Waituna Catchment: Temporal Variation

Clint Rissmann and Monique Beyer

Land and Water Science Report 2018/09
July 2018

Waituna Catchment: Physiographic Risk Assessment

Prepared by
Rissmann, C., and Beyer, M.

Land and Water Science Ltd.
www.landwaterscience.co.nz
61c Leet Street
Invercargill, 9810
New Zealand

Corresponding Author
Dr Clint Rissmann
Contact number: 03 214 3003
Email: clint@landwatersci.net

Document Information
Land and Water Science Report No: 2018/09
Report Date: 31.07.2018
Project Number: 17018

Land and Water Science Reviewer: Dr Lisa Pearson
Position: Lead Earth and Environmental Scientist
Review Date: 24.04.18

Living Water Reviewer: Nicki Atkinson
Organisation: Department of Conservation
Position: Freshwater Technical Advisor, Living Water South Island Manager
Review Date: 30.07.2018

Document Status: Final

Citation Advice
Rissmann, C. and Beyer, M. (2018). Waituna Catchment: Temporal Variation. Land and Water Science Report 2018/09. Prepared for Living Water. 12p.

Disclaimer: This report has been prepared by Land and Water Science Ltd. (Land and Water Science) exclusively for, and under contract to the Department of Conservation and Fonterra Cooperative (Living Water). Land and Water Science accepts no responsibility for any use of, or reliance on any contents of this report by any person or organisation other than Living Water, on any ground, for any loss, damage, or expense arising from such use or reliance. Information presented in this report is available to Living Water for use from April 2018.

Table of Contents

List of Figures

List of Tables

Abstract

Water in a stream has a mixed source which varies throughout the year due to both the inherent hydrological properties of the landscape and the frequency and magnitude of precipitation events. Typically, over summer, or an extended dry period, streamflow is predominantly groundwater sourced and flows are low. Over the wetter months, soil water is the dominant source volumetrically, through either lateral drainage or artificial subsurface drainage. During a storm event, additional flow paths become active, such as overland flow. In lowland and intensively farmed catchments with fine textured and imperfectly to poorly drained soils the overall contaminant load to stream generally increases as flow transitions from dominance by groundwater > soil water >> surficial runoff reflecting the higher nutrient and microbial concentrations at the soil surface and lesser time for attenuation by soil and plant systems. By combining the timing of contaminant export from each compartment with the geographical depiction of inherent risk for each key water quality contaminant (Pearson et al., 2018), a powerful platform for guiding day-to-day farm management activities and prioritising efforts to minimise losses to waterways can be developed. This work further elucidates the important role of peak runoff mediated by infiltration excess or saturation excess overland flow as a key control over contaminant loads to streams and ultimately the Waituna Lagoon. It also highlights that although groundwater is not an important volumetric source of water or load to the stream network, the quality of baseflow waters are likely to play an important role over in stream eutrophication where nitrogen or phosphorus species are elevated.

1 Introduction

Surface water quality varies in both space and time (4 dimensions). Water sampled from the topsoil is often very different to that sampled from the subsoil. Further, shallow groundwater is often different in composition from deep groundwater. Water quality also varies in time (4th dimension) according to the flow path water takes which is determined by both the inherent hydrological properties of the landscape as well as climatic conditions[1]. For example, during an extended dry period, only one flow path to a stream may be active such as baseflow from the connected aquifer. During a storm event, additional flow paths become active such as vertical and lateral soil drainage and, in some instances, overland flow (Figure 1).

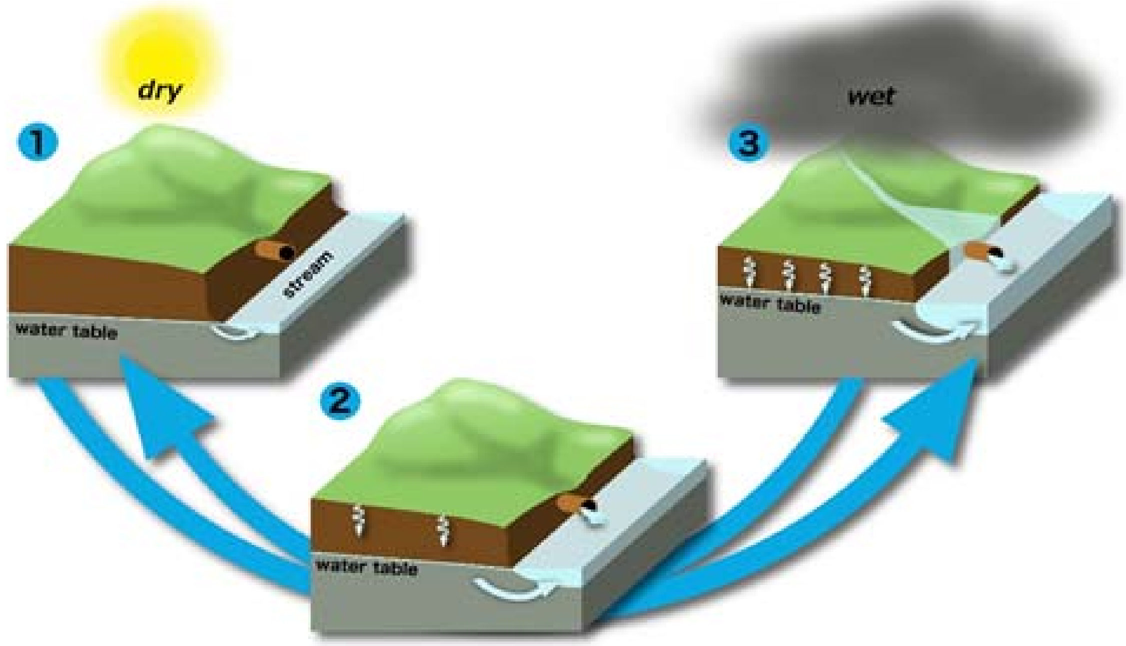

Figure 1: Temporal variation in the flow path is a critical factor in water quality outcomes. Most systems swing between each of the three states although the shift is often gradual. Flow path activation is influenced by both seasonal and higher frequency event flows.

