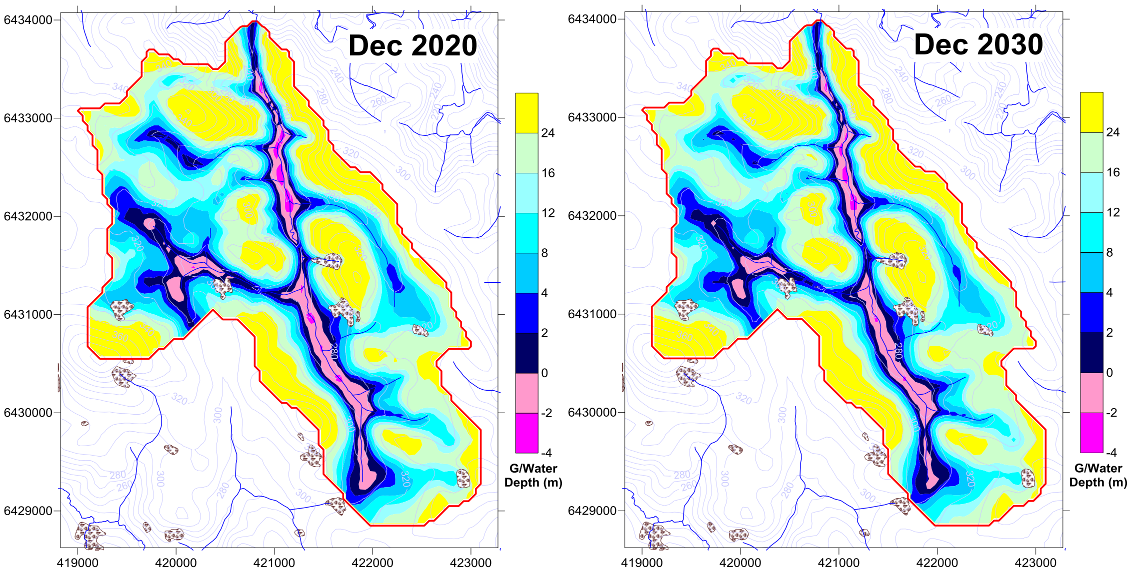

Figure 35 cont'd.

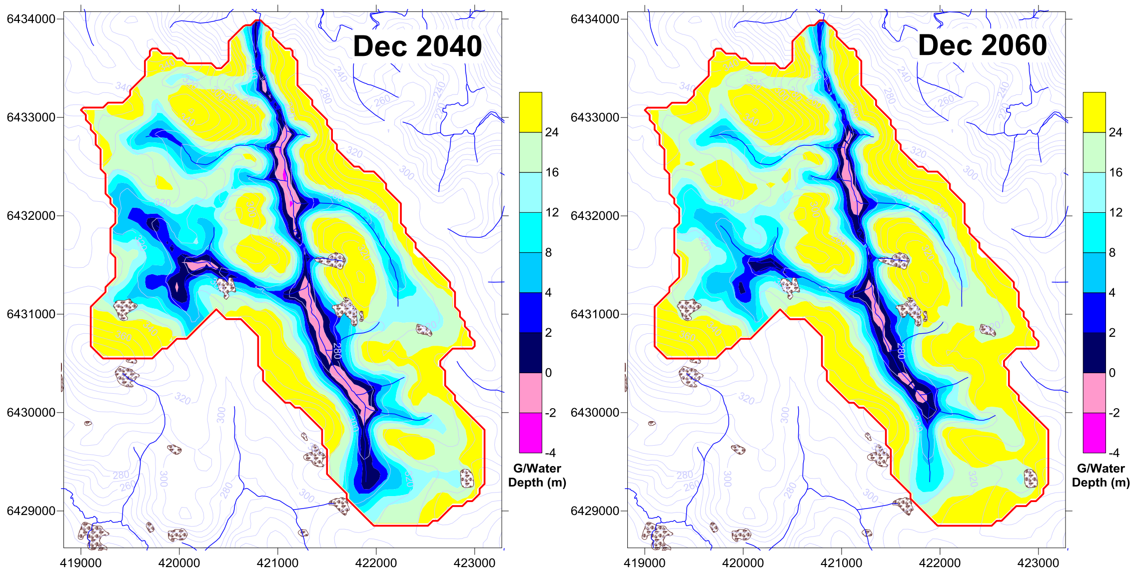

Figure 35: Simulated depth to groundwater for December 2020, 2030, 2040 and 2060 for the full-treatment but once only case (LAI 0.6 FT Once) for the rainfall scenario 2000 to 2009 repeated.

Figure 36 shows the depth-to-water for the rainfall scenario 2000 to 2009 repeated for December 2020, 2030, 2040 and 2060 for the lower-slope only treated every nine years case (LAI 0.6 LS 9yr). As expected, the groundwater levels for this case are displaying the same behaviour as observed for the soil-water storage of this case in Figure 32; they reach an elevated level by 2020 after which they remain virtually unchanged till simulation end.

Figure 37 shows the depth-to-water for the rainfall scenario 2000 to 2009 repeated for December 2020, 2030, 2040 and 2060 for the full-treatment every nine years case (LAI 0.6 FT 9yr). As we would expect from the soil-water storage given in Figure 32 for this case, the groundwater levels rise rapidly during the first two decades after which they level out about midway between the historical 1970 and 1990 groundwater levels.

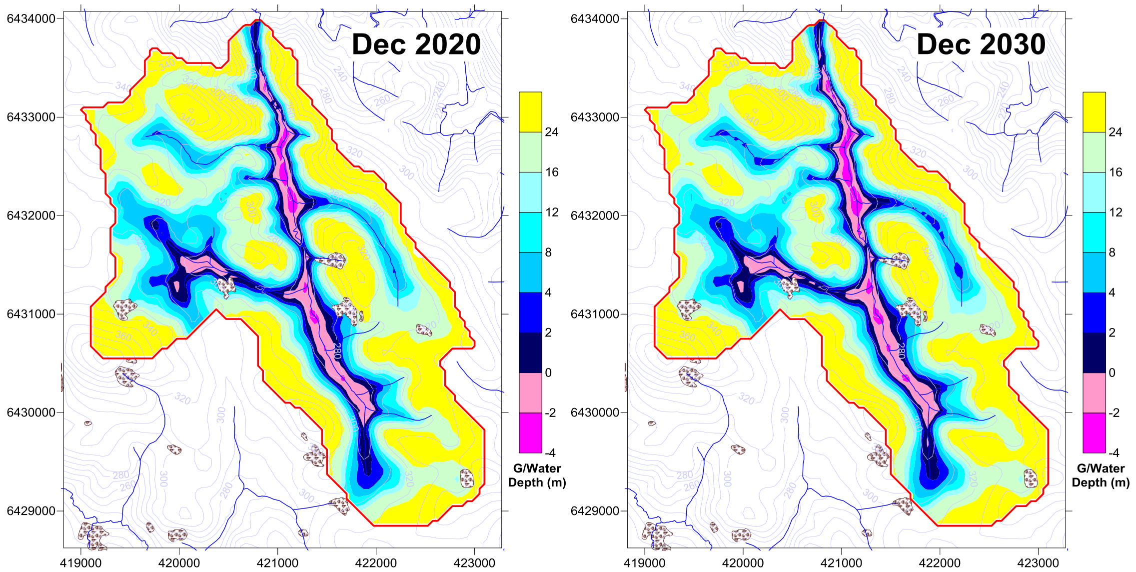

Figure 36 cont'd.

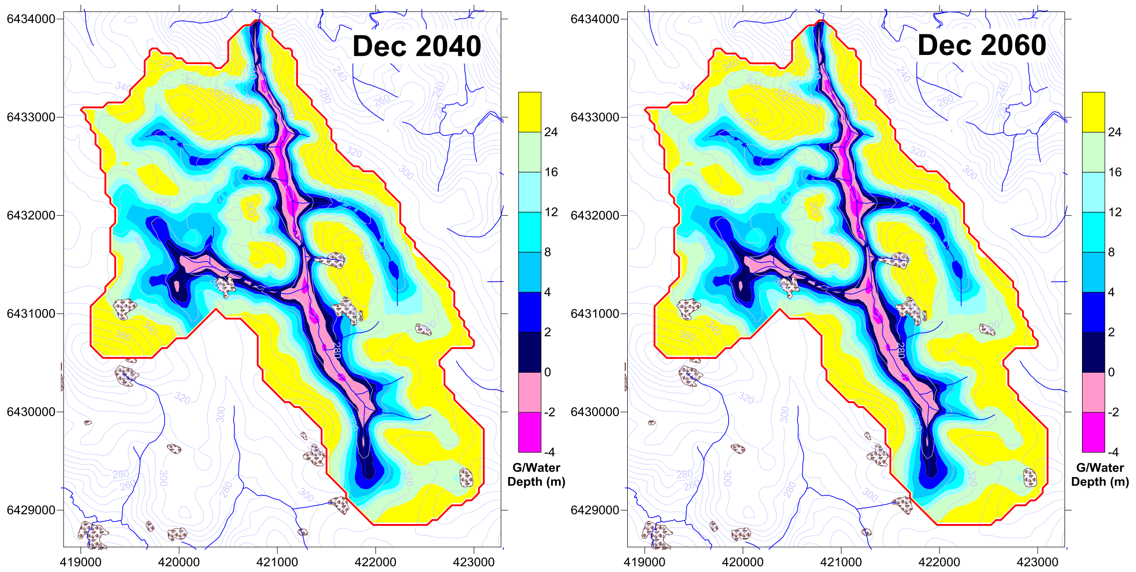

Figure 36: Simulated depth to groundwater for December 2020, 2030, 2040 and 2060 for the LAI 0.6 LS 9yr case for the rainfall scenario 2000 to 2009 repeated.

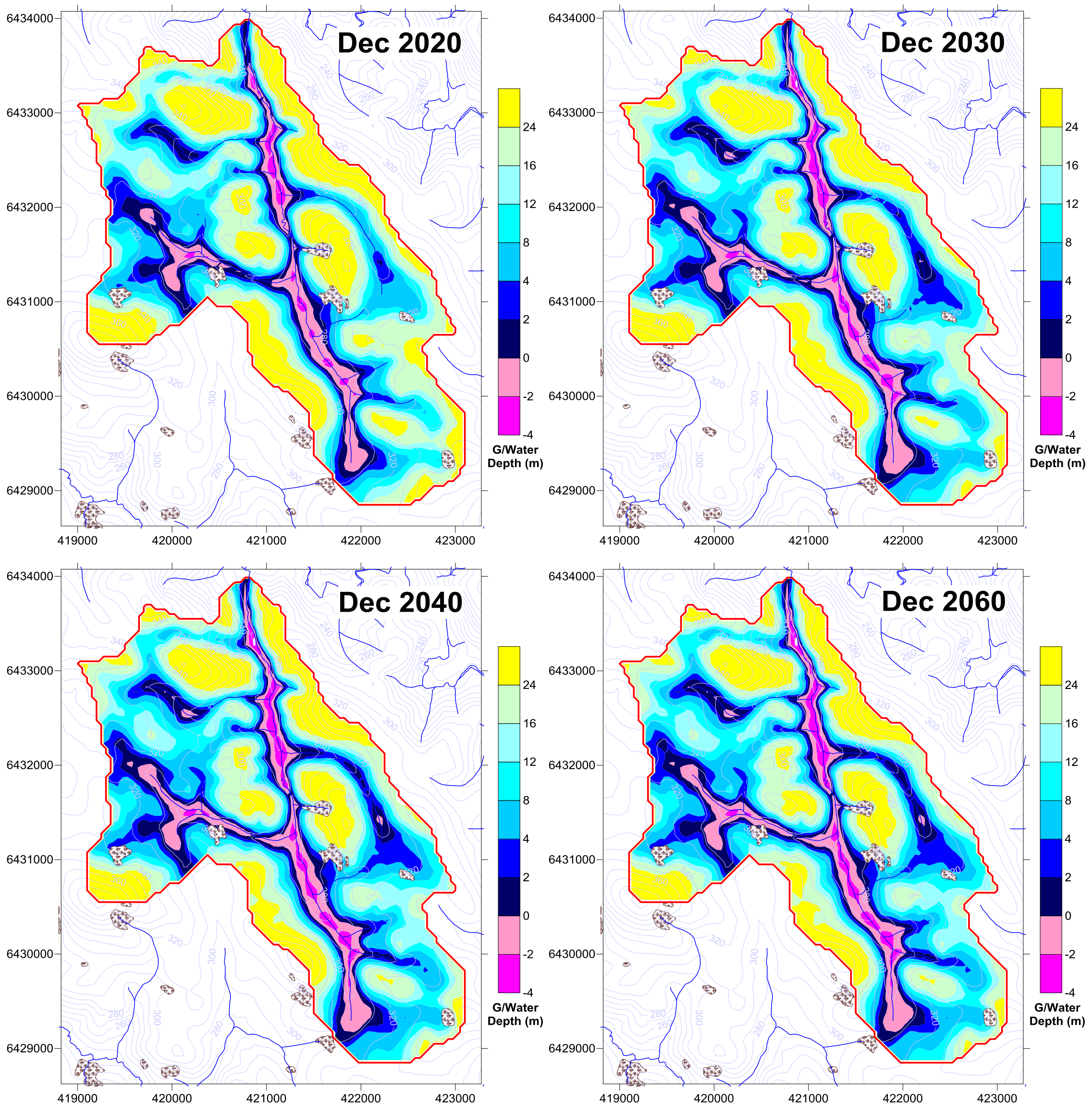

Figure 37: Simulated depth to groundwater for December 2020, 2030, 2040 and 2060 for the LAI 0.6 FT 9yr case for the rainfall scenario 2000 to 2009 repeated.

