Hydrological Assessment of Dams and Irrigation of Almonds on Portions 4 and 9 of Farm 232 Redford, The Crags, Western Cape.

FINAL REPORT

For:

Brenda Niehaus

By:

Dr. J.M. Dabrowski

Confluent Environmental

November 2021

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14 November 2021

EXECUTIVE SUMMARY

Four dams have been constructed on two non-perennial watercourses (two dams on each watercourse) that flow through Portions 4 and 9 of the Farm Redford 232. The dams store surface runoff for the purposes of ultimately irrigating 20 hectares of almonds. The watercourses that these dams are located in ultimately discharge into the Whiskey Creek River, which is an important tributary of the Keurbooms River.

As part of the Water Use License Application, the Breede-Gouritz Catchment Management Agency (BGCMA) requested that a hydrological assessment be undertaken to:

1. Determine estimated surface water flows into the dams,
2. Estimate the water requirements for irrigating 20 hectares of almond trees under drip irrigation;
3. Determine the appropriate total storage requirement for irrigating 20 hectares of almonds for the four dams; and
4. Assess the impact of storage and abstraction from the dams on downstream water resources.

Three dams (Dam 2, 3 and 4) are located on Portion 4 of Farm 232 and one dam (Dam 1) on Portion 9 of Farm 232. All dams are instream, with Dam 1 and Dam 2 located on one non-perennial drainage line (Eastern Drainage) and Dam 3 and Dam 4 located on a separate non-perennial drainage line (Western Drainage). Both drainage lines ultimately flow into the Whiskey Creek River.

For the purposes of this study, the affected catchment area has been divided into three separate catchment areas:

- Redhaus East (catchment area of the Eastern Drainage),
- Redhaus West (catchment area of the Western Drainage) and
- Whiskey Creek (remaining catchment area for the Whiskey Creek River).

Numerous instream farm dams are located throughout these respective catchment areas.

For this study the calibrated WRSM2000/Pitman model for the quaternary catchment K60E (Water Resources of South Africa 2012 - WR2012 - Study) was adjusted to reflect the size and land use of the catchment area of the dams and the broader Whiskey Creek catchment, and then used to simulate the long-term present-day flow timeseries into the dams on Portions 4 and 9 and out of the broader Whiskey Creek catchment. The main findings of the study can be summarised as follows:

- The mean estimated irrigation requirements for 20 ha of almond trees under drip irrigation is approximately 40 000 m^3 per annum, with a maximum of 60 000 m^3;
- The total storage capacity of 39 000 m^3 is optimal with regards to storage of surface flows from the Redhaus catchments. Lower storage results in substantial deficits in irrigation requirements over a 50-year simulation period, while increasing dam volume does not yield a significant increase in assurance of supply that would warrant a larger dam volume;
- Supplementary irrigation from a borehole will be required, particularly during very dry periods when surface inflows will be insufficient to meet the irrigation demands;

- Storage and irrigation from Dams 1 to 4 results in a slight decrease in mean annual runoff from the Whiskey Creek catchment. Flow reductions occur during peak high flow periods, whilst no reductions are estimated to occur during low flow periods;
- Any implementation of the Reserve must focus on discharges from the lowest dam in the Whiskey Creek catchment to determine whether these flows are sufficient to meet the ecological flow requirements. Any shortfall in ecological flow requirements must be addressed through a catchment scale study that focusses on ensuring equitable releases from all farm dams located throughout the catchment area; and
- Based on the analyses presented in this report an annual abstraction of 60 000 m^3 from the Redhaus catchments and 24 000 m^3 abstraction from a borehole will ensure security of supply for irrigation of 20 hectares of almonds over the medium to long term.

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1 INTRODUCTION

1.1 Project Background

Four dams have been constructed on two non-perennial watercourses (two dams on each watercourse) that flow through Portions 4 and 9 of the Farm Redford 232. The dams store surface runoff for the purposes of ultimately irrigating 20 hectares of almonds. The watercourses that these dams are located in ultimately discharge into the Whiskey Creek River, which is an important tributary of the Keurbooms River.

As part of the Water Use License Application, the Breede-Gouritz Catchment Management Agency (BGCMA) requested that a hydrological assessment be undertaken to:

- Assess the yield of surface water flows available in the immediate catchment of the dams;
- Estimate the irrigation requirements of the proposed almond orchards and determine whether the surface water yield is sufficient to meet these requirements;
- Develop a water balance for the dam and estimate the collective storage of the four dams required to meet the irrigation requirements; and
- Assess the impacts of the dams and irrigation on flows from the catchment area and in the Whiskey Creek River

2 METHODOLOGY

Data and model configurations developed as part of the Water Resources of South Africa 2012 (WR2012) Study (Bailey and Pitman, 2016) were used to estimate hydrological flows originating from the catchment areas of the dam and furrow system, respectively. The WR2012 study developed long-term monthly time-step simulated streamflow timeseries for most quaternary catchments throughout South Africa. The timeseries represent the volume of water that was likely be produced at the outlet of each modelled quaternary catchment over a time period covering October 1920 to September 2010. The data is produced by the WRSM-Pitman Model which is a rainfall-runoff model that simulates streamflow from long-term monthly rainfall data. As part of the WR2012 Study, the outputs of the model were calibrated against measured hydrological data collected from streamflow gauging stations located throughout the country. The WR2012 therefore provides the most comprehensive database of the estimated flow volumes for quaternary catchments throughout the country. The WRSM2000-Pitman Model modelled all land and water use activities upstream of the flow gauging stations to estimate the reduction in streamflow due to human development over time. The model can therefore be used to simulate Present-Day (PD) flow conditions over the long-term and to assess the impact of additional activities (e.g. construction of a dam) on hydrological flows over the long term.

For this study the calibrated WRSM2000/Pitman model for the quaternary catchment K60E (as produced by WR2012) was adjusted to reflect the size and land use of the catchment area of the dams and the broader Whiskey Creek catchment, and then used to simulate the long-term PD flow timeseries into the dams on Portions 4 and 9 and out of the broader Whiskey Creek catchment. Catchment areas were determined through a hydrological analysis of a

Digital Elevation Model (DEM) for the area. The DEM was obtained from the USGS Earth Explorer website (https://earthexplorer.usgs.gov/).

2.1 Irrigation Requirements

The SAPWAT 4.0 model (van Heerden and Walker, 2016) was used to estimate irrigation requirements and the following assumptions were made in the estimation of irrigation requirements:

- Water requirements were estimated for 20 hectares of almond trees under drip irrigation;
- The default setting of 75 % was used for water distribution efficiency;
- Irrigation scheduling was set to take place when readily available water (RAW) reached 70 %; and
- Long-term 50 year climatic data (including rainfall) for quaternary catchment K60E was used in the estimation of irrigation requirements.

