Flow Paths, Drawdown, Recharge, Vertical Leakage and Perched Swamps

Within the Drawdown Influence of the Barwon Downs Borefield.

Otway Water Book 35

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"The new monitoring program will increase understanding of the Barwon Downs groundwater system in its normal state."

(SKM 2015)

Introduction

The lead up to the June 2019 renewal of the Barwon Downs Borefield licence had been a frenetic time. Barwon Water planned to submit its application for the renewal of its licence by the end of 2017 and in an effort to facilitate this application Barwon Water instigated a modified monitoring program. Unfortunately, the emphasis was the creation of a baseline data dating from 2014. Many of the reports and much of the data going back 30 years had been all but omitted from these deliberations.

A multitude of studies resulting from the new monitoring program were based on the 14-18 months of data collected since the new monitoring program started. It would appear that many of the conclusions and statements arrived at failed to apply sound technical and scientific expertise.

Kay, my wife says one should be able to trust what people have to say, but she also says to trust your instincts. With much of the Jacobs material therein lies a conundrum. One should be able to trust the reports prepared as a result of the new monitoring program but instincts dictate that this work required close scrutiny. Clarity could only be reached through review and examination of the documentation.

This Otway Water book scrutinises and the examines conclusions and statements made by Jacobs and also gives some insight into the way the hydrology of the region functions.

Otway Water Book 31[(14)] challenges the statement that no impact on the health or condition of vegetation has taken place from groundwater extraction at the Barwon Downs Borefield. Also, up until now, little effort has been given challenging the following dot points: This Book 35 makes such an effort.

- Several of the 14 sites chosen in 2014 were cited as sitting on perched aquifers with little to no connection to the regional groundwater system. That is the Lower Tertiary Aquifers.
- The Big Swamp is given as an example of a wetland possibly sitting on a perched swamp.
- Vegetation impacts on vegetation within the influence of the Barwon Downs Borefield are stated as not the result of groundwater extraction.

- It is also stated there can be no influence from groundwater extraction as extraction ceased in August 2010 (A minor extraction took place in 2016).
- This minor 3267 ML (This figure varies depending on the source of the information.) extracted between April 2016 and September 2016 has been stated as having no impact on vegetation (see graph, page 30).
- Vertical leakage is relegated as of minor concern

- "***No evidence was found that declining groundwater levels caused by groundwater extraction at Barwon Downs had a negative impact on vegetation health in the catchment.***"

(Jacobs 2016)

- "***...water table drawdown occurs during pumping, but no long-term environmental impacts have been linked to borefield operation.***"

(Barwon Water, February 2012:Water Supply Demand Strategy 2012-2062, Draft.)

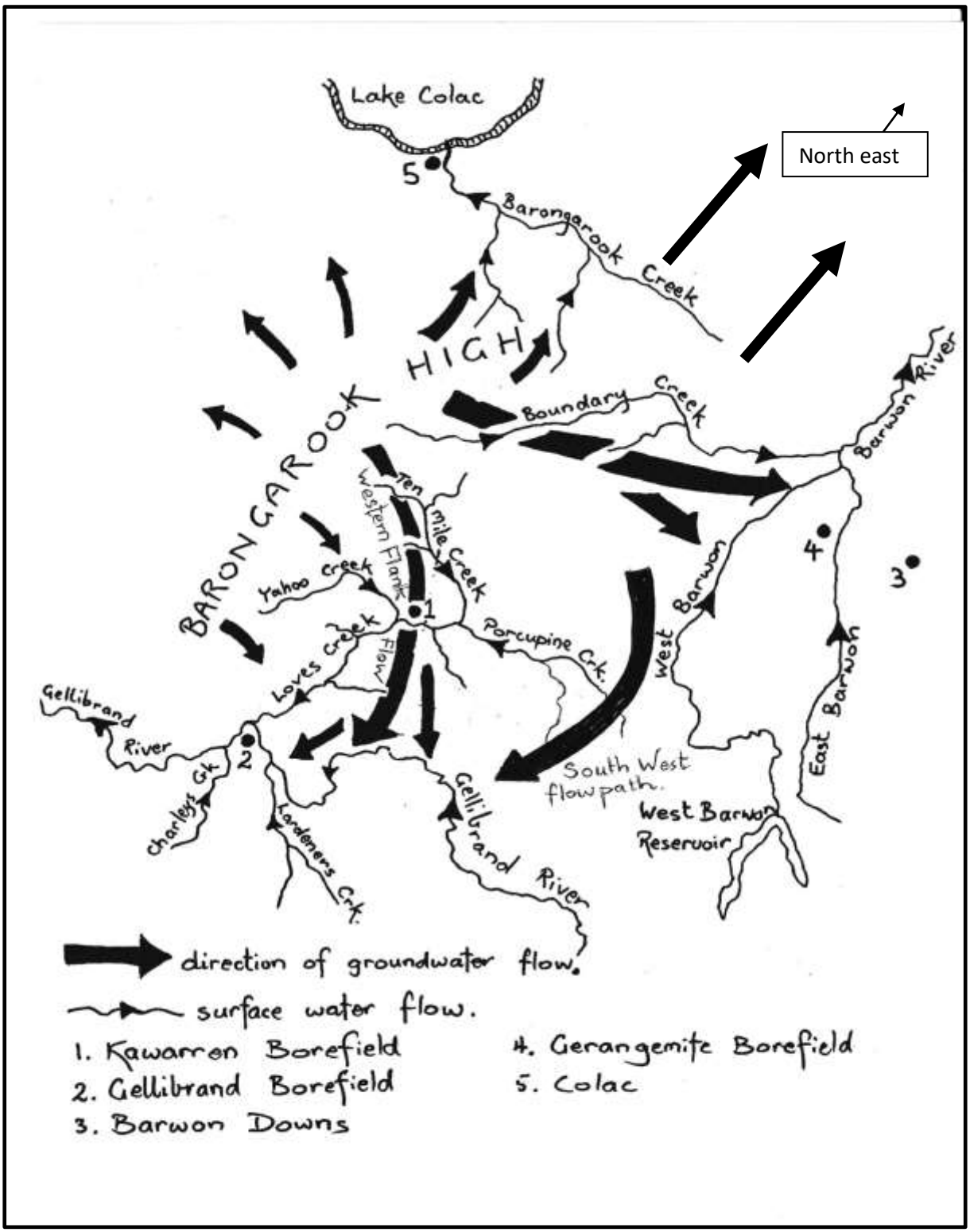
Geological Cross Section of Units found in the Study Area.

Geologic unit		Type
SKY		
Quanternary		Aquifer
Gelli Marl		Aquitard
CLifton		Aquifer
Narrawaturk		Aquitard
Mepunga		Aquifer
Dilwyn		Aquifer
Pember		Aquitard
Pebb lepoint		Aquifer
Bedrock		Aquitard

Mid Tertiary Aquitard (MTD).

Lower Tertiary Aquifers (LTA).

GROUNDWATER FLOWPATHS & RECHARGE



Map showing groundwater flowpaths.

In a pre-groundwater extraction and natural state the major recharge area for the Lower Tertiary Aquifers is where the Lower Tertiary Aquifers (LTAs)

outcrop on the Barongarook High. There will always be some dispute over the amount of recharge this area does contribute, however, the amount of rain falling on the Barongarook High soaking into the LTAs has seen study results ranging from 3% to 28%.[24][26][28][30] The latest Jacobs report[26] suggests that a realistic level of rainfall recharge is around the 10% mark. "***The results suggest that recharge to the Barongarook High is approximately 10% of average rainfall and unlikely to exceed 14% of average rainfall.***"

Under rainfall conditions through the Barongarook High region vegetation and the dry surface soils make first use of the rain. Next to receive precipitation is the LTAs. Runoff occurs when there is a high rainfall event, the subsurface is saturated and or the Lower Tertiary Aquifers are full. Under normal conditions and without extensive groundwater extraction, springs and perennial creeks continue to discharge from a full LTA, adding to catchment runoff. In effect the full Lower Tertiary Aquifers buffer drought and low rainfall periods.

In 1986 Farmar-Bowers[5] calculated the recharge from rainfall to be in the order of 1600 ML/year. After an extensive stress test pump between 1986 and 1990, Witebsky et al.[38] calculated it to be "...***from 1500 ML/year in the undisturbed state to about 4000 ML/year under stressed conditions***." Extract more than is recharging and impacts at the surface will become apparent.
"***Any significant development of the groundwater resource (i.e. greater than 1500 ML/year), will result in the watertable being lowered on the Barongarook High and will have an impact on the Boundary Creek system and associated spring systems, because of the high degree of hydraulic connection that exists between the aquifer system in the graben and aquifer outcrop on the Barongarook High.***"

In 1994 HydroTechnology estimated that 12 km^2 of the Barongarook High landform supported the groundwater recharge down the Kawarren corridor and 16 KM^2 through the Barwon Downs Borefield corridor."***The results from drilling in this region has provided sufficient data to accurately delineate the areas providing recharge to each sub-region.***"[22]

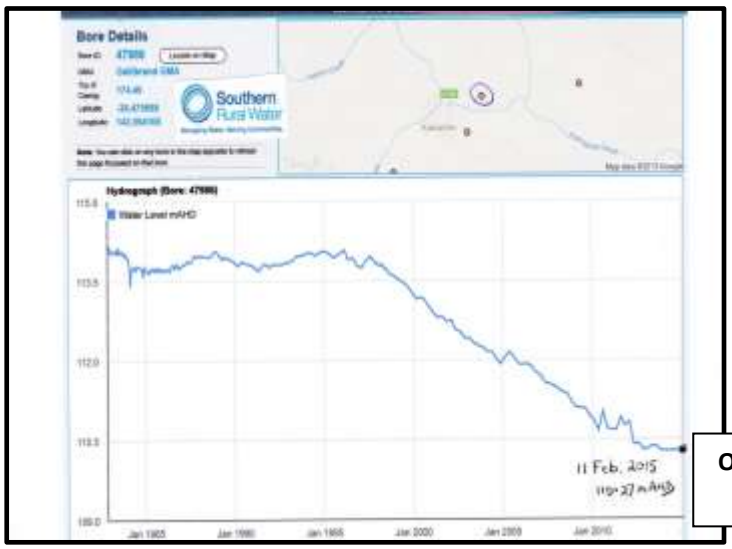
It was also postulated that extensive groundwater extraction would drop the watertable level on the Barongarook High increasing the amount of rainfall as recharge.
"***A significant fall in the water level in the Barongarook High area will enhance recharge to the regional aquifer system by reducing the volume of rejected recharge which discharges locally to the springs and streams in this area.***"[22]

In 2002 SKM had this to say, "***It has been noted that during periods of significant pumping from the aquifer, the flow in Boundary Creek is reduced and in some instances it has ceased flowing altogether.***"[33]

Another impact predicted was the cessation or reversal of groundwater flowpaths. In 1984 Leonard[29] had this to say, "***Creation of a cone of depression in the potentiometric surface in the Gerangamete area will distort the present flow pattern and absorb the northeasterly and southwesterly components of recharge from the Yeodene recharge avenue***." In other words the aquifer flowpaths into the Kawarren/Gellibrand and Deans Marsh regions will be impacted.