This report assesses the temporal variation in water composition at the four long-term water quality monitoring sites in the Waituna Catchment and provides flow and soil moisture thresholds of when surficial, soil and aquifers are contributing to streamflow. A key benefit of identifying of the compartment supplying stream is the ability to connect through physiographic maps to the geographical location of each compartment controlling streamflow and associated water quality outcomes (Rissmann et al., 2018; Pearson et al., 2018). An ability to identify both where and when water and associated contaminants enter waterways is powerful information when seeking the most effective and efficient methods for reducing land use losses.

---

[1] Water residence time also influences water composition due to biogeochemical reactions some of which may take decades to centuries.

This short report accompanies two scientific documents for the Waituna Catchment high-resolution physiographic application:

- *Waituna Catchment: Technical Information and Physiographic Application* by Rissmann et al. (2018). This document details technical background information and summarises current research in Waituna Lagoon Catchment. The method for developing the high-resolution physiographic map and predictive model is reported.
- *Waituna Catchment: Risk Assessment* by Pearson et al. (2018). This report shows how the high-resolution Waituna Lagoon Catchment physiographic map was used to produce a risk assessment for the Waituna Lagoon Catchment for the environmental contaminants particularly nitrogen (N), phosphorus (P), sediment (S) and microbes (such as *E. coli*, M). The physiographic model, developed in Rissmann et al. (2018) was then applied to estimate water quality for each subcatchment and the zone of direct contribution to Waituna Lagoon.

2 Method

Separation of streamflow into each compartment for the 4 long-term monitoring sites within the Waituna Lagoon Catchment was guided by a form of hydrograph separation (Rissmann et al. in prep). The method identifies the most suitable water quality measures within the stream and then applies a multivariate approach to unmix the source of water. There is a long history of exploiting differences in the water quality and hydrochemical composition of water to separate streamflow hydrographs into individual source components and/or hydrological flow paths (Pinder and Jones 1969; Sklash and Farvolden 1979; O'Brien and Hendershot, 1993; Bazemore et al. 1994; Buttle 1994; Hooper, 2003; Inamdar et al., 2011). All such studies are founded upon a common assumption that waters flowing through various watershed compartments (or geographic sources) acquired unique signatures representative of the characteristics of those compartments and that these distinct signatures could be used to determine the contributions from each (Inamdar et al., 2011).

As applied to long-term time series surface water sites in Waituna Catchment, hydrograph separation identified 3 main sources of water supplying stream: (i) the surficial layer which includes the land surface and the upper 150 – 300 mm of soil; (ii) the soil zone and 'C' horizon which overlies the shallow aquifer, and; (iii) the shallow aquifer(s) that are strongly connected to the stream channel (Figure 2). These 3-main compartments are common to many studies of lowland catchments (Inamdar et al., 2011). The approach provides a measure of the dominant water source and the relative fraction of each compartment (i.e., aquifer, soil, surficial) contributing to any given flow. From this information the thresholds in streamflow and soil moisture at which each compartment is switching on and off can be identified. The water quality characteristic of each compartment can also be summarised.