2.2 Farm Dam Volumes

The volumes of the dams that form the focus of this study have been surveyed and are accurate. The volumes (m^3) of farm dams located outside of the properties that form the focus of this study were estimated using the following equation:

$$Volume = A \times D \times 0.4$$

where:

A = surface area (m^2)

D = maximum depth (m)

Surface area measurements were obtained using desktop satellite imagery and Geographical Information Systems (GIS). Given that the majority of dams throughout the catchment area are relatively small, the maximum depth of each dam was estimated at 3 m.

2.3 Assumptions & Limitations

- Numerous instream farm dams and farm portions are located throughout the catchment area of the four dams that form the subject of this report and the larger Whiskey Creek River catchment. The combined storage of water in farm dams and irrigation practices per farm portion all influence flows in watercourses. It is therefore important to understand these existing impacts when determining hydrological flows throughout the catchment area. While every effort was made to determine accurate dam volumes (i.e. from the DWS Dam Safety Register), no publicly accessible records were available. Given the large scale of the catchment area as well as the number of dams located throughout the catchment, desktop estimate of farm dam volumes were made based on established surface area to volume ratios (see Section 2.2). Irrigation requirements per farm portion were estimated based on calibrated irrigation demand that had been determined for the WRSM model in the WR2012 study;
- Modelled hydrological estimates were based on rainfall data collected from 1920 to 2009. The model therefore provides a good indication of anticipated hydrological flows

associated with variations in rainfall and climate records that cover a long period of time. The model may however not account for recent shifts in rainfall volumes associated with climate change impacts that may have occurred within the last ten years.

3 CATCHMENT CHARACTERISTICS

3.1 Study Site

The dams are located on Portions 4 and 9 of Farm 232 Redford in quaternary catchment K60E (Figure 1). This catchment falls within the South-Eastern Coastal Belt ecoregion which is characterised by year-round rainfall and a mean annual precipitation (MAP) of 775 mm. Precipitation occurs throughout the year, but generally peaks from the end of winter into the beginning of summer (i.e. August to November) (Figure 2).

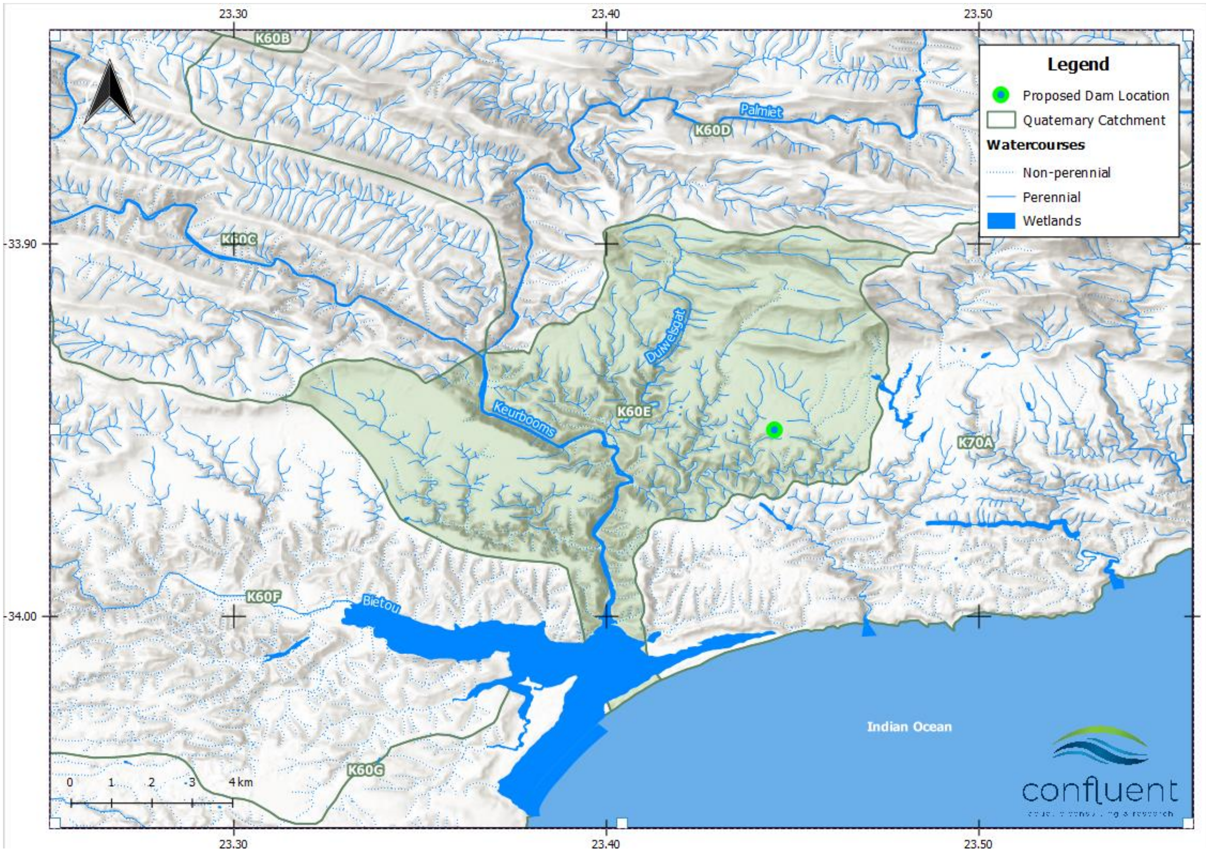

Figure 1: Location of the properties within the context of quaternary catchment K60E.

