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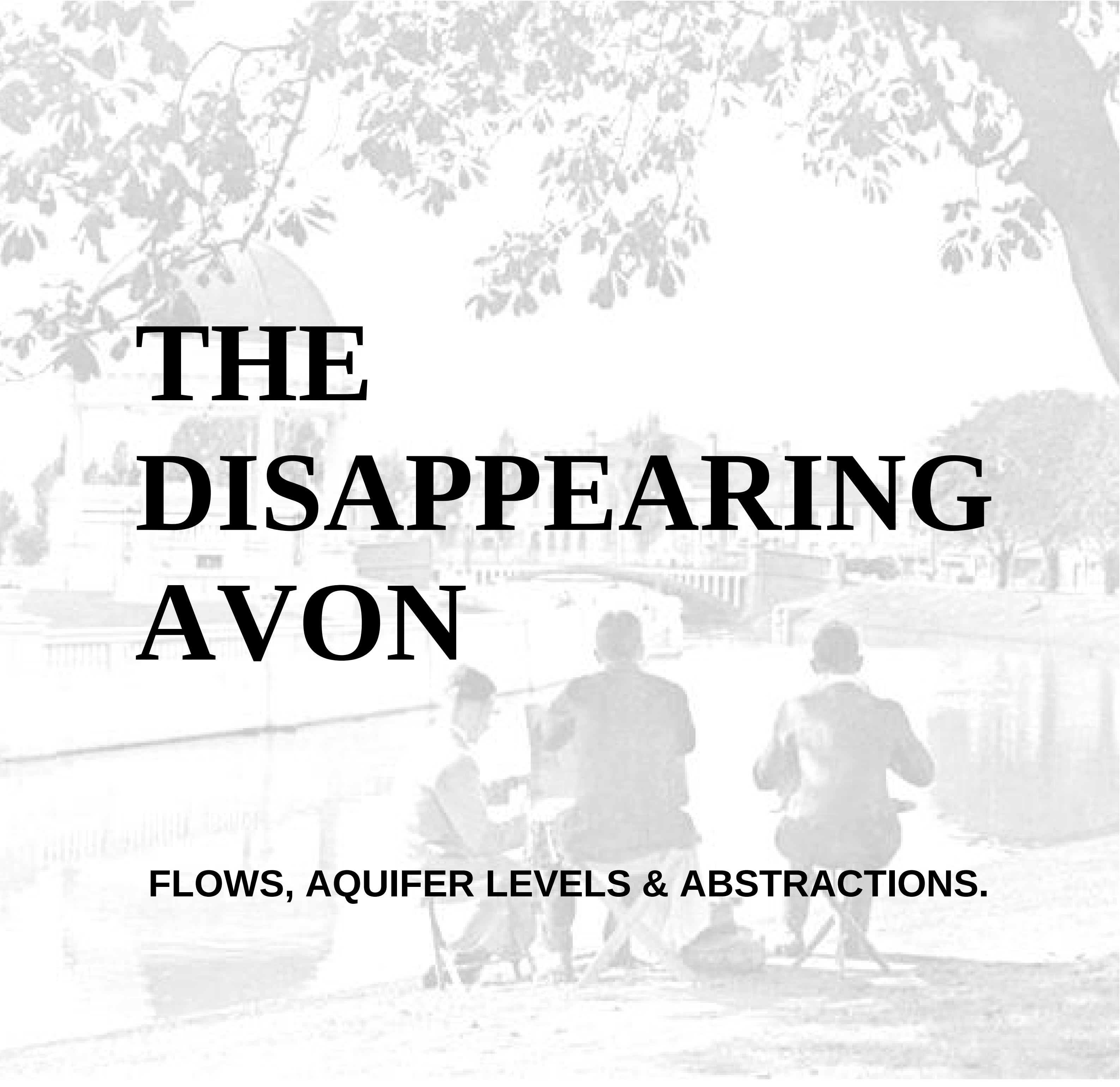

THE DISAPPEARING AVON

FLOWS, AQUIFER LEVELS & ABSTRACTIONS.

A Summary Paper of investigations conducted by R.English, BSc(Hons); MIPENZ; MICE.
February - December 2006.

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Acknowledgement.

The author wishes to gratefully acknowledge the co-operation and aid of Environment Canterbury staff in supplying the background river flow and aquifer level data used in this report.

Cover Photograph: Sketching by the Avon – 1932; Christchurch City Council Library Collection

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THE DISAPPEARING AVON.

- FLOWS, AQUIFER LEVELS AND ABSTRACTIONS

Summary.

Introduction.

After a number of years of declining flows, the upper sections of most of the Avon's tributaries are now almost permanently dry. In the summer of 2005 / 06 the headwater springs of the Avon itself ran dry for the first time.

These occurrences have prompted the present research into the reasons for these declines in flow. The outcomes of these investigations are summarised in this paper.

Declining Flows

The events described are reflected in an ongoing decline in average flows in the Avon. These declines total approximately 15% of the average flow over the period under study.
- 1992 to 2005

A greater, underlying decline has been masked by concurrent increases in inputs from artificial sources. These inputs now constitute at least 10 -15% of the flow of the river. Once the effect of these inputs are removed, it has been calculated that the underlying decline in the flows in the Avon, over the study period, is of the order of 25%

Inter-relationships

The study has demonstrated that close inter-relationships exist between:

- Aquifer levels adjacent to the upper Avon and the quantum of flows in the upper Avon
- Aquifer levels adjacent to the upper Avon and the quantum of flows in the Avon in the central city.
- Aquifer levels adjacent to the upper Avon and aquifer levels adjacent to the Waimakariri River.

The study also shows that:

- Variations in average annual rainfall run-off have only a minor impact on overall average annual flows in the Avon.
- Variations in rainfall infiltration recharge into the aquifer also have only minor direct effects on aquifer levels.
- Recharge of the system is dominated by losses from the Waimakariri River into the local aquifers.
- Abstractions for domestic, commercial and industrial uses have risen only slowly over the study period. However abstractions for irrigation uses have increased significantly and now constitutes in excess of 60% of demand at peak times.

Conclusions.

A number of significant conclusions may be drawn from this investigation :-

- The local unconfined aquifer levels are declining.
- This is having a detrimental effect on the Avon and its tributaries.
- Recent urbanisation of the recharge zone has had only a minor impact on aquifer levels.
- It is possible / probable that the major cause of the declines in aquifer levels is abstractions beyond sustainable limits from both the local aquifer and those in the wider Central Plains area .
- Knowledge of the recharge mechanism for, and the inter-relationship between the aquifers is incomplete.
- In particular neither the quantum nor the mechanism for the loss of flow from the Waimakariri River are well understood.

Even without considering the potential effects of climate change, should present trends continue, the prognosis for the Avon is very poor. The effects witnessed in the summer of 2005 / 06 will occur both more frequently and with greater severity. The length of river containing stretches of stagnant water and sections of dry river bed will increase. These effects will continue to expand downstream. Without artificial inputs, the Avon will be permanently dry within 50 years.

Human activity, be it through abstractions in the recharge zone, abstractions in the Plains aquifers or a combination of the two are thought to be mainly responsible for these problems. Without adequate measures to reduce these abstractions, or at the least to hold them at present levels, the situation could ultimately lead to the Avon's permanent disappearance..

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THE DISAPPEARING AVON

- FLOWS AND AQUIFER LEVELS.

A Summary Paper of investigations conducted by R.English, BSc(Hons); MIPENZ; MICE.
February - December 2006.