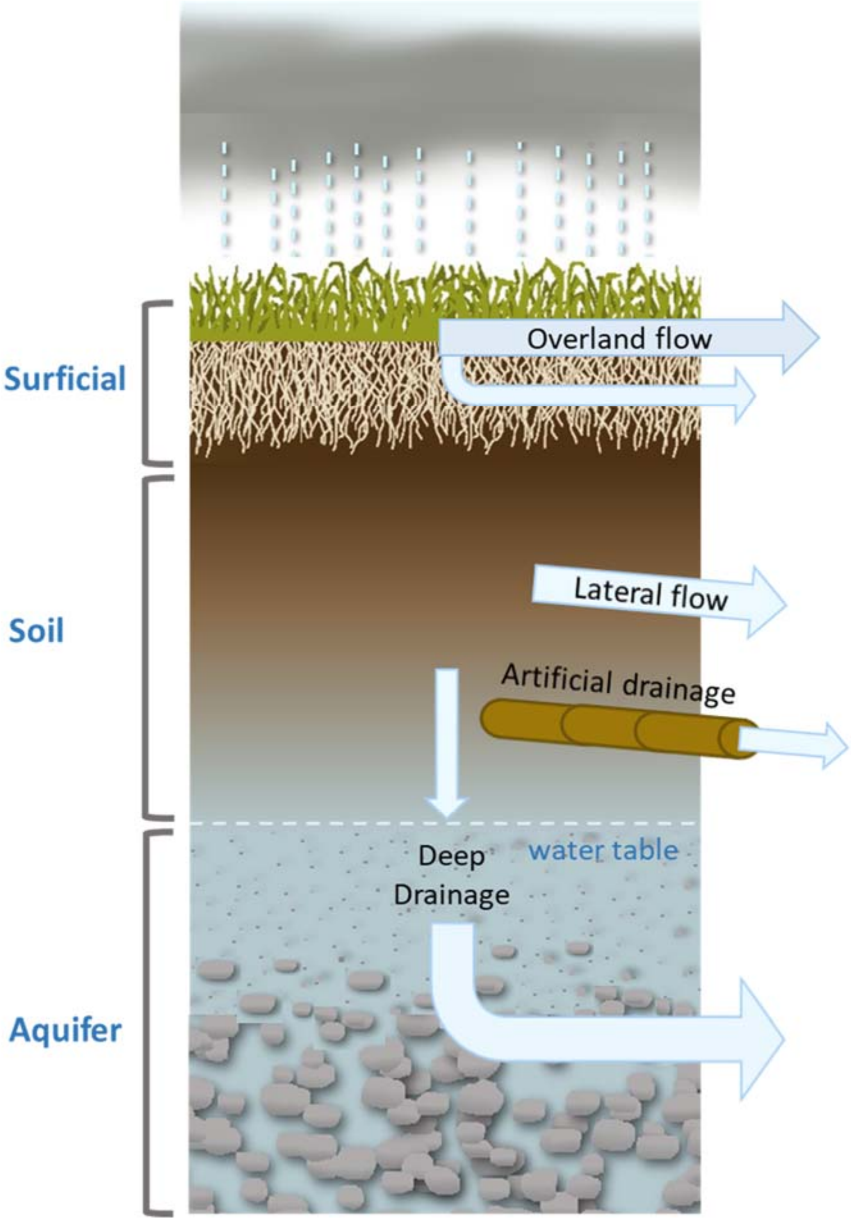

Figure 2: The main sources of water supplying streams identified by hydrograph separation are surficial which includes the land surface and the upper 150 – 300 mm of soil, the soil zone and 'C' horizon which overlies the shallow aquifer(s). Arrows showing water direction are not to scale.

3 Compartment Thresholds

The compartments supplying water and at times contaminants to stream switch on and off in response to how wet the catchment is. Hydrograph separation using water quality measures identifies key flow (Table 1, Figure 3) and soil moisture (Table 2, Figure 4) thresholds at which the 3 main compartments are switching on and off. Such knowledge is important for understanding how water quality risk and in this instance instream water quality vary with flow.

Table 1: Flow thresholds by dominant water source for 4 long-term monitoring sites associated with the developed part of Waituna catchment (95% confidence interval, Environment Southland data).

	Dominant Water Source by Flow (m^3/sec)		
	Aquifer	Soil	Surficial
Waituna Creek 1 m u/s Waituna Road	< 0.09	0.09 - 0.3	> 0.3
Waituna Creek at Marshall Road	< 0.60	0.6 - 1.2	> 5.0
Moffat Creek at Moffat Road	< 0.008	0.008 -0.3	> 0.3
Carran Creek at Waituna Lagoon Road	< 0.2	0.2 - 0.9	> 0.9

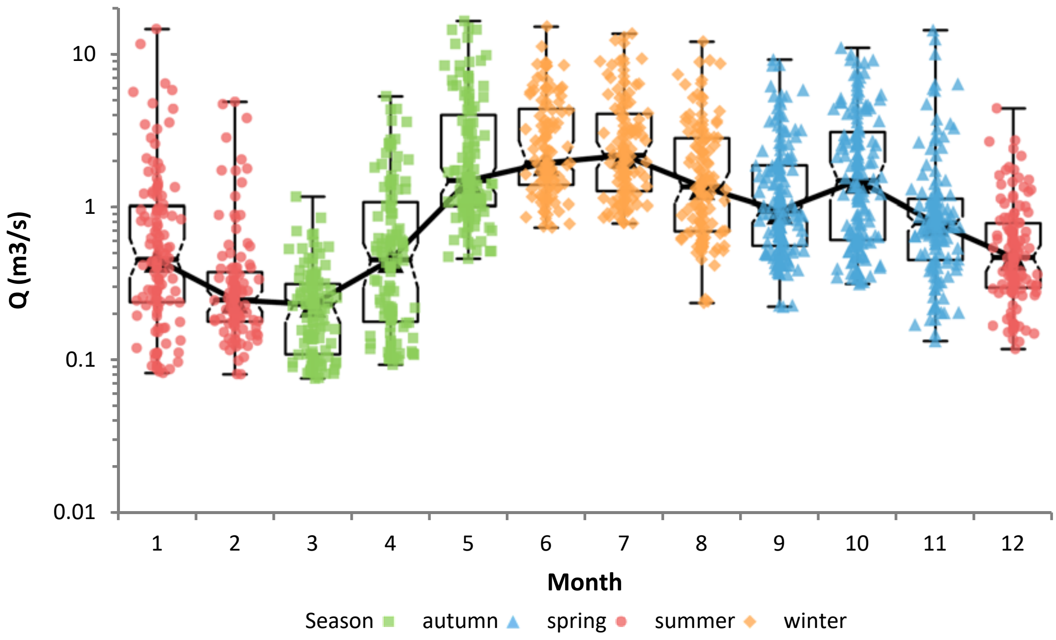

Figure 3: Streamflow for Waituna Creek at Marshall Rd by month and season (continuous record for 2012-2017; Environment Southland data).