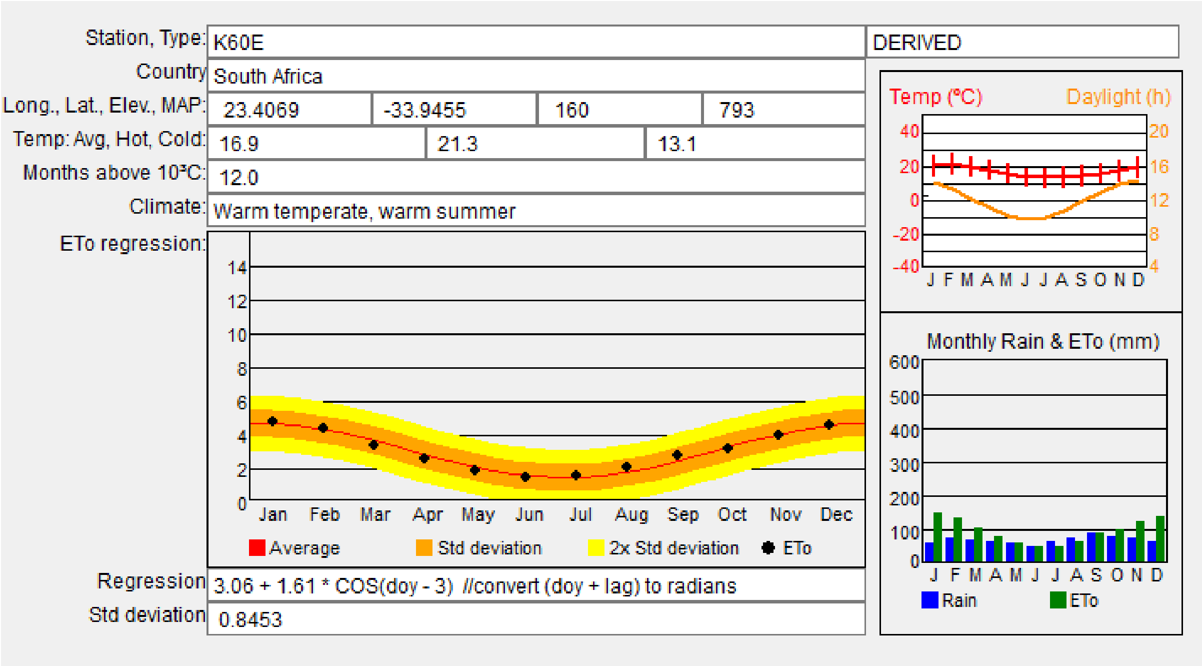

Figure 2: Summary of weather statistics for the K60E quaternary catchment (as supplied by the SAPWAT 4.0 model)

Three dams (Dam 2, 3 and 4) are located on Portion 4 of Farm 232 and one dam (Dam 1) on Portion 9 of Farm 232 (Figure 3). All dams are instream, with Dam 1 and Dam 2 located on one non-perennial drainage line (Eastern Drainage) and Dam 3 and Dam 4 located on a separate non-perennial drainage line (Western Drainage). Both drainage lines ultimately flow into the Whiskey Creek River. The volumes and surface area of each dam (at full supply capacity) are presented in (Table 1).

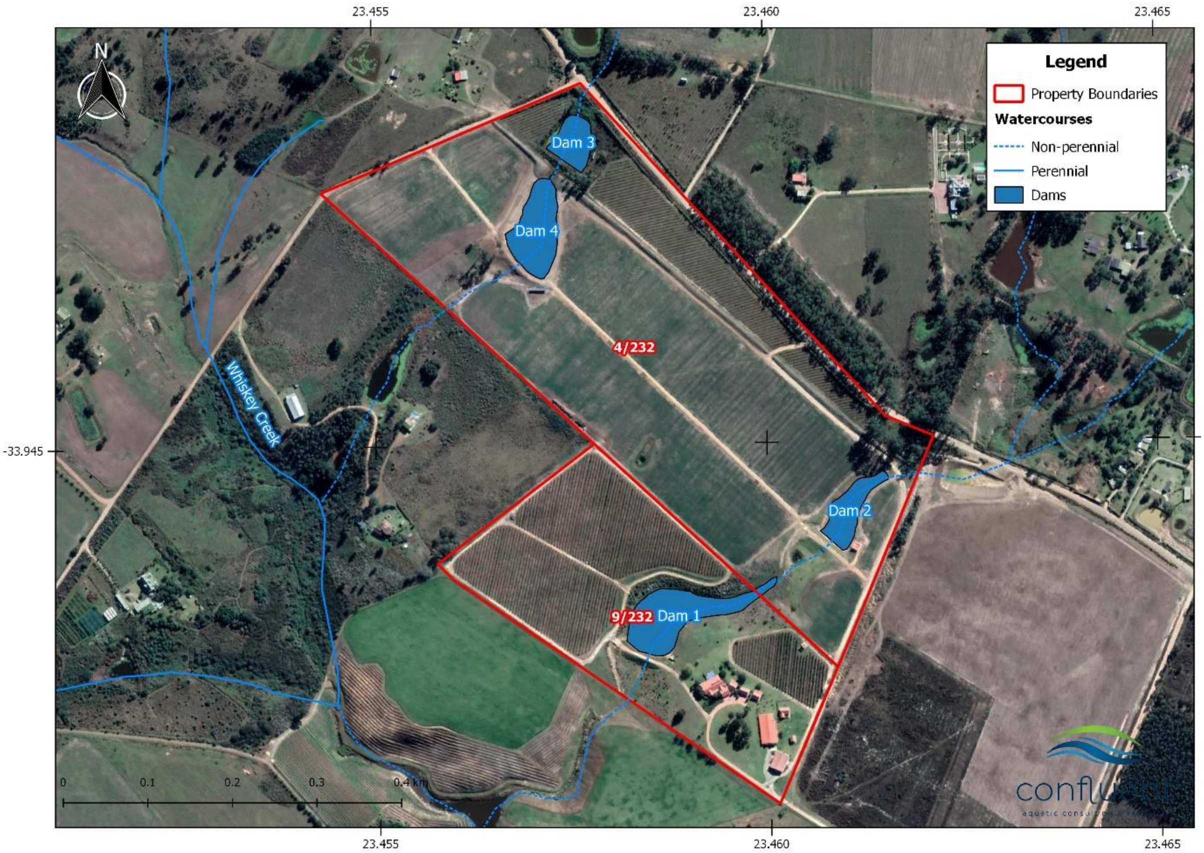

Figure 3: Map showing the locations of Dams 1 to 4 on Portions 4 and 9 of Farm 232 Redford.

Table 1: Location and dimensions of Dams 1 to 4.

Dame Name	Property	Surface Area (m^2)	Volume (m^3)
Dam 1	Portion 9 of Farm 232	7 859	17 552
Dam 2	Portion 4 of Farm 232	4 101	4 659
Dam 3	Portion 4 of Farm 232	3 067	5 805
Dam 4	Portion 4 of Farm 232	4 879	10 047
TOTAL		**19 906**	**38 066**

For the purposes of this study, the affected catchment area has been divided into three separate catchment areas (Figure 4):

- Redhaus East (catchment area of the Eastern Drainage),
- Redhaus West (catchment area of the Western Drainage) and
- Whiskey Creek (remaining catchment area for the Whiskey Creek River).

The delineated area of each catchment is presented in Table 2. Numerous instream farm dams are located throughout the study area. The total combined area and storage volume of all dams per catchment area is also presented in Table 2 (these estimates exclude the storage volume for Portions 4, and 9) (see Section 2.2 for methods). These estimated dam volumes were included in the hydrological model that was set up for the study.

