BEFORE THE HEARING COMMISSIONERS APPOINTED BY ENVIRONMENT CANTERBURY

IN THE MATTER	of the Resource Management Act 1991 (**RMA** or **the Act**)
AND	
IN THE MATTER	of Proposed Plan Change 7 to the Canterbury Land and Water Regional Plan

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STATEMENT OF EVIDENCE OF JACOB SCHERBERG (HYDROLOGY) ON BEHALF OF HORTICULTURE NEW ZEALAND

DATED 17 JULY 2020

ATKINS | HOLM | MAJUREY

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EXECUTIVE SUMMARY

1. I have undertaken an investigation on behalf of Horticulture New Zealand (**HortNZ**) to assess the effects of submissions requesting modifications to provisions 8.04.12, 8.04.18, and 14.04.13 in proposed Plan Change 7 to the Canterbury Land and Water Regional Plan (**PC7**). Each of these submissions have the goal of assuring that water is available for rootstock survival in times of drought, in order to support the viability of horticulture on the Canterbury Plains.

2. The Soil Moisture Water Balance Model (**SMWBM**) was used to evaluate flow generation for two study areas, one adjacent to the Ashley River in the northern Canterbury Plains and one adjacent to the Temuka River on the southern Canterbury Plains.

3. Allocation criteria were evaluated with the SMWBM applied to simulate historic conditions for the two study areas in accordance with Rule 5.123 of the operative Canterbury Land and Water Regional Plan (**CLWRP**). Horticultural allocation limits were used as the basis for assessing the impact of rootstock survival abstractions on surface flows.

4. Irrigation restrictions due to low-flow conditions were simulated to occur infrequently. However, there was a prolonged period with restricted irrigation in the driest year of the study period (1988).

5. The proposed allocation for rootstock survival amounts to 2.5% of 7-day Mean Annual Low-Flow (**7DMALF**).

6. Over the course of a 47-year simulation period, allowing for rootstock survival abstractions only increased the number of days below minimum flow threshold by a total of 4 days in the Ashley study area and 5 days in the Temuka Study area.

7. Flows low enough to require restrictions and hence abstractions for rootstock survival were predicted to occur only once every 16 years (16-year return interval). Abstracting water at the rate determined necessary for rootstock survival would cause <u>less than minor</u> effects on flow conditions.

8. It is my view that the amendments to PC7 provisions 08.04.12, 08.04.18, and 14.04.13 that have been proposed by HortNZ are appropriate. This conclusion is based on my assessment that any potential effects of allowing 2.5% of 7DMALF to be abstracted for rootstock survival occur infrequently (assessed

as a 16-year ARI drought) and are less than minor relative to the benefit of supporting the viability of horticultural development.

INTRODUCTION

Qualifications and experience

1. My full name is Jacob Nathan Scherberg.

2. I have a Bachelor of Science from Evergreen State University in Washington State, USA (2001), and a Masters of Science from Oregon State University in Oregon, USA (2012). I have been a member of the New Zealand Hydrological Society since 2018.

3. I am currently a hydrologist at Williamson Water & Land Advisory. I am typically tasked with the assessment of both surface water and groundwater resources using numerical modelling and other analytical methods.

4. I have 10 years of specialist technical experience in the assessment of surface water and groundwater resources. My experience includes numerical modelling, analyses of environmental effects, data collection and analysis, optimisation planning for managed aquifer recharge, and evaluation of horticultural potential. Below, I have provided a brief summary of projects I have been involved that are relevant to the evidence presented herein:

   (a) Aupouri Aquifer Groundwater Model, 2018-2020. I have been the lead developer of a calibrated numerical model developed to assess groundwater conditions and the potential effects of proposed groundwater takes.

   (b) Motutangi-Waiharara Water User Group Irrigation Scheduling Plan, 2019-2020. I undertook an evaluation of horticultural water requirements based on climate data, soil characteristics and crop types for a consortium of 17 orchardists in the Motutangi Region of the Aupouri Peninsula. This entailed a modelling effort in which optimised water requirements were determined based on soil types. This work included documentation of monitoring systems optimising water use efficiency.

   (c) Te Kao-Te Hapua Water Resource Assessment, 2020. I undertook a water resource assessment for two remote communities in the Far North District. This entailed a review of local conditions and climate to assess the potential for horticultural development and a domestic water supply. Information was summarised in terms of available groundwater and surface water resources in the context of allocation policy, including consideration of reservoir construction and sea water desalination as a means of providing water supply.

(d) Whangaroa Ngaiotonga Trust Water Resource Assessment, 2020. I undertook a water resource assessment for a remote community in Northland Region. This entailed a review of topography, geology, soils, climate, and land use in order to determine areas with potential for horticultural development. Findings were summarised with regard to the viability of surface water and groundwater for irrigation and domestic use in the context of available resources and regional policy.

(e) Walla Walla Basin Aquifer Surface Water-Groundwater Model, 2011-2018. I was the lead model developer for a basin scale numerical model simulating groundwater and surface water for the Walla Walla Basin in the north western USA. This model was used to evaluate an ongoing aquifer recharge programme and other water management options with the goal of sustaining environmental flows while maintaining a viable groundwater resource to support agriculture.

5. My evidence is provided on behalf of HortNZ. I am familiar with the subject area through desktop analysis, although I have not been involved in PC7 until now.

Expert Witness Code of Conduct

6. I have been provided with a copy of the Code of Conduct for Expert Witnesses contained in the Environment Court's Practice Note dated 1 December 2014. I have read and agree to comply with that Code. This evidence is within my area of expertise, except where I state that I am relying upon the specified evidence of another person. I have not omitted to consider material facts known to me that might alter or detract from the opinions that I express.

Involvement in project

7. The firm I work for, Williamson Water & Land Advisory (**WWLA**), was commissioned on 23 March 2020 by HortNZ to undertake

an investigation of horticultural water use and impacts on stream flow regime in selected areas of the Canterbury Plains. The investigation was specifically aimed at understanding the scale of effect on low flow hydrology that may result from the provision of water for rootstock survival during times of drought.

8. My involvement has comprised undertaking a modelling investigation of flow generation with and without low-flow water takes for rootstock survival.

Purpose and scope of evidence

9. This evidence addresses the HortNZ submission items that pertain to PC7 rules 08.04.12, 08.04.18, and 14.04.13.b and the Environment Canterbury (**ECan**) s42A response to the HortNZ submission.