1. Introduction.

The present, main headwater springs of the Avon, located approximately 150m east of Avonhead Road, ran dry in the summer of 2005 / 6. Local residents reported that this was the first time that this has occurred for at least 35 years (i.e. the time scale of observation by present residents) and was possibly the first time that the springs have ever failed to flow. Had it not been for the fortuitous positioning of two downstream weirs an additional 2km of river bed would have been exposed as a result of the disappearance of the springs.

This event follows reports of other Avon springs, in the vicinity of Corfe Street, disappearing or falling to low flow levels in February / March 2003, and January 2004.

These spring failures have been preceded by a slow, overall decline in water levels in the Avon headwaters. For example several residents reported children regularly canoeing in these sections of the river twenty years ago whereas the same sections of river are now often only ankle deep.

Residents adjacent to the previous Ilam Stream headwater springs, located approximately 100m west of Waimairi Road, report that the springs ran continuously in the mid 1980's but as the decade proceeded the vigor of the springs began to decline until they occasionally disappeared altogether. By the mid 1990's these disappearances had become regular and of ever increasing duration until by the end of the decade they had disappeared on a more or less permanent basis. They have subsequently only reappeared for approximately one month in Spring 2000 and for two months in Winter 2006.

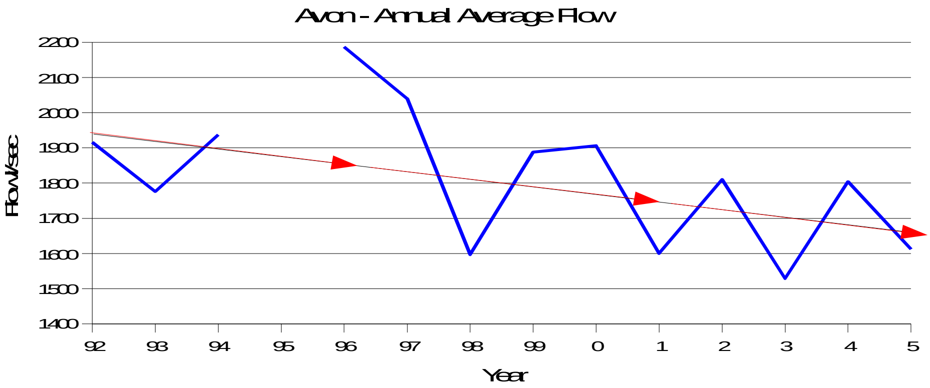
This pattern of gradual decline and then disappearance also appears to have been repeated in at least the Okeover and Waimairi Streams, both of which are tributaries of the Avon. (The other main Avon tributaries – i.e. the Waiarapa and Wai-iti Streams - may also have been similarly affected but were not studied.)

These occurrences have prompted the present research into the reasons for these declines in flow The outcomes of these investigations are summarised in this paper.

2. Avon Flow Trends.

Annual average flow rates for the Avon at Gloucester Street are plotted below for the period 1992 to 2005.

Graph 1: Avon Flow (Central City) v Year.



Notes: *Y Axis: Avon Average Annual Flow Rate (l / sec)*
Data for 1995 flows are incomplete and has therefore been omitted

A clear declining trend in flows can be seen over the period under study.
(i.e. Approximately 15% overall decrease.)

3. Rainfall Variations, Run - Off and Flows.

3.1 Average Annual Flows.

The effects of variations in annual rates of rainfall run-off induced flow were removed by adjusting the flow figures (actual blue, adjusted red) to take account of variations in rainfall from average.

For example where rainfall for a year was greater than average, the run-off and hence the flow figures were reduced proportionately and vice-a-versa to produce flows that would have occurred if rainfall run-off had in fact been 'average' for each year.

Graph 2: Avon Flow (Central City) and Avon Flows (Central City) adjusted for rainfall run-off variations v Year

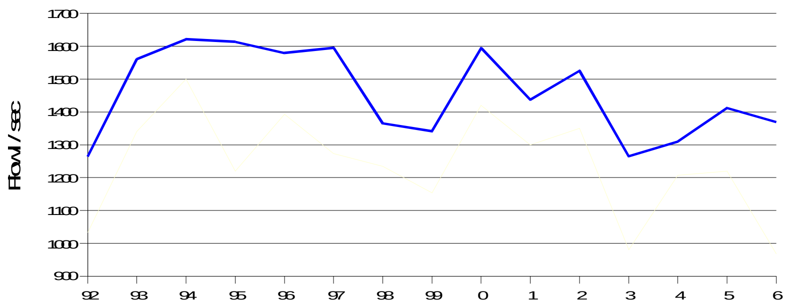
Notes: *Y Axis: Avon Average Annual Flow Rate (l / sec)*
Recorded Flow (Blue)
Recorded flow corrected for variations in rainfall (Red)
Data for 1995 flows are incomplete and has therefore been omitted

Given that annual rainfall totals vary by approximately +/- 30% from average and that rainfall run-off constitutes approx 15% of total flow in the Avon at Gloucester Street (figure ex ECan) then it is not surprising that the adjustment to 'normalise' the flows is generally, relatively small (i.e. Total flows are altered by a maximum of about +/- 5%) and the declining trend remains.

3.2 Minimum Flows.

Plotted below are the monthly minimum Avon flows for each year (at Gloucester Street) for the period 1992 to 2005 (Note: The actual minima may differ but the monthly average will provide a reasonable indication of the order that they may have been)

Graph 3: Minimum Average Monthly Avon Flow (Central City) v Year



Note: *Y Axis: Avon Flows : Monthly Minima (l /sec)*
Figure for 1995 estimated as data incomplete.

Again a downward trend is apparent although not as marked as that of the decline identified in annual average flows..

(Note that no adjustment is required for rainfall run-off as minimum flows will, by default, occur at times of nil rainfall)

4. Flows and Artificial Inputs.

A number of long term artificial inputs into the river have been identified. (Note: there may be others). It is important to note that “short” term inputs, usually from construction site dewatering activities, have not been individually identified although it is known that the quantities involved can, cumulatively, be quite large (e.g. 300 l / sec) and can occur over relatively extended periods (e.g. Women’s Hospital construction dewatering operations lasted for at least twelve months.) Both these long and short term artificial inputs have the potential to mask underlying flow trends in the Avon.

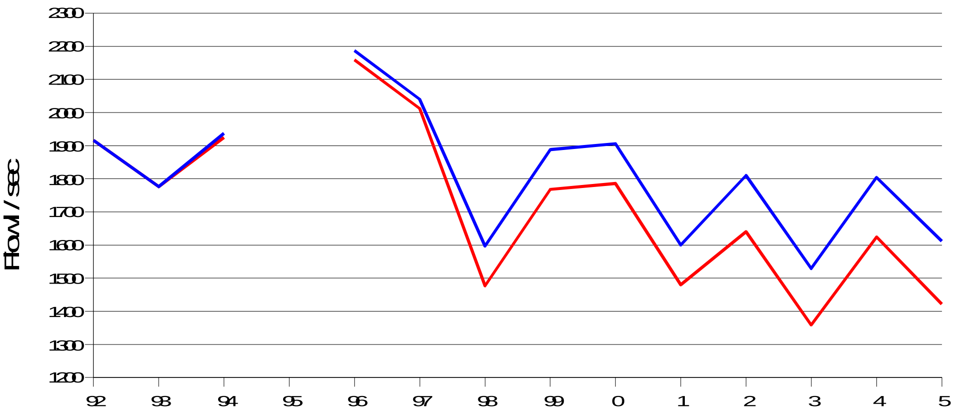
An attempt has been made to identify when the long term inputs began and their volume. Those identified so far are:

• University into Avon near Students Union	65 l/sec
• University into Okeover Stream (several points)	55 l/sec
• Aqualand into Waiararpa Stream at Jellie Park	50 l/sec
• CCC at Clarence St into Riccarton Stream	20 l/sec
• Fendalton Drain (source unknown)	45 l/sec
TOTAL	235l/sec

(Note: The Dairy Factory on Russely Road - defunct about 12 months ago - used to feed approx 20 litres / sec into the upper Avon)

These flows constitute of the order of 10 -15% of the flow of the Avon at Gloucester Street. (Note that “short term” dewatering inputs could at times contribute an additional 15% of flow but are not included in this analysis as a result of difficulties in obtaining data.)