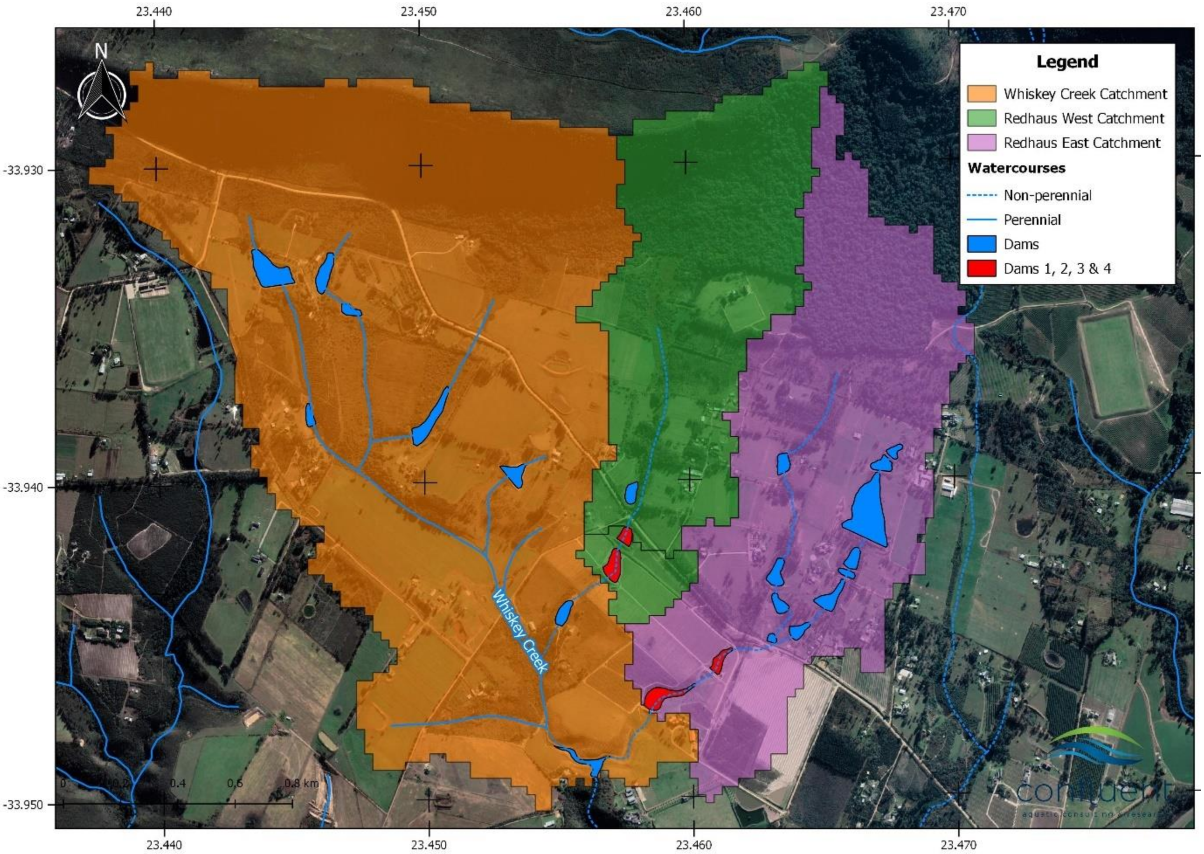

Figure 4: Delineated catchment area of the Rondebosch Furrow (green) and the proposed dam.

Table 2: Catchment area and estimated dam volums per catchment

Catchment	Area (m^2)	Total Dam Surface Area (m^2)	Total Storage (m^3)
Redhaus East	1 323 703	48 809	39 074
Redhaus West	966 605	2 000	1600
Whiskey Creek	3 034 513	30 244	24 195
TOTAL	**5 324 821**	**81 053**	**64 869**

4 WATER RESOURCES DEVELOPMENT PLAN

4.1 Water Source Analysis - Redhaus Catchments

Graphs showing the results of the hydrological flow modelling are presented in Figures 5 to 6. These graphs represent the combined inflow from Redhaus West and Redhaus East catchments into the combined storage (38 000 m^3) provided for by Dams 1 to 4. Annual flow volumes are highly variable ranging from less than 30 000 m^3 to just over 700 000 m^3 per annum with a mean annual runoff (MAR) of 163 000 m^3/annum. This represents approximately 11.2 % of the MAP. While rain typically does fall throughout the year, results show that runoff is highly seasonal with the majority of rainfall occurring during spring from August up until November. January through to April represents the low flow period.

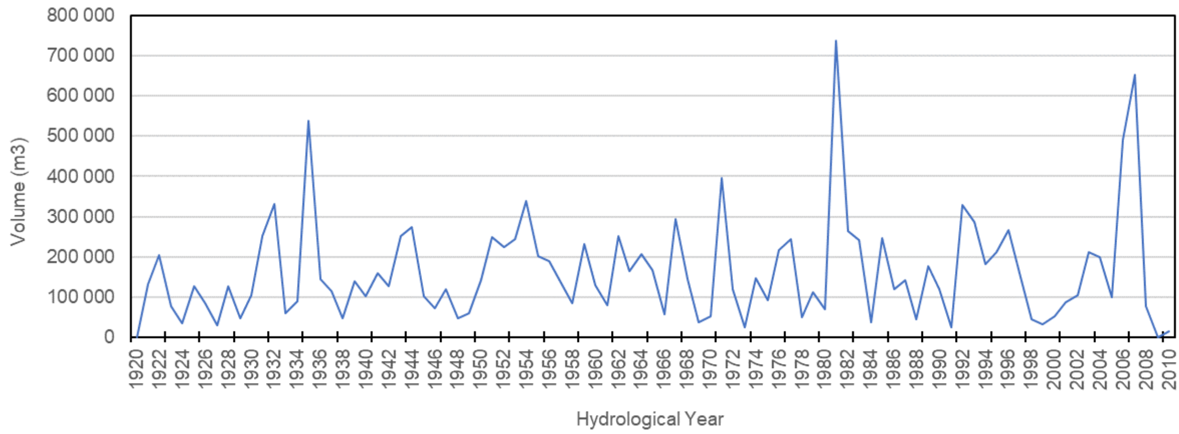

Figure 5: Annual hydrograph for the combined Redhaus East and West catchment areas.