10. This evidence is focused on the provision of rootstock survival water to horticultural enterprises in the Canterbury Plains.

11. I have undertaken a technical assessment to evaluate the impact of the proposed provisions on allowing water to continue being abstracted for rootstock survival under low flow conditions.

12. This evidence provides an assessment of the following matters:

    (a) A review of methodology for determining minimum flow, total allocation limits, and horticultural allocation limits under the current version of the proposed regional plan;

    (b) Proposed methodology for determining the timing and volume of water allocated for rootstock survival;

    (c) A technical analysis of the effects of rootstock survival abstractions on the recurrence interval of low flows, minimum stream flows, and frequency of water take restrictions due to low flows; and

    (d) Summary and conclusions as related to the above.

13. I note that other experts from HortNZ have accepted that there is likely to an issue of scope in pursuing the rootstock survival plan provisions. I further note that this evidence is presented to assist ECan in relation to future work HortNZ would like to see undertaken on the root stock survival water issue.

IMPORTANCE OF ROOTSTOCK SURVIVAL WATER

14. PC7 does not address rootstock survival as a component of water resource management in Canterbury.

15. Provision for rootstock survival is important to protect the viability of horticultural enterprises in time of drought. Unlike seasonal crops, there is a significant lag time between planting and any level of production, and further lag time until full production on horticultural land uses. Hence, the impact of losing horticultural plants is far longer reaching than other land uses.

EFFECTS OF PC7

16. HortNZ has submitted three suggested modifications aimed at including provisions for rootstock survival water in the framework of PC7. The provisions where modifications have been suggested are 8.04.12, 8.04.18, and 14.04.13. The full text of these provisions and suggested modifications are provided later in this document under the heading 'response to officers report'.

17. I have undertaken a desktop analysis to assess the effects of providing rootstock survival water under low-flow conditions. This entailed developing a water balance model to evaluate flow generation and flow rates with and without abstractions for rootstock survival.

18. Two study areas with a reasonable amount of horticultural land use within the Canterbury Plains were selected for this assessment. These areas are adjacent to the Ashley and Temuka Rivers, representing regions in the northern and southern portions of the Canterbury Plains, respectively. The study areas are shown in **Figure 1**.

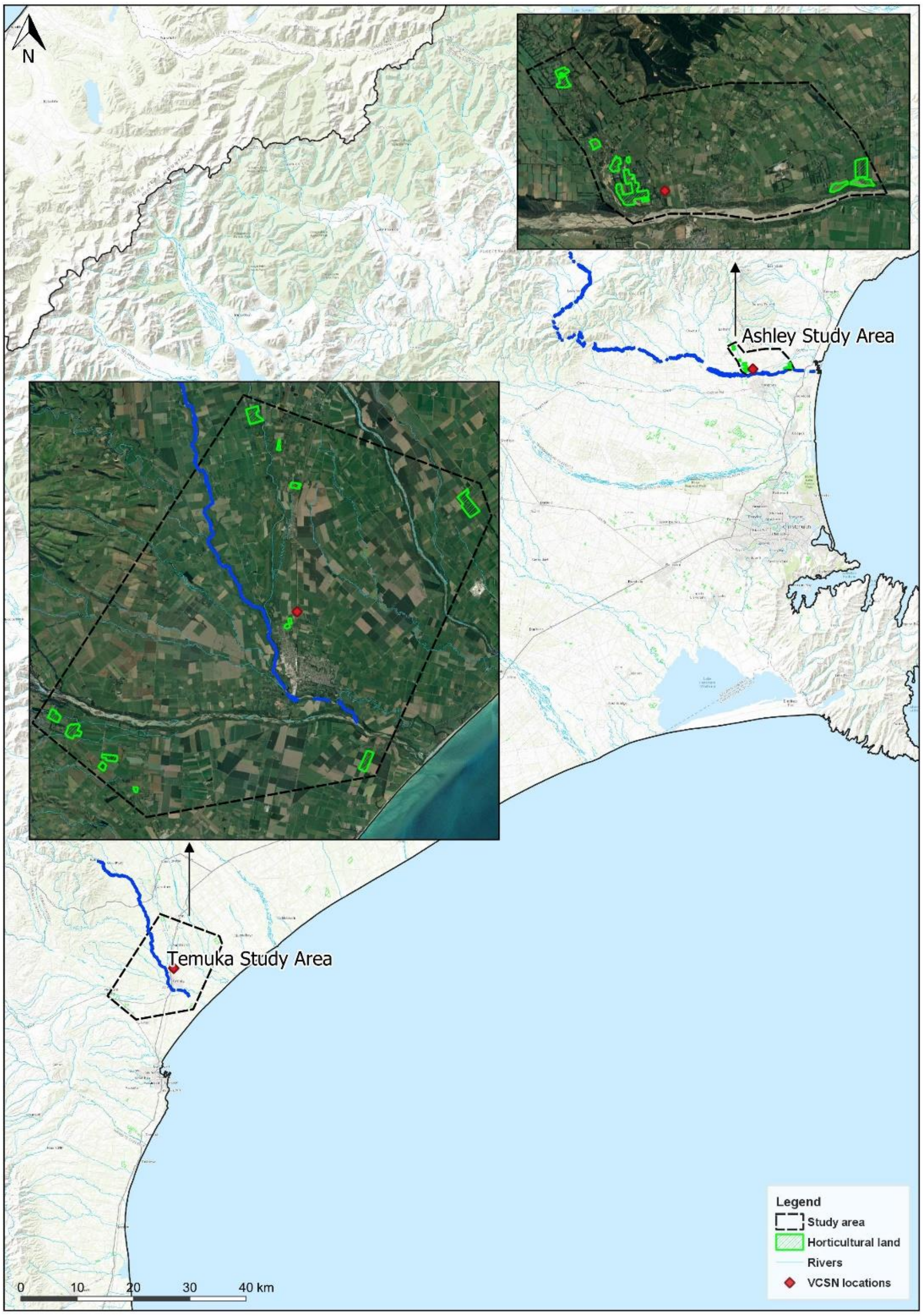

Figure 1. Study area locations.