Graph 4: Annual Average Avon Flow (Central City) and Annual Average Flow less Artificial Inputs v Year.

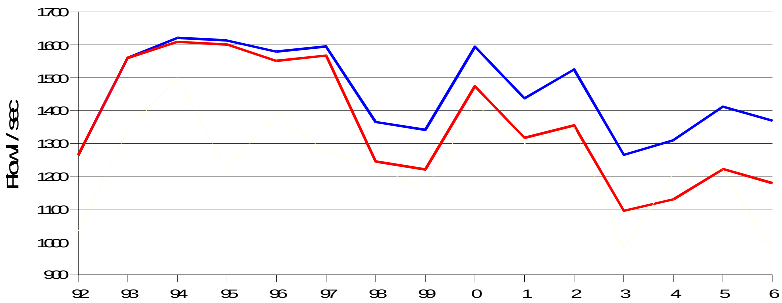


Note: *Average annual Avon flows as recorded (l /sec) - Blue*
Average annual Avon flows less Artificial Inputs (l /sec) - Red
Data for 1995 flows are incomplete and has therefore been omitted

The re-plotted flow data shows an increased downward trend which, as noted before, has to an extent been hidden by the artificial inputs (which are the difference between the blue and red plots.) The underlying decrease in flow over the study period could be of the order of 25% (c.f. actual recorded loss of 15%) Should this trend continue, the Avon would, without artificial inputs, be permanently dry in less than 50 years.

Plotted below are the monthly minimum Avon flows for each year (at Gloucester Street) for the period 1992 to 2005 together with the same data less the relevant artificial inputs.(Again note that “short” term artificial inputs are not included)

Graph 5: Minimum Monthly Avon Flow (Central City) and Minimum Monthly Flow less Artificial Inputs v Year.



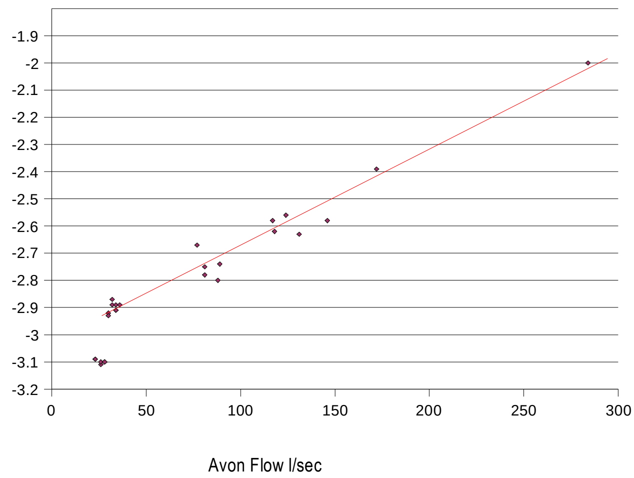
Note: Y Axis Avon flow rates (l / sec).
Avon Flows : Monthly Minima (l /sec) - Blue
Avon Flows : Monthly Minima less Artificial Inputs (l /sec) - Red
Figure for 1995 estimated as data incomplete

The underlying decline in minimum flows (i.e. approximately 20%) although not as large as that for average flows is still significant. As can be seen, as the minimum flow decreases the artificial flows gain in significance and will increasingly mask the under lying trends.

5. Relationship between Aquifer Levels and Upper Avon Flows.

Aquifer levels measured at the ECan monitoring well in the Ilam Homestead Gardens (M35/5560) have been plotted against the concurrent upper Avon flows measured at Ilam Road, which is approximately 250m downstream from the monitoring well.

Graph 6: Avon Flow (Ilam) v Aquifer Level (Ilam)



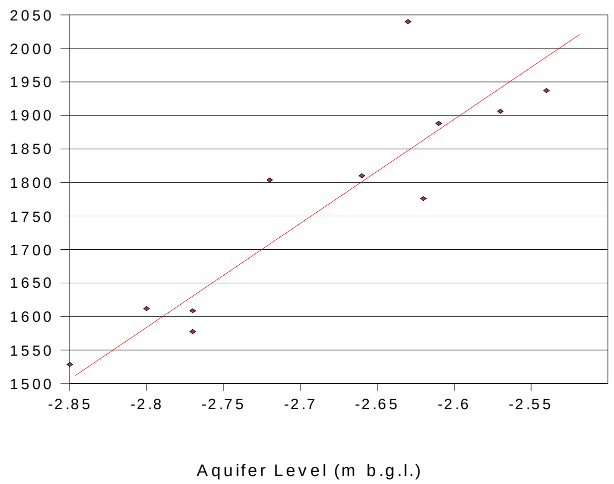
Notes: *Y Axis: Aquifer level (m below Ground Level)*
The discontinuity at approx 30l/sec is probably the point at which the upper springs stop flowing

There is a clear linear relationship over a wide range of flows and aquifer levels (i.e. Flow rates from the upper Avon springs and seeps are directly proportional to local aquifer levels.)

6. Relationship between Aquifer Level and Central City Avon Flows.

Average annual aquifer levels measured at the Ilam Homestead Gardens have been plotted against the average annual flow of the Avon measured at the Gloucester Street Bridge in the central city.

Graph 7: Avon Flow (Central City) v Aquifer Level (Ilam)



Notes: *Y Axis: Avon Average Annual Flow Rate (l / sec)*
All records are taken from the period 1992 – 2005

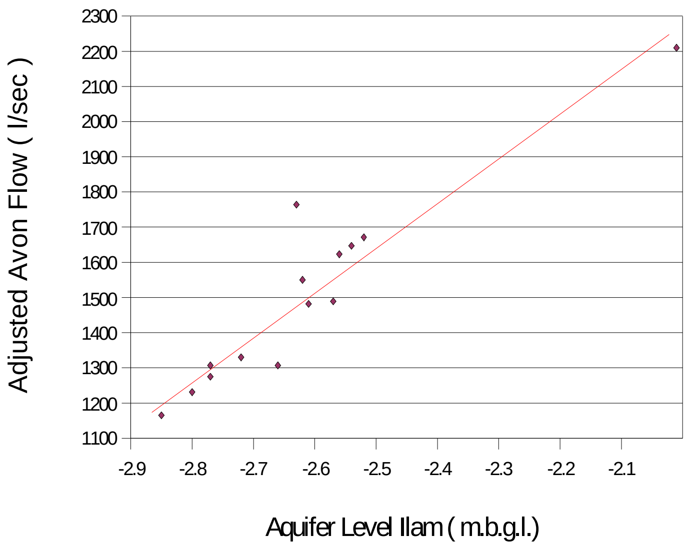
Again there is a relationship evident, however this is somewhat masked by the use of average annual flow data which includes varying artificial inputs and storm induced rainfall run-off events.

Given that the flow in the Avon in the central city is a combination of flows from all of its upper tributaries (i.e. the Avon itself, Ilam, Okeover, Waimairi, Wairarapa, and Wai-iti Streams and Fendalton, Riccarton and Taylors Drains.) the Ilam aquifer levels appear to be a surprisingly good predictor of central city flows.