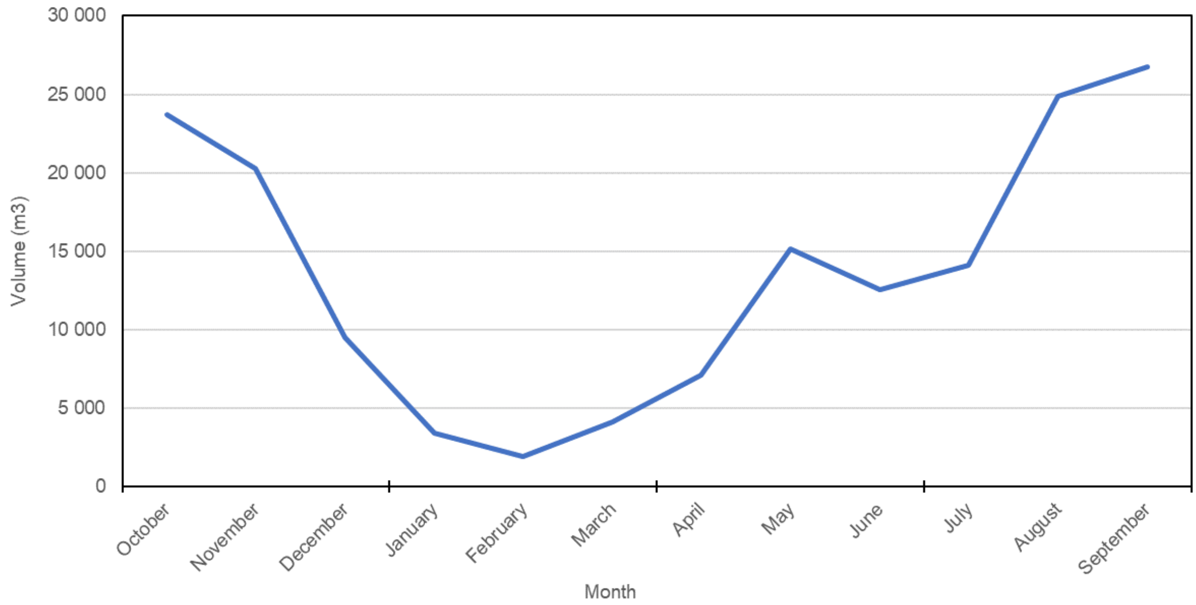

Figure 6: Mean monthly hydrograph for the combined Redhaus East and West catchment areas.

4.2 Water Requirements Analysis

Based on the assumptions described in the methodology section, the mean monthly irrigation requirements for 20 hectares of almonds under drip irrigation are presented in (Table 3 and Figure 7). These volumes are irrigation volumes that required over and above rainfall. Mean irrigation requirements are approximately 40 000 m^3 per annum, with maximum requirements totalling approximately 60 000 m^3 per annum (i.e. under below average rainfall conditions). While irrigation requirements can potentially be met by the hydrological inflows, storage of water is still required given the highly intermittent flow characteristics of the streams.

Table 3: Estimated irrigation requirements for 20 hectares of almonds.

Month	Min	0.05	0.25	Median	0.75	0.95	Max	Average
January	0	0	5000	5000	10000	15000	15000	6042
February	0	0	0	5000	5000	10000	10000	4063
March	0	0	0	0	5000	5000	10000	2604
April	0	0	0	1100	4300	7790	10000	2342
May	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	5000	104
October	0	0	0	5000	10000	10000	15000	5104
November	0	0	5000	10000	10000	15000	20000	8542
December	0	5000	5000	10000	10000	15000	30000	9792
Annual	**15 000**	**23570**	**31850**	**39800**	**45000**	**52370**	**62600**	**38592**

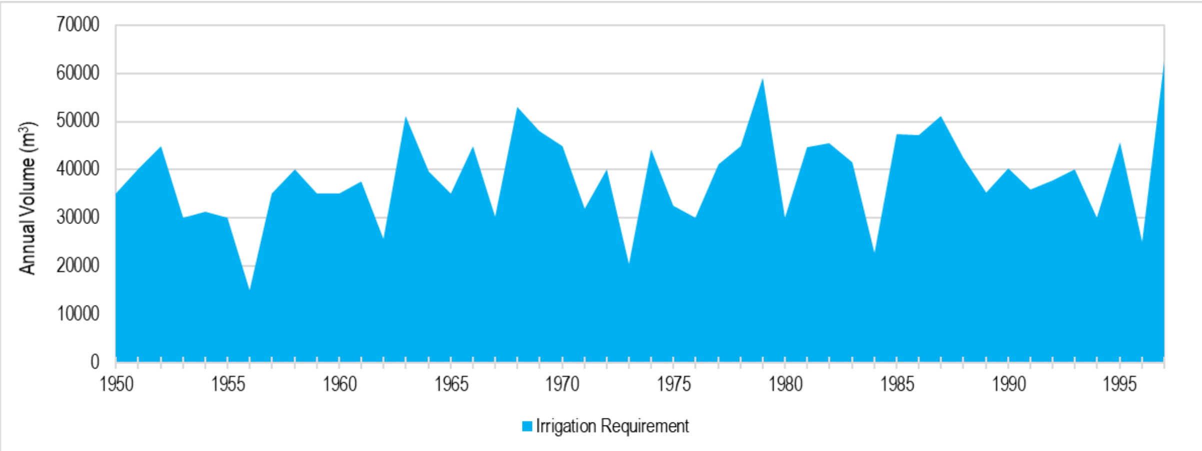

Figure 7: 50 year time-series of irrigation requirements for 20 hectares of almonds.

4.3 Water Balance

Establishment of almond orchards represents a significant financial investment. As such security of water supply, particularly during below average rainfall conditions is critical for protection of the investment. Storage of water (during high flow periods) is therefore essential to meet irrigation demands, particularly during low rainfall periods.

A detailed monthly time series water balance was therefore compiled to assess the current dam storage volume to ensure assurance of supply covering the full range of expected climatic conditions over a 50-year period. The SAPWAT model was used to produce monthly irrigation requirements using weather data (supplied with the model) covering the period from 1950 to 2000 (i.e. a 50-year period). The water balance estimated the dam volume at the end of each month taking the following into consideration:

- A maximum storage volume was defined such that the stored volume at the end of each month could not exceed this volume;

- The starting balance at each month comprised of the volume of stored water from the preceding month, and incoming monthly surface water flows (i.e. from the immediate catchment area of the dam);
- The monthly time series of surface runoff from the catchment was derived using the output of WRSM/Pitman model;
- The balance at the end of each month was calculated by subtracting the evaporative loss from the dam and the irrigation requirement for the month from the starting balance;
- The evaporative loss for each month was estimated based on the monthly evaporation and the combined surface area of all four dams. The surface area was estimated for each month assuming a surface area to volume ratio of 0.54 (as determined from the survey of the dams).
- Supply of irrigation water was derived only from surface water stored in the dam. This scenario was tested for a range of dam volumes ranging from 20 000 m^3 to 50 000m^3.