Leonard also stated that, "***Underflow via the Barwon Downs Graben to the Gellibrand River catchment will cease; gradient reversal will result in components of recharge being drawn away in the northeast and southwest and from any as yet undelineated recharge zone along the Bambra fault.***"[29]
The words "cease," "gradient reversal," and "drawn away" are quite precise and contain a powerful meaning and warning given in 1984 that groundwater extraction could/would have dire consequences unless managed in a sustainable way. Unfortunately, Leonard's predictions have come to pass and the north east groundwater flowpath has been reversed (see the diagram on pages 8 and 9) with spring, creek and river flow impacted.

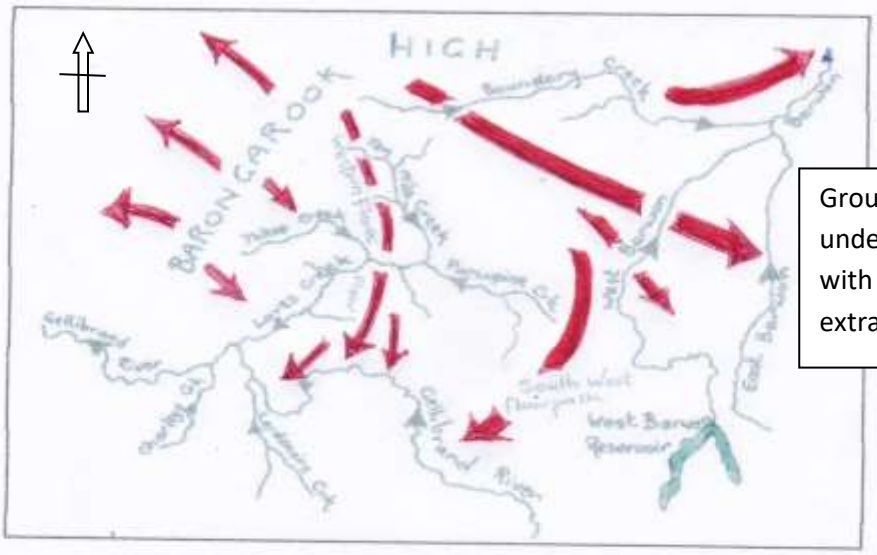
A similar trend is happening in the south westerly direction down the Kawarren and Gellibrand River flowpaths. "***An investigation by Jacobs (2016f) confirmed that drawdown extends to Kawarren area.***"[24]
In 2016 Wade found that the Borefield extractions had reduced Loves Creek's summer baseflow by 50%.[34] By 2019 it had been reduced by 60%.[36]



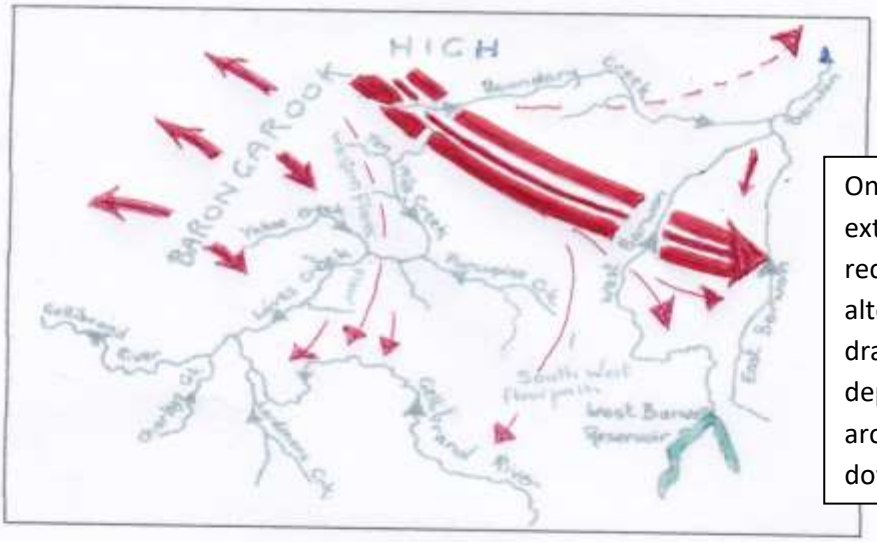
This hydrograph for an observation bore down the Kawarren flowpath shows a steady decline in the water level since 1997. This is despite reasonably wet winters since 2010 when groundwater extraction stopped.

On 12/05/2017 the AHD level was 110.13 metres.)

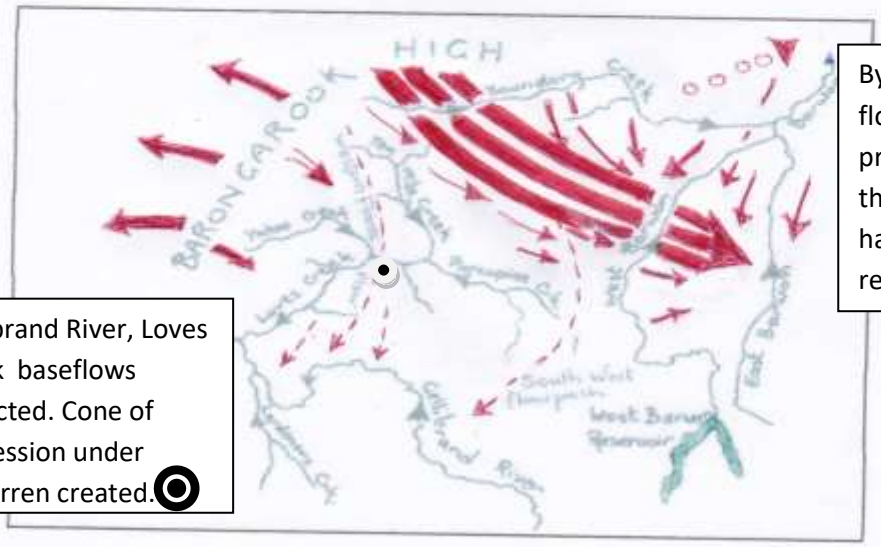
Changing Aquifer Flowpaths from Barongarook High Intake Area



Groundwater flowpaths under natural conditions with no groundwater extraction.

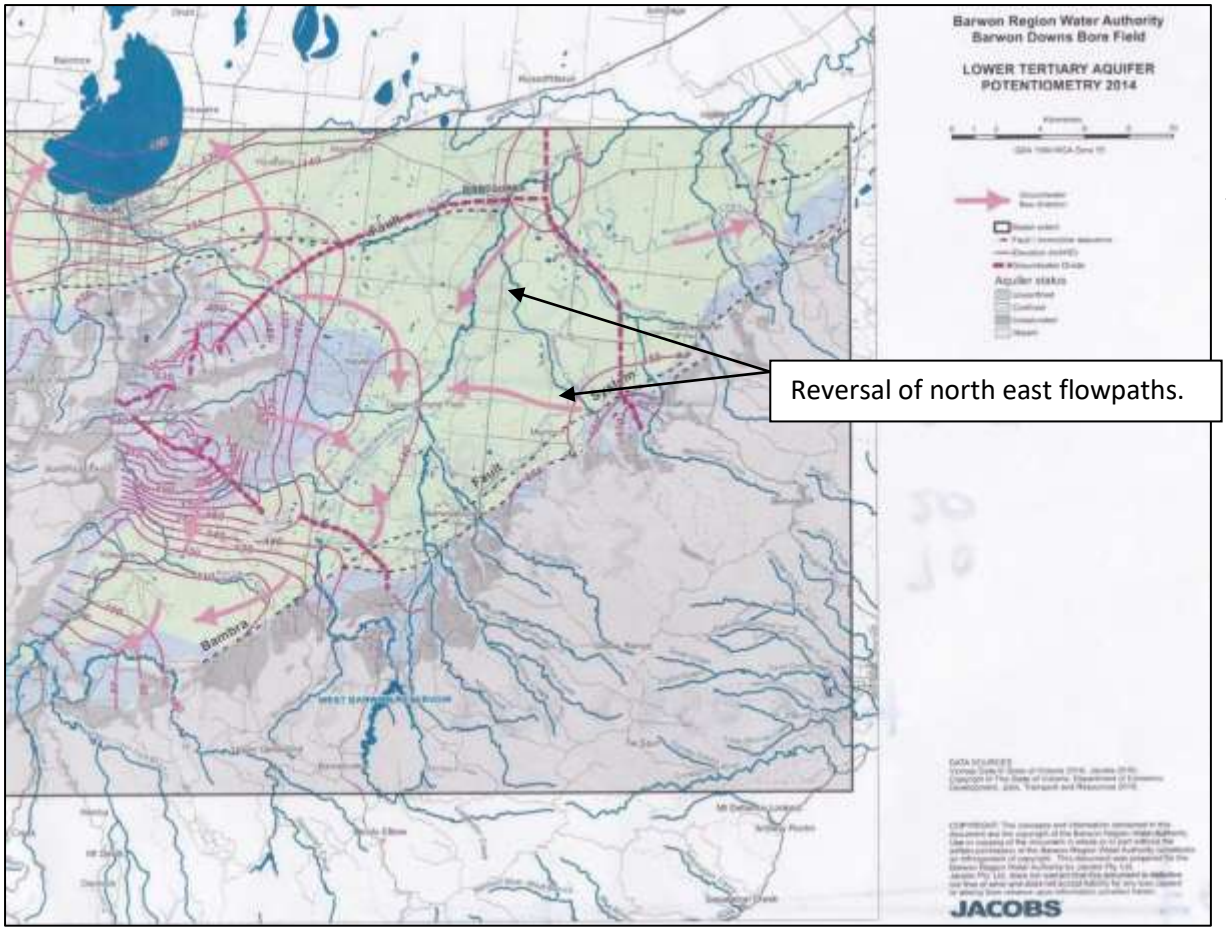


Once groundwater extraction exceeds recharge the flowpaths alter. More water is drawn into the cone of depression created around the Barwon downs Borefield.