6. DISCUSSION

The study found that treatments to the forest cover of the 31 Mile Brook catchment did have the potential to reverse the hydrological effects of the present below-average rainfall period, and even with a fairly pessimistic future rainfall scenario it was possible to maintain a hydrological situation which approaches historical levels. However, it was also obvious that for such management practices to be successful, it was necessary for the treatments to be both to the lower end of the LAI scale and for the treatments to be repeated on a regular basis.

Work prior to the study identified that the most likely treatment scenario was to a target LAI of 0.6 with retreatment every nine years and this being to all forest outside of the stream buffer (LAI 0.6 FT 9yr case). The study found that under a low rainfall scenario, based on repeating the 2001 to 2010 rainfall five times to create a simulation series from 2011 to 2060, this particular treatment case resulted in good overall gains in streamflows, flow-days and groundwater levels. Decadal streamflow increases were 35.7 mm/yr in the first decade, 2011 to 2020, 69.8 mm/yr in the second decade, 2021 to 2030, and 81.3, 84.6 and 85.9 mm/yr in subsequent decades. Such flow-increases may sound modest but untreated streamflows are predicted to decline, reaching just 28.1 mm/yr by the decade 2051 to 2060; the streamflow increase due to treatment is therefore 306% for this decade. For flow-days, they were predicted for the untreated case to decline to 154 days/yr by 2051 to 2060, whereas the treatment for the LAI 0.6 FT 9yr case resulted in more than double the flow-days, 312 days/yr by 2051 to 2060. For groundwater levels, the LAI 0.6 FT 9yr case resulted in significant rises and a restoration of the capacity for groundwater discharge for a large percentage of the catchment valley-floor, whereas the untreated scenario had declining groundwater levels that no longer contacted the soil-surface in any part of the catchment.

The above results relate to the behaviour of the untreated and LAI 0.6 FT 9yr cases under a rainfall scenario constructed by repeating the rainfall for the years 2001 to 2010 inclusive. This scenario was considered to be similar in form to that predicted as the most likely future climate scenario for the Darling Plateau. A second, more optimistic scenario was also studied, constructed by repeating the 2000 to 2009 rainfalls, thereby missing the historically low year of 2010. For this rainfall scenario, the untreated streamflow was found to reach stability at 50.4 mm/yr and the LAI 0.6 FT 9yr case averaged 164.7 mm/yr in the last simulation decade; this equates to an increase of 114.3 mm/yr or 227% due to treatment. This is an average increase in flow of 1.3 GL/yr for the 31 Mile Brook catchment of 11.2 km^2.

An alternative treatment that was considered was the treatment of just the lower-slope half of the potentially treatable area, that is treating 44% of the catchment instead of 88%. This halving of the treated area but targeting it to the lower slope reduces the average flow distance from the treated area to the streamzone; logic implies that it will have a greater effect per unit area than the treatment to the full 88% of the catchment. This was indeed the case, though this effect tended to decline as the simulation progressed and by the last decade the streamflow increase was 163% compared to 306% for the full-treatment; this is an area-weighted difference of just 10%.

Key comparative treatments were those where the treatment was undertaken only once. Almost the full gain was by definition available during the first decade; the responses fell considerably by the second decade when they were little more than half those of the re-treated cases. By the fourth decade the response was less than 10 mm/yr even for the case with 88% of the catchment treated.

A final variation studied was the effect of altering the target LAI. An LAI of 0.6 was considered to be the likely treatment to be used in future management, but LAI targets of 0.4, 0.8 and 1.0 were also tried. The results from this range of target LAIs highlighted the need to achieve a reasonably low LAI during treatment, else the response was small. It was also realised that in terms of cost benefit, the lower the target LAI the higher the relative benefit. The pre-treatment LAI is about 1.8, so a reduction to 1.0 means the removal of 0.8 units of LAI; a reduction to 0.6 is the removal of 1.2 units of LAI, only 50% more. As a significant percentage of the cost of a treatment is associated with fixed overheads, the cost difference between these two treatments is likely to be of order 20%, while the flow increase in the last decade compared to untreated is 87% for one and 306% for the other for the 2001 to 2010 rainfall scenario. Therefore, cost effectiveness is always in favour of going to the lowest practical treatment LAI.

As a summary of all simulations, Figure 38 shows the average annual streamflows for the complete simulation period 2011 to 2060 for all 57 cases for the 2001 to 2010 repeated rainfall scenario plotted against the average catchment LAI for the complete simulation period. The untreated scenario is the black dot the bottom right-hand corner. This plot shows the relative advantage of the lower-slope only treatments in that they plot to the right with higher average LAIs for the same streamflow compared to the full treatments, and also the consistency but non-linearity of the relations between streamflow and catchment vegetation cover.

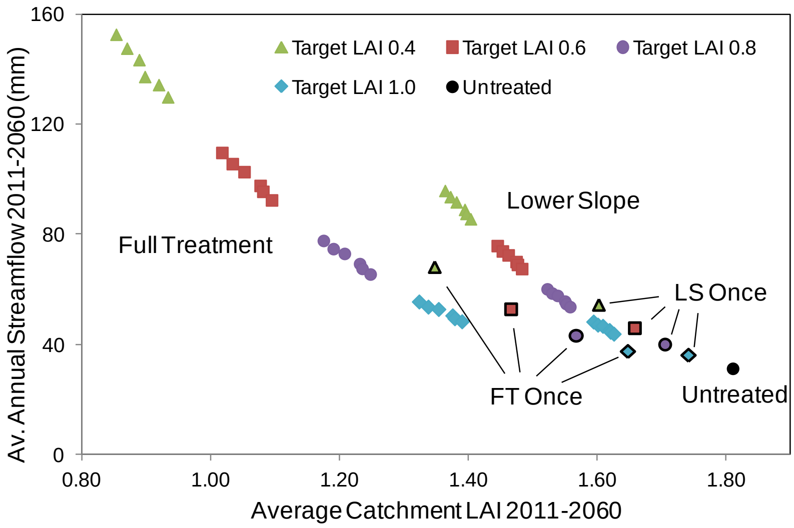

Figure 38: Average catchment LAI for 2011 to 2060 vs. average annual streamflow for 2011 to 2060 for all cases using the 2001 – 2010 rainfall scenario. The once only treatment cases are distinguished by a black border and the untreated case is the solid black dot in the bottom right-hand corner.

7. CONCLUSION

A modelling study was undertaken to assess the potential hydrological benefits from the management of the forest vegetation-cover in the jarrah forest of the south-west of WA. The requirement for the study stems from the present protracted below-average rainfall period and the effects it is having in terms of groundwater and streamflow declines in the jarrah forest. The study used a variety of possible management scenarios in combination with two rainfall scenarios to produce sets of possible catchment hydrological responses. The catchment modelled was 31 Mile Brook near Jarrahdale; it was chosen due to its use already in a number of forest management modelling studies and because it appears to be well suited to having its results up-scaled to the water-supply catchments within the Integrated Water-Supply Scheme. The model used was WEC-C, which is custom designed for studies of vegetation treatment and has been successfully applied to a number of catchment studies on the Darling Plateau, both within the jarrah forest and in the lower-rainfall agricultural areas to the east.

The primary findings of the study were that if a useful hydrological response is to be attained through the treatment of the forest cover, then the treatments need to be to low vegetation densities, be undertaken over most of the catchment, and have regular follow-up treatments. The treatment which seemed to most closely fit these criteria, and still probably be acceptable from aesthetics, timber production, and other non-hydrological viewpoints, was to a Leaf Area Index (LAI) of 0.6 over all except the streamzone buffer and to have follow-up treatments at a nominal nine year rotation. An LAI of 0.6 is approximately a basal area of 9 m^2/ha. An average streamflow-increase of 36 mm/yr was predicted for this treatment in the first decade following treatment, for an assumed rainfall scenario of the rainfall for 2001 to 2010 repeated; the increase in the second decade was 70 mm/yr. This rainfall scenario is considered to be close to what is most likely to be predicted to occur during the near future. There were also predicted hydrological benefits in terms of flow-days, increases of 66 and 131 days/yr for the first two decades, and predicted benefits in terms of soil-water storages and groundwater levels. While this option appears to be the preferred one, the study tabulated the results for 55 other combinations of target treatment LAIs and retreatment frequencies. These were combined with two rainfall scenarios, the 2001 to 2010 low-rainfall scenario and the 2000 to 2009 medium-rainfall scenario, to create 114 simulation cases in total. Overall, the study seems to have created a logical and realistic set of results that allow treatment options to be considered on their hydrological merits and to be divided into those which should be considered further and those which are unlikely to be of value.

8. REFERENCES

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APPENDICES

A.1 Treatment Cases Modelled and Their Nomenclature

The following is a listing of the cases that were modelled and the nomenclature used to describe them. The basic division is by:

1. The forest-treatment target LAI. The forest-treatment target LAIs simulated in the study were: 0.4, 0.6, 0.8 and 1.0. Using the relationship between tree basal-area and LAI of 15 to 1, these correspond to basal areas of 6.0, 9.0, 12.0 and 15.0 m^2/ha. An untreated scenario was also included. Nomenclature was LAI 0.4, LAI 0.6, etc., plus Untreated for the untreated case.
2. Area of treatment. Two options were studied: one where all the catchment except a stream buffer was treated, and another where only the lower-slope half of this area was treated. The stream-buffer was 12% of the catchment area, thereby leaving 88% of the catchment being treated in the full-treatment area scenario and 44% where the lower-slope-only was treated. Nomenclature was FT for full-treatment area and LS for lower-slope-only treatment.
3. The period between treatments. Treatment periods were: seven, eight, nine, 10, 11 and 12 years. There was also a once-only treatment case. Nomenclature was Once for the once-only treatments, and 7yr, 8yr, etc. for the periods between treatments of seven years, eight years, etc.

A.2 LAIs for the Various Cases

For the what-if future simulations, an LAI map has been produced for January of every year. The untreated LAI maps are based on the 2010 LAI map with growth applied for 10 years to the small area of eucalyptus planted in 2009. The LAI is held constant after this growth period at the 2020 level.

The lower-slope (LS) and full-treatment (FT) treatment areas are shown in Figure A1 below. The major stream zones are within the stream-buffer and excluded from the treatment areas. The defined areas are potential treatment areas, only areas with an LAI of greater than the target LAI (0.4, 0.6, 0.8 or 1.0) are treated, areas with low LAIs that are within the treatment outline are kept at the value of the corresponding untreated LAI map.