The objective of the monthly time series water balance is to ensure that there is sufficient storage so as to ensure assurance of supply over the majority of the period of the time series. Negative monthly balances imply that irrigation demands for the month exceed the total volume of water available for the month (i.e. combined volume of water stored in the dam together with incoming surface water flows and borehole allocation for the month).

Simulations of the different dam volumes show that the 38 000 m^3 provides optimal storage when taking surface flows and irrigation requirements into account. Lower storage volumes (i.e. 20 000 m^3 and 30 000 m^3) result in a marked increase in the number of deficit months and/or the % of the total irrigation requirement in deficit (Table 4 and Figure 8). Increasing the dam size to 50 000 m^3 did not however show a marked improvement in terms of deficit months and the total percentage irrigation deficit.

For all simulations there was a significant deficit over an extended dry period (1978 to 1980 - with a deficit of 62 % for a storage volume of 38 000 m^3). This indicates that during these dry periods surface flows from the catchment will not be sufficient to meet irrigation demands. The percentage deficit is very high (62 % for a storage volume of 38 000 m^3) and represents a serious risk to the survival of the trees. For this reason, supplemental abstraction from a borehole supply will be required to ensure security of supply during very dry periods.

The 38 000 m^3 scenario was therefore simulated to include supplementary borehole abstraction of 2 000 m^3 per month (or 24 000 m^3 per annum). This dramatically reduced the deficit over the dry period and reduced the overall number of months in irrigation deficit (Figure 9).

Table 4: Summary of months in deficit under different dam volumes.

Dam Volume (m^3)	Number of Months in Deficit	% of Time in Deficit	Mean Monthly Deficit (% of Irrigation Requirement)
20 000	37	6.4	56
30 000	21	3.6	53
40 000	**15**	**2.6**	**62**
50 000	14	2.4	55

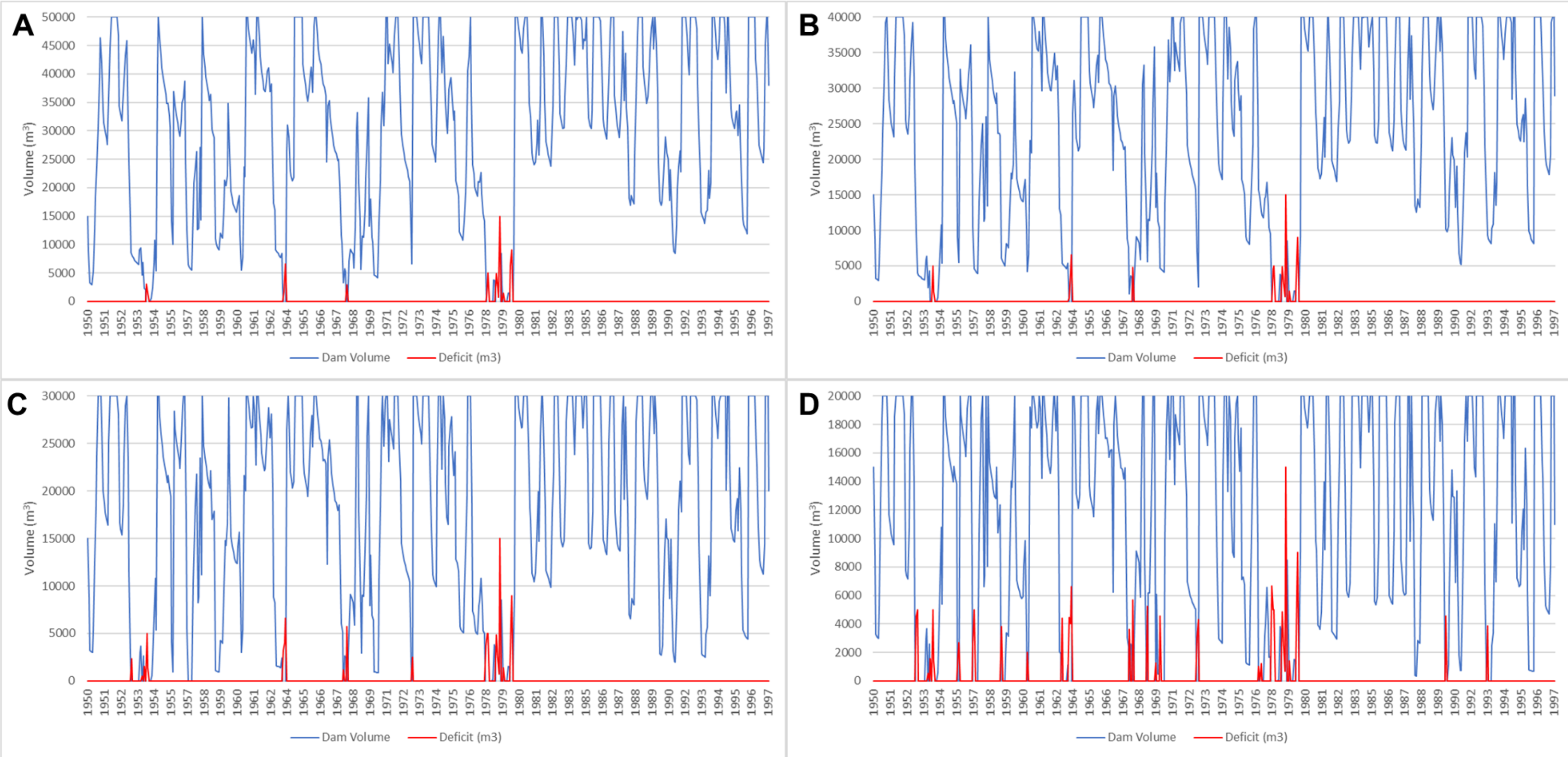

Figure 8: Graphs showing monthly dam volumes plotted against irrigation deficits for maximum dam size storage volumes of 50 000, 40 000, 30 000 and 20 000 m^3 (A, B, C and D, respectively).