7. Aquifer Levels, Flows, Run-Off and Artificial Inputs.

The Ilam Homestead well data was re-plotted against the river flow (at Gloucester Street) minus the calculated rainfall run-off and artificial input contributions for each individual year as noted in Sections 3.1 and 4.

Graph 8: Avon Flow (Central City) less rainfall run-off and artificial inputs v Aquifer Level (Ilam)



Notes: *Y Axis: Avon Average Annual Flow Rate adjusted for rainfall run-off and artificial inputs (l / sec)*
All records are taken from the period 1992 – 2006

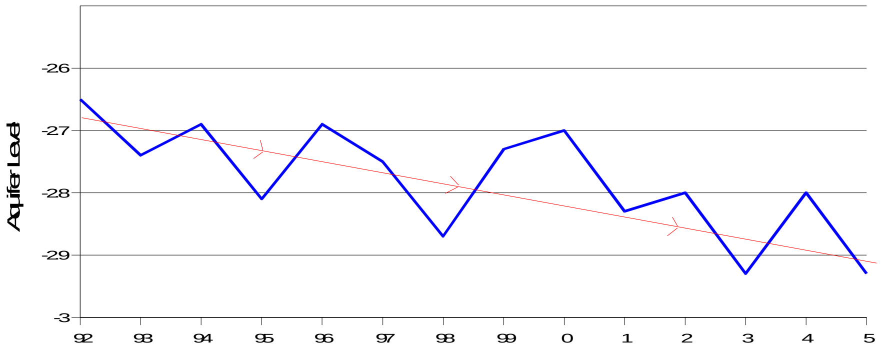
The artificial input adjusted flow reading taken on 5 September 2006 (i.e. 2210 l/s @ -2.01m), when the Ilam well level was at a recent peak and there was no run-off contribution to the flow, has also been plotted.

Apart from two points, in 1997 and 2002 - which are probably related to data inaccuracies due to the uncertainty of the timing of the start of artificial inputs - the relationship seems to hold over a wide range of flows despite, as noted previously, only using one set of well data for the investigation.

8. Avon Flows predicted from Local Aquifer Levels.

Annual average local aquifer levels, as recorded at the ECan Ilam Homestead Gardens monitoring well, have been plotted below.

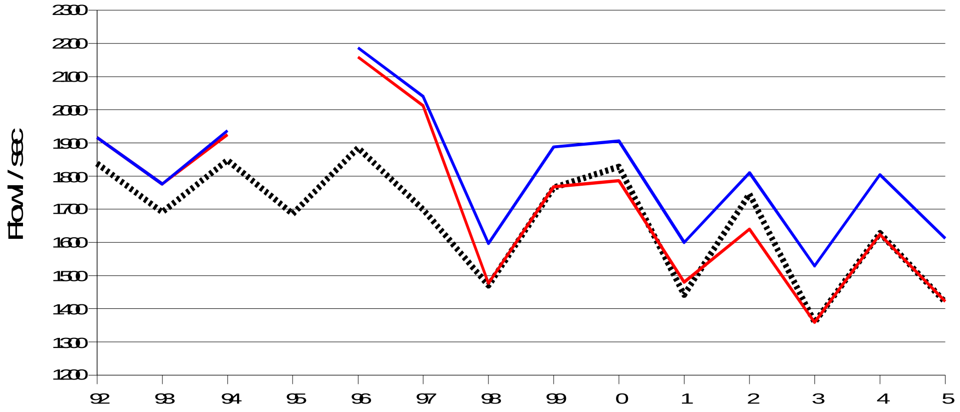
Graph 9: Annual Average Aquifer Level (Ilam) v Year



Notes: *Y Axis Aquifer level (m. below ground level)*

The flows (i.e. not including artificial inputs), predicted from the annual aquifer level data and the relationship described in Section 7, were then calculated and plotted against the actual recorded flows. This data is illustrated in the graph below:

Graph 10: Avon Flows (Central City) v Year



Notes: *Y Axis: Avon Average Annual Flow Rate (l / sec)*
Annual Avon Flows Actual (Blue)
Annual Avon Flows Actual Less Artificial Inputs (Red)
Avon Flows Less Artificial Inputs calculated from Aquifer Levels (Black dashed)

There is generally good agreement* between the actual flows (less the artificial inputs) and those calculated from the aquifer level data – confirming the strong relationship between aquifer levels and flow.

* Poorer correlations in 97 and 02 are probably related to timing issues with respect to artificial inputs.

9. Sources of Recharge for Local Aquifers.

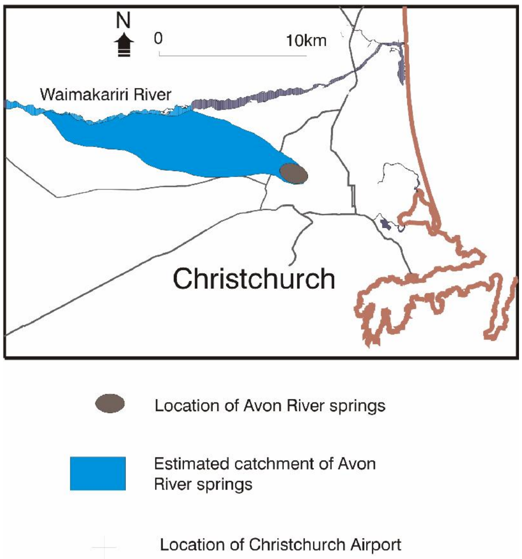
The three generally recognised sources of recharge for the local aquifer are; in ascending order of importance:- irrigation races, local rainfall infiltration and the Waimakariri River. (Adjoining aquifers may potentially act as a fourth source of recharge but they may also be a cause of loss of recharge.)

9.1 Irrigation Races.

A number of irrigation races traverse the potential recharge zone. Little information appears to be readily available to quantify their effects, if any, on groundwater flows. One earlier paper suggests an effect equivalent to approximately 10% of the Waimakariri recharge value, however more recent race management methods may have reduced this figure to a potential of about 2% (i.e. small)

9.2 Rainfall Infiltration.

The Canterbury Plains through which the Waimakariri Avon recharge water flows (the 'recharge zone') and over which rainfall infiltration occurs is illustrated below.



Extract from: " Catchment of Avon River Springs, Christchurch City" – Dr P.A.White, Institute of Geological and Nuclear Sciences; October 2005

The area of the recharge zone is only large enough to potentially create a rainfall infiltration contribution of less than 20% of the total of the Avon River base flow - even if all of this recharge re-emerged as flow in the Avon, which is unlikely.

Quantum of Rainfall Infiltration Recharge.

The rainfall catchment area for the aquifer feeding the Avon springs, according to the IGNS study referenced above, is approximately 50 sq km. The local average annual rainfall infiltration over the area is approx 200mm (data supplied by ECan) Mathematically, assuming that all of the rainfall recharge reached the aquifer - which it may not - the rainfall infiltration recharge is equivalent to an average flow rate of approximately:-

(50,000,000 x 0.2) / (365 x 24 x 60 x 60) = <u>0.3 cu.m / sec</u>

9.3 The Waimakariri River.

Reports, over a period of twenty years, indicate that the Waimakariri River is the most significant contributor to the shallow groundwater aquifer, north-west of Christchurch, which itself maintains the base flows in the springs. (This is in line with personal experience in the mid 1980's and the recent IGNS paper.)