19. For each of these areas, a focus study area was determined based on current horticultural lands and physical characteristics with regard to potential horticultural suitability (soil type, topography). These are referred to herein as the **Ashley study area** and the **Temuka study area**, respectively.

Methodology Overview

20. The objective of this analysis is to assess the potential impact of abstracting surface water during low-flow times for the

purpose of protecting horticultural crops. This entails an assessment of flow conditions with and without abstractions for irrigation and rootstock survival.

21. The analysis of flow generation and low-flow conditions was undertaken by developing an application of the Soil Moisture Water Balance Model (**SMWBM**), which is a model used for soil moisture accounting, rainfall-runoff and irrigation models as described in **Appendix A**.

22. The SMWBM is used here as a tool to assess hydraulic functionality in indicative horticultural areas on the Canterbury Plains using soil and climate data for those areas.

23. The SMWBM is not calibrated to a flow gauge, but rather developed to assess a relative response. As such, flow statistics discussed in this assessment pertain to a relative response to simulated management scenarios.

24. In the following sections I will cover the following topics in detail:

(a) SMWBM development and application;

(b) Calculation of 7DMALF and allocation limits;

(c) Irrigation demand analysis;

(d) Irrigation restriction analysis; and

(e) Low-flow analysis.

SMWBM development and application

25. Flow generation was estimated based on soil type from the Fundamental Soils Layer (**FSL**), and a 47-year record (1972-2018) of climate data obtained from the NIWA Virtual Climate Station Network (**VCSN**).

26. Key inputs to the SMWBM, specifically soil permeability (**ZMAX**) and subsoil drainage (**FT**) were based on area weighted averages of FSL soil properties on horticultural lands as identified in the Land Cover Database.

27. The soil moisture storage capacity (ST parameter), was based on water holding capacities for Canterbury soils compiled by Trevor Webb (1995) (http://soilphysics.okstate.edu/S257/fl/drainage/awc.html). SMWBM inputs were determined using an area weighted average based on FSL soil types.

28. The above parameters, as well as several others described in **Appendix A** were used to generate daily flow produced per unit area for each study area. Results were multiplied by the study area to calculate total flow.

Calculation of 7DMALF and allocation limits

29. Simulated flow results were evaluated based on rules in PC7 pertaining to the determination of allocation limits and minimum flows. Specifically, Rule 5.123 of the LWRP states that minimum flow is 50% of 7-day Mean Annual Low-Flow and that the allocation limit is 20% of 7DMALF.

30. It was assumed that 50% of the allocation limit was to be used for horticultural purposes. Under current land use, horticultural water use accounts for less than 50% of available allocation in the Canterbury Plains. However, this value was used to test effects at a level that accounts for the potential expanded horticultural development.

31. Rootstock survival water requirements were calculated in previous analyses at 25% of the peak application rate (**PAR**) in Northland and Bay of Plenty[1]. Values lower than this caused the wilting point to be reached and therefore crops died, whereas values above this maintained production as well as plant survival. The rootstock survival allowance of 25% PAR equates to 12.5% of the total allocation limit.

32. The rootstock survival allocation is not in addition to the total allocation limit. It is a portion of the total allocation limit that is available to use for rootstock survival under low-flow conditions. The minimum flow is the threshold where access to the total limit is restricted, and growers only have access to the portion of the limit permitted for rootstock survival, equivalent to 25% of PAR.

33. The allocation required for rootstock survival under the proposed guidelines is equivalent to 2.5% of 7DMALF.

34. SMWBM outputs were used as the basis for predicting flow that would be generated within each study area. These data sets were used to determine minimum flow, allocation limits, and

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[1] Statement of Evidence by Nicholas Ashley Conland for Horticulture New Zealand in the Matter of the Hearing of Submissions on Bay of Plenty Regional Council's Proposed Plan Change 9 (Version 6) dated 15 March 2018.

rootstock protection water following the guidelines provided in the preceding paragraphs.

35. Flow assessment results for the two study areas are shown in **Table** ***1***.

Table 1. Management criteria for study areas based on simulated flows.

Analysis Parameter	Ashley Study Area	Temuka Study Area
Study area (ha)	4,033	23,136
7 Day MALF (L/s)	159.4	829.4
Minimum flow (L/s)	79.7	414.7
Allocation limit (L/s)	31.9	165.9
Horticultural allocation limit (L/s)	15.9	82.9
Root stock survival allocation (L/s)	4.0	20.7

Irrigation demand analysis

36. This section describes the process of calculating irrigation demand for the two study areas.

37. The SMWBM was also used to estimate daily irrigation demand assuming a representative crop (i.e. apples, cherries) with an annually averaged crop coefficient of 1.0.[2]

38. The irrigation demand is based on the assessment of the soil moisture deficits for horticultural land as determined from the following SMWBM input parameters:

(a) critical deficit (**CD**) is the soil moisture level where irrigation is commenced;

(b) allowable deficit (**AD**) is the soil moisture level where irrigation is ceased; and

(c) wilting point is the soil moisture level at which crops die.

39. The SMWBM has an optimisation function which iteratively determines the minimum irrigation rate required to maintain

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[2] Crop coefficient varies by season, climate and ground cover. However, 1.0 was determined to be representative for common horticulture crops.

soil moisture above the wilting point threshold with the given CD and AD inputs.

40. Daily irrigation demand per unit area is calculated by the SMWBM based on the optimised application rate and frequency required to maintain soil moisture at a level sufficient for horticultural production over the simulation period.

41. Daily irrigation demand was estimated for each study area by multiplying daily irrigation depth, as determined by SMWBM outputs, by the horticultural area within the study area as per the Land Cover Database. These data sets were used to calculate total daily and yearly irrigation demand for each study area.

42. For both study areas, SMWBM outputs were compared to the range of irrigation demand suggested in the Irrigation Reasonable Use Database (http://mycatchment.info/) for several crops grown on the Canterbury Plains, including apples, stone fruit, and olives. Of these crops, stone fruit requires the most water, apples require somewhat less, and olives considerably less than the others. Based on this information apples were used as a point of reference for ensuring that the simulated annual water demand aligned with values in the database.

Irrigation restriction analysis

43. In this section I review the frequency where irrigation restrictions would apply based on the rules in the PC7.

44. The 47-year data set applied in the SMWBM simulation was analysed to determine the total number of days over the 47-year historical sequence, and days per year, where water take restrictions would apply based on simulated flow rates. The maximum number of consecutive restriction days were also assessed.