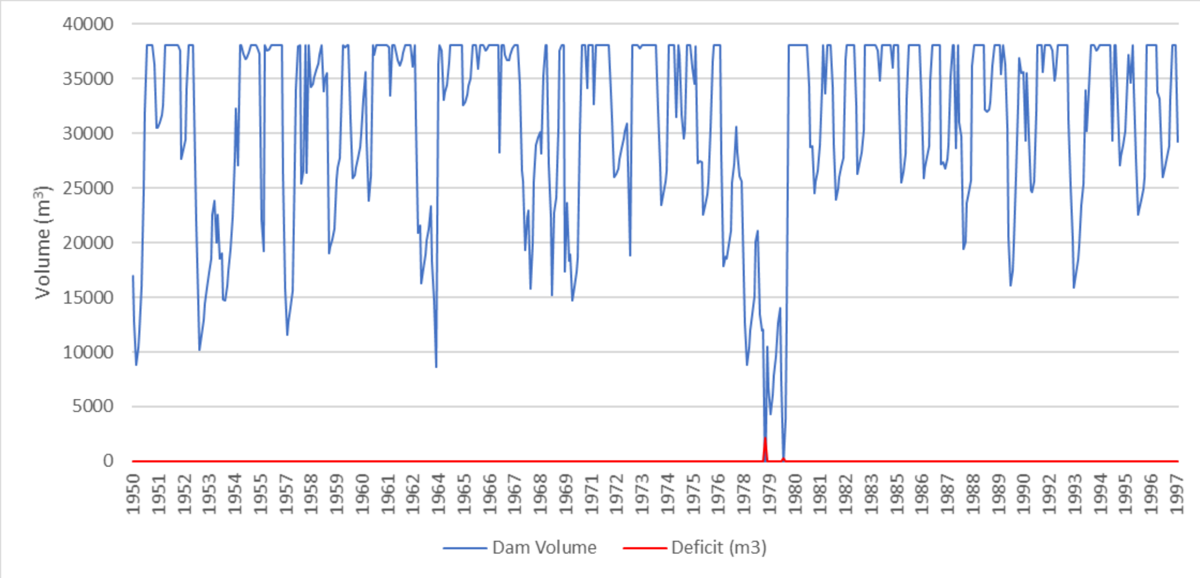

Figure 9: Graph showing monthly dam volumes plotted against irrigation deficits for a dam size of 38 000 m^3 (including supplementary irrigation of 2 000 m^3 per month from a borehole).

4.4 Impact of Dam and Irrigation on the Whiskey Creek River

Hydrological flows were modelled for Whiskey Creek downstream of the last dam in its catchment (Figure 10). These flows are representative of all runoff received from the Whiskey Creek and Redhaus East and West catchments after they exit the most downstream dam in the modelled catchment area. Flows were estimated under two different scenarios:

- **Scenario 1:** Flows were estimated **excluding** Dams 1 and 4 and the associated abstraction for irrigation of almonds (i.e. historical flows prior to the construction of Dams 2, 3 and 4).
- **Scenario 2:** Flows were estimated **including** Dams 1 to 4 and the associated abstraction for irrigation of almonds.

A graph showing mean monthly flow volumes associated with both scenarios is presented in Figure 11. From this graph it can be seen that the impact of Dams 1 to 4 (and associated irrigation) on flows in Whiskey Creek results in a slight reduction in flows during the summer high flow periods (i.e. September through to February). Flows out of the lower dam during the winter months (April to August) under Scenario 1 are very low, largely as a result of the lower rainfall over this period (see Figure 2) and the cumulative storage of water in dams located throughout the catchment area. Scenario 2 does not result in reduced flows during this low flow period.

The mean annual reduction in flows is approximately 28 000 m^3. This is less than the mean annual volume abstracted for irrigation of almonds in the Redhaus catchments (see Section 4.4). This can however be explained by the fact that a proportion of the additional flow volumes (i.e. approximately 40 000 m^3) that would ordinarily be available under Scenario 1 would still have been captured by the lower most dam in the Whiskey Creek catchment, preventing them from flowing further down into the Whiskey Creek. The net reduction in flow volumes (taking storage of the Whiskey Creek Dam into account) represents an 8 % reduction in mean annual flow volumes.

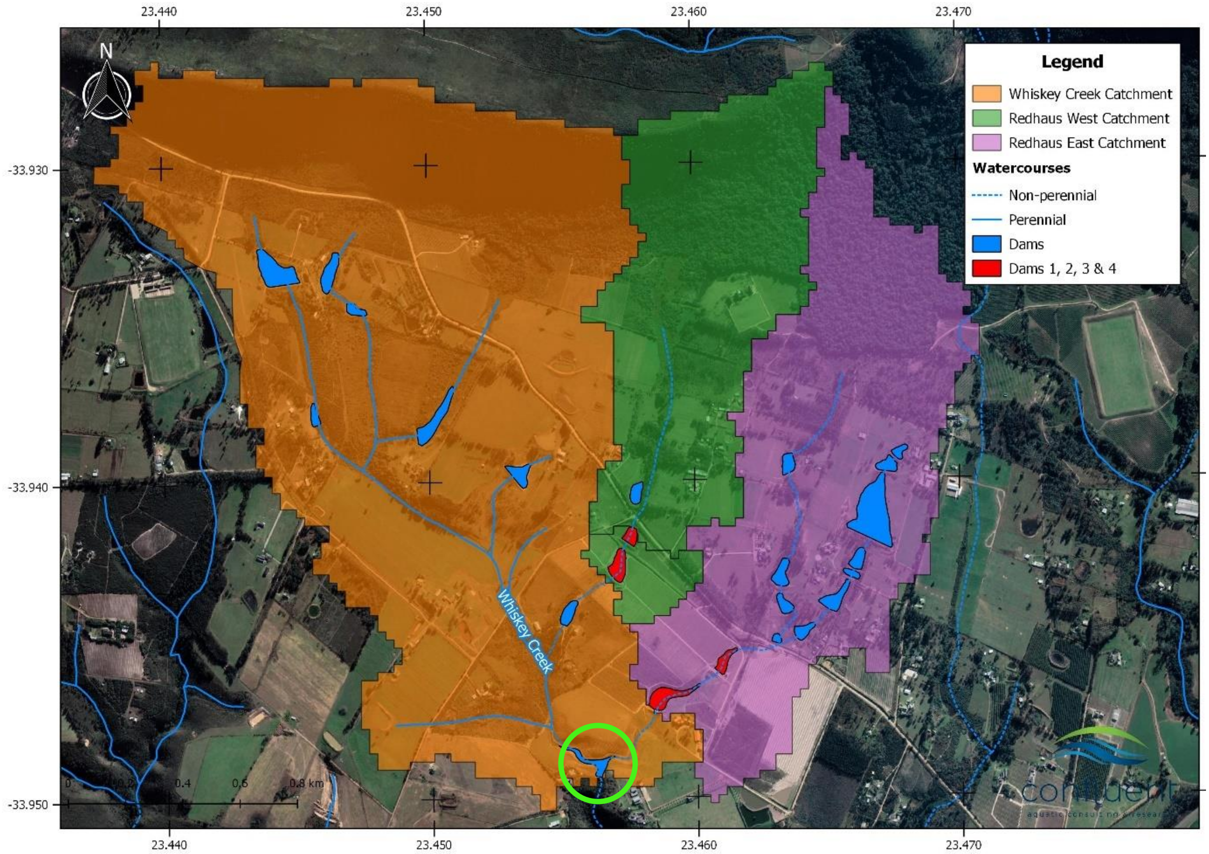

Figure 10: Map indicating the location of the lower most dam in the Whiskey Creek catchment (highlighted in the green circle)