Short term events associated with the Waimakariri (i.e. at times of flood flows) may also impact on Avon spring flows as a result of transitory pressure transmission through the aquifers.[1]

The quantum of loss of water from the Waimakariri, as recharge into the adjoining aquifers, is subject to debate and, it appears, a significant degree of uncertainty, however it is thought to average approximately 8 cumecs. This loss occurs between the Gorge Bridge and the old SH 1 bridge however the actual distribution and the mechanism of the loss along the river is not well understood.[2]

The quantum of the Waimakariri River recharge into the IGNS postulated Avon recharge zone is very uncertain. However, for the purposes of comparison only, the recharge may be considered to be of the order of 3 cumecs.[3] (i.e. approximately 10 times larger than rainfall infiltration recharge)

9.4 The Adjacent Canterbury Plains Aquifers

Leakage may occur to or from adjacent aquifers depending on the differential pietzometric pressures between the aquifers.[4] These effects do not presently appear to have been quantified but are potentially significant at times of larger pressure differentials (e. g. as during the Summer of 2005 / 06)

10. Relationship between "Ilam" Aquifer Levels and those Adjacent to the Waimakariri River.

Aquifer levels recorded at the Ilam Gardens well were plotted in a time series, from January 1998 to March 2006, together with those from the ECan monitoring well at McLeans Island (M35/0948), which is adjacent to the Waimakariri and within the IGNS postulated Avon River recharge zone.
(refer next page)

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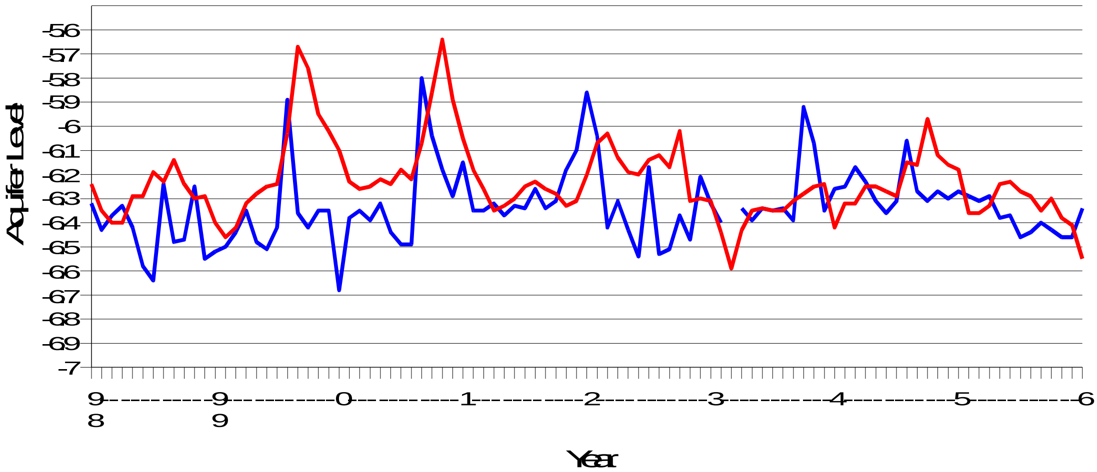
(1) Refer Section 10 for further discussion on this topic.
(2) The quantum and mechanism of the recharge from the Waimakariri River is discussed in a separate paper by the same author entitled " Waimakariri River Flow Losses – Constant or Varying?"
(3) This somewhat arbitrarily assumes that two thirds of the loss from the river is to the south and that the distribution of the loss is uniform along the length of the river over which measurements are made
(4) Refer Section 12.3 below for further discussion on this topic

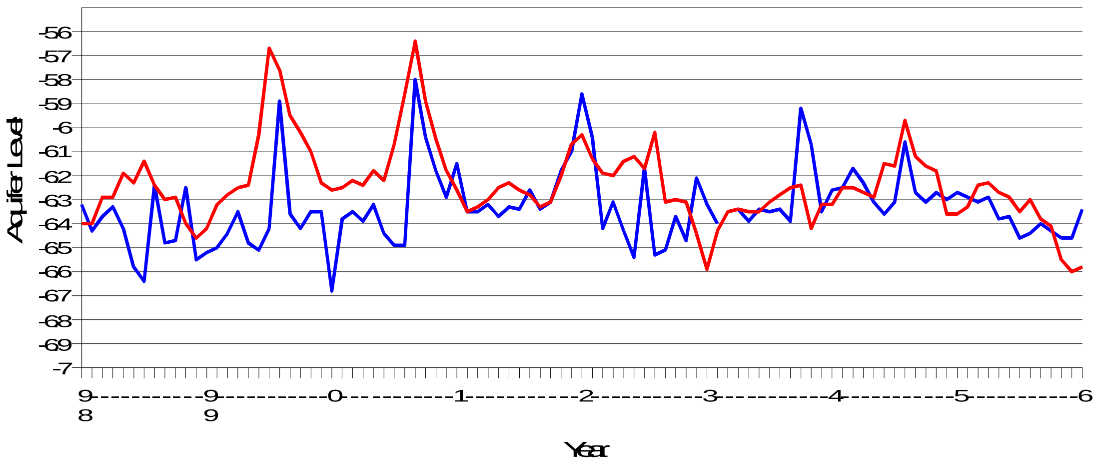
Graph 11: Aquifer Levels (Mcleans and Ilam) v Month



Notes: *Y Axis Aquifer level (m. below ground level)*
Ilam Gardens aquifer levels (Red)
Ilam well readings include a constant 3.5m deduction to readings to enhance visual comparison
McLeans Island aquifer levels (Blue)
X Axis markers set at January of each year

There is a clear correlation between the two sets of data. As can be seen below, offsetting the Ilam data by two months improves this correlation further – the two month offset probably represents the time taken for pressure changes to transmit through the aquifer from McLeans Island to Ilam Gardens.

Graph 12: Aquifer Levels (Mcleans and Ilam with Two Month Off-set) v Month



Notes: *Y Axis Aquifer level (m. below ground level)*
Ilam Gardens aquifer levels (Red)
Ilam well readings include a constant 3.5m deduction to readings to enhance visual comparison
McLeans Island aquifer levels (Blue)
X Axis markers set at January of each year
Ilam well readings moved 2 months backwards (e.g. Ilam March 98 reading paired with Jan 98 reading at McLeans)

Clearly the aquifer levels recorded at Ilam - and hence the quantum of the underlying flows in the Avon - are strongly influenced by aquifer levels at McLeans Island.

However when annual average data is compared between the two wells another picture emerges.

Graph 13: Annual Average Aquifer Level (Ilam and McLeans) v Year

Notes: *Y Axis: Aquifer level (m below Ground Level)*
Ilam Gardens aquifer levels (Brown)
McLeans Island aquifer levels (Blue)
Ilam well readings include a constant 3.5m deduction to readings to enhance visual comparison

It can be seen that the McLeans Island average annual aquifer levels have varied by approximately + / - 150 mm.[1] from average over the study period (i.e. levels have been neither trending up nor down) This suggests that the quantum of recharge entering the system from the Waimakariri River has been approximately constant on an average annual basis.[2]

However aquifer levels at Ilam Gardens have fallen by approximately 250mm.[1] over the same period (i.e. levels have been trending downwards.)

The question arises as to why this longer term disconnection may be occurring between the two sets of data given the apparent close inter-relationship described in the first part of this Section.

Accordingly the following two Sections discuss potential factors in the lack of well correlation and possible reasons for the declines in aquifer levels at Ilam - and hence declines in flows in the Avon.

(1) To place these figures in context, the well at McLeans Island has recorded an average variation from average levels of +600mm / - 600mm, whilst the well in the Ilam Homestead Gardens has recorded average variations from average levels of +500mm / - 300mm (i.e. an overall decline in level of approximately 250mm at Ilam is significant.)