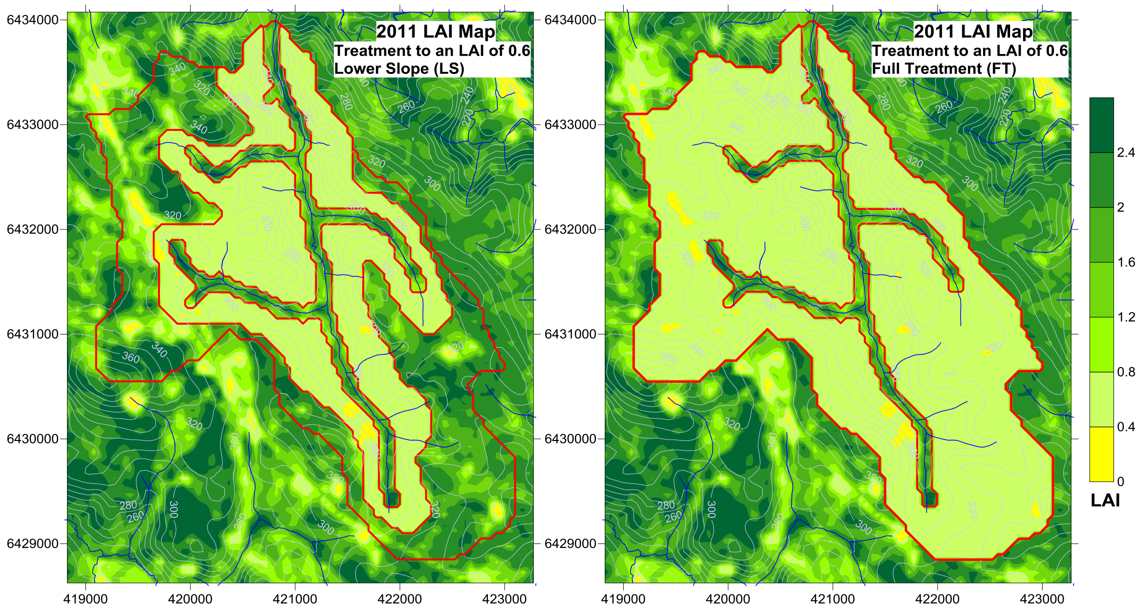

Figure A1: The 2011 LAI maps for LS and FT treatment to an LAI of 0.6.

The growth pattern of the LAIs post-treatment is the same for all target LAIs. The growth after treatment is 0.179 LAI units each year for the first two years, 0.0775 LAI units in the third year, and 0.0275 LAI units each additional year (Jack Bradshaw, pers. comm.). Table A1 shows the growth cycle of the treatment area for the LAI 0.6 LS/FT 9yr cases. The LAIs shown are maximums, the LAIs grow only until they reach the corresponding LAI for the untreated case, after which they remain constant until the next treatment.

Table A1: The growth cycle for the LAI 0.6 LS/FT 9yr cases. Growth is in LAI units per year.

Year of Cycle	Years	Growth	Max. LAI in Treatment Area
1	2011, 2020, 2029, 2038, 2047	-	0.60
2	2012, 2021, 2030, 2039, 2048	0.179	0.78
3	2013, 2022, 2031, 2040, 2049	0.179	0.96
4	2014, 2023, 2032, 2041, 2050	0.0775	1.04
5	2015, 2024, 2033, 2042	0.0275	1.06
6	2016, 2025, 2034, 2043	0.0275	1.09
7	2017, 2026, 2035, 2044	0.0275	1.12
8	2018, 2027, 2036, 2045	0.0275	1.15
9	2019, 2028, 2037, 2046	0.0275	1.17

The annual average LAIs for the whole catchment for each of the primary cases are shown in Figure A2. Annual catchment average LAI data for all simulations are given in Tables A2 to A5.

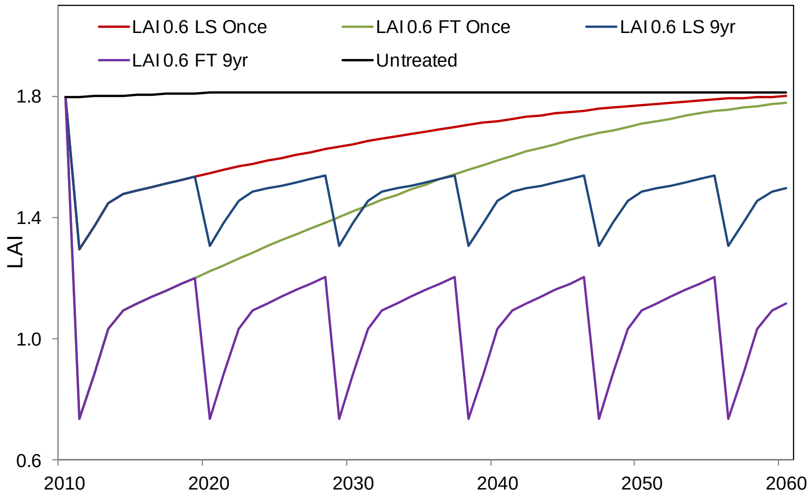

Figure A2: Annual catchment average LAIs for the primary simulation set.

The average LAI for the modelled period vs. the average annual-streamflow for the period for 2001 – 2010 rainfall cases are shown in Figure A3. The relationship between streamflow and LAI is clearly nonlinear, as discussed in Section 4.3. Power regressions for the retreatment cases plus the untreated case are as follows; note that these equations only have validity for 31 Mile Brook and the what-if cases in Figure A3 and should not be considered as general relationships between streamflow and LAI.

- For the lower-slope only treatment cases. Streamflow (mm/yr) = $286*LAI^2 - 1052*LAI + 1000$
- For the full-treatment cases. Streamflow (mm/yr) = $162*LAI^2 - 557*LAI + 509$

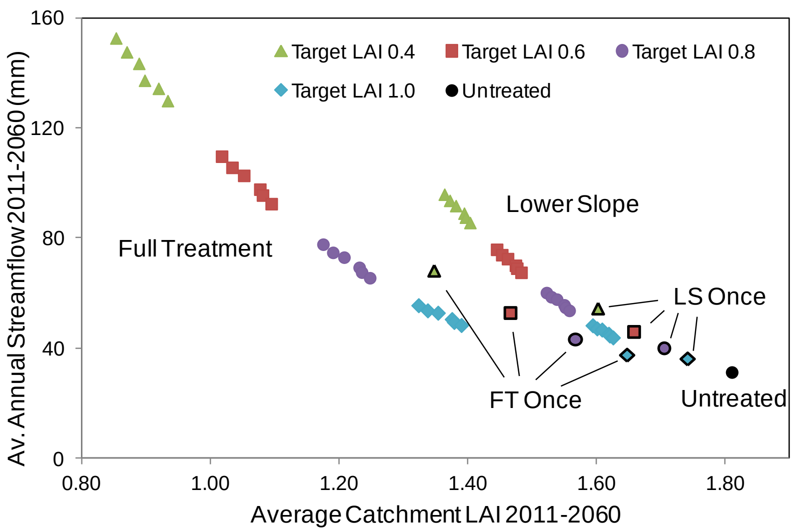

Figure A3: Average catchment LAI for 2011 to 2060 vs. average annual-streamflow for 2011 to 2060 for all cases using the 2001 – 2010 rainfall scenario. The once only treatment cases are distinguished by a black border and the untreated case is the solid black dot in the bottom right-hand corner.

Table A2: Annual catchment-average LAIs for simulations with a target LAI of 0.4.

LAI	Untreated	LAI 0.4 LS Once	LAI 0.4 LS 7yr	LAI 0.4 LS 8yr	LAI 0.4 LS 9yr	LAI 0.4 LS 10yr	LAI 0.4 LS 11yr	LAI 0.4 LS 12yr	LAI 0.4 FT Once	LAI 0.4 FT 7yr	LAI 0.4 FT 8yr	LAI 0.4 FT 9yr	LAI 0.4 FT 10yr	LAI 0.4 FT 11yr	LAI 0.4 FT 12yr
Average 2011-2060	1.81	1.60	1.36	1.37	1.38	1.39	1.40	1.40	1.35	0.85	0.87	0.89	0.90	0.92	0.93
2010	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80
2011	1.80	1.21	1.21	1.21	1.21	1.21	1.21	1.21	0.56	0.56	0.56	0.56	0.56	0.56	0.56
2012	1.80	1.29	1.29	1.29	1.29	1.29	1.29	1.29	0.72	0.72	0.72	0.72	0.72	0.72	0.72
2013	1.80	1.36	1.36	1.36	1.36	1.36	1.36	1.36	0.87	0.87	0.87	0.87	0.87	0.87	0.87
2014	1.80	1.40	1.40	1.40	1.40	1.40	1.40	1.40	0.93	0.93	0.93	0.93	0.93	0.93	0.93
2015	1.80	1.41	1.41	1.41	1.41	1.41	1.41	1.41	0.95	0.95	0.95	0.95	0.95	0.95	0.95
2016	1.81	1.42	1.42	1.42	1.42	1.42	1.42	1.42	0.98	0.98	0.98	0.98	0.98	0.98	0.98
2017	1.81	1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2018	1.81	1.45	1.22	1.45	1.45	1.45	1.45	1.45	1.02	0.56	1.02	1.02	1.02	1.02	1.02
2019	1.81	1.46	1.30	1.22	1.46	1.46	1.46	1.46	1.04	0.72	0.56	1.04	1.04	1.04	1.04
2020	1.81	1.47	1.37	1.30	1.22	1.47	1.47	1.47	1.07	0.87	0.72	0.56	0.56	1.07	1.07
2021	1.81	1.48	1.40	1.37	1.30	1.22	1.48	1.48	1.09	0.93	0.87	0.72	0.72	1.09	1.09
2022	1.81	1.49	1.42	1.40	1.37	1.30	1.22	1.49	1.11	0.95	0.93	0.87	0.87	0.56	1.11
2023	1.81	1.50	1.43	1.42	1.40	1.37	1.30	1.22	1.13	0.98	0.95	0.93	0.93	0.72	0.56
2024	1.81	1.51	1.44	1.43	1.42	1.40	1.37	1.30	1.15	1.00	0.98	0.95	0.95	0.87	0.72
2025	1.81	1.52	1.22	1.44	1.43	1.42	1.40	1.37	1.17	0.56	1.00	0.98	0.98	0.93	0.87
2026	1.81	1.53	1.30	1.45	1.44	1.43	1.42	1.40	1.20	0.72	1.02	1.00	1.00	0.95	0.93
2027	1.81	1.54	1.37	1.22	1.45	1.44	1.43	1.42	1.22	0.87	0.56	1.02	1.02	0.98	0.95
2028	1.81	1.55	1.40	1.30	1.46	1.45	1.44	1.43	1.24	0.93	0.72	1.04	1.04	1.00	0.98
2029	1.81	1.56	1.42	1.37	1.22	1.46	1.45	1.44	1.26	0.95	0.87	0.56	1.07	1.02	1.00