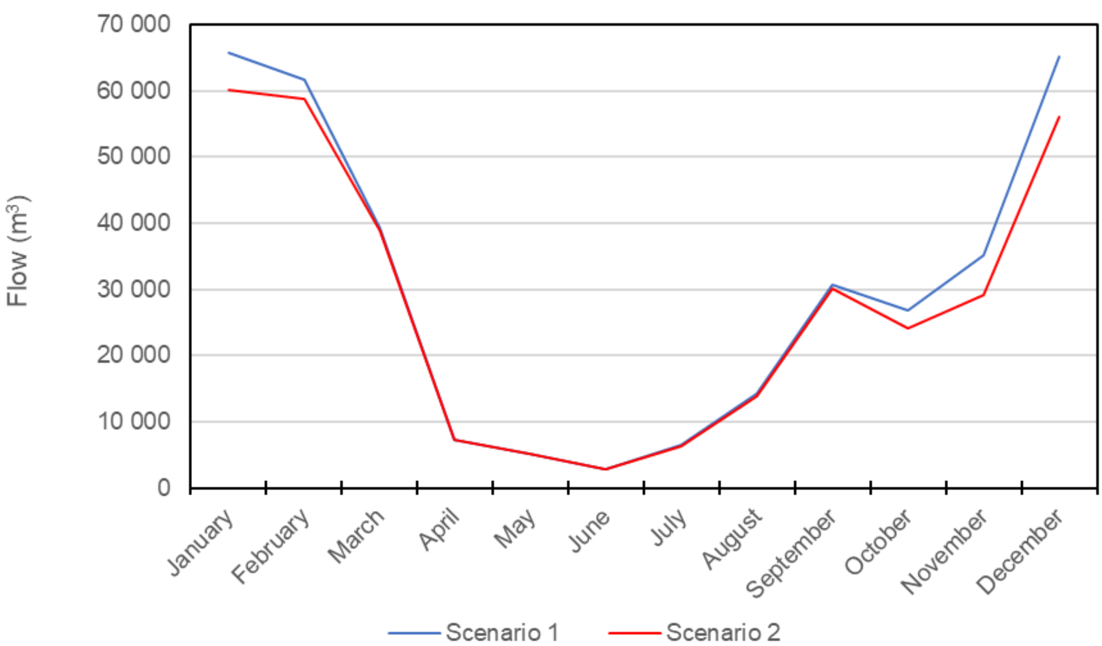

Figure 11: Mean monthly flows (1950 – 2000) for flows downstream of the lower most dam in the Whiskey Creek catchment.

4.4.1 *The Reserve & Ecological Flow Requirements*

The Reserve refers to the quantity and quality of water required to (a) supply basic human needs and (b) protect aquatic ecosystems. The ecological component of the Reserve (i.e. water to protect aquatic ecosystems), refers to water quantity and water quality within water resources, including groundwater, wetlands, rivers and estuaries.

The water quantity component for a river will typically refer to the flows and flow patterns (magnitude, timing and duration) needed to maintain a river ecosystem within acceptable limits of change, or the specified Ecological Category. The Reserve is met by purposefully releasing water from dams at critical time periods to ensure that sufficient flow or flow patterns (i.e. base flow conditions or floods) are available to meet the ecological requirements of the watercourse.

Flow from Dam 1 immediately discharges into the lower most dam in the Whiskey Creek Dam. Flow from Dam 4 immediately discharge into another instream dam on the watercourse, after which flow discharges into the Whiskey Creek River and finally into the lower most dam in Whiskey Creek Dam. From a hydrological perspective, given that the Redhaus dams discharge almost immediately into additional dams located further downstream, there is little point in implementing a Reserve for the Redhaus dams if there is no Reserve implemented further downstream of these dams (unless very sensitive aquatic habitat occurs in between the dams). Furthermore, for small river systems such as those in the Redford area, low flows and base flows are generally most heavily impacted by instream dams. In this respect, the hydrological analysis shows that storage in Dams 1 to 4 is unlikely to affect low flow volumes (Figure 11).

Any implementation of the Reserve must focus first on determining the outflows required from the lowest dam in the Whiskey Creek catchment to determine whether these flows are sufficient to meet the ecological flow requirements of the river further downstream. Any failure in meeting ecological flow requirements must be addressed through a catchment scale study that focusses on ensuring equitable releases from all instream farm dams located throughout the catchment area.

5 CONCLUSION

This report summarises the hydrological yields to fours instream dams located on Portions 4 and 9 of Farm 232 Redford for the purposes of a WULA. The dams have store water for the irrigation of 20 ha of almond trees under drip irrigation. The main findings can be summarised as follows:

- The mean estimated irrigation requirements for 20 ha of almond trees under drip irrigation is approximately 40 000 m^3 per annum, with a maximum of 60 000 m^3;
- The total storage capacity of 38 000 m^3 is optimal with regards to storage of surface flows from the Redhaus catchments. Lower storage results in substantial deficits in irrigation requirements over a 50-year simulation period, while increasing dam volume does not yield a significant increase in assurance of supply that would warrant a larger dam volume;
- Supplementary irrigation from a borehole will be required, particularly during very dry periods when surface inflows will be insufficient to meet the irrigation demands;

- Storage and irrigation from Dams 1 to 4 results in a slight decrease in mean annual runoff from the Whiskey Creek catchment (~ 8 %). Flow reductions occur during peak high flow periods, whilst no reductions are estimated to occur during low flow periods;
- Any implementation of the Reserve must focus on discharging from the lowest dam in the Whiskey Creek catchment to determine whether these flows are sufficient to meet the ecological flow requirements. Any shortfall in ecological flow requirements must be addressed through a catchment scale study that focusses on ensuring equitable releases from all farm dams located throughout the catchment area; and
- Based on the analyses presented in this report an annual abstraction of 60 000 m^3 from the Redhaus catchments and 24 000 m^3 abstraction from a borehole will ensure security of supply for irrigation of 20 hectares of almonds over the medium to long term.

6 REFERENCES

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