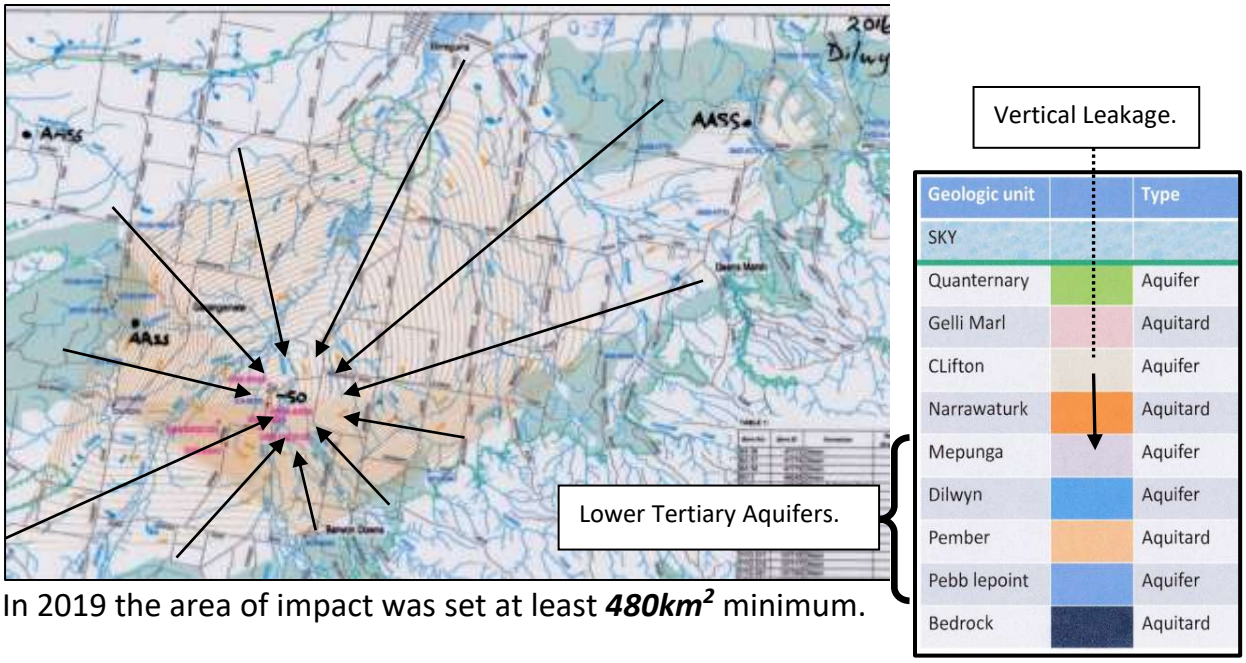


By 2014 the north east flow had reversed as predicted by Leonard, & the south west flowpath has been significantly reduced.

Gellibrand River, Loves Creek baseflows impacted. Cone of depression under Kawarren created.



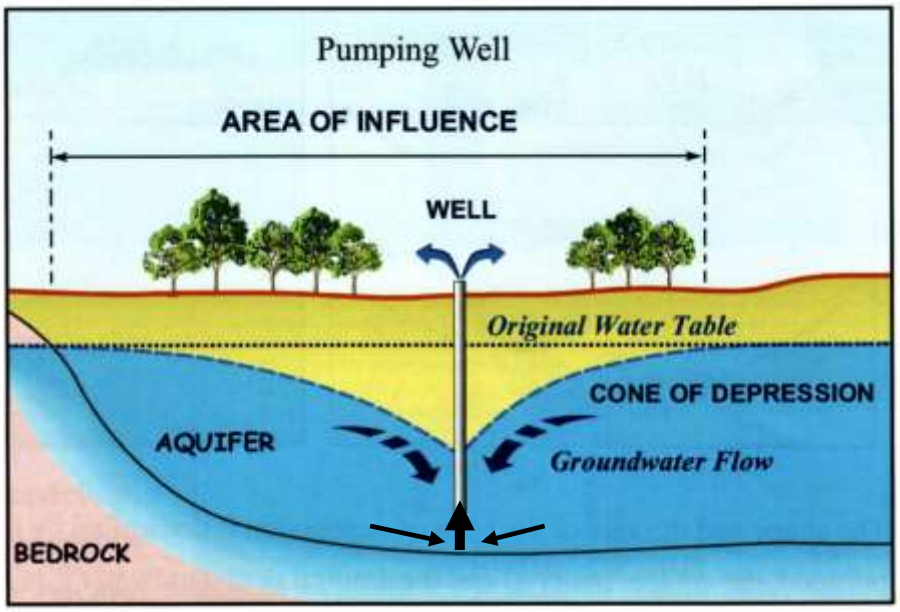
Not only do the depleted Lower Tertiary Aquifers suck water in from all directions altering flowpaths they also receive recharged from downward vertical leakage out of the saturated formations above. This is discussed in more detail in the vertical leakage section (see page 19).



In 2019 the area of impact was set at least ***480km²*** minimum.

CONES of DEPRESSION

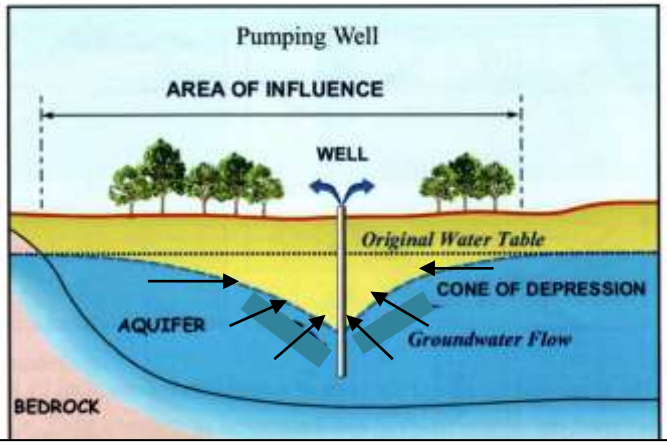
The greater the amount of groundwater extraction that takes place faster than it can be replenished, the deeper the cone of depression becomes, and, the further out from the extraction bores the watertable is lowered. The area of impact gets wider and wider (as at 2019 480km^2 nine years after serious pumping ceased) as water from the outer reaches is sucked in to the centre of the dewatered cone.



SOURCE: Centre for Groundwater Studies, Blackwood South Australia.

This diagram demonstrates the cone and area of influence under groundwater extraction conditions.

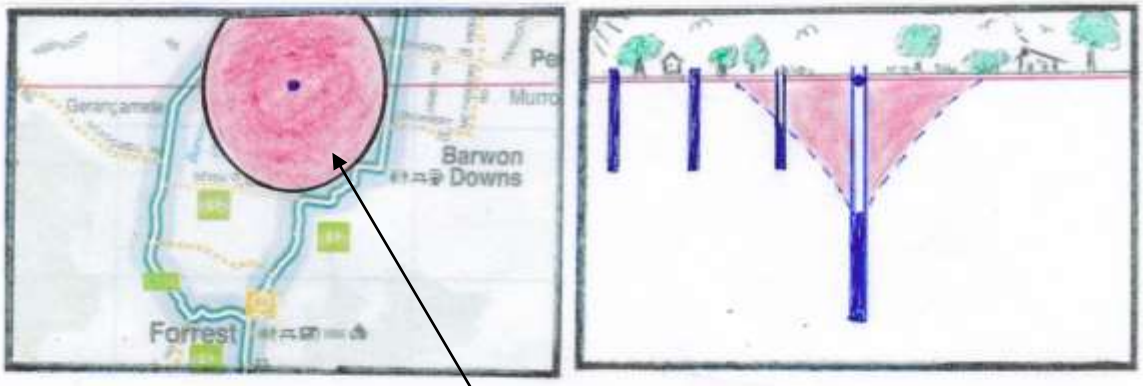
Once groundwater extraction ceases, water is drawn into the cone from all directions. Groundwater extraction stopped early in 2010. "***However, at a distance from the borefield in outcrop areas, groundwater levels in 2012 were lower than in 2010 due to the continued expansion of the drawdown cone at large distances from the borefield after cessation of pumping.***"(23) Even though "***...water levels near the borefield had been in recovery for around two years.***"(23)



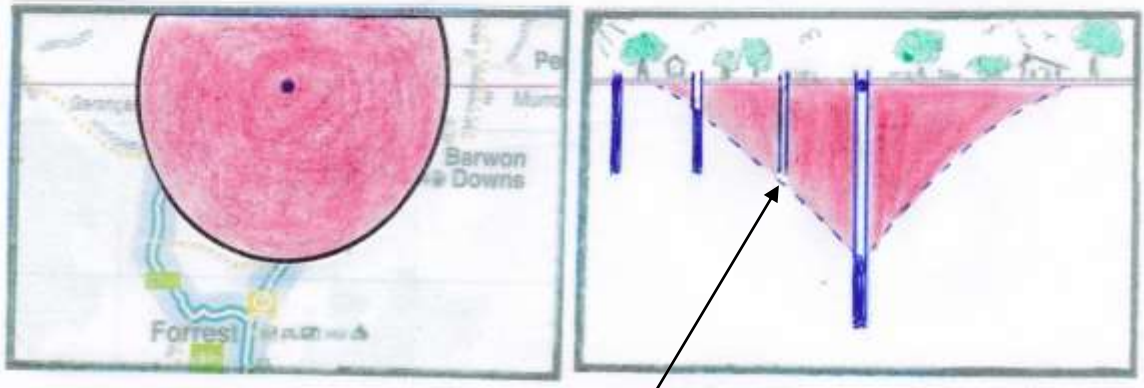
When groundwater is being extracted observation bores within the cone of depression can be felt sucking air. When the pumps stop and the cone begins to fill, air in the bore hole space is blown out and replaced with water.

The Area of Drawdown Influence and Impact Increases When Extraction Exceeds Recharge.

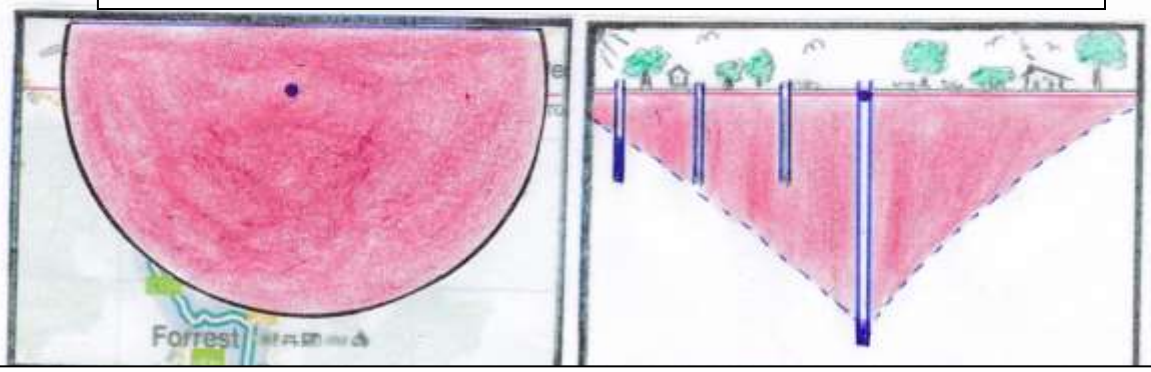
Early stages of groundwater extraction and the cone of drawdown is small.



As the extraction proceeds the area of influences expands further and further out.