(2) Aquifer levels recorded adjacent to the Waimakariri are thought to generally (i.e. at times other than high rainfall infiltration) be indicative of the recharge inflows from the river. Refer paper by same author *"Waimakariri River Flow Losses – Constant or Varying?"*

11. Rainfall and Infiltration Recharge.

11.1 Potential Aquifer Level changes due to Rainfall Infiltration Recharge

11.1.1 Historical Data.

Looking back over the past 25 years of local annual rainfall recharge data - supplied by ECan for the Christchurch / West Melton area - the recharge for 2005, although only approximately one third of average, was not dissimilar to another 4 years over the same time scale. There were also a further 2 years where the recharge had been less than half of the recharge in 2005. (i.e. 2005 was not particularly unusual from a rainfall recharge perspective yet the Avon's main headwater springs failed for the first time.)

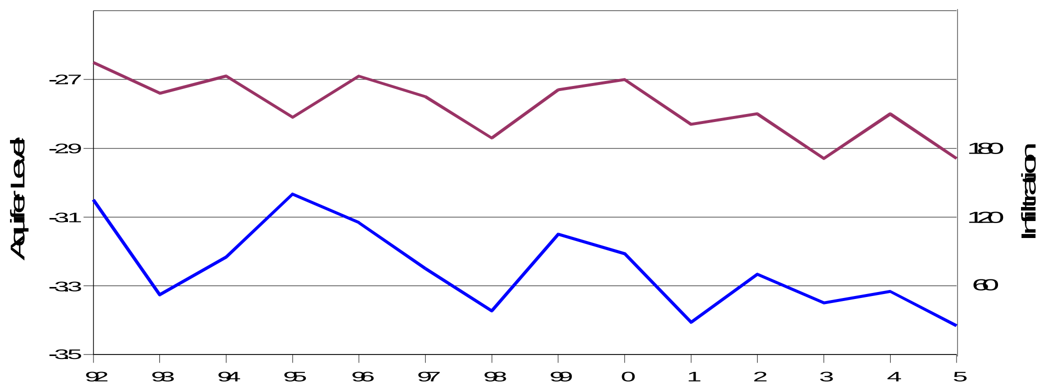
The two earlier, lower recharge years (in 1982 and 1988) did not, as far as can be determined, result in the springs drying up.

The question could therefore be posed:-

"*If rainfall recharge is the main driver behind the flow in the springs why didn't they run dry in 1982 and 1988 when the infiltration recharge volumes were much lower than in 2005?*"

Annual rainfall infiltration data, supplied by ECan, for the Christchurch – West Melton area has been plotted below together with annual average aquifer levels measured at Ilam.

Graph 14: Annual Rainfall Infiltration (Christchurch – West Melton) and Aquifer Levels (Ilam) v Year



Notes: *Y Axis– Left hand side, Ilam Aguifer Level (m.b.g.l.)*
Y Axis – Right hand side, Rainfall Infiltration (million cu.m.)
Ilam Aquifer Annual Average Level (Red)
Annual Rainfall Infiltration(Blue)

It can be seen that there has been an absolute decline in rainfall recharge between 1992 and 2005 of approximately 80%, or from an approximate equivalent 'Avon aquifer' recharge of 0.5 cumecs to 0.1 cumecs. (refer also Section 9.2) The trend decline is approximately 65%, or from an approximate equivalent 'Avon aquifer' recharge of 0.45 cumecs to 0.15 cumecs.)

As could be anticipated, there appears to be a degree of correlation between aquifer levels and infiltration. However the change in infiltration recharge volumes over the study period is relatively small in the context of the approximately 3 cumecs overall flows postulated to occur within the system. (The drop in overall recharge volumes, assuming recharge from other sources to be constant, equates to approximately 8%)

It is likely that the recorded changes in infiltration are a surrogate for abstraction demand rather than being the direct major determinant of level change. – which overall resulted in a drop in flow in the Avon of approximately 25% over the same period. (refer Section 4)

11.1.2 Timing.

It is possible to correlate many of the "spikes" in level at the ECan Ilam Gardens monitoring well with rainfall infiltration events recorded two months prior to the rise in aquifer level.

The "width" of the spikes (i.e. the time the levels were above the underlying levels) suggest that it takes an average of 2 months for the level effect of the infiltration to pass through the aquifer. Where there were consecutive months of infiltration there was a partial cumulative increase in level effect with about a 1 month or so carry over from one month's recharge to the next.

Accordingly recharge events separated by approximately two month intervals or more will not have a cumulative effect on aquifer levels - and hence spring flows. (The monthly infiltration data shows that there are often two month gaps or more between recharge events, particularly but not exclusively over summer.)

Occasionally, and normally over winter, the records show three or four consecutive months of recharge which could have a more marked affect on aquifer levels but again this effect appears to be only transitory.

In summary this data indicates that the effects of rainfall recharge events will dissipate relatively rapidly and will have only a transitory effect on aquifer levels at Ilam and hence spring flows.*
.

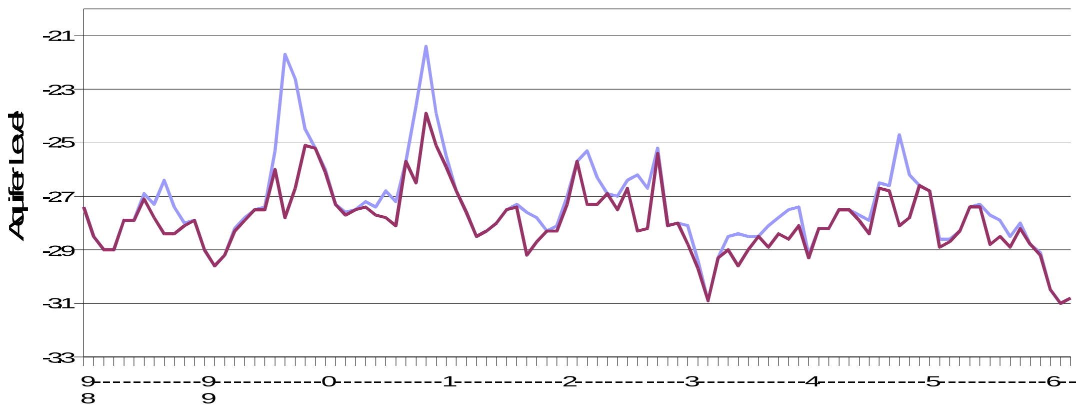
11.1.3 Quantum of Rises in Level

The 'average' monthly recharge is 17mm. Assuming that all of an ‘average’ recharge reaches the aquifer, the recharge will (simplistically) result in an equivalent rise in the aquifer level of about 60mm - allowing for the porosity of the aquifer. Given that the aquifer at Ilam rises and falls on average over a 800mm range, the rise created by an ' average ' recharge event is not large. (i.e. less than 10% of the average range.)

However as noted above, where there are three or four consecutive months of rainfall recharge levels may rise by generally up to 500mm but once again this effect is only transitory.

The Ilam well data has been re-plotted below after "removing" the effects of rainfall recharge..
(i.e. The aquifer level recorded was reduced by the equivalent recorded rainfall recharge including allowance for timing differences and any cumulative effects.)

Graph 15: Aquifer Levels (Ilam) with (Blue) and without (Red) Rainfall Recharge v Month



It may be helpful therefore to visualise the aquifer, at least to the point where it becomes confined, as a 'river', rather than a 'lake', and the rainfall infiltration events as ‘flood flows’ passing down that river.

It can be seen that the difference between the two traces (i.e. blue unmodified; red adjusted) is generally small. (i.e.. The underlying level pattern is not influenced greatly by rainfall recharge.)