Table 2: Soil moisture thresholds as water filled pores by dominant water source for 4 long-term monitoring sites associated with the developed part of Waituna catchment (95% confidence interval, Environment Southland data).

	Dominant Water Source by Water Filled Pores (%) at Lawson Rd		
	Aquifer	Soil	Surficial
Waituna Creek 1 m u/s Waituna Road	< 78 (73 - 79)	82 (80 - 84)	> 83 (80 - 100)
Waituna Creek at Marshall Road	< 80 (77 - 80.5)	84 (82 - 85)	> 93 (87 - 100)
Moffat Creek at Moffat Road	< 78 (75 - 80)	82 (80 - 84)	> 86 (82 - 100)
Carran Creek at Waituna Lagoon Road	< 79 (77 - 82)	82 (81 - 85)	> 89 (83 - 100)

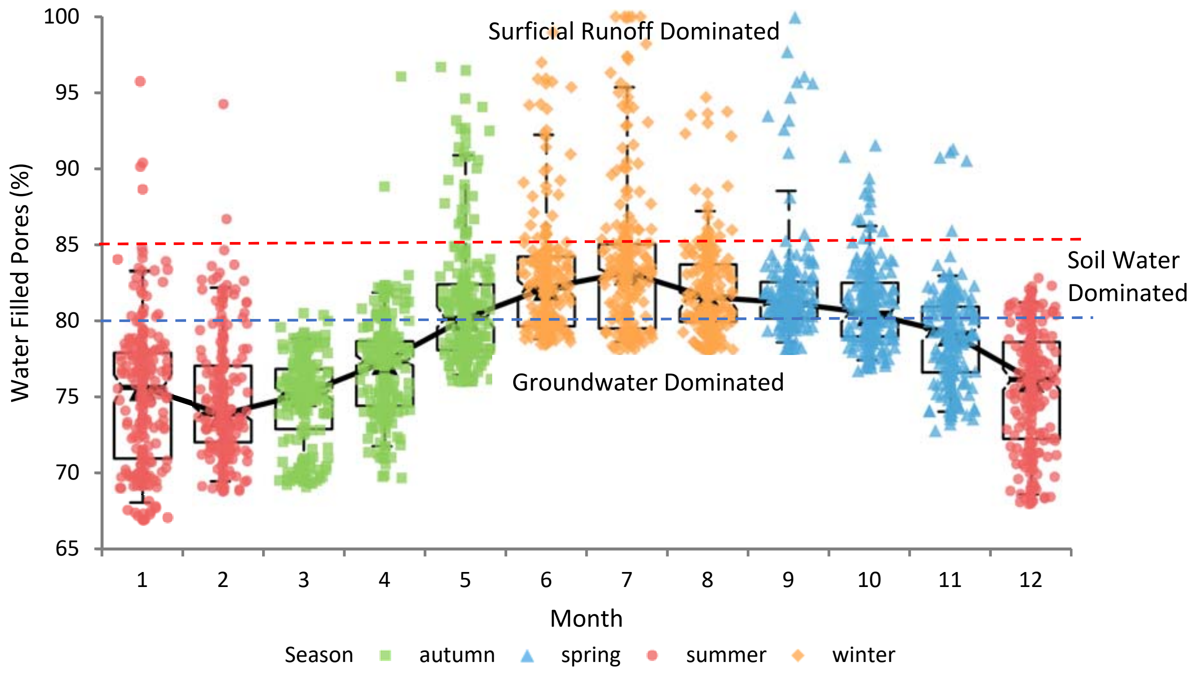

Figure 4: Soil moisture content as % of water-filled pores for Lawson Road soil moisture site by month and season (continuous record for 2012- 2017; Environment Southland data). Soil moisture varies over the year in response to seasonal patterns. Streamflow follows the seasonality of soil moisture with lowest flows occurring during periods of low (<80%) soil moisture, soil dominated flow between 80-85% and a greater frequency of surficial runoff >85% water-filled pores. Streamflow peaks in response to surficial runoff as water filled pores exceed 85%.

For all sites, aquifer dominated flow to stream occurs over the summer months and early autumn when soil moisture levels are generally at their lowest (i.e., <80%; Figures 3-4). Soil water drainage starts in late April and is sustained by higher soil moisture values in the range of 80 - 85%. Soil water dominated flow has the highest relative frequency as a water source for streams associated with the Waituna Lagoon Catchment (Figure 5). Above 85% water-filled pores the frequency of surficial runoff becomes an increasingly important source of water and contaminants to stream. In terms of relative frequency, the soil moisture conditions that favour surficial runoff occur 10% of the year according to the long-term (2012 – 2016) flow and soil moisture (Lawson Road) record for the Waituna Catchment (Figure 5). The conditions that favour aquifer dominate flows (baseflow) dominate 40% of the time and lateral soil water flow 50% of the time. Infiltration excess overland flow is typically restricted to the drier months of the year and appears less frequent and associated with smaller flow response than saturation excess events.