2030	1.81	1.57	1.43	1.40	1.30	1.47	1.46	1.45	1.28	0.98	0.93	0.72	0.56	1.04	1.02
2031	1.81	1.58	1.44	1.42	1.37	1.22	1.47	1.46	1.30	1.00	0.95	0.87	0.72	1.07	1.04
2032	1.81	1.59	1.22	1.43	1.40	1.30	1.48	1.47	1.32	0.56	0.98	0.93	0.87	1.09	1.07
2033	1.81	1.60	1.30	1.44	1.42	1.37	1.22	1.48	1.34	0.72	1.00	0.95	0.93	0.56	1.09
2034	1.81	1.61	1.37	1.45	1.43	1.40	1.30	1.49	1.36	0.87	1.02	0.98	0.95	0.72	1.11
2035	1.81	1.62	1.40	1.22	1.44	1.42	1.37	1.22	1.38	0.93	0.56	1.00	0.98	0.87	0.56
2036	1.81	1.63	1.42	1.30	1.45	1.43	1.40	1.30	1.40	0.95	0.72	1.02	1.00	0.93	0.72
2037	1.81	1.64	1.43	1.37	1.46	1.44	1.42	1.37	1.42	0.98	0.87	1.04	1.02	0.95	0.87
2038	1.81	1.65	1.44	1.40	1.22	1.45	1.43	1.40	1.43	1.00	0.93	0.56	1.04	0.98	0.93
2039	1.81	1.66	1.22	1.42	1.30	1.46	1.44	1.42	1.45	0.56	0.95	0.72	1.07	1.00	0.95
2040	1.81	1.67	1.30	1.43	1.37	1.47	1.45	1.43	1.47	0.72	0.98	0.87	0.56	1.02	0.98
2041	1.81	1.67	1.37	1.44	1.40	1.22	1.46	1.44	1.49	0.87	1.00	0.93	0.72	1.04	1.00
2042	1.81	1.68	1.40	1.45	1.42	1.30	1.47	1.45	1.51	0.93	1.02	0.95	0.87	1.07	1.02
2043	1.81	1.69	1.42	1.22	1.43	1.37	1.48	1.46	1.52	0.95	0.56	0.98	0.93	1.09	1.04
2044	1.81	1.70	1.43	1.30	1.44	1.40	1.22	1.47	1.54	0.98	0.72	1.00	0.95	0.56	1.07
2045	1.81	1.70	1.44	1.37	1.45	1.42	1.30	1.48	1.55	1.00	0.87	1.02	0.98	0.72	1.09
2046	1.81	1.71	1.22	1.40	1.46	1.43	1.37	1.49	1.57	0.56	0.93	1.04	1.00	0.87	1.11
2047	1.81	1.72	1.30	1.42	1.22	1.44	1.40	1.22	1.58	0.72	0.95	0.56	1.02	0.93	0.56
2048	1.81	1.72	1.37	1.43	1.30	1.45	1.42	1.30	1.60	0.87	0.98	0.72	1.04	0.95	0.72
2049	1.81	1.73	1.40	1.44	1.37	1.46	1.43	1.37	1.61	0.93	1.00	0.87	1.07	0.98	0.87
2050	1.81	1.74	1.42	1.45	1.40	1.47	1.44	1.40	1.63	0.95	1.02	0.93	0.56	1.00	0.93
2051	1.81	1.74	1.43	1.22	1.42	1.22	1.45	1.42	1.64	0.98	0.56	0.95	0.72	1.02	0.95
2052	1.81	1.75	1.44	1.30	1.43	1.30	1.46	1.43	1.65	1.00	0.72	0.98	0.87	1.04	0.98
2053	1.81	1.75	1.22	1.37	1.44	1.37	1.47	1.44	1.66	0.56	0.87	1.00	0.93	1.07	1.00
2054	1.81	1.76	1.30	1.40	1.45	1.40	1.48	1.45	1.68	0.72	0.93	1.02	0.95	1.09	1.02

2055	1.81	1.76	1.37	1.42	1.46	1.42	1.22	1.46	1.69	0.87	0.95	1.04	0.98	0.56	1.04
2056	1.81	1.77	1.40	1.43	1.22	1.43	1.30	1.47	1.70	0.93	0.98	0.56	1.00	0.72	1.07
2057	1.81	1.77	1.42	1.44	1.30	1.44	1.37	1.48	1.71	0.95	1.00	0.72	1.02	0.87	1.09
2058	1.81	1.77	1.43	1.45	1.37	1.45	1.40	1.49	1.72	0.98	1.02	0.87	1.04	0.93	1.11
2059	1.81	1.78	1.44	1.22	1.40	1.46	1.42	1.22	1.72	1.00	0.56	0.93	1.07	0.95	0.56
2060	1.81	1.78	1.22	1.30	1.42	1.47	1.43	1.30	1.73	0.56	0.72	0.95	0.21	0.98	0.72

Table A3: Annual catchment-average LAIs for simulations with a target LAI of 0.6.

LAI	**Untreated**	**LAI 0.6 LS Once**	**LAI 0.6 LS 7yr**	**LAI 0.6 LS 8yr**	**LAI 0.6 LS 9yr**	**LAI 0.6 LS 10yr**	**LAI 0.6 LS 11yr**	**LAI 0.6 LS 12yr**	**LAI 0.6 FT Once**	**LAI 0.6 FT 7yr**	**LAI 0.6 FT 8yr**	**LAI 0.6 FT 9yr**	**LAI 0.6 FT 10yr**	**LAI 0.6 FT 11yr**	**LAI 0.6 FT 12yr**
Average 2011-2060	1.81	1.66	1.44	1.45	1.46	1.47	1.48	1.48	1.47	1.02	1.03	1.05	1.08	1.08	1.09
2010	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80
2011	1.80	1.29	1.29	1.29	1.29	1.29	1.29	1.29	0.73	0.73	0.73	0.73	0.73	0.73	0.73
2012	1.80	1.37	1.37	1.37	1.37	1.37	1.37	1.37	0.88	0.88	0.88	0.88	0.88	0.88	0.88
2013	1.80	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.03	1.03	1.03	1.03	1.03	1.03	1.03
2014	1.80	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.09	1.09	1.09	1.09	1.09	1.09	1.09
2015	1.80	1.49	1.49	1.49	1.49	1.49	1.49	1.49	1.12	1.12	1.12	1.12	1.12	1.12	1.12
2016	1.81	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.14	1.14	1.14	1.14	1.14	1.14	1.14
2017	1.81	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.16	1.16	1.16	1.16	1.16	1.16	1.16
2018	1.81	1.52	1.30	1.52	1.52	1.52	1.52	1.52	1.18	0.73	1.18	1.18	1.18	1.18	1.18
2019	1.81	1.54	1.38	1.30	1.54	1.54	1.54	1.54	1.20	0.88	0.73	1.20	1.20	1.20	1.20
2020	1.81	1.55	1.45	1.38	1.31	1.55	1.55	1.55	1.22	1.03	0.88	0.73	1.22	1.22	1.22
2021	1.81	1.56	1.48	1.45	1.38	1.31	1.56	1.56	1.24	1.09	1.03	0.88	0.73	1.24	1.24

2022	1.81	1.57	1.49	1.48	1.45	1.38	1.31	1.57	1.26	1.12	1.09	1.03	0.88	0.73	1.26
2023	1.81	1.58	1.51	1.49	1.48	1.45	1.38	1.31	1.28	1.14	1.12	1.09	1.03	0.88	0.73
2024	1.81	1.59	1.52	1.51	1.49	1.48	1.45	1.38	1.30	1.16	1.14	1.12	1.09	1.03	0.88
2025	1.81	1.60	1.31	1.52	1.51	1.49	1.48	1.45	1.32	0.73	1.16	1.14	1.12	1.09	1.03
2026	1.81	1.61	1.38	1.53	1.52	1.51	1.49	1.48	1.34	0.88	1.18	1.16	1.14	1.12	1.09
2027	1.81	1.62	1.45	1.31	1.53	1.52	1.51	1.49	1.36	1.03	0.73	1.18	1.16	1.14	1.12
2028	1.81	1.62	1.48	1.38	1.54	1.53	1.52	1.51	1.38	1.09	0.88	1.20	1.18	1.16	1.14
2029	1.81	1.63	1.49	1.45	1.31	1.54	1.53	1.52	1.40	1.12	1.03	0.73	1.20	1.18	1.16
2030	1.81	1.64	1.51	1.48	1.38	1.55	1.54	1.53	1.42	1.14	1.09	0.88	1.22	1.20	1.18
2031	1.81	1.65	1.52	1.49	1.45	1.31	1.55	1.54	1.44	1.16	1.12	1.03	0.73	1.22	1.20
2032	1.81	1.66	1.31	1.51	1.48	1.38	1.56	1.55	1.46	0.73	1.14	1.09	0.88	1.24	1.22
2033	1.81	1.67	1.38	1.52	1.49	1.45	1.31	1.56	1.47	0.88	1.16	1.12	1.03	0.73	1.24
2034	1.81	1.68	1.45	1.53	1.51	1.48	1.38	1.57	1.49	1.03	1.18	1.14	1.09	0.88	1.26
2035	1.81	1.68	1.48	1.31	1.52	1.49	1.45	1.31	1.51	1.09	0.73	1.16	1.12	1.03	0.73
2036	1.81	1.69	1.49	1.38	1.53	1.51	1.48	1.38	1.53	1.12	0.88	1.18	1.14	1.09	0.88
2037	1.81	1.70	1.51	1.45	1.54	1.52	1.49	1.45	1.54	1.14	1.03	1.20	1.16	1.12	1.03
2038	1.81	1.71	1.52	1.48	1.31	1.53	1.51	1.48	1.56	1.16	1.09	0.73	1.18	1.14	1.09
2039	1.81	1.71	1.31	1.49	1.38	1.54	1.52	1.49	1.57	0.73	1.12	0.88	1.20	1.16	1.12
2040	1.81	1.72	1.38	1.51	1.45	1.55	1.53	1.51	1.59	0.88	1.14	1.03	1.22	1.18	1.14
2041	1.81	1.73	1.45	1.52	1.48	1.31	1.54	1.52	1.60	1.03	1.16	1.09	0.73	1.20	1.16
2042	1.81	1.73	1.48	1.53	1.49	1.38	1.55	1.53	1.62	1.09	1.18	1.12	0.88	1.22	1.18
2043	1.81	1.74	1.49	1.31	1.51	1.45	1.56	1.54	1.63	1.12	0.73	1.14	1.03	1.24	1.20
2044	1.81	1.74	1.51	1.38	1.52	1.48	1.31	1.55	1.64	1.14	0.88	1.16	1.09	0.73	1.22
2045	1.81	1.75	1.52	1.45	1.53	1.49	1.38	1.56	1.65	1.16	1.03	1.18	1.12	0.88	1.24
2046	1.81	1.75	1.31	1.48	1.54	1.51	1.45	1.57	1.67	0.73	1.09	1.20	1.14	1.03	1.26

2047	1.81	1.76	1.38	1.49	1.31	1.52	1.48	1.31	1.68	0.88	1.12	0.73	1.16	1.09	0.73
2048	1.81	1.76	1.45	1.51	1.38	1.53	1.49	1.38	1.69	1.03	1.14	0.88	1.18	1.12	0.88
2049	1.81	1.77	1.48	1.52	1.45	1.54	1.51	1.45	1.70	1.09	1.16	1.03	1.20	1.14	1.03
2050	1.81	1.77	1.49	1.53	1.48	1.55	1.52	1.48	1.71	1.12	1.18	1.09	1.22	1.16	1.09
2051	1.81	1.78	1.51	1.31	1.49	1.31	1.53	1.49	1.72	1.14	0.73	1.12	0.73	1.18	1.12
2052	1.81	1.78	1.52	1.38	1.51	1.38	1.54	1.51	1.73	1.16	0.88	1.14	0.88	1.20	1.14
2053	1.81	1.78	1.31	1.45	1.52	1.45	1.55	1.52	1.73	0.73	1.03	1.16	1.03	1.22	1.16
2054	1.81	1.79	1.38	1.48	1.53	1.48	1.56	1.53	1.74	0.88	1.09	1.18	1.09	1.24	1.18
2055	1.81	1.79	1.45	1.49	1.54	1.49	1.31	1.54	1.75	1.03	1.12	1.20	1.12	0.73	1.20
2056	1.81	1.79	1.48	1.51	1.31	1.51	1.38	1.55	1.76	1.09	1.14	0.73	1.14	0.88	1.22
2057	1.81	1.79	1.49	1.52	1.38	1.52	1.45	1.56	1.76	1.12	1.16	0.88	1.16	1.03	1.24
2058	1.81	1.80	1.51	1.53	1.45	1.53	1.48	1.57	1.77	1.14	1.18	1.03	1.18	1.09	1.26
2059	1.81	1.80	1.52	1.31	1.48	1.54	1.49	1.31	1.77	1.16	0.73	1.09	1.20	1.12	0.73
2060	1.81	1.80	1.31	1.38	1.49	1.55	1.51	1.38	1.78	0.73	0.88	1.12	1.22	1.14	0.88

Table A4: Annual catchment-average LAIs for simulations with a target LAI of 0.8.