45. The results are shown in **Table 2**, with values in brackets relating to the annual average figure. The restriction days counted in **Table 2** only include days where SMWBM results indicate that irrigation would be required. Low flow days that occurred outside of irrigation season were not counted.

Table 2. Analysis of days with restricted allocation due to low-flows (annual average in brackets).

Analysis Criteria	Ashley Study Area	Temuka Study Area
Full restriction days (days/yr)	13 (0.3)	28 (0.6)
Partial restriction days (days/yr)	38 (0.8)	65 (1.4)
Maximum consecutive restriction days	11	35

46. For the Ashley study area there was 0.3 days per year where a full restriction on water takes would be required based on flows being below the minimum level, whereas there was 0.8 days per year where a partial restriction on horticultural water takes would be required to maintain the minimum flow. Of the 41 total days where a restriction (full or partial) was required, 11 occurred in October1988.

47. For the Temuka study area there was 0.6 days per year where a full restriction on water takes would be required based on flows being below the minimum level, whereas there was 1.4 days per year where a partial restriction on horticultural water takes would be required to maintain the minimum flow. Of the 93 total days where a restriction (full or partial) was required, 35 occurred over October/November 1988, which was the longest period of consecutive days where irrigation would be restricted.

Low flow analysis

48. In this section simulated flow results are considered in the context of the effects of irrigation restrictions and rootstock survival on low-flow recurrence intervals (**RI**).

49. The SMWBM results were used to assess flows under several alternative scenarios. These were:

1. Naturalised conditions - no irrigation;
2. Restricted Irrigation - minimum flow restrictions applied;
3. Restricted Irrigation & rootstock survival - minimum flow restrictions applied with rootstock survival allocation; and
4. Unrestricted Irrigation - irrigation applied without minimum flow restrictions.

50. The number of days below minimum flow for each scenario are summarised for each study area in **Table 3**. For this assessment, flow rates were considered without regard to daily irrigation demand (i.e. all days where flow was below the minimum threshold were counted).

Table 3. Days below minimum flow with and without restrictions and rootstock survival.

Location	Analysis Criteria	Days below minimum flow			
		Naturalised	Restricted Irrigation	Restricted Irrigation & Root Stock Survival	Unrestricted Irrigation
Ashley Study Area	Total (47 yr simulation)	33	33	37	71
	Annual average	0.7	0.7	0.8	1.5
	Annual maximum	15	15	16	18
Temuka Study Area	Total (47 yr simulation)	33	33	38	98
	Annual average	0.7	0.7	0.8	2.1
	Annual maximum	19	19	21	38

51. **Table 3** shows that Restricted Irrigation does not affect the number of days where flow is below the minimum because the restrictions only apply for low-flow times. With water abstracted for rootstock survival there are a few occasions where the extra abstraction decreases flow slightly below the minimum. Over the 47-year simulation period this occurs for a total of four days for the Ashley study area and five days for the Temuka study area.

52. By comparison, irrigation abstractions in the Unrestricted Irrigation scenario increased the number of days below the minimum flow threshold over two-fold in the Ashley study area and nearly three-fold in the Temuka study area relative to Naturalised or Restricted Irrigation scenarios.

53. The low-flow RI of 7-day averaged flow was evaluated for the four scenarios to determine the relative effects of applying minimum flow restrictions and rootstock survival. The results are shown for the Ashley study area in **Figure 2** and for the Temuka study area in **Figure 3**.

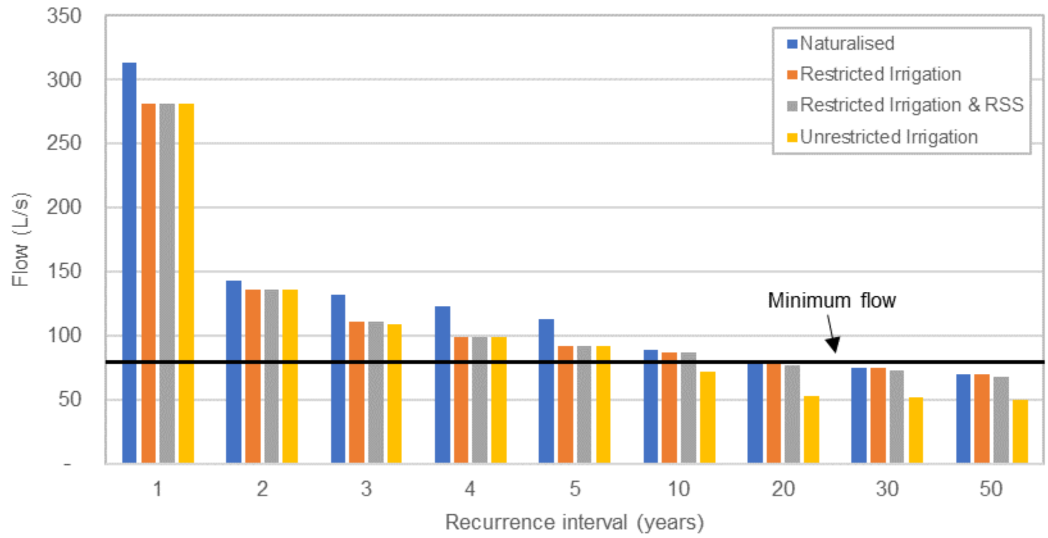


Figure 2. Recurrence interval for annual minimum flow in the Ashley study area.