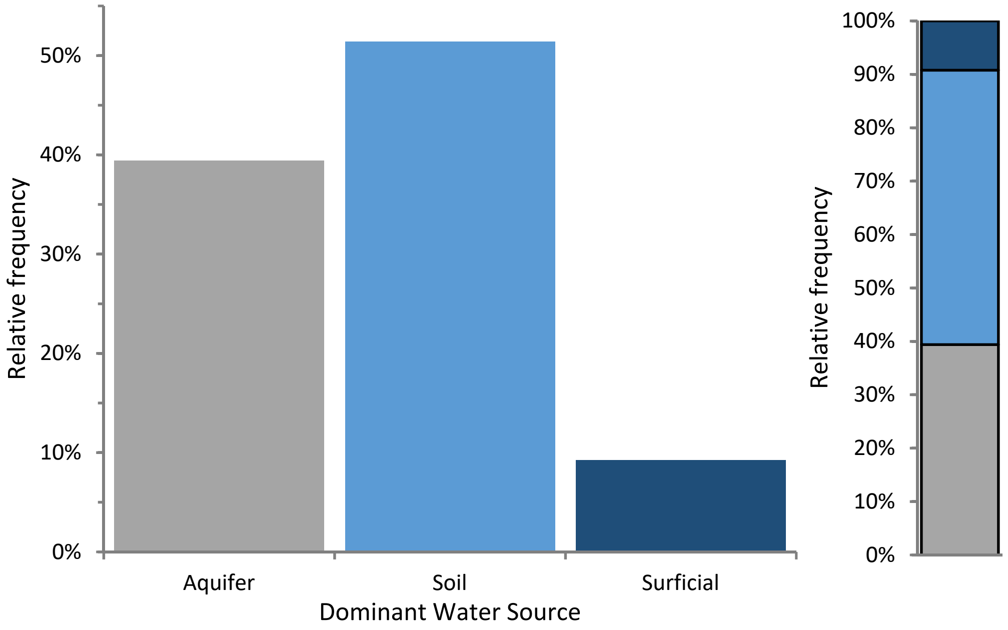

Figure 5: Relative frequency of dominant water source using soil moisture thresholds (as water filled pores) for Lawson Rd (Environment Southland Data).

As anticipated, thresholds in streamflow and soil moisture and associated water source show a clear seasonal pattern (Figure 6). Soil drainage starts in April and peaks in July, surficial runoff is elevated during May-August with fewer runoff events in Oct – November (Table 2).

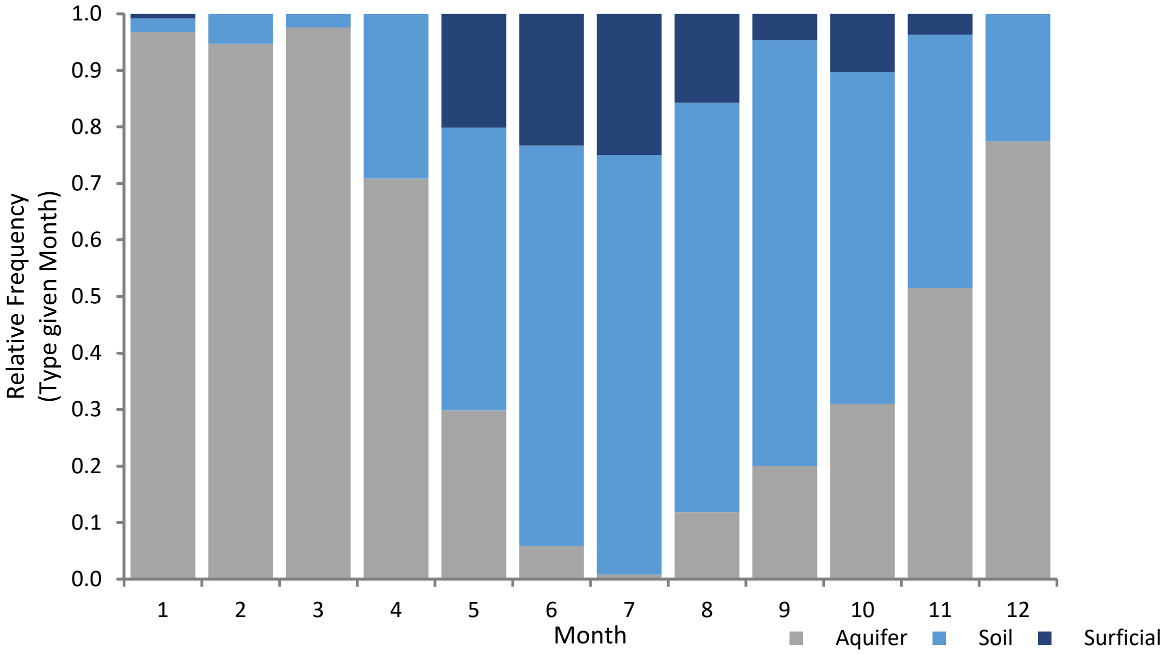

Figure 6: Frequency of dominant water source by month for the 2012 – 2016 time period. Water source-based hydrograph separation and associated soil moisture and flow thresholds for the 4 main sites.

Summary statistics of flow variation by dominant water source is present for each key site in Table 3. The magnitude of flow also varies according to soil moisture thresholds with the lowest flows occurring during summer and early autumn and the highest flows during periods of surficial runoff. Under soil-water dominated flow conditions, median flows are between 3.8 to 8.8 times larger than median aquifer flows - Waituna Creek at Marshall Rd shows the greatest difference between median aquifer and median soil flow (8.8 times). The difference between median aquifer and surficial flows is even greater ranging between 11.4 to 31.7 times larger – Waituna Creek at Marshall Rd shows the greatest difference (31.7). Recognising the difference in streamflows associated with each compartment is important when considering load.