LAI	Untreated	LAI 0.8 LS Once	LAI 0.8 LS 7yr	LAI 0.8 LS 8yr	LAI 0.8 LS 9yr	LAI 0.8 LS 10yr	LAI 0.8 LS 11yr	LAI 0.8 LS 12yr	LAI 0.8 FT Once	LAI 0.8 FT 7yr	LAI 0.8 FT 8yr	LAI 0.8 FT 9yr	LAI 0.8 FT 10yr	LAI 0.8 FT 11yr	LAI 0.8 FT 12yr
Average 2011-2060	1.81	1.71	1.52	1.53	1.54	1.55	1.55	1.56	1.57	1.17	1.19	1.21	1.23	1.23	1.25
2010	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80
2011	1.80	1.38	1.38	1.38	1.38	1.38	1.38	1.38	0.90	0.90	0.90	0.90	0.90	0.90	0.90
2012	1.80	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.05	1.05	1.05	1.05	1.05	1.05	1.05
2013	1.80	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.19	1.19	1.19	1.19	1.19	1.19	1.19

2014	1.80	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.25	1.25	1.25	1.25	1.25	1.25	1.25
2015	1.80	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.27	1.27	1.27	1.27	1.27	1.27	1.27
2016	1.81	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.29	1.29	1.29	1.29	1.29	1.29	1.29
2017	1.81	1.59	1.59	1.59	1.59	1.59	1.59	1.59	1.31	1.31	1.31	1.31	1.31	1.31	1.31
2018	1.81	1.60	1.39	1.60	1.60	1.60	1.60	1.60	1.33	0.90	1.33	1.33	1.33	1.33	1.33
2019	1.81	1.61	1.46	1.39	1.61	1.61	1.61	1.61	1.35	1.05	0.90	1.35	1.35	1.35	1.35
2020	1.81	1.62	1.53	1.46	1.39	1.62	1.62	1.62	1.37	1.19	1.05	0.90	1.37	1.37	1.37
2021	1.81	1.63	1.56	1.53	1.46	1.39	1.63	1.63	1.39	1.25	1.19	1.05	0.90	1.39	1.39
2022	1.81	1.64	1.57	1.56	1.53	1.46	1.39	1.64	1.41	1.27	1.25	1.19	1.05	0.90	1.41
2023	1.81	1.64	1.58	1.57	1.56	1.53	1.46	1.39	1.42	1.29	1.27	1.25	1.19	1.05	0.90
2024	1.81	1.65	1.59	1.58	1.57	1.56	1.53	1.46	1.44	1.31	1.29	1.27	1.25	1.19	1.05
2025	1.81	1.66	1.39	1.59	1.58	1.57	1.56	1.53	1.46	0.90	1.31	1.29	1.27	1.25	1.19
2026	1.81	1.67	1.46	1.60	1.59	1.58	1.57	1.56	1.48	1.05	1.33	1.31	1.29	1.27	1.25
2027	1.81	1.68	1.53	1.39	1.60	1.59	1.58	1.57	1.50	1.19	0.90	1.33	1.31	1.29	1.27
2028	1.81	1.69	1.56	1.46	1.61	1.60	1.59	1.58	1.51	1.25	1.05	1.35	1.33	1.31	1.29
2029	1.81	1.69	1.57	1.53	1.39	1.61	1.60	1.59	1.53	1.27	1.19	0.90	1.35	1.33	1.31
2030	1.81	1.70	1.58	1.56	1.46	1.62	1.61	1.60	1.55	1.29	1.25	1.05	1.37	1.35	1.33
2031	1.81	1.71	1.59	1.57	1.53	1.39	1.62	1.61	1.56	1.31	1.27	1.19	0.90	1.37	1.35
2032	1.81	1.71	1.39	1.58	1.56	1.46	1.63	1.62	1.58	0.90	1.29	1.25	1.05	1.39	1.37
2033	1.81	1.72	1.46	1.59	1.57	1.53	1.39	1.63	1.59	1.05	1.31	1.27	1.19	0.90	1.39
2034	1.81	1.73	1.53	1.60	1.58	1.56	1.46	1.64	1.61	1.19	1.33	1.29	1.25	1.05	1.41
2035	1.81	1.73	1.56	1.39	1.59	1.57	1.53	1.39	1.62	1.25	0.90	1.31	1.27	1.19	0.90
2036	1.81	1.74	1.57	1.46	1.60	1.58	1.56	1.46	1.63	1.27	1.05	1.33	1.29	1.25	1.05
2037	1.81	1.74	1.58	1.53	1.61	1.59	1.57	1.53	1.64	1.29	1.19	1.35	1.31	1.27	1.19
2038	1.81	1.75	1.59	1.56	1.39	1.60	1.58	1.56	1.66	1.31	1.25	0.90	1.33	1.29	1.25

2039	1.81	1.75	1.39	1.57	1.46	1.61	1.59	1.57	1.67	0.90	1.27	1.05	1.35	1.31	1.27
2040	1.81	1.76	1.46	1.58	1.53	1.62	1.60	1.58	1.68	1.05	1.29	1.19	1.37	1.33	1.29
2041	1.81	1.76	1.53	1.59	1.56	1.39	1.61	1.59	1.69	1.19	1.31	1.25	0.90	1.35	1.31
2042	1.81	1.77	1.56	1.60	1.57	1.46	1.62	1.60	1.70	1.25	1.33	1.27	1.05	1.37	1.33
2043	1.81	1.77	1.57	1.39	1.58	1.53	1.63	1.61	1.71	1.27	0.90	1.29	1.19	1.39	1.35
2044	1.81	1.78	1.58	1.46	1.59	1.56	1.39	1.62	1.72	1.29	1.05	1.31	1.25	0.90	1.37
2045	1.81	1.78	1.59	1.53	1.60	1.57	1.46	1.63	1.73	1.31	1.19	1.33	1.27	1.05	1.39
2046	1.81	1.78	1.39	1.56	1.61	1.58	1.53	1.64	1.74	0.90	1.25	1.35	1.29	1.19	1.41
2047	1.81	1.79	1.46	1.57	1.39	1.59	1.56	1.39	1.74	1.05	1.27	0.90	1.31	1.25	0.90
2048	1.81	1.79	1.53	1.58	1.46	1.60	1.57	1.46	1.75	1.19	1.29	1.05	1.33	1.27	1.05
2049	1.81	1.79	1.56	1.59	1.53	1.61	1.58	1.53	1.76	1.25	1.31	1.19	1.35	1.29	1.19
2050	1.81	1.80	1.57	1.60	1.56	1.62	1.59	1.56	1.76	1.27	1.33	1.25	1.37	1.31	1.25
2051	1.81	1.80	1.58	1.39	1.57	1.39	1.60	1.57	1.77	1.29	0.90	1.27	0.90	1.33	1.27
2052	1.81	1.80	1.59	1.46	1.58	1.46	1.61	1.58	1.77	1.31	1.05	1.29	1.05	1.35	1.29
2053	1.81	1.80	1.39	1.53	1.59	1.53	1.62	1.59	1.78	0.90	1.19	1.31	1.19	1.37	1.31
2054	1.81	1.80	1.46	1.56	1.60	1.56	1.63	1.60	1.78	1.05	1.25	1.33	1.25	1.39	1.33
2055	1.81	1.80	1.53	1.57	1.61	1.57	1.39	1.61	1.79	1.19	1.27	1.35	1.27	0.90	1.35
2056	1.81	1.81	1.56	1.58	1.39	1.58	1.46	1.62	1.79	1.25	1.29	0.90	1.29	1.05	1.37
2057	1.81	1.81	1.57	1.59	1.46	1.59	1.53	1.63	1.79	1.27	1.31	1.05	1.31	1.19	1.39
2058	1.81	1.81	1.58	1.60	1.53	1.60	1.56	1.64	1.80	1.29	1.33	1.19	1.33	1.25	1.41
2059	1.81	1.81	1.59	1.39	1.56	1.61	1.57	1.39	1.80	1.31	0.90	1.25	1.35	1.27	0.90
2060	1.81	1.81	1.39	1.46	1.57	1.62	1.58	1.46	1.80	0.90	1.05	1.27	1.37	1.29	1.05

Table A5: Annual catchment-average LAIs for simulations with a target LAI of 1.0.

LAI	Untreated	LAI 1.0 LS Once	LAI 1.0 LS 7yr	LAI 1.0 LS 8yr	LAI 1.0 LS 9yr	LAI 1.0 LS 10yr	LAI 1.0 LS 11yr	LAI 1.0 LS 12yr	LAI 1.0 FT Once	LAI 1.0 FT 7yr	LAI 1.0 FT 8yr	LAI 1.0 FT 9yr	LAI 1.0 FT 10yr	LAI 1.0 FT 11yr	LAI 1.0 FT 12yr
Average 2011-2060	1.81	1.74	1.59	1.60	1.61	1.62	1.62	1.63	1.65	1.32	1.34	1.35	1.37	1.38	1.39
2010	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80
2011	1.80	1.46	1.46	1.46	1.46	1.46	1.46	1.46	1.06	1.06	1.06	1.06	1.06	1.06	1.06
2012	1.80	1.53	1.53	1.53	1.53	1.53	1.53	1.53	1.20	1.20	1.20	1.20	1.20	1.20	1.20
2013	1.80	1.59	1.59	1.59	1.59	1.59	1.59	1.59	1.34	1.34	1.34	1.34	1.34	1.34	1.34
2014	1.80	1.62	1.62	1.62	1.62	1.62	1.62	1.62	1.39	1.39	1.39	1.39	1.39	1.39	1.39
2015	1.80	1.63	1.63	1.63	1.63	1.63	1.63	1.63	1.41	1.41	1.41	1.41	1.41	1.41	1.41
2016	1.81	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.43	1.43	1.43	1.43	1.43	1.43	1.43
2017	1.81	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.45	1.45	1.45	1.45	1.45	1.45	1.45
2018	1.81	1.66	1.47	1.66	1.66	1.66	1.66	1.66	1.46	1.07	1.46	1.46	1.46	1.46	1.46
2019	1.81	1.67	1.54	1.47	1.67	1.67	1.67	1.67	1.48	1.21	1.07	1.48	1.48	1.48	1.48
2020	1.81	1.68	1.60	1.54	1.47	1.68	1.68	1.68	1.50	1.34	1.21	1.07	1.50	1.50	1.50
2021	1.81	1.69	1.63	1.60	1.54	1.47	1.69	1.69	1.52	1.40	1.34	1.21	1.07	1.52	1.52
2022	1.81	1.69	1.64	1.63	1.60	1.54	1.47	1.69	1.53	1.41	1.39	1.34	1.21	1.07	1.53
2023	1.81	1.70	1.65	1.64	1.63	1.60	1.54	1.47	1.55	1.43	1.41	1.39	1.34	1.21	1.07
2024	1.81	1.71	1.66	1.65	1.64	1.63	1.60	1.54	1.56	1.45	1.43	1.41	1.39	1.34	1.21
2025	1.81	1.72	1.47	1.66	1.65	1.64	1.63	1.60	1.58	1.07	1.45	1.43	1.41	1.39	1.34
2026	1.81	1.72	1.54	1.66	1.66	1.65	1.64	1.63	1.59	1.21	1.47	1.45	1.43	1.41	1.39
2027	1.81	1.73	1.60	1.47	1.66	1.66	1.65	1.64	1.61	1.34	1.07	1.47	1.45	1.43	1.41
2028	1.81	1.73	1.63	1.54	1.67	1.66	1.66	1.65	1.62	1.39	1.21	1.49	1.47	1.45	1.43
2029	1.81	1.74	1.64	1.60	1.47	1.67	1.66	1.66	1.63	1.41	1.34	1.07	1.49	1.47	1.45