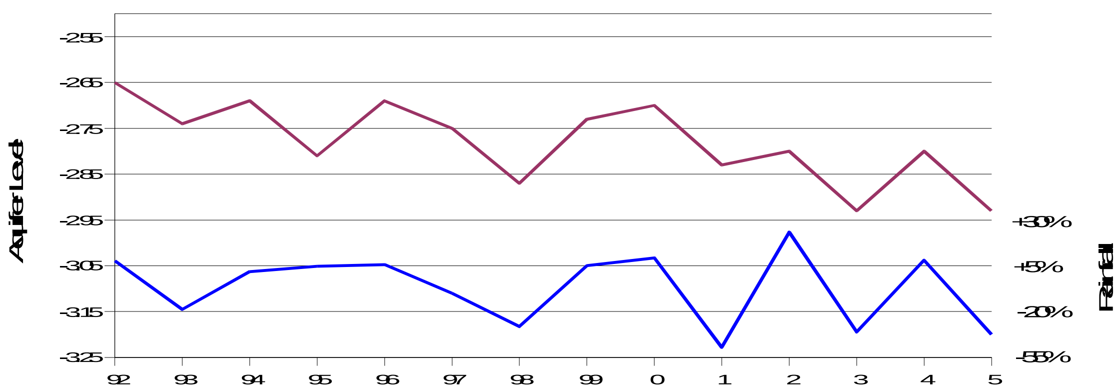
11.1.4 Overall Relationship with Aquifer Levels.

The investigations above all indicated that rainfall infiltration recharge for this system has only a secondary and transitory affect. (i.e. Rainfall recharge is not a major, direct determinant of long term aquifer levels in the system.) As a consequence variations in rainfall infiltration are unlikely to be a significant factor in the lack of correlation under study between the Ilam and Mcleans wells.

11.2 Rainfall.

Annual rainfall totals have been plotted below in a time series together with the average annual aquifer levels at Ilam.

Graph 16: Annual Average Aquifer Levels (Ilam) and Annual Rainfall v Year



Notes: *Y Axis– Left hand side, Ilam Aguifer Level (m.b.g.l.)*
Y Axis – Right hand side. Annual Rainfall (% average)
Ilam Aquifer Annual Average Level (Red)
Annual Rainfall (Blue)

It appears that there is a general inter-relationship between aquifer levels at Ilam and annual rainfall. However this is not a direct relationship - direct rainfall infiltration effects have been shown above to be minor. It can be concluded, however, that rainfall over the recharge zone, which will affect soil moisture levels, will influence irrigation demand and the consequential abstraction rates.

The degree of influence on demand will vary with a number of factors including timing in relation to the “irrigation season”. Increasing abstraction demand will however accentuate the effects on aquifer levels.

(Refer Section 12 for more detailed discussion on irrigation abstractions.)

11.3 Urbanisation.

Loss of rainfall infiltration into the local aquifers as a result of increasing urbanisation is often quoted as being a major contributory factor to the observed declines in flows in - and in some cases in the complete loss of - the Avon’s tributaries. Is this argument valid?

11.3.1 Avon Rainfall Catchment Area.

If all the rainfall, that would have otherwise infiltrated as recharge, is lost because of urbanisation of the Avon rainfall catchment then the loss of aquifer recharge, expressed as a rate is calculated to be 0.23 cumecs. (refer below for calculation details)

In reality not all of the surfaces are impermeable and much of the area was urbanised prior to the beginning of the study period (i.e.1992) Adjusting for these factors the reduction in recharge falls to approximately 60 l /sec. (c.f. average flow in the Avon at Gloucester Street of 1800 l / sec)

This reduction in recharge is small and in fact is likely to be an overestimate as a conservative approach has been taken to the loss of permeability effects, their timing and the quantum re-emergence of recharge as flow in the Avon.

11.3.2 Waimakariri Recharge Zone

The urban area of the IGNS model of the aquifer feeding the Avon springs is approximately 6.sq.km. Assuming that all of this urban area is now covered with impermeable surfaces, the area 'lost' to recharge is approximately 12% of the total Waimakariri recharge zone of 50 sq.km.

The overall potential rainfall recharge was calculated as approximately equivalent to 300 l / sec (refer Section 9.2), then the maximum potential loss of rainfall recharge is 40 l /sec.

This figure should then, conservatively, be adjusted for an average impermeability of 50% over the urbanised area . The calculated loss then reduces to 20 l /sec, (i.e. Approximately 1% of the annual average flow in the Avon.)

As noted in 11.3.1, it should be borne in mind that even this small figure will be an overestimate of the effect of loss of recharge area with respect to the present discussion as much of the area was urbanised prior to the period under study

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ECan estimate the rainfall catchment area for the Avon and its tributaries, prior to Gloucester Street, to be approximately 36.5 sq km and the rainfall infiltration rate for unmodified agricultural ground locally to be approximately 200mm per year.

If all the rainfall that would have otherwise infiltrated is lost because of urbanisation of the Avon rainfall catchement then the loss of aquifer recharge, expressed as a rate would therefore be:

36.5 X 1,000,000 x 0.2 / (365 x 24 x 60 x 60) = 0.23 cumecs

In reality the impermeable surfaces constitute say 50% of the urbanised area, so the loss of recharge becomes

0.23 X 100 / 2 = 115 l /sec

If we consider only the area of urbananisation since 1992 (i.e. the present study period) the infiltration loss reduces further - conservatively in the order of another 50%, since much of the Avon's rainfall catchment area under study was urbanised prior to 1992.

So the probable loss of recharge to the aquifer is only of the order of 60 l /sec.
(c.f. average flow of the Avon at Gloucester Street of 1800 l / sec)

11.3.3 Summary of Effect of Rainfall, Rainfall Infiltration Recharge, and Urbanisation.

It can be concluded therefore that variations in rainfall, rainfall infiltration, and urbanisation, are only of minor significance as causes of the observed decline in local aquifer levels and Avon flows.

Overall it would appear that, for practical purposes, the inflows into the aquifer have remained relatively constant .between 1992 and 2005. Outflows / abstractions are therefore potentially the major cause of the observed declines in local aquifer levels.

12. Abstractions.

12.1 Abstraction in Recharge Zone*.

12.1.1 Annual Abstractions.

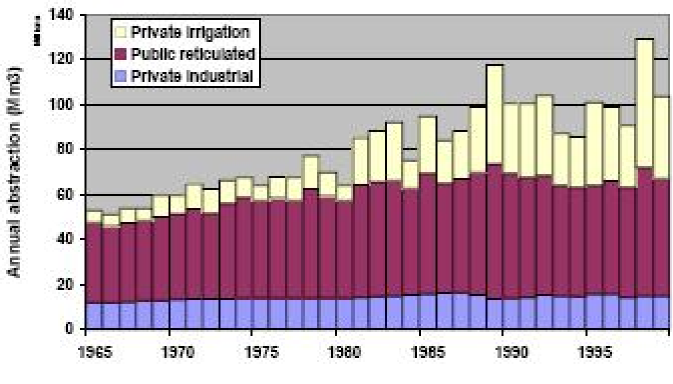
Abstractions from the area, and in the immediate vicinity of the recharge zone are numerous and in some cases large (e.g. The Christchurch International Airport holds resource consents totaling in excess of 300 l / sec – which alone is equivalent to the total rainfall infiltration recharge for the whole recharge zone.)

Public water supply demand is a potential influence on local aquifer levels, however abstraction rates appear to have been relatively stable over recent years as has commercial and industrial water use.