Table 3: Flow statistics (m^3/s) by dominant water source for the four key sub-catchments, Waituna Lagoon Catchment.

	Waituna Creek at Waituna Rd			**Waituna Creek at Marshall Rd**			**Moffat Creek at Moffat Rd**			**Carran Creek at Waituna Lagoon Rd**		
	Aquifer	Soil	Surficial	Aquifer	Soil	Surficial	Aquifer	Soil	Surficial	Aquifer	Soil	Surficial
Mean	0.04	0.15	1.47	0.4	3.5	9.7	0.07	0.27	1.52	0.13	0.57	2.47
Median	0.04	0.15	0.72	0.3	2.4	9.5	0.05	0.24	0.92	0.10	0.47	1.14
C.V.	0.52	0.46	1.18	0.7	0.9	0.4	0.72	0.54	0.87	0.68	0.68	1.12
Min.	0.02	0.04	0.32	0.1	0.6	6.0	0.01	0.08	0.33	0.03	0.18	0.49
Max.	0.09	0.24	5.96	1.2	11.8	18.7	0.17	0.65	3.59	0.40	1.54	8.40
Range	0.07	0.20	5.64	1.1	11.2	12.7	0.16	0.57	3.26	0.37	1.37	7.91

Due to the larger increase in flow as soils wet up and start to drain and in response to surficial runoff events the role of the soil and surficial compartments over contaminant loads to stream and ultimately the Waituna Lagoon are important. However, although aquifer volumes are small, and as such load, the quality of aquifer derived baseflow is likely important for in-stream eutrophic response during the warmer months of the year and in terms of recreational contact (i.e. *E. coli*). Legacy sediment, N, P and microbes supplied to stream and the lagoon from May – October are also critical determinants of instream and lagoon water quality and ecosystem health.

4 Water Quality

The mean and median concentrations of key water quality parameters are summarised for each compartment and each site in Table 4.

4.1 Nitrogen

Total Nitrogen (TN) peaks at all sites in response to surficial runoff and is lowest for aquifer dominated flow (Table 4). Nitrate, nitrite as nitrogen (NNN) makes up the biggest proportion of TN for Waituna Creek sites, whereas organic and ammoniacal (TKN) forms of nitrogen dominate for all other sites. In terms of compartment and timing, NNN and TN peaks in soil and surficial runoff from the north of the Waituna Creek subcatchment over the May-August period reflecting higher rates of flushing under wetter conditions. Early spring is also a key period of export if residual nitrate remains in the soil profile. TKN also peaks over the same period.

Table 4: Mean and median concentrations for dominant water source and key water quality measures by the main subcatchment. Concentrations reported in mg/L (ppm).

	Waituna Creek at Waituna Rd						**Waituna Creek at Marshall Rd**					
	Aquifer		**Soil**		**Surficial**		**Aquifer**		**Soil**		**Surficial**	
	Mean	**Median**	**Mean**	**Median**	**Mean**	**Median**	**Mean**	**Median**	**Mean**	**Median**	**Mean**	**Median**
TN	1.33	1.32	2.50	2.50	3.98	3.90	1.32	1.29	3.23	3.30	5.40	5.40
NNN	1.07	1.10	2.08	2.00	3.16	2.70	0.80	0.78	2.33	2.20	2.87	2.87
TKN	0.28	0.28	0.41	0.37	0.80	0.70	0.49	0.52	0.88	0.75	2.50	2.50
TP	0.02	0.02	0.02	0.03	0.06	0.05	0.04	0.04	0.06	0.05	0.33	0.33
DRP	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.06	0.06
TSS	2.51	3.00	3.00	3.00	13.13	11.00	4.93	3.30	17.13	8.30	75.50	75.50
VSS	2.46	3.00	3.00	3.00	5.25	5.50	2.37	2.00	4.48	3.00	18.00	18.00
E. coli	490	285	743	300	3289	850	550	370	743	170	26000	26000

	Moffat Creek at Moffat Rd						**Carran Creek at Waituna Lagoon Rd**					
	Aquifer		**Soil**		**Surficial**		**Aquifer**		**Soil**		**Surficial**	
	Mean	**Median**	**Mean**	**Median**	**Mean**	**Median**	**Mean**	**Median**	**Mean**	**Median**	**Mean**	**Median**
TN	0.98	0.98	1.82	1.82	3.70	3.85	0.76	0.72	1.63	1.55	3.65	3.65
NNN	0.08	0.05	0.66	0.63	1.84	1.76	0.11	0.08	0.75	0.70	1.67	1.67
TKN	0.91	0.90	1.16	1.14	1.90	2.00	0.66	0.62	0.87	0.81	1.98	1.98
TP	0.15	0.14	0.16	0.13	0.22	0.22	0.14	0.12	0.10	0.09	0.28	0.28
DRP	0.07	0.06	0.08	0.08	0.13	0.15	0.05	0.04	0.05	0.04	0.09	0.09
TSS	6.35	6.00	8.53	4.00	20.25	19.50	8.10	8.00	3.73	3.70	24.00	24.00
VSS	3.86	3.60	4.21	3.00	7.00	8.00	4.30	4.00	2.49	3.00	12.00	12.00
E. coli	1159	515	342	260	2980	3800	853	210	2038	120	25000	25000