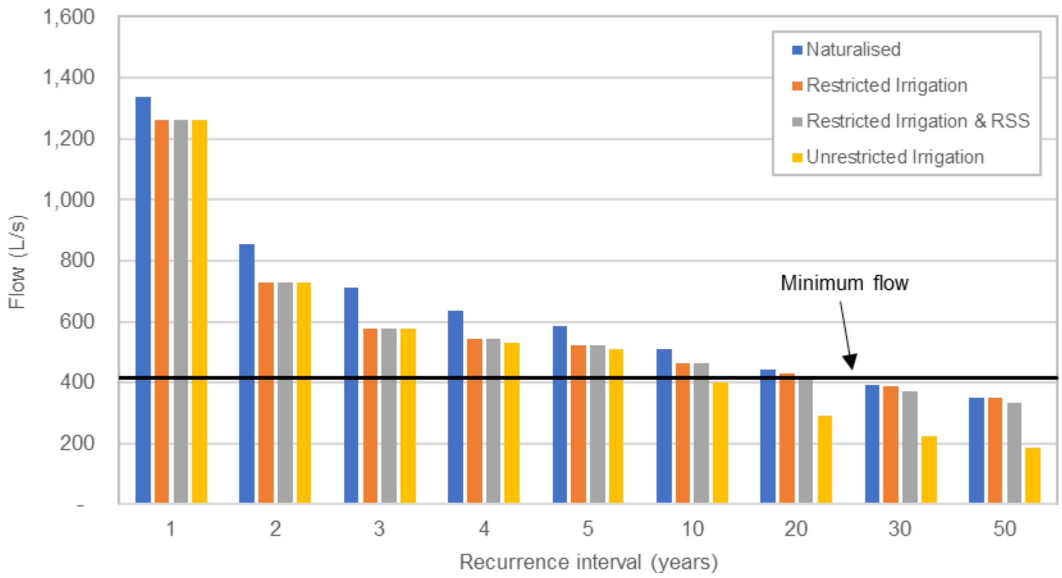


Figure 3. Recurrence interval for annual minimum flow in the Temuka study area.

54. **Figure 2** and **Figure 3** show that for both study areas the annual minimum flow is at approximately the minimum flow rate once every 20 years (20 year RI) in the scenario with naturalised conditions.

55. When the annual low-flow is greater than the minimum flow threshold, irrigation reduces flow equally in the three scenarios where it is applied up to the five year RI.

56. Flow conditions with RIs of 10 years or greater are significantly less in the Unrestricted Irrigation scenario because abstractions are not limited by flow conditions.

57. With irrigation restrictions at times of low-flow there is no difference between irrigated and naturalised flow levels.

58. Using rootstock survival has no impact on the one in ten year low flow (10 year RI) relative to Restricted Irrigation without rootstock survival. The lowest RI for a flow where rootstock survival is predicted to be necessary is 16 years.

59. Abstracting water at the rate determined necessary for rootstock survival causes less than minor effects on flow conditions.

RESPONSE TO SECTION 42A OFFICERS REPORT REGARDING HORTNZ SUBMISSION

60. The following paragraphs directly address amendments to provisions in PC7 that have been submitted by HortNZ. These items are addressed with regard to decisions in the S42A officers report (**s42A Report**) issued by ECan.

61. The amended versions submitted by HortNZ are as follows (amended text is underlined):

(a) Provision 08.04.12 (Pertains to surface water abstraction in the Waimakariri Sub-region)

> 'Avoid flows in surface waterbodies falling below the minimum flows in Tables 8-1 and 8-2 due to water abstraction, by implementing Waimakariri pro-rata partial restrictions on all abstractions except abstractions for stock drinking water, rootstock and crop survival water and community water supply purposes.'

(b) Provision 08.04.18 (Pertains to water transfers in the Waimakariri Sub-region)

> 'requiring, in over-allocated Surface Water Allocation Zones and except where the water is to be used for community supply ~~or~~, stock drinking water, and rootstock and crop survival water that 50 percent of the water proposed to be transferred is surrendered and not re-allocated.'

(c) Provision 14.04.13.b (Pertains to water transfers in the Orari-Temuka-Opihi-Pareora Sub-region)

> 'requiring in over-allocated surface water catchments and groundwater allocation zones and except where the water is to be used for community supply ~~or~~, stock drinking water, rootstock

> <u>and crop survival water</u> that a portion of water to be transferred is surrendered that is proportionate to the status of over-allocation in the catchment, up to a maximum of 75%; and'

62. Amendment 08.04.12 was not accepted in the s42A report for the reason that it allows for flows to be reduced below the minimum flow threshold.

63. In my opinion the amendment should be accepted for the following reasons:

    (a) Providing for rootstock survival is consistent with the NPSFM. The volume allocated for rootstock survival is within the allocation limit, it is not an additional allocation. The purpose of minimum flows within the NPSFM is a point at which allocation limits are restricted. The restriction can be a point where some takes are reduced or required to cease outright. The purpose of the volumetric take limit and the minimum flow level is together to manage impacts on flow regimes and associated ecosystem health.

    (b) As noted in paragraph 57, restricted irrigation based on minimum flow thresholds is effective in preserving instream flow during low flows periods, regardless of rootstock survival abstractions.

    (c) Paragraph 58 above concludes that rootstock survival allocation will only cause the flow to fall below the minimum threshold on average once every 16 years.

    (d) Paragraph 33 also concludes that rootstock survival allocation amounts to 2.5% of 7DMALF, so even when rootstock survival is used the impact effect on flow is minimal.

64. The proposed amendment to 08.04.18.b was not accepted in the s42A report. The amended provision (as amended in the report) is shown below with changes in red:

> <u>b. requiring, the surrender of water in over-allocated Surface Water Allocation Zones</u>~~, and except where the water is to be used for community supply or stock drinking water, that 50 percent of the water proposed to be transferred is surrendered and not re-allocated~~

65. In my opinion, the changes to the policy in the s42A report effectively eliminates leeway for water to be used for beneficial purposes if the zone is over allocated.

66. It is my view that this does not account for the fact that rootstock survival requires a small amount of water, that is within the reasonable use limit for an activity, and only on rare occasions, as shown in paragraphs 33, 50, and 58. In addition, due to irrigation restrictions other water users will not be exercising their water rights during low flows when rootstock survival would be required, therefore, water use would be low.

67. The proposed amendment to 14.04.13.b was not accepted in the s42A report. The amended language is shown below with changes in red:

> b. requiring in over-allocated surface water catchments and Groundwater Allocation Zones, ~~and~~ except where the water is to be used for community supply or stock drinking water, ~~that~~ a portion of water to be transferred is surrendered that is proportionate to the status of over-allocation in the catchment, ~~up to a maximum of 75%; and~~

68. Rootstock survival water is excluded in the amended text. Given the minimal requirements for rootstock survival (paragraph 35 and 50) and less than minor effects (paragraph 58), relative to the benefit of protecting viability for horticultural enterprises in Canterbury, it is my opinion that rootstock survival water should be included as part of the design of the limitations on water transfers in over allocated catchments.