2030	1.81	1.75	1.65	1.63	1.54	1.68	1.67	1.66	1.65	1.43	1.39	1.21	1.50	1.49	1.47
2031	1.81	1.75	1.66	1.64	1.60	1.47	1.68	1.67	1.66	1.45	1.41	1.34	1.07	1.50	1.49
2032	1.81	1.76	1.47	1.65	1.63	1.54	1.69	1.68	1.67	1.07	1.43	1.39	1.21	1.52	1.50
2033	1.81	1.76	1.54	1.66	1.64	1.60	1.47	1.69	1.68	1.21	1.45	1.41	1.34	1.07	1.52
2034	1.81	1.76	1.60	1.66	1.65	1.63	1.54	1.70	1.69	1.34	1.47	1.43	1.39	1.21	1.54
2035	1.81	1.77	1.63	1.47	1.66	1.64	1.60	1.47	1.70	1.39	1.07	1.45	1.41	1.34	1.07
2036	1.81	1.77	1.64	1.54	1.66	1.65	1.63	1.54	1.71	1.41	1.21	1.47	1.43	1.39	1.21
2037	1.81	1.78	1.65	1.60	1.67	1.66	1.64	1.60	1.72	1.43	1.34	1.49	1.45	1.41	1.34
2038	1.81	1.78	1.66	1.63	1.47	1.66	1.65	1.63	1.73	1.45	1.39	1.07	1.47	1.43	1.39
2039	1.81	1.78	1.47	1.64	1.54	1.67	1.66	1.64	1.74	1.07	1.41	1.21	1.49	1.45	1.41
2040	1.81	1.79	1.54	1.65	1.60	1.68	1.66	1.65	1.75	1.21	1.43	1.34	1.50	1.47	1.43
2041	1.81	1.79	1.60	1.66	1.63	1.47	1.67	1.66	1.75	1.34	1.45	1.39	1.07	1.49	1.45
2042	1.81	1.79	1.63	1.66	1.64	1.54	1.68	1.66	1.76	1.39	1.47	1.41	1.21	1.50	1.47
2043	1.81	1.80	1.64	1.47	1.65	1.60	1.69	1.67	1.77	1.41	1.07	1.43	1.34	1.52	1.49
2044	1.81	1.80	1.65	1.54	1.66	1.63	1.47	1.68	1.77	1.43	1.21	1.45	1.39	1.07	1.50
2045	1.81	1.80	1.66	1.60	1.66	1.64	1.54	1.69	1.78	1.45	1.34	1.47	1.41	1.21	1.52
2046	1.81	1.80	1.47	1.63	1.67	1.65	1.60	1.70	1.78	1.07	1.39	1.49	1.43	1.34	1.54
2047	1.81	1.80	1.54	1.64	1.47	1.66	1.63	1.47	1.78	1.21	1.41	1.07	1.45	1.39	1.07
2048	1.81	1.80	1.60	1.65	1.54	1.66	1.64	1.54	1.79	1.34	1.43	1.21	1.47	1.41	1.21
2049	1.81	1.81	1.63	1.66	1.60	1.67	1.65	1.60	1.79	1.39	1.45	1.34	1.49	1.43	1.34
2050	1.81	1.81	1.64	1.66	1.63	1.68	1.66	1.63	1.79	1.41	1.47	1.39	1.50	1.45	1.39
2051	1.81	1.81	1.65	1.47	1.64	1.47	1.66	1.64	1.80	1.43	1.07	1.41	1.07	1.47	1.41
2052	1.81	1.81	1.66	1.54	1.65	1.54	1.67	1.65	1.80	1.45	1.21	1.43	1.21	1.49	1.43
2053	1.81	1.81	1.47	1.60	1.66	1.60	1.68	1.66	1.80	1.07	1.34	1.45	1.34	1.50	1.45
2054	1.81	1.81	1.54	1.63	1.66	1.63	1.69	1.66	1.80	1.21	1.39	1.47	1.39	1.52	1.47

2055	1.81	1.81	1.60	1.64	1.67	1.64	1.47	1.67	1.80	1.34	1.41	1.49	1.41	1.07	1.49
2056	1.81	1.81	1.63	1.65	1.47	1.65	1.54	1.68	1.80	1.39	1.43	1.07	1.43	1.21	1.50
2057	1.81	1.81	1.64	1.66	1.54	1.66	1.60	1.69	1.81	1.41	1.45	1.21	1.45	1.34	1.52
2058	1.81	1.81	1.65	1.66	1.60	1.66	1.63	1.70	1.81	1.43	1.47	1.34	1.47	1.39	1.54
2059	1.81	1.81	1.66	1.47	1.63	1.67	1.64	1.47	1.81	1.45	1.07	1.39	1.49	1.41	1.07
2060	1.81	1.81	1.47	1.54	1.64	1.68	1.65	1.54	1.81	1.07	1.21	1.41	1.50	1.43	1.21

A.3 Results – Decadal Average Streamflows

The following are listings by rainfall scenario of the decadal average streamflows for the main cases that were simulated.

For Rainfall Scenario of 2001 to 2010 Repeated Five Times													
Nomenclature	**Avg. Flow in Decade** (mm/yr)					**LAI**	**Area** (%)	**Period** (yrs)	**Avg. Diff. Flow in Decade to Untreated** (mm/yr)				
	2011-20	2021-30	2031-40	2041-50	2051-60				2011-20	2021-30	2031-40	2041-50	2051-60
Untreated	39.6	31.2	29.2	28.4	28.1	-	-	-	-	-	-	-	-
LAI 0.4 LS Once	77.4	68.7	52.4	39.7	32.9	0.4	44	Once	37.9	37.5	23.2	11.4	4.8
LAI 0.4 LS 7yr	82.6	95.5	100.0	101.7	99.8	0.4	44	7	43.0	64.3	70.8	73.3	71.7
LAI 0.4 LS 8yr	80.7	95.2	96.6	96.5	99.3	0.4	44	8	41.2	64.0	67.4	68.1	71.2
LAI 0.4 LS 9yr	78.1	92.8	95.8	96.3	95.9	0.4	44	9	38.5	61.5	66.7	67.9	67.8
LAI 0.4 LS 10yr	77.4	89.3	92.0	93.0	93.4	0.4	44	10	37.9	58.1	62.8	64.6	65.3
LAI 0.4 LS 11yr	77.4	88.2	90.2	90.9	91.2	0.4	44	11	37.9	56.9	61.0	62.5	63.1
LAI 0.4 LS 12yr	77.4	86.8	88.0	88.3	87.5	0.4	44	12	37.9	55.5	58.9	59.9	59.4
LAI 0.4 FT Once	93.5	94.1	69.1	47.6	36.1	0.4	88	Once	53.9	62.8	40.0	19.2	8.0
LAI 0.4 FT 7yr	102.6	148.4	167.7	174.5	170.3	0.4	88	7	63.0	117.2	138.6	146.1	142.2
LAI 0.4 FT 8yr	99.5	147.5	159.8	162.1	169.4	0.4	88	8	59.9	116.3	130.7	133.7	141.3
LAI 0.4 FT 9yr	94.8	142.0	157.8	161.3	161.5	0.4	88	9	55.2	110.8	128.7	132.9	133.4
LAI 0.4 FT 10yr	93.5	134.3	149.1	154.0	155.8	0.4	88	10	53.9	103.0	120.0	125.6	127.7
LAI 0.4 FT 11yr	93.5	132.1	145.4	149.9	151.2	0.4	88	11	53.9	100.9	116.2	121.5	123.1
LAI 0.4 FT 12yr	93.5	129.2	140.8	143.7	142.5	0.4	88	12	53.9	98.0	111.6	115.3	114.4
LAI 0.6 LS Once	66.0	55.6	42.5	34.3	30.5	0.6	44	Once	26.4	24.4	13.4	5.9	2.4
LAI 0.6 LS 7yr	69.6	75.8	77.4	79.2	77.4	0.6	44	7	30.1	44.6	48.2	50.8	49.3
LAI 0.6 LS 8yr	68.2	75.6	75.0	74.6	76.2	0.6	44	8	28.7	44.4	45.9	46.2	48.1
LAI 0.6 LS 9yr	66.3	73.7	74.4	74.2	73.9	0.6	44	9	26.8	42.4	45.3	45.8	45.9
LAI 0.6 LS 10yr	66.0	70.7	71.1	71.2	71.4	0.6	44	10	26.4	39.4	42.0	42.9	43.3
LAI 0.6 LS 11yr	66.0	69.6	69.7	69.9	70.0	0.6	44	11	26.4	38.4	40.6	41.5	41.9

LAI 0.6 LS 12yr	66.0	68.5	68.2	67.9	67.1	0.6	44	12	26.4	37.3	39.0	39.5	39.0
LAI 0.6 FT Once	74.7	68.8	50.4	37.8	31.9	0.6	88	Once	35.1	37.6	21.2	9.4	3.8
LAI 0.6 FT 7yr	80.6	105.8	117.2	123.8	121.3	0.6	88	7	41.0	74.6	88.0	95.4	93.2
LAI 0.6 FT 8yr	78.4	105.0	112.0	114.0	119.1	0.6	88	8	38.8	73.8	82.8	85.6	91.0
LAI 0.6 FT 9yr	75.3	101.0	110.5	113.0	114.0	0.6	88	9	35.8	69.7	81.4	84.6	85.9
LAI 0.6 FT 10yr	74.7	95.1	103.5	106.9	108.7	0.6	88	10	35.1	63.9	74.3	78.5	80.6
LAI 0.6 FT 11yr	74.7	93.2	100.8	104.0	105.3	0.6	88	11	35.1	62.0	71.6	75.6	77.2
LAI 0.6 FT 12yr	74.7	91.3	97.6	99.6	99.3	0.6	88	12	35.1	60.1	68.4	71.2	71.2
LAI 0.8 LS Once	57.3	45.6	36.1	31.2	29.2	0.8	44	Once	17.7	14.4	7.0	2.9	1.1
LAI 0.8 LS 7yr	59.8	60.6	60.0	61.1	59.3	0.8	44	7	20.2	29.4	30.8	32.7	31.2
LAI 0.8 LS 8yr	58.7	60.4	58.6	57.5	58.0	0.8	44	8	19.1	29.2	29.5	29.1	29.9
LAI 0.8 LS 9yr	57.4	58.7	58.4	57.4	57.0	0.8	44	9	17.9	27.5	29.2	29.0	28.9
LAI 0.8 LS 10yr	57.3	56.3	55.4	54.9	54.7	0.8	44	10	17.7	25.1	26.2	26.5	26.6
LAI 0.8 LS 11yr	57.3	55.4	54.2	53.7	53.5	0.8	44	11	17.7	24.2	25.1	25.3	25.4
LAI 0.8 LS 12yr	57.3	54.6	53.0	52.2	51.5	0.8	44	12	17.7	23.4	23.8	23.8	23.4
LAI 0.8 FT Once	61.7	51.7	39.5	32.7	29.9	0.8	88	Once	22.2	20.4	10.3	4.3	1.8
LAI 0.8 FT 7yr	65.3	75.6	80.2	84.9	82.8	0.8	88	7	25.7	44.4	51.1	56.5	54.7
LAI 0.8 FT 8yr	63.7	75.0	77.3	77.8	80.1	0.8	88	8	24.2	43.8	48.1	49.4	52.0
LAI 0.8 FT 9yr	62.0	72.0	76.4	77.3	77.5	0.8	88	9	22.5	40.7	47.3	48.9	49.4
LAI 0.8 FT 10yr	61.7	68.1	71.1	72.5	73.3	0.8	88	10	22.2	36.8	41.9	44.1	45.2
LAI 0.8 FT 11yr	61.7	66.7	68.9	70.0	70.6	0.8	88	11	22.2	35.5	39.8	41.6	42.5
LAI 0.8 FT 12yr	61.7	65.3	66.6	67.0	67.1	0.8	88	12	22.2	34.1	37.4	38.7	39.0
LAI 1.0 LS Once	50.7	38.9	32.5	29.7	28.6	1.0	44	Once	11.1	7.6	3.3	1.3	0.5
LAI 1.0 LS 7yr	52.3	48.9	46.9	47.5	45.9	1.0	44	7	12.8	17.7	17.7	19.1	17.8
LAI 1.0 LS 8yr	51.5	48.7	46.2	44.8	44.7	1.0	44	8	11.9	17.4	17.0	16.4	16.6
LAI 1.0 LS 9yr	50.7	47.5	46.1	44.9	44.4	1.0	44	9	11.2	16.2	17.0	16.5	16.3
LAI 1.0 LS 10yr	50.7	45.7	43.9	43.0	42.7	1.0	44	10	11.1	14.5	14.7	14.6	14.6