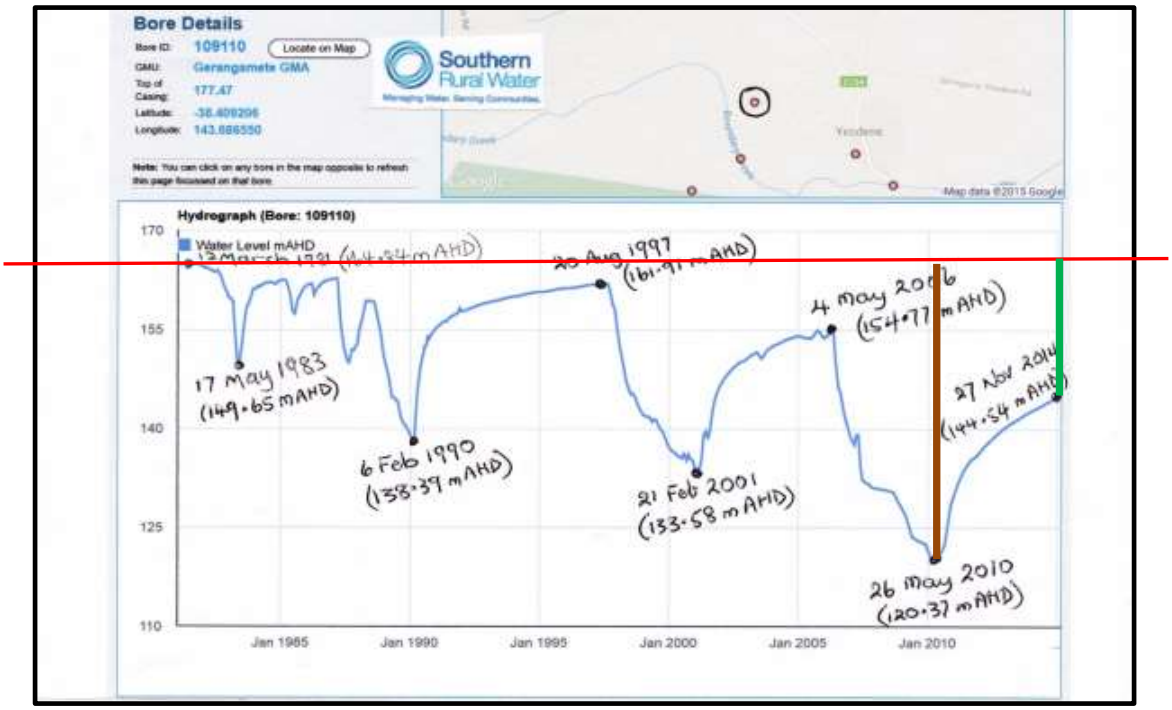
Bores, springs, creeks and wetland are impacted and begin to dry up



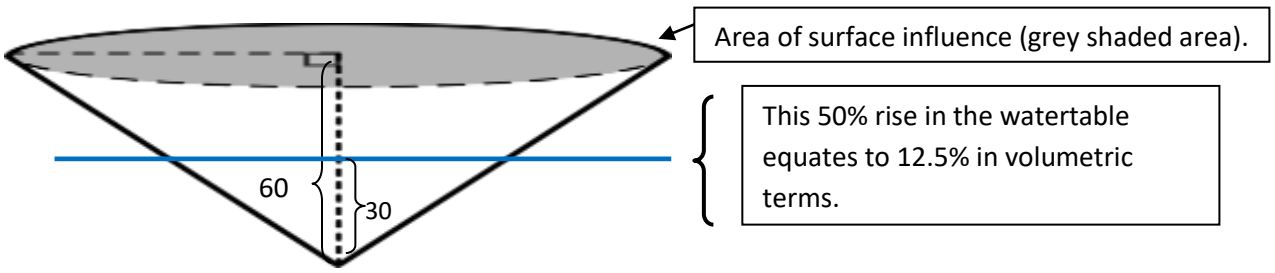
By 2016 the sphere of influence extended out to the Barongarook High. "***...drawdown in the LTA has extended to where the aquifer outcrops (around the Barongarook High)...***"[26]

FILLING the CONES of DEPRESSION

Once groundwater is stopped or rainfall exceeds extraction then the cone of depression begins to fill up. Although the depression formed is not a regular shaped cone the figure and calculations below illustrate how measuring recovery in the vertical plane can be deceiving and or easily misinterpreted.

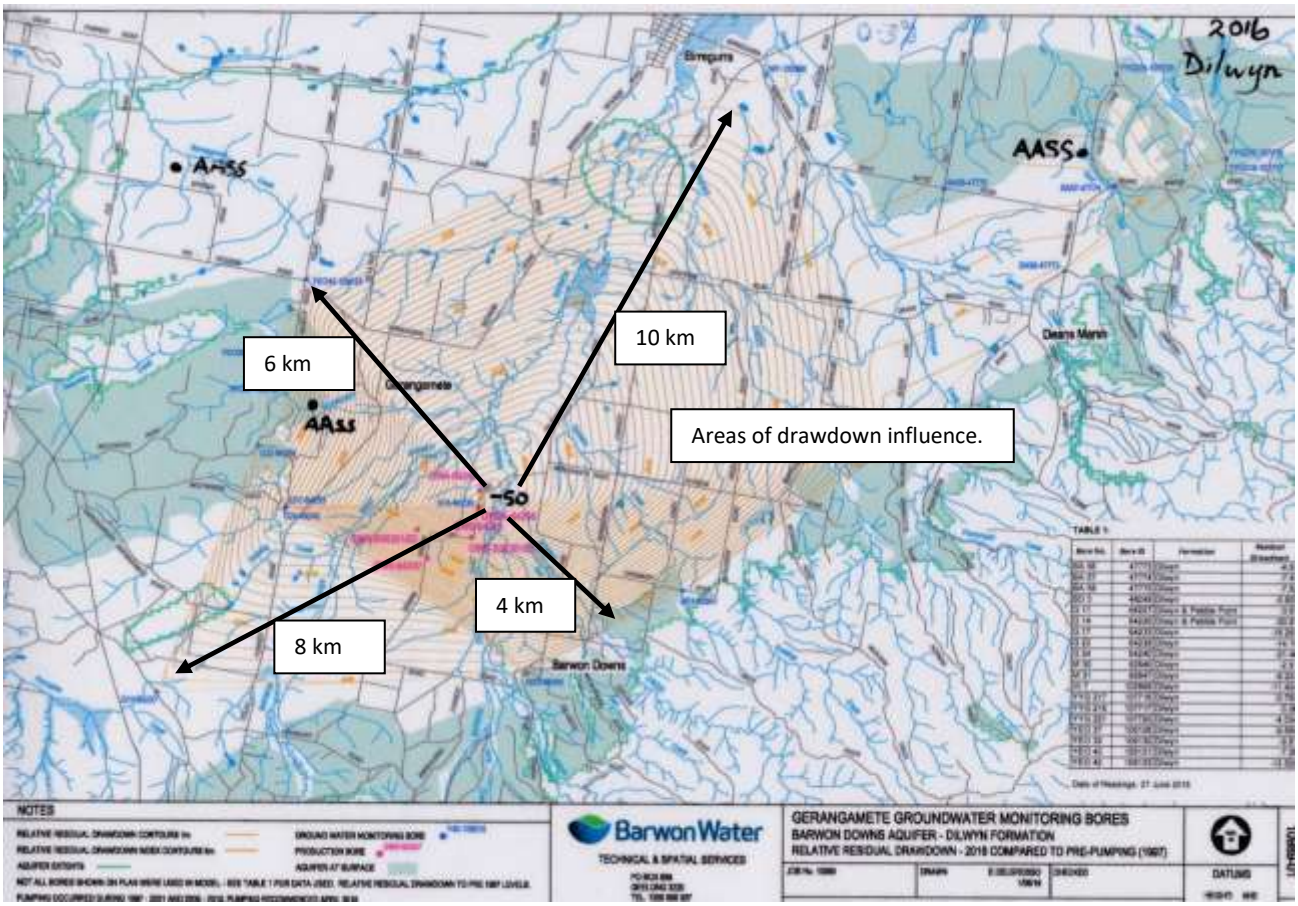


By the end of May 2010 the cumulative drawdown impact from groundwater extraction at observation bore 109110 was approximately 44 metres (brown line). Pumping stopped in 2010 and the vertical water level recovered by approximately half (24 metres – green line) by the end of November 2014. This gives the impression that the aquifer has recovered by 50%. This is not the case, even in the vertical plane, and the distortion in the volumetric sense is even more pronounced.



The depth of the cones at the Barwon Downs Borefield went down to approximately 60 metres before pumping was stopped. If the influence spread out uniformly with a radius of 1000 metres a vertical recovery of 24 m would equate to 6.4%% volumetric recovery. For the water table to rise 50% at the

Borefield the volumetric recovery over the area of impact would only be 12.5%. These figures are applicable to a rigid cone with a 1 kilometre radius and are simplistic and indicative only, as the cones of depression caused by the Barwon Downs Borefield does not stay constant; are parabolic and affected by irregular topography. As at 2016, in some directions the radius of the cone of drawdown was around 4 kilometres while in others it was over 10 kilometres. Realistically the volumetric recovery would be significantly less than 12.5%.



The red lines indicate the area of drawdown influence as at July 2016 and has a much wider spread than the 1 km radius used in the calculations above.

To further emphasise how easy it is to gain the wrong impression from a one dimensional vertical recovery a Barwon Water representative had this to say after the water tables in the Lower Tertiary Aquifers had risen by approximately half using the one dimensional calculations. "***Latest figures from Barwon Water's comprehensive monitoring program show groundwater levels in the area have recovered significantly since the borefield was last operated.***" (Letter to Colac Herald Editor from Barwon Water representative, Friday 18 March 2016.) At this date the Dilwyn Aquifer had recovered to -16 metres. A 2900 ML extraction between April and June, dropped it back down to -50

metres as seen in the map above. No three dimensional calculation was taken into account.

The earliest map available of the drawdown area of influenced goes back to 2002. Since this map was produced every yearly map has shown that the aquifers have never recovered to pre groundwater extraction levels. The influence of drawdown has been taking place for at least 30 years.

Sustainability

The word sustainability gives the impression that some action can repeated over and over again and the impacts on the resource being exploited are minimal – the source can be exploited indefinitely without causing serious problems – in many cases the use of the word conjures up the mental picture that there will be no impact or such a small one that it really does not count.

To give weight to this perception the only definition that should be universally used in Australia is the Australian nationally accepted one:
"The groundwater extraction regime, measured over a specific planning timeframe that allows acceptable levels of stress and protects dependent economic, social and environmental values."
Another way of saying this would be ***sustainable groundwater extraction is when the removal or withdrawal of water from an aquifer over a period does not exceed the recharge of the supply to that aquifer and should not impact on another area of the aquifer, surface water features and or ecosystems***.