Christchurch City Council has two public water supply pump stations in the recharge zone (i.e. Avonhead, on Russley Road; and Crosbie Park, adjacent to Woodbury Street) Prior to the early 1990's both stations drew water from the aquifer that supplies the Avon and the Ilam Stream. However deeper wells were drilled in approximately 1992 and 1995 and water to supply base demand is now drawn from aquifers below the one under consideration in this paper. (i.e. Abstraction demand from the 'Avon' aquifer from these sources has in fact reduced since1992.)

Agricultural demand for irrigation water however has grown rapidly, doubling in size in the Christchurch – West Melton area over the period 1984 to 1999, at which stage it constituted 35% of the total abstraction volumes. As a consequence overall annual abstraction volumes increased by over 50% in the twenty year period from 1980 to 1999 - the latest date for available overall data.

Graph 17: Groundwater Abstractions (Christchurch – West Melton) v Year



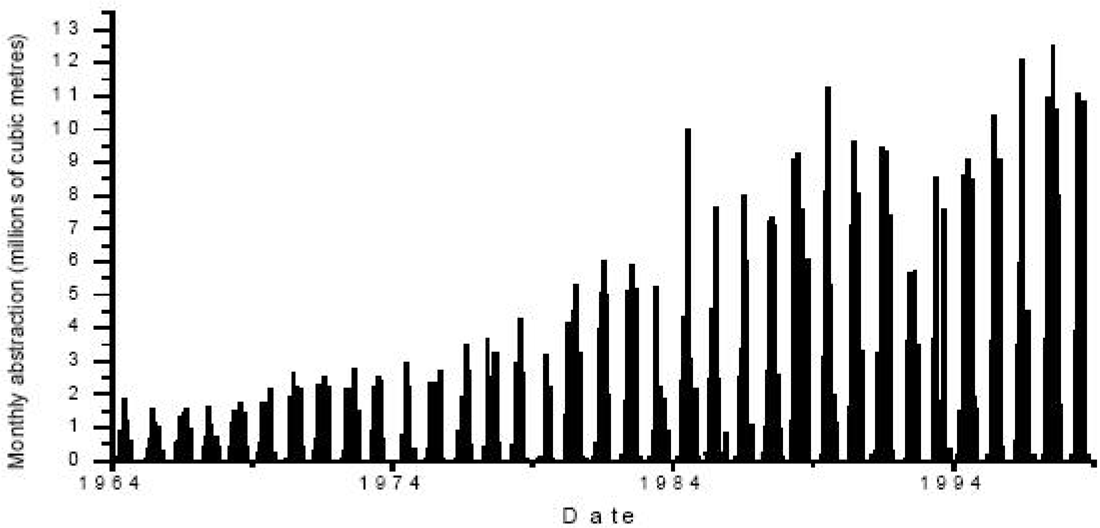
Graphs 17 & 18: Ecan Report No. U00 / 33: "Christchurch – West Melton Groundwater Investigation: Simulation of alternative groundwater abstraction scenarios and their effects on the baseflows of the Avon and Heathcote Rivers."

* I.E. As defined in Section 9.2

12.1.2 Irrigation Demand

Because of the seasonal nature of irrigation demand the peak monthly abstraction is considerably greater than for the other uses (i.e. of the order of 60% in 1999).

Graph 18: Irrigation Groundwater Abstractions (Christchurch – West Melton) v Month



Both the overall size and percentage takes of irrigation water are likely to have increased further since the data used above was collected. (i.e. year 2000)

12.2 Adjacent Canterbury Plains Aquifers

There appears to be a partial correlation between declining well levels as recorded at the Ilam site with those recorded in monitoring wells to the west of the recharge zone*.(These 'Plains' wells record aquifer levels in, what are considered by some authorities to be, separate but related aquifer systems from that feeding the Avon springs) This partial correlation decreases with distance from the Ilam well.

The Plains wells have, until recently, been running at or below previously recorded minima as a result of reduced rainfall infiltration recharge and increasing irrigation demand. It is therefore likely that the pietzometric data used in the past to determine generalised aquifer flow directions are not presently valid.

Consequently the assumed lack of interaction between the aquifers may also be incorrect. It is possible that there are significant volumes of Waimakariri recharge water being 'captured' by the adjacent aquifers with consequential detrimental effects on local aquifers and on Avon spring flows.

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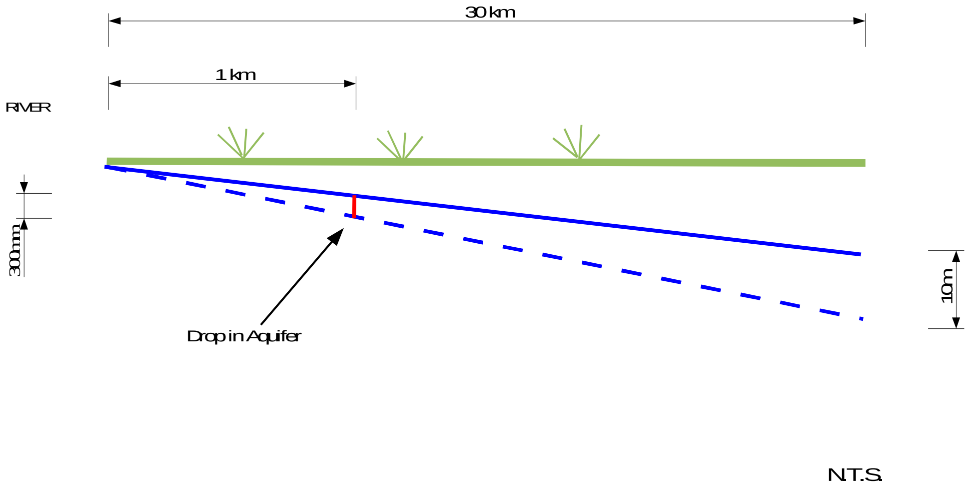
*The wells in the Plains to the west of Christchurch have been running on minimums until about Winter 2006 – i.e. about 6m below average.(Well average maximum variation = +16000mm / - 6000mm from average)

The wells immediately to the West of the presumed Avon River recharge zone have been an apparent blend of the two well types described immediately above.- i.e approximately 3m below average in Autumn 2006 (Well average maximum variation = +4000mm / - 3000mm from average)

The following drawing diagrammatically shows how a drop of aquifer level in the Central Plains has the potential to affect the aquifer levels close to the river. (The diagram is loosely based on data from ECan monitoring well L36/0092)



13. Conclusions.

The following significant conclusions have been drawn from these investigations :-

- The local unconfined aquifer levels are declining.
- This is having a detrimental effect on the Avon and its tributaries.
- Recent urbanisation of, and declines in rainfall infiltration over the recharge zone have had only minor impacts on aquifer levels.
- It is possible / probable that the major cause of the declines in aquifer levels is abstractions beyond sustainable limits from both the local aquifer and those in the wider Central Plains area .
- Knowledge of the recharge mechanism for, and the inter-relationship between the aquifers is incomplete.
- In particular neither the quantum nor the mechanism for the loss of flow from the Waimakariri River are well understood.

Even without considering the potential effects of climate change, should present trends continue, the prognosis for the Avon is very poor. The effects witnessed in the summer of 2005 / 06 will occur both more frequently and with greater severity. The length of river containing stretches of stagnant water and sections of dry river bed will increase These effects will increasingly move downstream. Without artificial inputs, the Avon will be permanently dry within 50 years.

In summary, human activity, be it through abstractions in the recharge zone, abstractions in the Plains aquifers or a combination of the two are having a marked detrimental effect on the Avon. Without adequate measures to reduce these abstractions, or at the least to hold them at present levels, the situation with respect to the springs and the iconic river itself could ultimately lead to the Avon's permanent disappearance.