LAI 1.0 LS 11yr	50.7	45.0	43.0	42.2	41.9	1.0	44	11	11.1	13.8	13.9	13.8	13.8
LAI 1.0 LS 12yr	50.7	44.5	42.3	41.2	40.7	1.0	44	12	11.1	13.2	13.1	12.8	12.6
LAI 1.0 FT Once	52.9	41.4	33.9	30.4	28.9	1.0	88	Once	13.4	10.2	4.7	2.0	0.8
LAI 1.0 FT 7yr	55.0	55.2	55.1	57.1	55.5	1.0	88	7	15.5	24.0	26.0	28.7	27.4
LAI 1.0 FT 8yr	54.0	54.7	53.8	52.9	53.1	1.0	88	8	14.4	23.5	24.6	24.5	25.0
LAI 1.0 FT 9yr	53.0	52.9	53.2	52.7	52.4	1.0	88	9	13.5	21.7	24.1	24.3	24.3
LAI 1.0 FT 10yr	52.9	50.6	50.0	49.6	49.6	1.0	88	10	13.4	19.3	20.8	21.2	21.5
LAI 1.0 FT 11yr	52.9	49.6	48.6	48.2	48.0	1.0	88	11	13.4	18.4	19.5	19.8	19.9
LAI 1.0 FT 12yr	52.9	48.9	47.3	46.6	46.2	1.0	88	12	13.4	17.6	18.2	18.2	18.1

For Rainfall Scenario of 2000 to 2009 Repeated Five Times

Nomenclature	**Avg. Flow in Decade** (mm/yr)					**LAI**	**Area** (%)	**Period** (yrs)	**Avg. Diff. Flow in Decade to Untreated** (mm/yr)				
	2011-20	2021-30	2031-40	2041-50	2051-60				2011-20	2021-30	2031-40	2041-50	2051-60
Untreated	52.1	51.6	50.8	50.4	50.4	-	-	-	-	-	-	-	-
LAI 0.4 LS Once	95.5	98.0	81.2	66.5	57.4	0.4	44	Once	43.4	46.4	30.4	16.1	7.0
LAI 0.4 LS 7yr	102.4	128.0	136.1	136.4	136.7	0.4	44	7	50.3	76.5	85.3	86.0	86.3
LAI 0.4 LS 8yr	100.2	127.1	131.4	131.6	136.2	0.4	44	8	48.2	75.6	80.6	81.1	85.8
LAI 0.4 LS 9yr	98.0	125.8	130.0	130.4	131.1	0.4	44	9	46.0	74.2	79.2	79.9	80.8
LAI 0.4 LS 10yr	95.5	121.8	126.8	128.1	128.7	0.4	44	10	43.4	70.3	76.0	77.7	78.4
LAI 0.4 LS 11yr	95.5	120.7	125.1	125.8	126.2	0.4	44	11	43.4	69.1	74.3	75.4	75.8
LAI 0.4 LS 12yr	95.5	119.3	122.6	123.1	122.8	0.4	44	12	43.4	67.7	71.8	72.7	72.5
LAI 0.4 FT Once	115.7	135.8	108.7	81.3	63.9	0.4	88	Once	63.6	84.3	57.9	30.9	13.6
LAI 0.4 FT 7yr	127.7	197.5	222.4	224.6	224.6	0.4	88	7	75.6	146.0	171.6	174.2	174.2
LAI 0.4 FT 8yr	123.7	195.4	212.9	214.2	223.5	0.4	88	8	71.7	143.8	162.1	163.8	173.1
LAI 0.4 FT 9yr	119.9	191.5	209.7	212.4	213.6	0.4	88	9	67.9	139.9	158.9	162.0	163.3
LAI 0.4 FT 10yr	115.7	182.9	202.8	207.2	208.6	0.4	88	10	63.6	131.3	151.9	156.8	158.3
LAI 0.4 FT 11yr	115.7	180.6	199.2	202.5	203.7	0.4	88	11	63.6	129.1	148.3	152.1	153.4

LAI 0.4 FT 12yr	115.7	177.6	193.8	196.8	195.9	0.4	88	12	63.6	126.1	143.0	146.3	145.5
LAI 0.6 LS Once	82.8	82.7	69.5	59.2	53.8	0.6	44	Once	30.7	31.2	18.7	8.8	3.4
LAI 0.6 LS 7yr	87.8	106.3	111.8	112.5	112.4	0.6	44	7	35.7	54.7	61.0	62.1	62.0
LAI 0.6 LS 8yr	86.1	105.7	108.4	108.4	111.8	0.6	44	8	34.1	54.1	57.6	58.0	61.5
LAI 0.6 LS 9yr	84.6	104.4	107.2	107.6	108.3	0.6	44	9	32.5	52.9	56.4	57.2	57.9
LAI 0.6 LS 10yr	82.8	101.2	104.7	105.7	106.3	0.6	44	10	30.7	49.7	53.9	55.2	55.9
LAI 0.6 LS 11yr	82.8	100.0	103.0	103.6	104.1	0.6	44	11	30.7	48.5	52.2	53.2	53.8
LAI 0.6 LS 12yr	82.8	98.6	101.0	101.6	101.5	0.6	44	12	30.7	47.0	50.2	51.2	51.2
LAI 0.6 FT Once	94.6	105.5	85.1	66.9	56.9	0.6	88	Once	42.6	53.9	34.3	16.5	6.6
LAI 0.6 FT 7yr	102.7	149.8	168.9	173.3	173.4	0.6	88	7	50.7	98.3	118.1	122.9	123.0
LAI 0.6 FT 8yr	100.0	148.3	162.1	164.6	171.8	0.6	88	8	47.9	96.7	111.3	114.2	121.4
LAI 0.6 FT 9yr	97.4	145.2	158.9	163.0	164.7	0.6	88	9	45.3	93.6	108.1	112.5	114.3
LAI 0.6 FT 10yr	94.6	138.8	153.3	158.1	160.0	0.6	88	10	42.6	87.2	102.5	107.7	109.7
LAI 0.6 FT 11yr	94.6	136.8	149.8	153.9	155.8	0.6	88	11	42.6	85.3	99.0	103.5	105.4
LAI 0.6 FT 12yr	94.6	134.1	145.8	149.8	150.4	0.6	88	12	42.6	82.5	95.0	99.4	100.0
LAI 0.8 LS Once	73.1	71.3	61.2	54.7	51.9	0.8	44	Once	21.0	19.7	10.4	4.3	1.6
LAI 0.8 LS 7yr	76.6	88.8	91.9	92.7	92.4	0.8	44	7	24.5	37.3	41.1	42.3	42.1
LAI 0.8 LS 8yr	75.4	88.5	89.6	89.3	91.6	0.8	44	8	23.3	36.9	38.8	38.9	41.2
LAI 0.8 LS 9yr	74.2	87.2	88.6	88.9	89.1	0.8	44	9	22.1	35.7	37.8	38.5	38.8
LAI 0.8 LS 10yr	73.1	84.9	86.5	87.0	87.3	0.8	44	10	21.0	33.3	35.7	36.5	36.9
LAI 0.8 LS 11yr	73.1	84.0	85.1	85.3	85.6	0.8	44	11	21.0	32.4	34.3	34.9	35.2
LAI 0.8 LS 12yr	73.1	82.8	83.7	84.0	83.9	0.8	44	12	21.0	31.3	32.9	33.6	33.6
LAI 0.8 FT Once	79.6	83.6	69.2	58.5	53.4	0.8	88	Once	27.5	32.0	18.4	8.1	3.1
LAI 0.8 FT 7yr	84.7	114.4	126.5	130.4	130.6	0.8	88	7	32.6	62.8	75.6	80.0	80.3
LAI 0.8 FT 8yr	82.9	113.4	121.9	123.6	128.8	0.8	88	8	30.8	61.8	71.1	73.2	78.4
LAI 0.8 FT 9yr	81.1	110.7	119.5	122.5	123.9	0.8	88	9	29.1	59.2	68.7	72.0	73.5
LAI 0.8 FT 10yr	79.6	106.1	115.2	118.4	120.1	0.8	88	10	27.5	54.6	64.4	68.0	69.7

LAI 0.8 FT 11yr	79.6	104.5	112.0	114.7	116.3	0.8	88	11	27.5	52.9	61.2	64.3	66.0
LAI 0.8 FT 12yr	79.6	102.3	109.0	112.0	113.0	0.8	88	12	27.5	50.7	58.2	61.6	62.6
LAI 1.0 LS Once	65.4	62.7	56.1	52.4	51.0	1.0	44	Once	13.4	11.2	5.3	2.0	0.7
LAI 1.0 LS 7yr	67.8	75.6	77.2	77.5	77.0	1.0	44	7	15.8	24.1	26.4	27.1	26.6
LAI 1.0 LS 8yr	67.0	75.5	75.6	75.0	76.5	1.0	44	8	15.0	23.9	24.8	24.6	26.2
LAI 1.0 LS 9yr	66.1	74.4	75.0	74.8	74.7	1.0	44	9	14.1	22.9	24.2	24.4	24.4
LAI 1.0 LS 10yr	65.4	72.5	73.2	73.3	73.4	1.0	44	10	13.4	21.0	22.4	22.9	23.1
LAI 1.0 LS 11yr	65.4	71.8	71.9	71.8	72.0	1.0	44	11	13.4	20.2	21.1	21.4	21.6
LAI 1.0 LS 12yr	65.4	70.8	70.8	70.8	70.8	1.0	44	12	13.4	19.2	20.0	20.4	20.4
LAI 1.0 FT Once	68.8	68.8	59.8	54.1	51.8	1.0	88	Once	16.7	17.2	9.0	3.7	1.4
LAI 1.0 FT 7yr	71.9	88.6	95.2	97.8	97.6	1.0	88	7	19.9	37.0	44.4	47.4	47.2
LAI 1.0 FT 8yr	70.8	88.1	92.4	93.0	96.0	1.0	88	8	18.7	36.5	41.6	42.5	45.6
LAI 1.0 FT 9yr	69.6	86.2	90.8	92.2	92.8	1.0	88	9	17.6	34.6	40.0	41.8	42.4
LAI 1.0 FT 10yr	68.8	83.1	87.7	89.3	90.2	1.0	88	10	16.7	31.5	36.9	38.9	39.9
LAI 1.0 FT 11yr	68.8	81.9	85.4	86.6	87.5	1.0	88	11	16.7	30.3	34.6	36.2	37.2
LAI 1.0 FT 12yr	68.8	80.3	83.3	84.9	85.5	1.0	88	12	16.7	28.7	32.5	34.5	35.2

A.4 Results – Decadal Average Stream Flow-Days

The following are listings by rainfall scenario of the decadal average stream flow-days for the main cases that were simulated.