When taking into consideration the following quotes found on pages 63 and 64 of Barwon Water's "Water Resources Development Plan" of March 2003, one should have felt confident that the continuation of groundwater extraction at the Barwon Downs Borefield would continue in a sustainable manner as outlined above.
"Extensive groundwater modelling and technical investigations have been carried out on the operation of the Barwon Downs wellfield. These studies have included:

- ***Groundwater modelling to determine the sustainable yield of the basin; investigations into potential subsidence due to drawdown of water levels in the basin***
- ***Assessment of the potential impact on local stock and domestic bores and baseflows in Boundary Creek (which runs through the recharge area).***
- ***Flora, terrestrial and fish fauna re-surveys of the Boundary Creek area (which were originally carried out in 1993/94)."***

"A number of conclusions can be drawn from the studies:

(Not all of the conclusions have been included here)

- ***The sustainable long-term yield of the Barwon Downs graben is 8,000 megalitres a year (twice that for which Barwon water has applied)***
- ***No long term flora and fauna impacts have been detected in the Boundary Creek area resulting from the operation of the Barwon Downs wellfield.***
- ***.....Substantial information has been obtained on groundwater over the past 30 years, including sensitive studies of the Barwon Downs wellfield. These have shown that pumping under the proposed conditions is sustainable....***
- ***As a result of the recent groundwater modelling determining that the proposed new licence conditions are sustainable...."***

Even in 2003 there was considerable evidence to support the argument that under the national sustainability definition that the Barwon Downs wellfield was not sustainable.

How could the word "sustainable" be used back in 2003 and still be used in the same way in 2017 justifying groundwater management decisions? Perhaps the answer to this can be found when looking at the definition of sustainability that both Barwon Water and SKM/Jacobs have been basing decisions on.

The 'effective safeguards" referred to here have nothing to do with surface water impacts.

Guarding against "unacceptable impacts" are at least 200 m below the surface.

SKM

8. Sustainability of Borefield Use

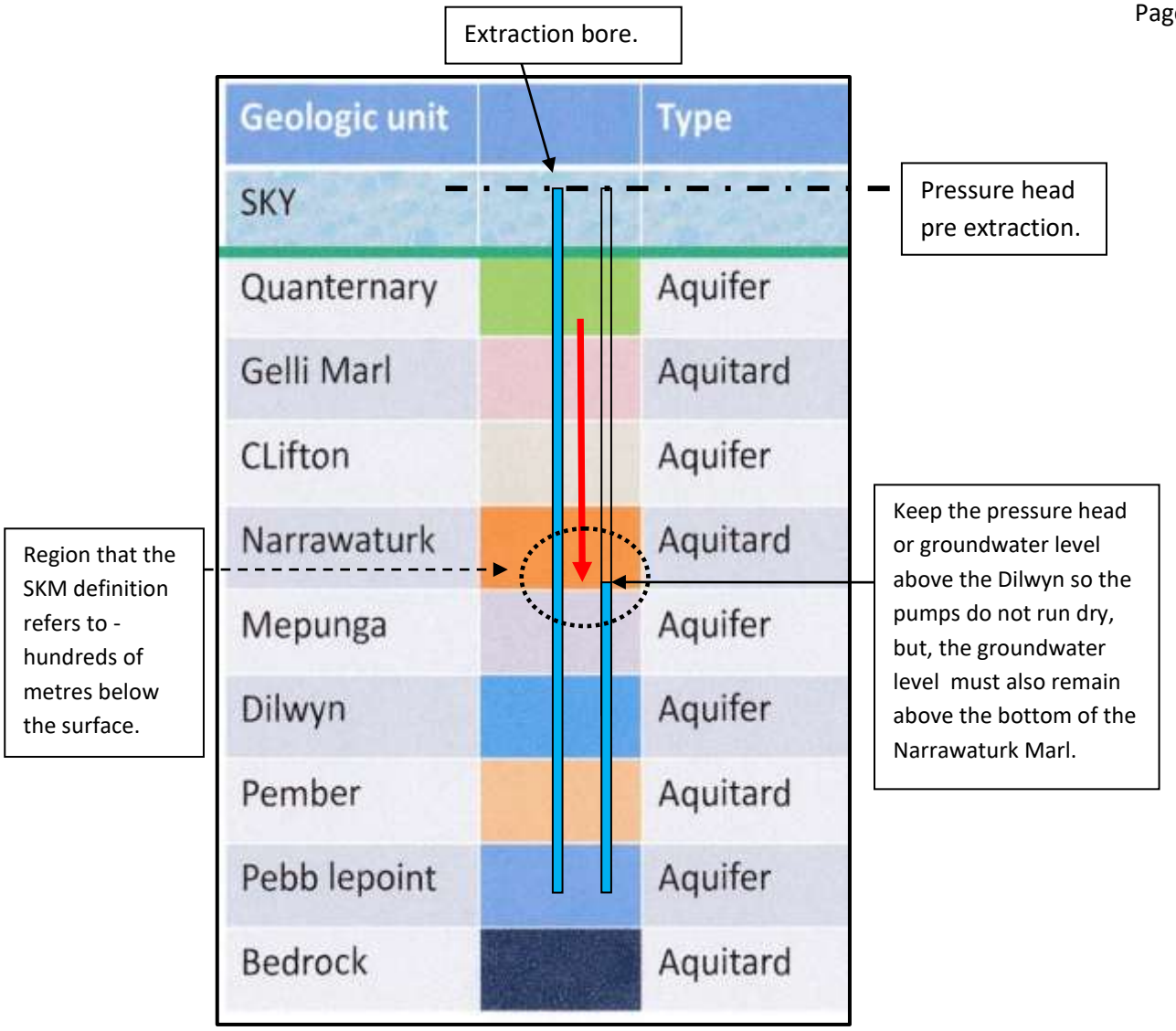
A key objective of the investigation is to assess whether the planned long term use of the Barwon Downs borefield is sustainable. In order to address this issue it is necessary to define a set of criteria that can be used to assess the sustainability of any proposed borefield use. These criteria must provide effective safeguards against unacceptable impacts that might accompany future groundwater extraction. Sustainability criteria used in the current investigation are as follows:

1. Pumping from the borefield must not exceed the available pumping capacity of the borefield. In other words the proposed use of the borefield must not exceed the pumping capacity associated with the current production wells. This criteria can be assessed by the numerical modelling results through the comparison between calculated water levels in individual pumping wells and the pump setting depths in these wells. It is assumed that if the calculated water level remains at least 10m above the pump setting depth then the required pumping rate can be maintained in the production well.
2. Groundwater levels must stabilise within 50 years when the borefield is pumping at a *"constant rate"*. This criterion can only be assessed if the model assumes wells pumping at a constant rate. In Scenarios 2 and 4 this assumption is not valid as the borefield is only used sporadically. However in Scenario 5 the modelled pumping includes an annually repeating cycle that approximates a constant pumping rate when assessed for the full 60 years of the scenario.
3. Groundwater levels in the confined parts of the principal aquifer (Dilwyn Formation Aquifer) must remain above the base of the overlying confining layer (ie the Narrawaturk Marl). This criterion is aimed at ensuring that the aquifer is not dewatered.

These three criteria can be used to assess whether the proposed borefield operation is sustainable.

SOURCE: SKM Climate Change Modelling for the Barwon Downs Aquifers, 2011.

These 3 sustainability criteria state that the water table in the Dilwyn Aquifer must stay above the extraction pumps and that the water table must not be dropped below the bottom of the MTD in the Narrawaturk Marl .



If the groundwater level in the Lower Tertiary Aquifers (Mepunga, Dilwyn and Pebble Point) was dropped to just above the bottom of the Narrawaturk Marl then downward vertical leakage would be a reality(red arrow). This means the very high storage capacity and good quality water of the Narrawaturk Marl would then become the most likely major source of recharge to the depleted aquifers below (see quotes in the Vertical Leakage section, page 19).

By 2016[24] the extraction had dropped groundwater levels below the MTD, and, by the SKM definition this constitutes an unsustainable level of extraction. Also under the SKM definition the "effective safe guards" and "unacceptable impacts" have no relevance to safeguards or impacts at the surface.

It has been convenient for Barwon Water to accept SKM's definition of sustainability. Doing this has allowed Barwon Water to maintain that the Barwon Downs Borefield is operated in a sustainable manner because the pumps can still extract water. Consequently the answer to any criticisms accusing the borefield of causing surface water impacts, has always been able to be counteracted stating that the groundwater extraction licence has been shown to be sustainable, and extraction follows strict licence conditions. The argument is given that groundwater extraction is only one of many reasons for groundwater drawdown and surface water impacts. Climate change, drought and land use changes being the others. Since 1977 land use changes have been minimal[21] leaving drought, groundwater extraction and climate change.

In 2011 Barwon Water asked Sinclair Knight Merz(SKM) to assess impacts of climate change on the extraction of groundwater.[32]
"***Sinclair Knight Merz (SKM) was commissioned by Barwon Water to revise existing groundwater flow model of the Barwon Downs Graben to provide a rigorous assessment of the impacts of climate change on the groundwater resource, and in particular on the sustainable extraction limit, for the Barwon Water borefield.***"[32] This is a very explicit and clearly defined brief.

The resulting report[32] found that climate change would have little impact on the sustainability of the groundwater extraction.
"***Future groundwater responses are not expected to be significantly impacted by future climate assumptions.***"[32]

This 2011 climate change report was referenced in a document tabled at a Barwon Downs Groundwater Community Reference Group meeting. However, when asked for a copy of this 2011 report its access was denied. An FOI request was also denied. My lawyer submitted a second FOI and after a lengthy process through the Freedom Of Information (FOI) method, a copy of the 2011 report was obtained. Part of the accompanying letter from Barwon Water included this statement.
"***In 2011, Barwon Water commissioned an update of the existing Barwon Downs Graben groundwater flow model to assess the impacts of climate change on the sustainable extraction limit of the borefield. Although the initial findings from this work indicated that future groundwater responses are not expected to be significantly impacted by future climate assumptions, Barwon water has reservations about the calculations used to produce the climate change modelling scenarios.***" (FOI reply from Barwon Water, Ref. Number FO79152)

Barwon Water cannot have it both ways. If Barwon Water maintains the stance that the borefield is sustainable then it has to be accepted that climate change has little impact on the groundwater extraction sustainability. If Barwon Water insists that climate change is a factor then the manner in which the word sustainability is used, must be modified to reflect the nationally agreed definition. Whichever way the word sustainability is used, the following pages will demonstrate that under normal, natural conditions the Lower Tertiary Aquifers upward pressure buffers groundwater dependent ecosystems, streams and springs from the influence of climate change and drought.

The Big Swamp is a classic example of the impact from groundwater extraction. Under natural and normal conditions this wetland would have survived the Millennium Drought and any climate change influences (see page 40).