	Carran Creek (Craws Creek) Tributary					
	Aquifer		**Soil**		**Surficial**	
	Mean	**Median**	**Mean**	**Median**	**Mean**	**Median**
TN	0.73	0.70	0.72	0.72	0.74	0.74
NNN	0.04	0.02	0.05	0.05	0.05	0.05
TKN	0.72	0.70	0.67	0.67	0.69	0.69
TP	0.08	0.08	0.08	0.08	0.10	0.10
DRP	0.06	0.06	0.06	0.06	0.07	0.07
TSS	3.69	3.00	3.00	3.00	4.50	4.50
VSS	2.99	3.00	3.00	3.00	3.50	3.50
E. coli	65	40	175	175	3100	3100

4.2 Phosphorus

Total Phosphorus (TP) and Dissolved Reactive Phosphorus (DRP) concentrations vary with the dominant compartment and subcatchment (Table 4). The lowest TP and DRP concentrations are associated with the most northern portion of the Waituna Creek subcatchment, due to lower surficial runoff risk and greater P-retention by soil and aquifers. Phosphorus, at the mostly natural state Carran Creek Tributary (Craws Creek), is dominated by DRP with little evidence of Particulate Phosphorus (PP). Here, DRP is naturally elevated but does not increase much with streamflow (compartment) due to source limitation. However, all sites with a significant area of developed 'wetland' exhibit an increase in DRP with compartment flow as soil and surficial compartments switch on, although the magnitude of DRP increase is small relative to TP. Comparison of DRP and TP along with sediment fractions (TSS and VSS) suggests the majority of P export to stream across the developed areas of the catchment is occurring as Particulate Phosphorus (PP). As anticipated, the concentration of PP is lowest in aquifer derived waters, increases in soil waters and peaks in surficial runoff. Once again, the largest export of TP, mainly as PP, occurs over the months May-August reflecting higher rates of flushing and overland flow under wet soil conditions. Early spring, depending on soil moisture conditions may also be a key period for export.

4.3 Suspended Sediment

Sediment concentrations show a similar pattern to TP, peaking in surficial runoff for all sites, with the exception of the near-natural state Carran Creek Tributary (Craws Creek) which is source limited (Table 4). However, the relative export of sediment to stream via soil and surficial runoff increases as the proportion of developed 'wetland' increases within the capture zone of a site. Comparison of the ratio of Total (TSS) to Volatile Suspended Sediment (VSS) supports a predominantly inorganic sediment export that peaks in response to surficial runoff. Once again, the largest export of sediment occurs over the May-August period reflecting higher rates of flushing and overland flow under wet soil conditions. Early spring is also a key period of export, especially if the spring is wet.

4.4 Microbes

The location and timing of *E. coli* export is similar to that observed for TP and sediment (Table 4). However, it is notable that *E. coli* is elevated under aquifer dominated flows for those catchments with a significant developed 'wetland' component (i.e. Moffat and Carran creeks). For Moffat Creek aquifer *E. coli* is significantly higher than soil zone derived *E.coli*. The exact cause of elevated *E. coli* at low flows is difficult to decipher although it is apparent that mean concentrations of *E. coli* are higher than median suggesting an episodic source. Overall, the near-natural state Carran Creek Tributary has the lowest *E. coli* across each compartment followed by the northernmost portion of the Waituna Creek sub-catchment. Once again, the largest export of *E. coli* occurs over the May-August period and early spring (September/October) in response to wetter soil conditions and saturation excess overland flow.

5 Application

Combining the timing of contaminant export from each compartment with the geographical depiction of inherent risk for each key water quality contaminant (Figure 7; Pearson et al., 2018), provides a powerful platform for guiding day-to-day farm management activities and prioritising efforts to minimise losses to waterways. For example, across the northern portion of the Waituna Creek subcatchment, the knowledge that soils typically start draining in late April/May (>80% water-filled pores) raises questions as to what can be done in the month(s) prior to reduce excess nitrate in the soil zone prior to the onset of wet soil conditions and subsequent export of nitrate to stream (e.g. a catch crop).

Combining knowledge of the inherent risk and the timing of soil zone drainage and surficial runoff could also be used to guide the irrigation of Farm Dairy Effluent (FDE) and the application of fertiliser to times of the year where the risk of losses to waterways are lowest. Such an approach also ensures the economic benefits of fertiliser and FDE irrigation are maximised. Similarly, recognising where the inherent risk of surficial runoff is greatest and the thresholds in soil moisture (i.e., water-filled pores >85%) above which surficial runoff is activated provides a basis for focussing efforts regarding wintering practices.