For Rainfall Scenario of 2001 to 2010 Repeated Five Times													
Nomenclature	**Avg. Flow-Days in Decade** (days/yr)					**LAI**	**Area** (%)	**Period** (yrs)	**Avg. Diff. Flow-Days in Decade to Untreated** (days/yr)				
	2011-20	2021-30	2031-40	2041-50	2051-60				2011-20	2021-30	2031-40	2041-50	2051-60
Untreated	173	159	155	154	154	-	-	-	-	-	-	-	-
LAI 0.4 LS Once	256	225	193	174	163	0.4	44	Once	83	66	38	20	9
LAI 0.4 LS 7yr	273	310	323	325	323	0.4	44	7	100	152	167	171	169
LAI 0.4 LS 8yr	268	305	312	316	319	0.4	44	8	95	146	156	161	165
LAI 0.4 LS 9yr	265	304	312	305	311	0.4	44	9	92	145	157	151	157
LAI 0.4 LS 10yr	256	297	305	307	308	0.4	44	10	83	138	149	153	154
LAI 0.4 LS 11yr	256	292	301	302	298	0.4	44	11	83	134	146	148	144
LAI 0.4 LS 12yr	256	291	292	284	285	0.4	44	12	83	132	136	130	131
LAI 0.4 FT Once	280.9	268.4	208.4	182.4	167.2	0.4	88	Once	108.1	109.7	53	28	13.2
LAI 0.4 FT 7yr	290.9	345.4	354.4	365.2	355.7	0.4	88	7	118.1	186.7	199	210.8	201.7
LAI 0.4 FT 8yr	285.9	349.4	353.9	352.1	356.2	0.4	88	8	113.1	190.7	198.5	197.7	202.2
LAI 0.4 FT 9yr	282.9	347.3	359.2	358.7	356.1	0.4	88	9	110.1	188.6	203.8	204.3	202.1
LAI 0.4 FT 10yr	280.9	342.1	351.9	352.9	353.7	0.4	88	10	108.1	183.4	196.5	198.5	199.7
LAI 0.4 FT 11yr	280.9	336.3	339.7	342.4	346.8	0.4	88	11	108.1	177.6	184.3	188	192.8
LAI 0.4 FT 12yr	280.9	329.6	333.6	344.1	349	0.4	88	12	108.1	170.9	178.2	189.7	195
LAI 0.6 LS Once	217	197	178	166	157	0.6	44	Once	44	38	23	12	3
LAI 0.6 LS 7yr	234	250	260	259	255	0.6	44	7	61	91	104	104	101
LAI 0.6 LS 8yr	229	249	247	243	255	0.6	44	8	56	90	92	89	101
LAI 0.6 LS 9yr	222	247	247	244	244	0.6	44	9	49	88	91	90	90
LAI 0.6 LS 10yr	217	233	234	234	235	0.6	44	10	44	74	79	80	81
LAI 0.6 LS 11yr	217	231	234	234	235	0.6	44	11	44	73	78	80	81

LAI 0.6 LS 12yr	217	231	232	227	222	0.6	44	12	44	73	76	73	68
LAI 0.6 FT Once	231.8	208.9	187	170.2	159.7	0.6	88	Once	59	50.2	31.6	15.8	5.7
LAI 0.6 FT 7yr	250.2	295.5	319.1	328	323.2	0.6	88	7	77.4	136.8	163.7	173.6	169.2
LAI 0.6 FT 8yr	244.1	291.9	309.2	316.3	322.8	0.6	88	8	71.3	133.2	153.8	161.9	168.8
LAI 0.6 FT 9yr	238.8	289.6	310.9	309.5	312.1	0.6	88	9	66	130.9	155.5	155.1	158.1
LAI 0.6 FT 10yr	231.8	275.7	298.5	304.2	308.5	0.6	88	10	59	117	143.1	149.8	154.5
LAI 0.6 FT 11yr	231.8	273.1	291.7	295.9	292.1	0.6	88	11	59	114.4	136.3	141.5	138.1
LAI 0.6 FT 12yr	231.8	271.1	283.5	277.1	284.6	0.6	88	12	59	112.4	128.1	122.7	130.6
LAI 0.8 LS Once	198	182	169	159	155	0.8	44	Once	25	23	13	5	1
LAI 0.8 LS 7yr	205	207	207	210	205	0.8	44	7	33	49	51	56	51
LAI 0.8 LS 8yr	204	206	205	200	204	0.8	44	8	31	48	49	46	50
LAI 0.8 LS 9yr	200	205	204	202	202	0.8	44	9	27	46	48	47	48
LAI 0.8 LS 10yr	198	198	197	196	196	0.8	44	10	25	39	41	42	42
LAI 0.8 LS 11yr	198	196	195	195	195	0.8	44	11	25	38	39	41	41
LAI 0.8 LS 12yr	198	196	194	194	194	0.8	44	12	25	37	39	39	40
LAI 0.8 FT Once	202.2	188.1	172.4	161.1	156.2	0.8	88	Once	29.4	29.4	17	6.7	2.2
LAI 0.8 FT 7yr	212.4	235	241.1	249.1	245.6	0.8	88	7	39.6	76.3	85.7	94.7	91.6
LAI 0.8 FT 8yr	211	229.2	237	231.5	238.4	0.8	88	8	38.2	70.5	81.6	77.1	84.4
LAI 0.8 FT 9yr	206	220.1	227	231.8	236.7	0.8	88	9	33.2	61.4	71.6	77.4	82.7
LAI 0.8 FT 10yr	202.2	209.5	213.2	216.2	217.7	0.8	88	10	29.4	50.8	57.8	61.8	63.7
LAI 0.8 FT 11yr	202.2	207.6	212.8	217.1	220.5	0.8	88	11	29.4	48.9	57.4	62.7	66.5
LAI 0.8 FT 12yr	202.2	206.8	212.6	213.2	214.1	0.8	88	12	29.4	48.1	57.2	58.8	60.1
LAI 1.0 LS Once	189	173	161	156	155	1.0	44	Once	16	14	6	2	1
LAI 1.0 LS 7yr	187	187	186	186	184	1.0	44	7	14	28	31	31	30
LAI 1.0 LS 8yr	191	188	184	181	182	1.0	44	8	18	29	29	27	28
LAI 1.0 LS 9yr	189	187	184	182	181	1.0	44	9	17	28	29	28	27
LAI 1.0 LS 10yr	189	182	180	179	179	1.0	44	10	16	24	25	25	25

LAI 1.0 LS 11yr	189	181	178	177	177	1.0	44	11	16	23	23	23	23
LAI 1.0 LS 12yr	189	181	178	176	177	1.0	44	12	16	22	22	22	23
LAI 1.0 FT Once	189.8	174.9	163.5	157.1	154.9	1.0	88	Once	17	16.2	8.1	2.7	0.9
LAI 1.0 FT 7yr	193.9	193.5	194.6	195.5	194.1	1.0	88	7	21.1	34.8	39.2	41.1	40.1
LAI 1.0 FT 8yr	193.2	193.2	191	189.1	191.8	1.0	88	8	20.4	34.5	35.6	34.7	37.8
LAI 1.0 FT 9yr	191	192	192	189.7	188.9	1.0	88	9	18.2	33.3	36.6	35.3	34.9
LAI 1.0 FT 10yr	189.8	187.3	186.5	185.7	185.6	1.0	88	10	17	28.6	31.1	31.3	31.6
LAI 1.0 FT 11yr	189.8	185.7	184.2	183.7	184	1.0	88	11	17	27	28.8	29.3	30
LAI 1.0 FT 12yr	189.8	184.5	183.3	181.7	181.5	1.0	88	12	17	25.8	27.9	27.3	27.5

For Rainfall Scenario of 2000 to 2009 Repeated Five Times													
Nomenclature	**Avg. Flow-Days in Decade** (days/yr)					**LAI**	**Area** (%)	**Period** (yrs)	**Avg. Diff. Flow-Days in Decade to Untreated** (days/yr)				
	2011-20	2021-30	2031-40	2041-50	2051-60				2011-20	2021-30	2031-40	2041-50	2051-60
Untreated	189	190	189	188	189	-	-	-	-	-	-	-	-
LAI 0.4 LS Once	277	286	241	213	199	0.4	44	Once	88	96	52	24	11
LAI 0.4 LS 7yr	287	350	361	364	361	0.4	44	7	98	160	172	175	173
LAI 0.4 LS 8yr	286	353	352	355	360	0.4	44	8	97	163	163	167	172
LAI 0.4 LS 9yr	279	352	356	358	354	0.4	44	9	91	162	167	170	165
LAI 0.4 LS 10yr	277	347	351	351	352	0.4	44	10	88	157	161	163	164
LAI 0.4 LS 11yr	277	350	349	347	347	0.4	44	11	88	159	159	159	159
LAI 0.4 LS 12yr	277	340	344	340	341	0.4	44	12	88	150	154	152	153
LAI 0.4 FT Once	298	329	275	233	207	0.4	88	Once	109	139	86	45	18
LAI 0.4 FT 7yr	307	365	365	365	365	0.4	88	7	118	175	176	177	177
LAI 0.4 FT 8yr	305	365	365	365	365	0.4	88	8	116	175	176	177	177
LAI 0.4 FT 9yr	305	364	365	365	365	0.4	88	9	116	174	176	177	177
LAI 0.4 FT 10yr	298	365	365	365	365	0.4	88	10	109	175	176	177	177
LAI 0.4 FT 11yr	298	365	365	365	365	0.4	88	11	109	175	176	177	177

LAI 0.4 FT 12yr	298	364	365	365	363	0.4	88	12	109	174	176	177	174
LAI 0.6 LS Once	241	245	217	202	193	0.6	44	Once	52	55	28	13	5
LAI 0.6 LS 7yr	252	314	323	324	321	0.6	44	7	63	124	134	136	132
LAI 0.6 LS 8yr	247	307	316	313	317	0.6	44	8	58	117	127	125	129
LAI 0.6 LS 9yr	242	301	305	311	312	0.6	44	9	53	110	116	123	124
LAI 0.6 LS 10yr	241	297	305	306	307	0.6	44	10	52	107	116	118	119
LAI 0.6 LS 11yr	241	294	300	303	305	0.6	44	11	52	104	111	114	117
LAI 0.6 LS 12yr	241	288	297	293	292	0.6	44	12	52	98	108	105	103
LAI 0.6 FT Once	252	271	239	210	198	0.6	88	Once	63	81	49	21	9
LAI 0.6 FT 7yr	263	348	360	365	362	0.6	88	7	75	158	171	177	173
LAI 0.6 FT 8yr	260	346	356	357	360	0.6	88	8	71	156	167	169	171
LAI 0.6 FT 9yr	253	346	355	362	361	0.6	88	9	64	156	166	174	173
LAI 0.6 FT 10yr	252	341	351	352	352	0.6	88	10	63	151	162	163	163
LAI 0.6 FT 11yr	252	344	349	349	351	0.6	88	11	63	154	159	161	162
LAI 0.6 FT 12yr	252	333	344	346	350	0.6	88	12	63	143	155	158	161
LAI 0.8 LS Once	216	219	205	195	190	0.8	44	Once	27	29	16	6	2
LAI 0.8 LS 7yr	223	263	270	273	269	0.8	44	7	34	73	81	85	80
LAI 0.8 LS 8yr	217	263	266	264	268	0.8	44	8	28	73	77	75	79
LAI 0.8 LS 9yr	216	253	260	264	264	0.8	44	9	27	63	71	76	76
LAI 0.8 LS 10yr	216	246	255	256	257	0.8	44	10	27	56	66	68	68
LAI 0.8 LS 11yr	216	242	248	250	255	0.8	44	11	27	52	59	62	66
LAI 0.8 LS 12yr	216	237	246	251	243	0.8	44	12	27	47	57	63	55
LAI 0.8 FT Once	219	233	213	199	192	0.8	88	Once	30	43	24	11	4
LAI 0.8 FT 7yr	230	299	320	321	324	0.8	88	7	41	109	131	132	135
LAI 0.8 FT 8yr	221	290	311	312	319	0.8	88	8	32	100	122	124	130
LAI 0.8 FT 9yr	219	283	298	308	311	0.8	88	9	30	93	109	119	122
LAI 0.8 FT 10yr	219	279	296	301	305	0.8	88	10	30	89	107	113	117

LAI 0.8 FT 11yr	219	274	290	297	301	0.8	88	11	30	84	101	109	113
LAI 0.8 FT 12yr	219	269	286	285	284	0.8	88	12	30	79	96	97	96
LAI 1.0 LS Once	206	206	197	191	189	1.0	44	Once	17	15	8	3	1
LAI 1.0 LS 7yr	207	223	227	231	225	1.0	44	7	18	33	38	43	36
LAI 1.0 LS 8yr	206	224	224	222	227	1.0	44	8	17	34	35	33	38
LAI 1.0 LS 9yr	206	222	224	223	223	1.0	44	9	17	32	35	35	34
LAI 1.0 LS 10yr	206	219	221	221	222	1.0	44	10	17	29	32	33	33
LAI 1.0 LS 11yr	206	216	217	216	217	1.0	44	11	17	26	28	28	29
LAI 1.0 LS 12yr	206	215	215	215	216	1.0	44	12	17	25	26	27	27
LAI 1.0 FT Once	207	211	201	193	190	1.0	88	Once	18	21	12	5	2
LAI 1.0 FT 7yr	209	239	247	261	253	1.0	88	7	20	48	58	73	65
LAI 1.0 FT 8yr	208	240	248	245	251	1.0	88	8	19	50	59	57	62
LAI 1.0 FT 9yr	207	233	244	248	249	1.0	88	9	18	43	54	60	61
LAI 1.0 FT 10yr	207	229	238	240	243	1.0	88	10	18	39	48	52	55
LAI 1.0 FT 11yr	207	224	229	231	236	1.0	88	11	18	34	40	43	48
LAI 1.0 FT 12yr	207	222	227	233	235	1.0	88	12	18	32	38	44	47