69. Limiting rootstock survival water allocations, as stated in the policy suggested in the s42A report, would be likely to prevent the rootstock survival water applications from achieving their intended goal of keeping the crops alive.

70. The risk entailed in operating a horticultural enterprise without provision for rootstock survival water in drought conditions make horticulture unviable as there is no alternative to water to protect crops during a drought.

CONCLUSIONS AND RECOMMENDATIONS

71. WWLA has undertaken an assessment of study areas in the northern and southern portions of the Canterbury Plains, adjacent to the Ashley and Temuka Rivers, respectively. The aim of this assessment was determining the effects of abstracting water for rootstock survival during times of drought.

72. The SMWBM was used to simulate flow conditions generated over the study areas over a 47-year period. Results were used to calculate 7DMALF and allocation levels in accordance with Section 5.123 of the Proposed PC7.

73. Based on the proposed guidelines for rootstock survival allocation levels 2.5% of 7DMALF would be required to sustain crops through low flow periods where irrigation would otherwise be restricted. This level of abstraction would not be expected to cause significant effects beyond those already associated with low flow conditions.

74. SMWBM results indicated that rootstock survival water would only be required once every 16 years.

75. Based on the evidence presented in this analysis, I recommend that the HortNZ submissions pertaining to rootstock survival be included in the relevant provisions of PC7 as specified above in paragraphs 61 through 64.

76. In my view the amendments to PC7 provisions 08.04.12, 08.04.18, and 14.04.13 that have been proposed by HortNZ are appropriate. This conclusion is based on our assessment that the effects of allowing 2.5% of 7DMALF to be abstracted for rootstock survival in times of drought are less than minor relative to the benefit of supporting the viability of horticultural development.

Jacob Scherberg

17 July 2020

Appendix A: Soil Moisture Water Balance Modelling

To develop a detailed understanding of flow generation and irrigation demand, daily water requirements for each irrigation cycle were calculated using the irrigation module of the SMWBM. In essence, the model informs the irrigation return period given the prescribed application depth and criteria for wilting point, minimum allowable soil moisture (or soil moisture deficit), and allowable soil moisture deficit where irrigation ceases (fill point). The irrigation return period is typically greater in the shoulder periods than during peak summer months.

A schematic diagram of SMWBM inputs is shown in **Figure 4** and a screen shot of the user interface is shown in **Figure 5**. The primary parameters and associated values used in the model are shown in **Table 4**.

The SMWBM was run using the optimisation feature, which seeks the minimum irrigation peak application rate (PAR) required, while still maintaining soil moisture levels above the crop wilting point, though an allowance for a percentage of days below the wilting point can be set in the user interface. By minimising the PAR, this inherently maximising water use efficiency.

Daily rainfall and evaporation data applied in the SMWBM from 1972 through 2018 were obtained through the Virtual Climate Station Network (VCSN) produced by NIWA. Station numbers19945 and 15285 were used for the Ashley and Temuka study areas, respectively. **Figure 6** shows the annual distribution of mean monthly rainfall and evaporation, which highlights that in typical years evaporation exceeds Rainfall from October through to March.

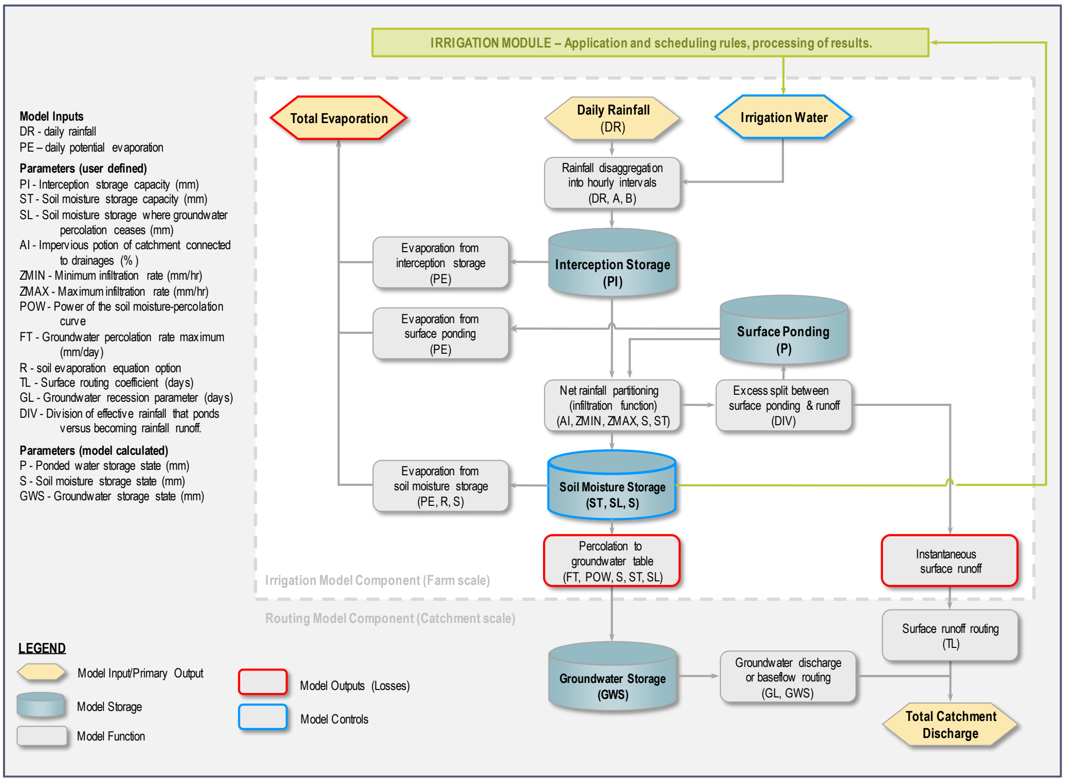


Figure 4. Flow diagram of the SMWBM structure and parameters.