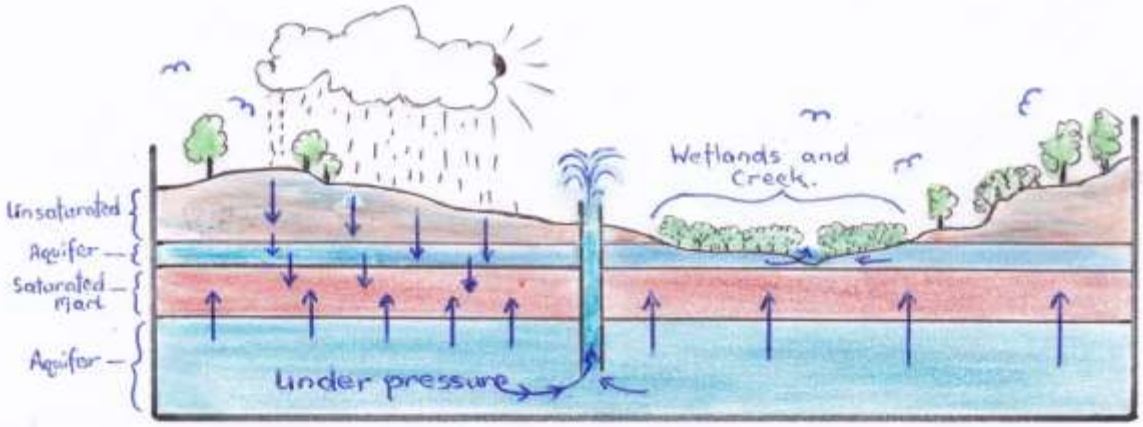
VERTICAL LEAKAGE

Vertical Leakage can be in an upwards or downwards direction. Water can be forced up from one layer to another. For example when the aquifers in the LTA are under pressure they force water up into the Narrawaturk Marl above (see page 20) and so on to the surface. Lower the pressure in the LTA and the water in the Narrawaturk Marl will begin to leak down in an attempt to fill the depleted LTAs below. E.g. during a test pump in the late 1980s "…***a significant amount of leakage occurred from the confining layer into the aquifer.***"[38] When this happens springs, creeks and wetlands will dry out.

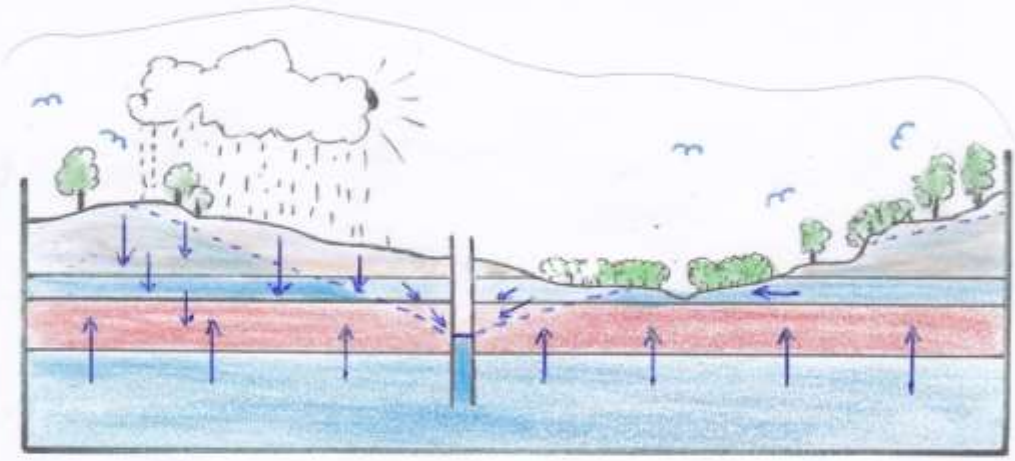
Leonard[29] was discussing the certainty of vertical leakage in this very area as far back as 1984. At the conclusion of the extensive evaluation of the Barwon Downs Borefield stress test pump between 1986 and 1990, Witebsky et al [38] wrote this "...***Leakage from the overlaying marls is likely to be the major source of recharge under stressed conditions.***" That is downward vertical leakage replenishing the depleted LTA. Witebsky continues... "***The immediately overlaying Narrawaturk Marl is up to 170 m in thickness and grades from silty sands to marl. It has very high storage capacity and within the borefield area is known to contain groundwater of good quality. Under undisturbed conditions an upward vertical, hydraulic gradient exists between the marl and the Lower Tertiary aquifer system and the marl is recharged with groundwater of good quality from below.***" Under undisturbed conditions the leakage is upwards. In 2016 Jacobs[24] stated that when an upward hydraulic gradient exists "***This facilitates upward leakage from the aquifers into the overlaying aquitard and is a key discharge process for the aquifer.***" Unfortunately the same Jacobs report[24] has this to say "***...groundwater levels in the LTA have fallen below the overlaying MTD for periods of time.***" The MTD being the overlaying aquitard, the Narrawarturk Marl (see page 4).

Page 31 of the SKM Report 2009[30] discusses the possibility of vertical leakage and states that at this stage there is no evidence that this has occurred. The reason for this lack of evidence is that only 3 of the 61 regional observation bores used in Report 2009 were monitoring this possibility. The principle of vertical leakage has been a reality for decades and it seems unbelievable that scant data has been collected over the 34 year period of groundwater pumping at Barwon Downs, especially when it was stated in 1995 that vertical leakage into the depleted aquifer would be a major source of recharge. Just because data does not exist doesn't automatically rule out that vertical leakage is taking place.

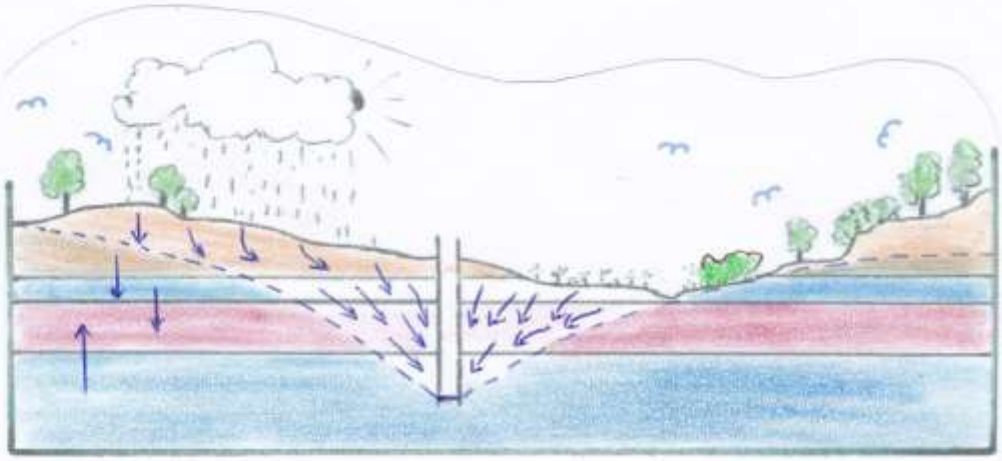
The following page illustrates the upward and downward vertical leakage that takes place in the undisturbed situation with no groundwater extraction, to a very different upward and downward leakage that takes place with major groundwater extraction.



This conceptual diagram shows how rainfall from above and an aquifer under pressure from below reach a natural balance whereby the creeks keeps flowing and groundwater dependent wetlands remain healthy.



Lower the water pressure in the deep water aquifer and a cone of depression is formed. The natural flow of water is upset and water from around this cone moves towards the area of depletion.



Deplete the aquifer enough and flow paths will change with springs, creeks and wetlands drying up. As the water moves into the cone of depression the area of influence expands.

Dynamic Equilibrium Water Level Zone.

In 1986 Farmar-Bowers found that the water dynamics in the Barongarook High area had been relatively stable for some considerable time,[5] and that under natural fluctuations of drought and wet periods the vegetation would have adapted to these conditions changing very little. However, substantial ground water extraction altered this natural fluctuation considerably, upsetting the natural balance. First signs of change became apparent in groundwater dependent wetlands, springs and creeks. At the completion of the 1994, 2002 and 2008 vegetation surveys, these signs were glaring evident.[11][12][13][15][16][17][18][19][20][7][27]

However, up until recent times these detrimental impact signs were only observable in groundwater dependent ecosystems found inside the area of residual drawdown from the Barwon Downs Borefield.

The Green Belt Illusion.

Under natural conditions the Dynamic Equilibrium Water Level Zone south of the Princes Highway in the Otway ranges, oscillates within a band width that has an extraordinary ability to buffer the Ranges from drought. The springs, creeks and rivers that keep flowing do so because the lower level of the Dynamic Equilibrium Water Level Zone would never drop below ground level. However, once unsustainable groundwater extraction drops the level of this zone below ground level short and long term impacts at the surface begin to take place.

Short term impacts include:

- Spring, creeks and rivers stop flowing.
- Wetlands dry out.
- Potential Acid Sulfate Soils turn into Actual Acid Sulfate Soils .
- Farmland is decimated, creeks begin to flow acidic and heavy metal laden water.
- Fire danger is enhanced.

Long term impact include:

- The normal cycle of summer, autumn, winter and spring begins to change.
- The summers come earlier and earlier and stay longer.
- Droughts become more pronounced.
- Vegetation begins the slow transition to drier and drier species, eventually leading to a desert like state.

This long term creation of a desert is often viewed with some scepticism. The slow transition taking place over numerous years is extremely hard to detect

one year from another. The response from rainfall maintains a green, vibrant healthy looking autumn, winter and spring cyclic illusion. In a lifetime little appears to change, a false impression is gained that things are maintaining a natural form of order. However, the reverse is the case. Over the long term the dewatering of the subsurface has a slow and insidious impact on this Green Belt Zone.

What Did the Dynamic Equilibrium Water Level Zone Look Like Pre Groundwater Extraction?

Farmar-Bowers included these two statements in his 1986 report that supports the notion that under conditions where there is no significant groundwater extraction the hydrologically sensitive vegetation ecosystems directly connected to the Lower Tertiary Aquifers in the Barongarook High region maintain a basic equilibrium.

"*Current water tables appear to be quite stable and there is little movement between seasons or years. (J. Leonard Pers.Com.)*"[5] **Note**: little movement between seasons or ***years***.(John Leonard being a hydrogeologist with extensive experience and knowledge of the region.)

"***Aquifer pumping during droughts, as is proposed, would tend to exacerbate the effects of natural variability by extending the effects of drought.***"[5]

In 2002 SKM described how rainfall has little bearing on discharge from an aquifer "***The baseflow component generally does not respond rapidly to rainfall and often represents a relatively stable and constant streamflow component.***"[7] Not so when there has been extensive groundwater extraction way beyond the sustainable level.