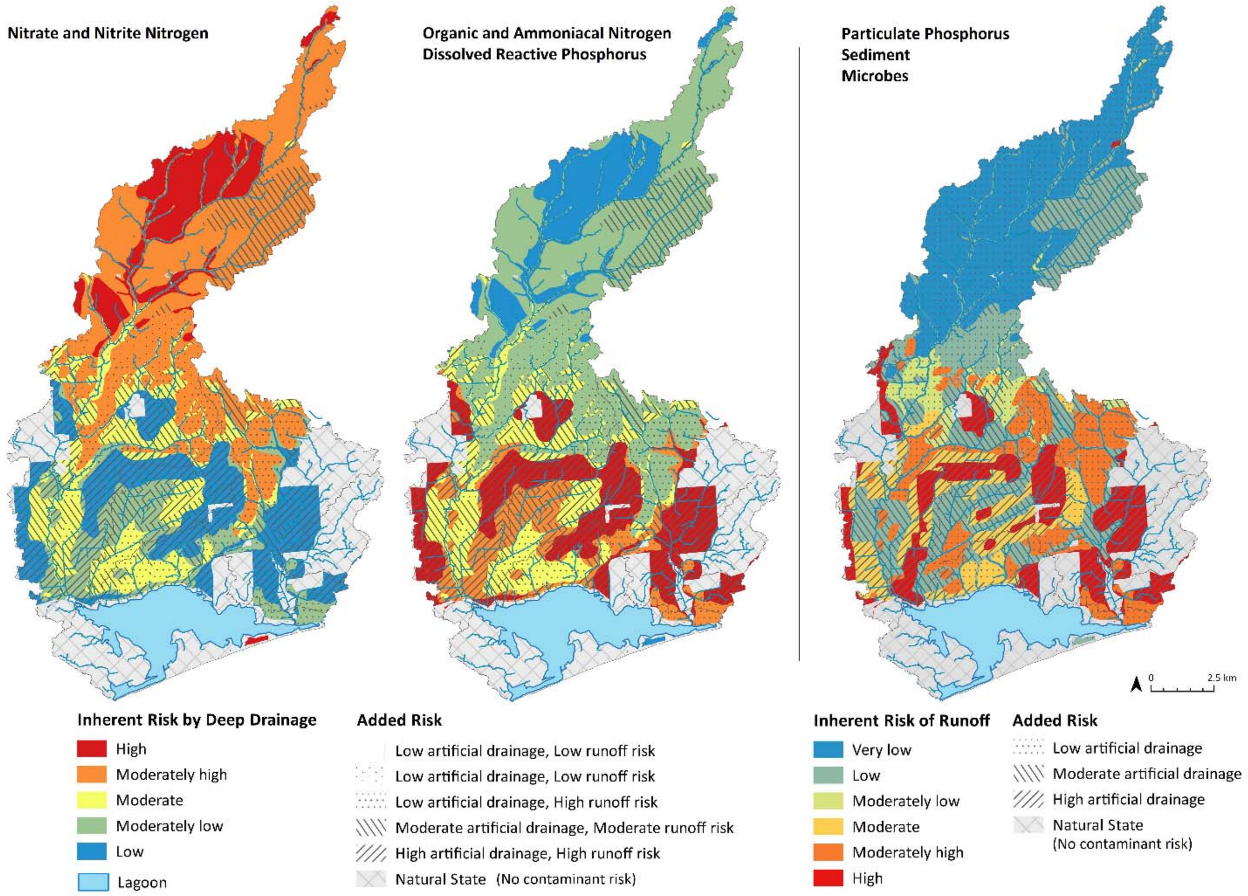

Figure 7: Inherent risk for contaminant loss from Waituna Catchment (Pearson et al., 2018).

6 References

Bazemore, D. E., Eshleman, K. N., and Hollenbeck, K. J. (1994). The role of soil water in stormflow generation in a forested headwater catchment: synthesis of natural tracer and hydrometric evidence. Journal of Hydrology, 162(1–2), 47–75. https://doi.org/10.1016/0022-1694(94)90004-3

Buttle, J. M. (1994). Isotope hydrograph separations and rapid delivery of pre-event water from drainage basins. Progress in Physical Geography, 18(1), 16–41. https://doi.org/10.1177/030913339401800102

Hooper, R. P. (2003). Diagnostic tools for mixing models of stream water chemistry. Water Resources Research, 39(3). https://doi.org/10.1029/2002WR001528

Inamdar, S. (2011). The Use of Geochemical Mixing Models to Derive Runoff Sources and Hydrologic Flow Paths (pp. 163–183). Springer Netherlands. https://doi.org/10.1007/978-94-007-1363-5_8

O'Brien, C., and Hendershot, W. H. (1993). Separating streamflow into groundwater, solum and upwelling flow and its implications for hydrochemical modelling. Journal of Hydrology, 146(C), 1–12. https://doi.org/10.1016/0022-1694(93)90266-C

Pearson, L., Rissmann, C., and Lindsay, J. (2018). Waituna Catchment: Risk Assessment. Land and Water Science Report 2018/02. Prepared for Living Water, 41p.

Pinder, G. F., and Jones, J. F. (1969). Determination of the ground-water component of peak discharge from the chemistry of total runoff. Water Resources Research, 5(2), 438–445. https://doi.org/10.1029/WR005i002p00438

Rissmann, C., Pearson, L., Lindsay, J. Marapara, M., and Badenhop, A. (2018). Waituna Catchment: Technical Information and Physiographic Application. Land and Water Science Report 2018/01. Prepared for Living Water, 133p.

Rissmann, C., Beyer, M., Pearson, L., … (in prep). A novel approach to hydrograph separation for long-term surface water quality monitoring sites. Land and Water Science Report.

Sklash, M. G., Farvolden, R. N., and Farvolden, R. N. (1979). The role of groundwater in storm runoff. Developments in Water Science, 12(C), 45–65. https://doi.org/10.1016/S0167-5648(09)70009-7