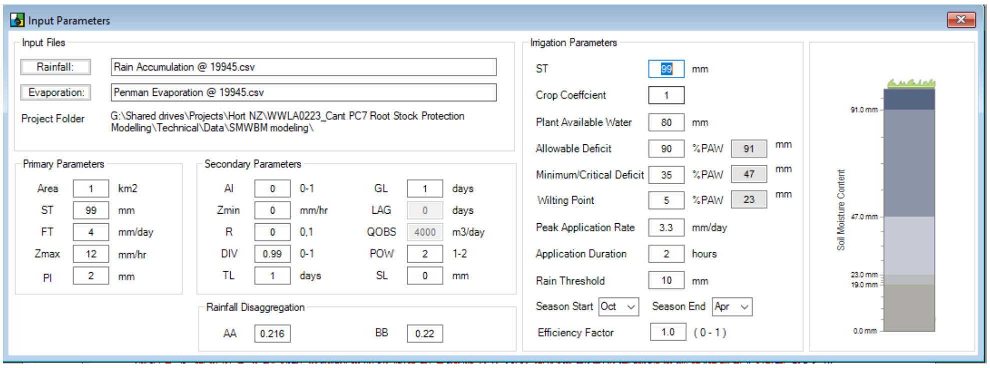


Figure 5. User interface of the SMWBM Irrigation Module.

Table 4. SMWBM parameter definitions and values.

Parameter	Description	Soil type	Values	Basis of Values
Maximum Soil Moisture Content (ST)	The capacity of water in mm in the soil at field capacity.	Ashley	99	ST is approximately equivalent to root zone depth divided by soil porosity. Values were taken from area weighted averages from based on horticultural soil types (http://soilphysics.okstate.edu/S257/fl/drainage/awc.html).
		Temuka	133	
ZMAX (mm/hr)	Maximum infiltration rate.	Ashley	12	ZMAX is the nominal maximum infiltration rate in mm/hr used by the model to calculate the actual infiltration rate ZACT. ZMAX regulates the volume of water entering soil moisture storage and the resulting surface runoff. ZMAX was based on area weighted average for FSL soil properties on horticultural land.
		Temuka	10	
FT (mm/day)	Sub-soil drainage rate from soil moisture storage at full capacity.	Ashley	4.0	Together with POW, FT (mm/day) controls the rate of sub-soil drainage from the soil moisture storage zone. FT is the maximum rate of drainage from the soil zone occurring at field capacity. The actual drainage rate reduces according to a power function as soil moisture content decreases. FT was based on area weighted average for FSL soil properties on horticultural land.
		Temuka	2.9	
Plant Available Water (PAW)	The amount of water physically accessible by the plants in the root zone in mm.	Ashley	90	PAW values were taken to be equal to representative values in the irrigation use database.
		Temuka	100	

Parameter	Description	Soil type	Values	Basis of Values
Allowable Deficit (AD) (%of PAW)	Soil moisture level where irrigation ceases.	Ashley	90%	To avoid flooding and surface runoff, soil moisture levels during irrigation should not exceed 90% of field capacity.
		Temuka	90%	
Minimum / Critical Deficit (CD) (% of PAW)	Percentage of PAW at which further drying of soil would start to have an impact on plant growth rates, and hence CD represents the soil moisture level at which irrigation commences.	Ashley	35%	The rule of thumb for critical deficit is 50% of PAW. However, a grower aiming to maximise crop yield may want a small critical deficit of only 20% (80% PAW). A balance is also required between a small critical deficit (high soil moisture levels) and water wastage, which results under high moisture conditions when rainfall occurs during summer. Through trial and error, we have used CD values of between 30 - 40% PAW.
		Temuka	35%	
Wilting Point (% of PAW)	Percentage of PAW at which soil moisture is not accessible to plants and crops die.	Ashley	5%	Judgement based on previous modelling experience.
		Temuka	5%	
Maximum daily irrigation depth (mm/day).	Optimised peak application rate.	Ashley	3.3	Selected through optimisation target of minimisation in losses, while maintaining moisture levels at or above the CD. Note. This is the amount of irrigation water reaching the soil surface, which is less that the amount applied by the irrigator *per se*. due to application inefficiencies (losses).
		Temuka	2.8	
Crop coefficient (-)	Actual evapotranspiration of the crop relative to PET	Ashley & Temuka	1.0	The applied value was representative of a mid-range value for apples and stone fruit with some ground cover
Application Duration (hours)	Duration in hours over which the peak application depth is applied	Ashley & Temuka	2	Data estimated
Rain Threshold (mm)	Daily rainfall total when a grower would choose not to irrigate.	Ashley & Temuka	10	Judgement

Parameter	Description	Soil type	Values	Basis of Values
Season	Irrigation season start and finish	Ashley & Temuka	October – April	Typical extent of summer irrigation season

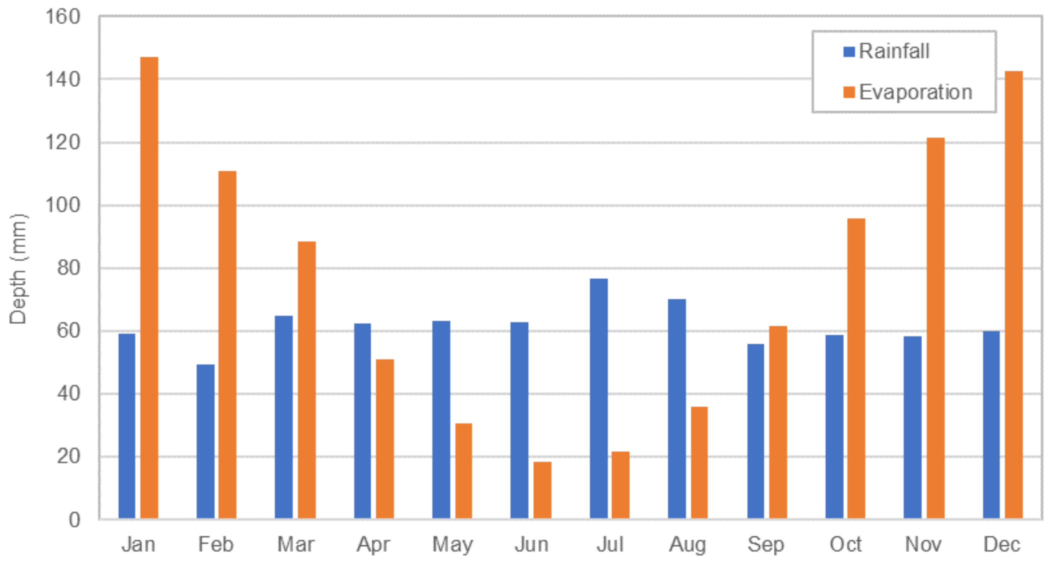
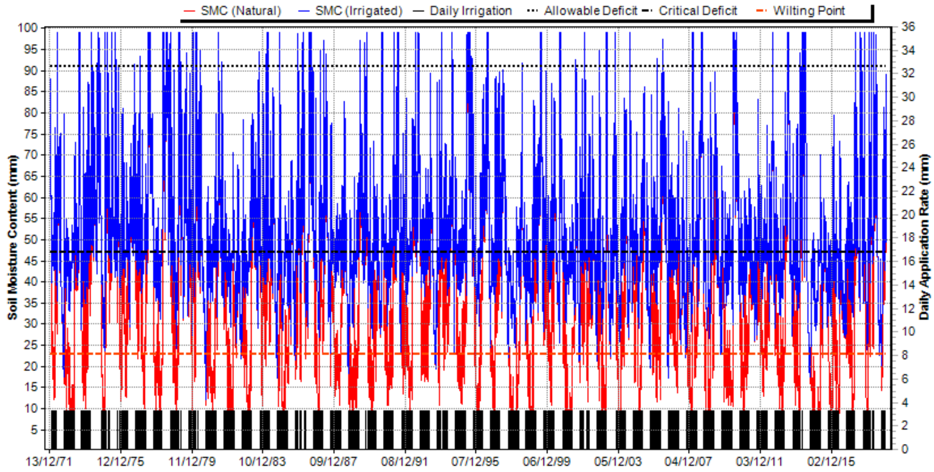