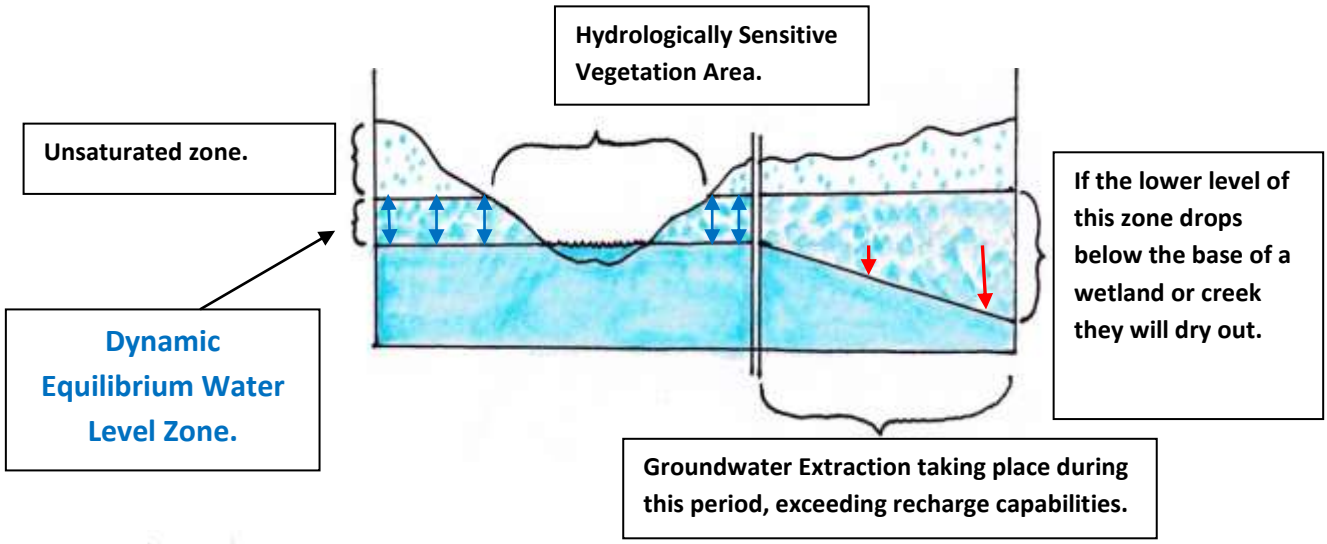
Even up to the early 2000s hydrologically sensitive vegetation in the Ten Mile and Loves Creek Catchments had shown little impact from the climatic changes that have taken place before, during and since the millennium drought. The Lower Tertiary Aquifers' discharge acted as a buffer against drought in these two areas. Similarly, aquifer discharge sites in the Barwon Downs Borefield area should have also experienced the same form of buffering, but hadn't.

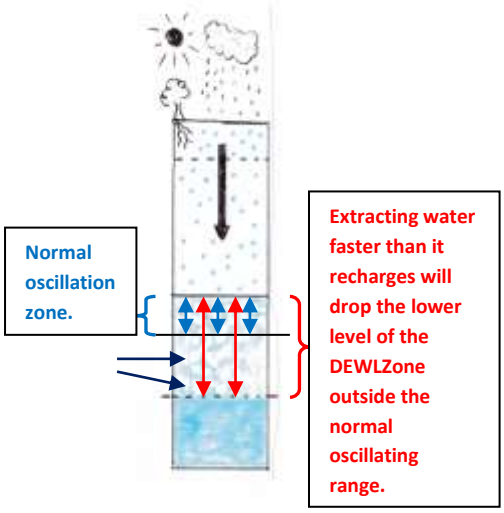
Within the area of drawdown influence from the Barwon Downs Borefield a much bigger change than would be expected under normal "***natural variability***" or "***normal undisturbed conditions***" took place. For this to happen over such a small timeframe is also most unusual. The evidence and data available clearly showed that this natural variability had been dramatically altered by ground water extraction at the Borefield.

Rick Evans (SKM) speaks of this natural variability as a zone where the watertable naturally rises and falls to the "beat" of nature. Having come across this explanation of natural variability on numerous occasions I coined this zone

of natural variability, the Dynamic Equilibrium Water Level Zone (DSEWLZ). During drier periods and including droughts the watertable drops and then recovers in wetter periods. This DSEWLZ zone is that area where there is a rise and fall of the water table and is what Farmar-Bowers described as "***natural variability***." The influencing factor being the natural upward pressure head of an untapped Lower tertiary Aquifer system.

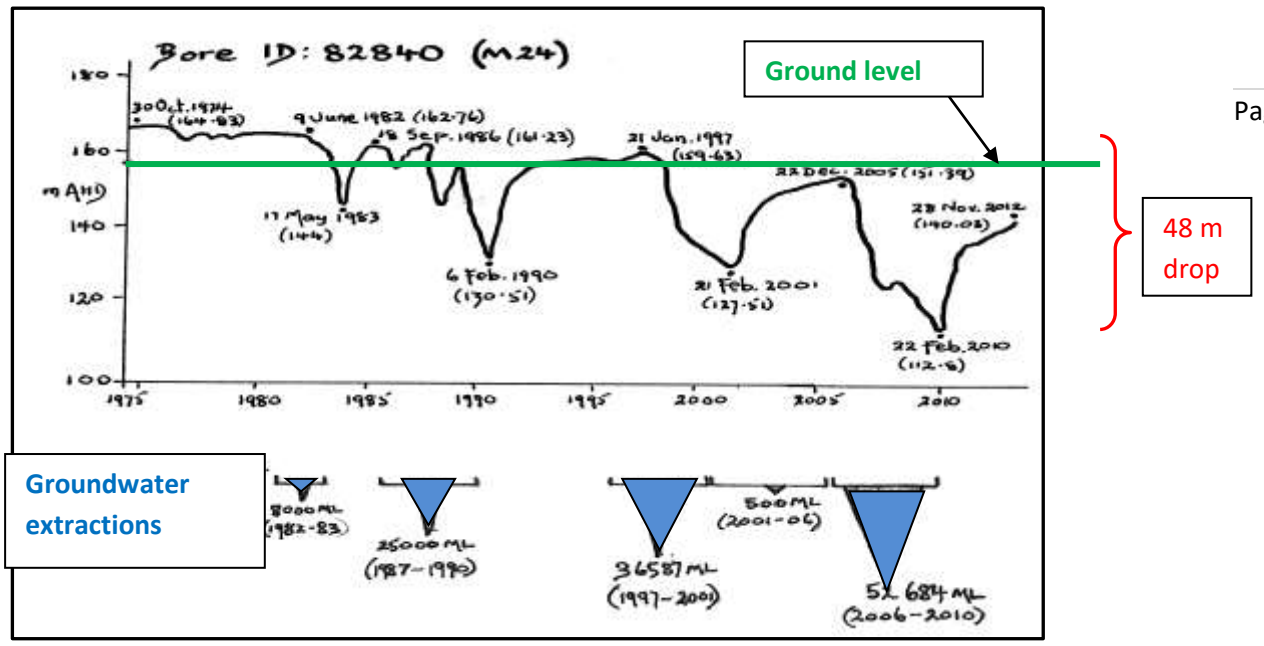
Once groundwater extraction on a massive scale is placed into the equation, the lower level of the Dynamic Equilibrium Water Level Zone will drop further than can be justified as normal. A return to a normal natural variable state after groundwater extraction will take much longer, may never happen and will depend on the amount of groundwater extracted. Any effect will be magnified if the water is extracted during dry or drought events.



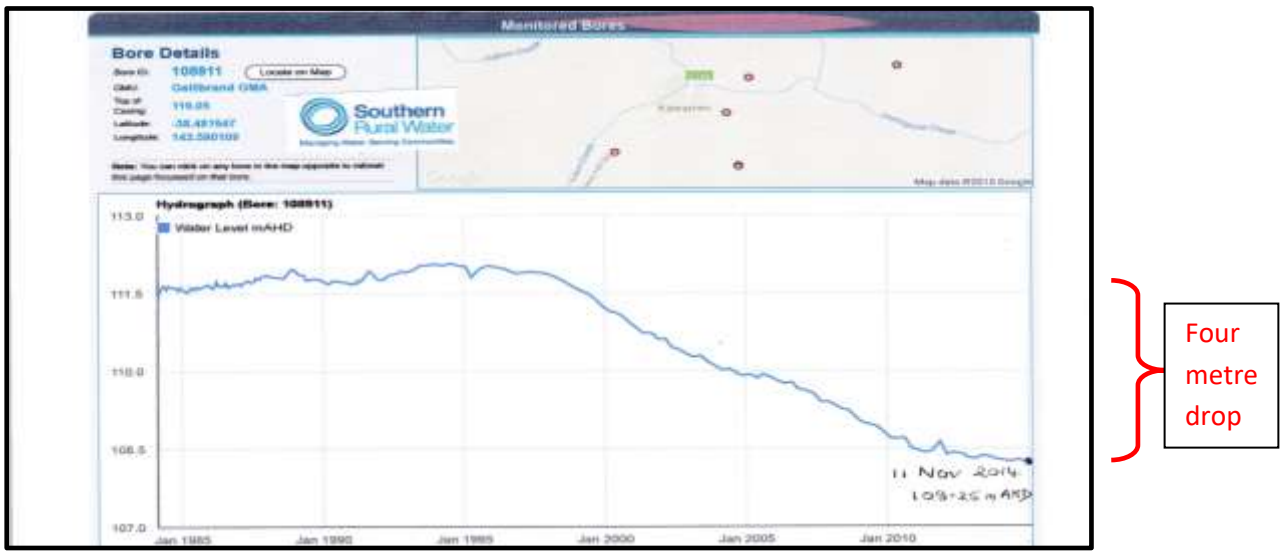


In December 2006 the Department of Sustainability & Environment (DSE) tabled a report "Regional Groundwater Monitoring Network Review for the Deep Water Aquifer System in South West Victoria."[(3)] This report states that groundwater is declining generally at rates less than 10 centimetres a year. That is to say besides there being a natural variability the overall Dynamic Equilibrium Water Level Zone (DEWLZ) is dropping by 10cm a year**.** This report goes on to say that at the current rate of decline watertables will drop in the order of one metre in ten years. This report took into account climate change and present groundwater extraction in the South West. However, this study did not include the Barwon

Downs Borefield area of influence where water table levels have been forcibly dropped tens of metres.