Figure 6. Average monthly rainfall and evaporation for VCSN Station 19945 (1972-2018).

Results

The simulated soil moisture content with/without irrigation are shown for **Figure 7A** for the Ashley study area and in **Figure 7B** for the Temuka study area. The SMWBM outputs show soil moisture content without irrigation and with irrigation. The key difference between profiles is soil moisture content is maintained above the critical deficit using irrigation from October through April.

A. Ashley



B. Temuka

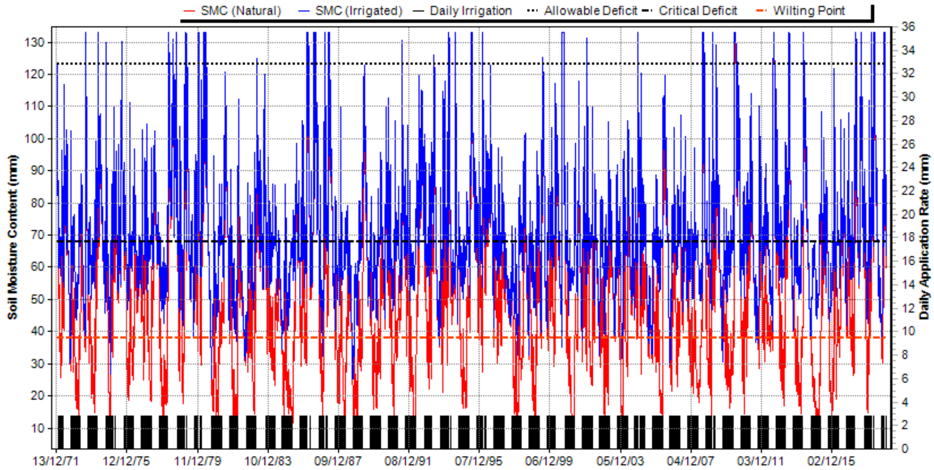


Figure 7. Irrigation scheduling / demand results for three soil types.

As indicated above, the daily peak application rate was automatically optimised through a set of simulations that aimed to minimise the water losses through surface runoff and sub-soil drainage, while maintaining a soil moisture content that is above the plant wilting point. The optimised peak daily application rates based on plant/soil demand only[3] for the various soil types are as follows:

- Ashley – 3.3 mm/day;
- Temuka – 2.8 mm/day.

Total number of days requiring irrigation for each soil type and water year as calculated by SMWBM are shown in **Figure 8**. On average, 5% more irrigation was required for the Temuka study are than for the Ashley study area.

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[3] **Note:** These figures show the plant/soil demand as calculated by the SMWBM. System distribution and application efficiencies for orchards typically mean additional water is required at the point of take (typically ~10%).

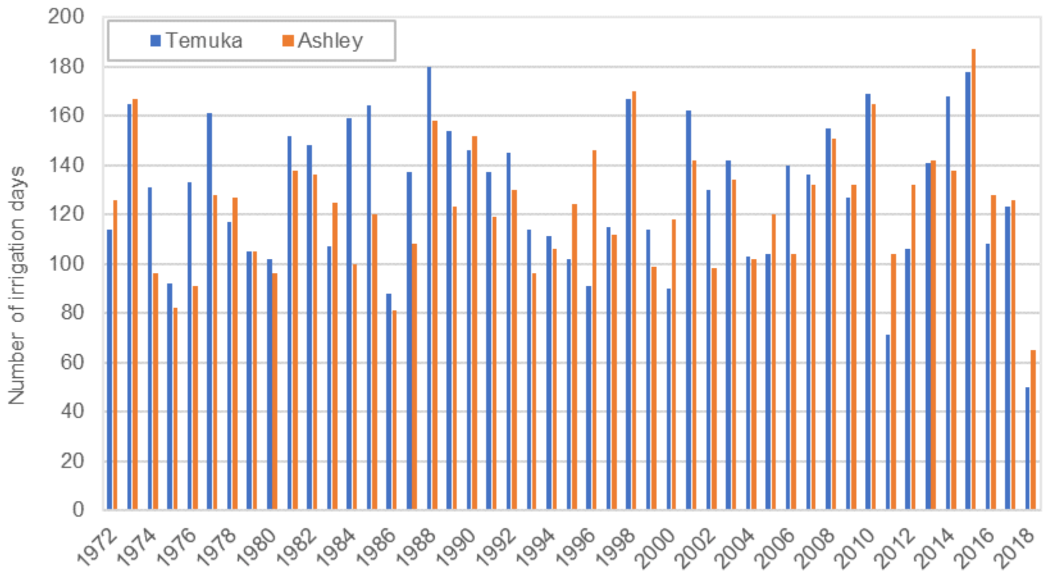

Figure 8. Annual number of irrigation days required based on SMWBM simulation.