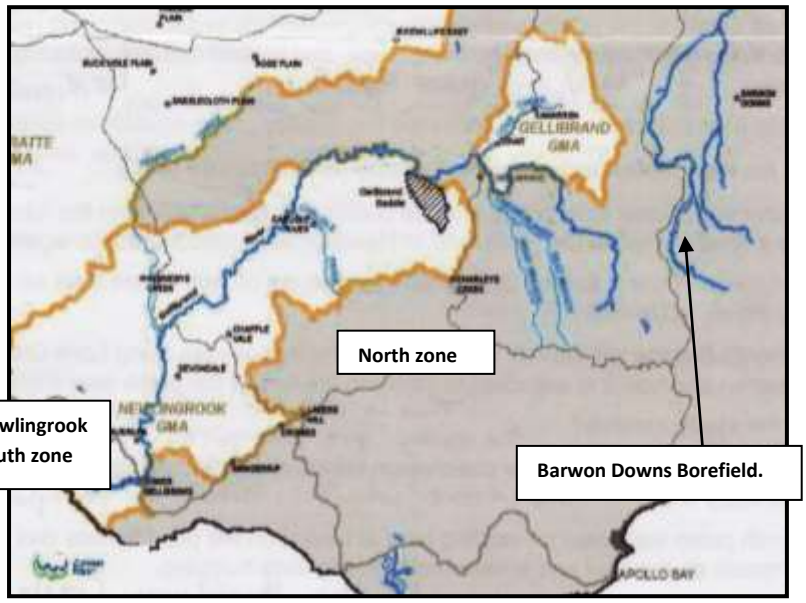


The above observation bore's water table levels show how the Barwon downs Borefield extractions have skewed the DEWLZ way below the natural variability.



This observation bore hydrograph down the Kawarren flowpath shows a constant decline associated with and impacted by the Barwon downs Borefield extractions. There are no extraction bores in the Kawarren area that can account for this decline. This decline is much more than the 2006 GHD report predicted and is not a natural variability. A 2010 SKM report titled "*Lower Tertiary Aquifer Groundwater Resource Appraisal*"[31] confirms that there is more at play in the Barwon Downs Borefield area of influence than a natural

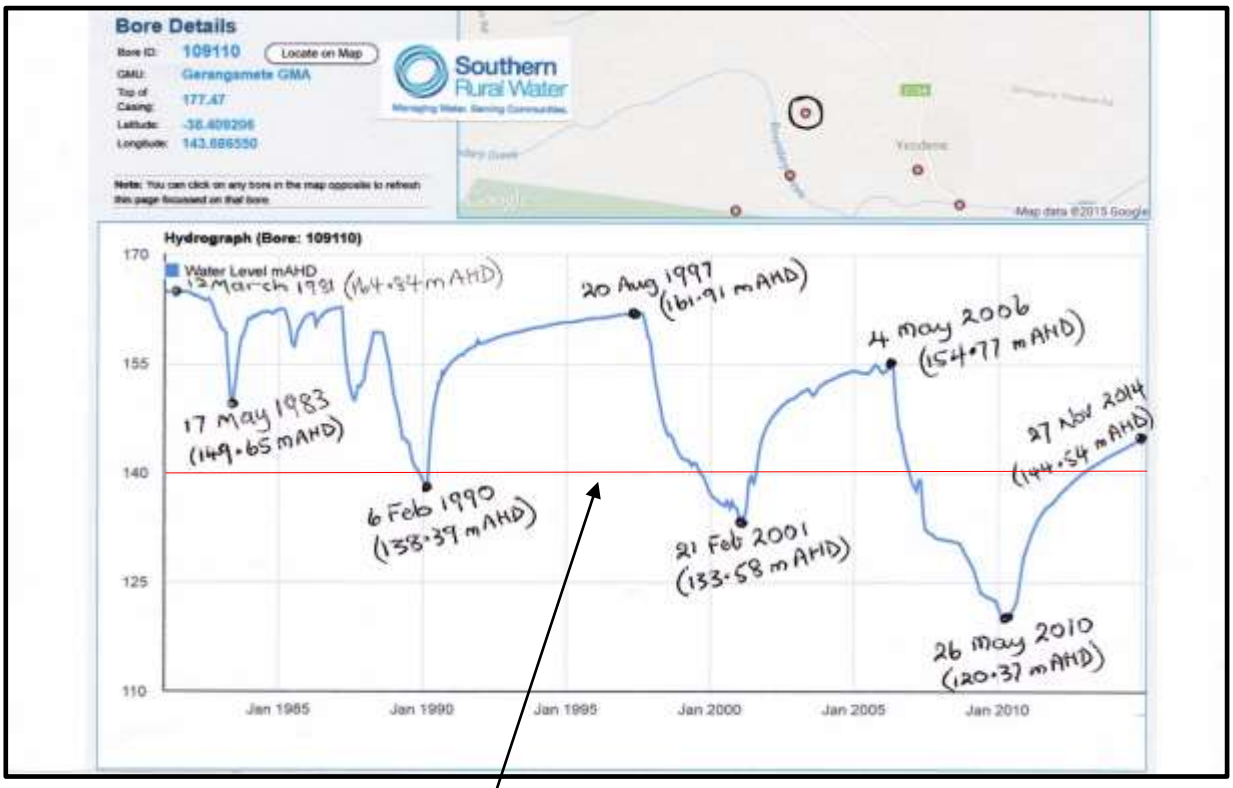
variation. "***...the Newlingrook South zone has not experienced falling water levels and it is likely that climate change has less impact in this area. It is unlikely that the Newlingrook North zone presents slowly falling trends as a result of climate change, because it is a similar climate to that of the southern zone. Therefore, the trends of the Newlingrook North zone are possibly associated with the faster rate of decline in the Barwon Downs Graben.***" The Gellibrand/Kawarren groundwater flowpaths are found in the westerly section of the Barwon Downs Graben adjoining the Newlingrook Northern zone. Just as the Newlingrook Northern zone should not be showing greater groundwater decline than the Southern zone, neither should the Gellibrand/Kawarren zone. Under natural variation in the Dynamic Equilibrium Water Level Zone and because of a buffering discharge from the Lower Tertiary Aquifers, the groundwater levels in these three areas should be reacting in a similar fashion to whatever natural forces are at work. The Newlingrook South zone has not experienced falling water levels whereas the Newlingrook North zone is experiencing slowly falling trends. In the adjoining Groundwater Management Area to the east, the Gellibrand/Kawarren zone is experiencing extraordinary falls in the water table. Closer still to the Barwon Downs Borefield the water tables had dramatic and massive drawdown effects.



This highlights that there is a greater impact the closer one gets to the Barwon Downs Borefield. Confirmation of this is found in a quote from a Wannon Water document, "*Improving Environmental Flows in the Gellibrand River: Assessment of Water Supply Augmentation Options. May 2016*." From an observation bore screened in "***...the Pebble Point Formation (this is the largest aquifer for the proposed production bore). Water levels show***

seasonal fluctuations less than 20cm. A slight decline (20cm) in water levels has occurred between 1999 and 2008."[37]

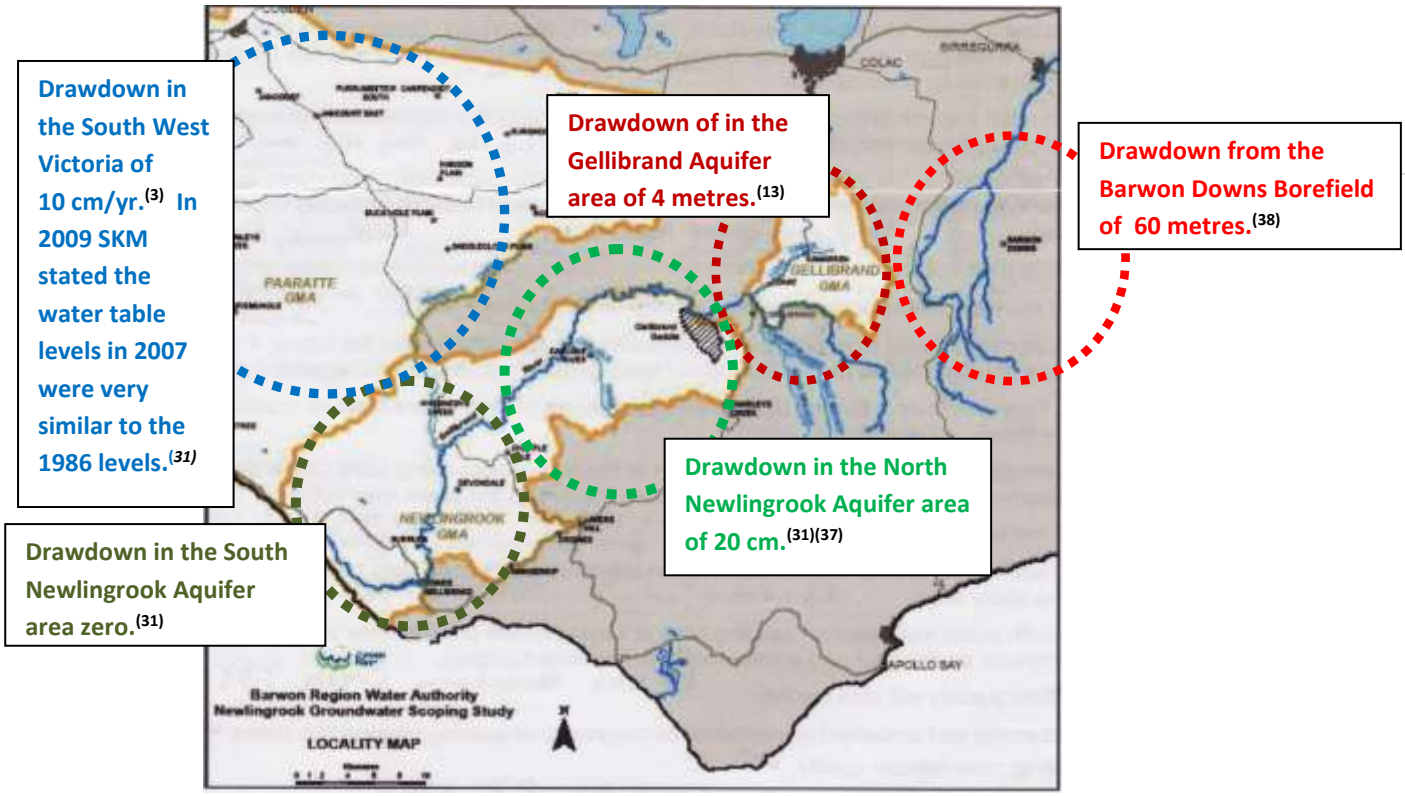
This seasonal fluctuation is the Dynamic Equilibrium Water Level Zone. The Pebble Point formation is one of the Lower Tertiary Aquifers the Barwon Downs Borefield extracts groundwater from and, as seen in the hydrographs in the Barwon Downs Borefield region, they have suffered enormous fluctuation and drawdown impact.



The thickness of this red line represents an approximate 20cm fluctuation.

This observation bore is situated inside the drawdown impacts from the Barwon Downs Borefield and demonstrates the enormity of the impact on natural variation from groundwater extraction. The Lower Tertiary Aquifers have been drawn down that far they were no longer able to buffer the hydrological sensitive and water dependent surface receptors.

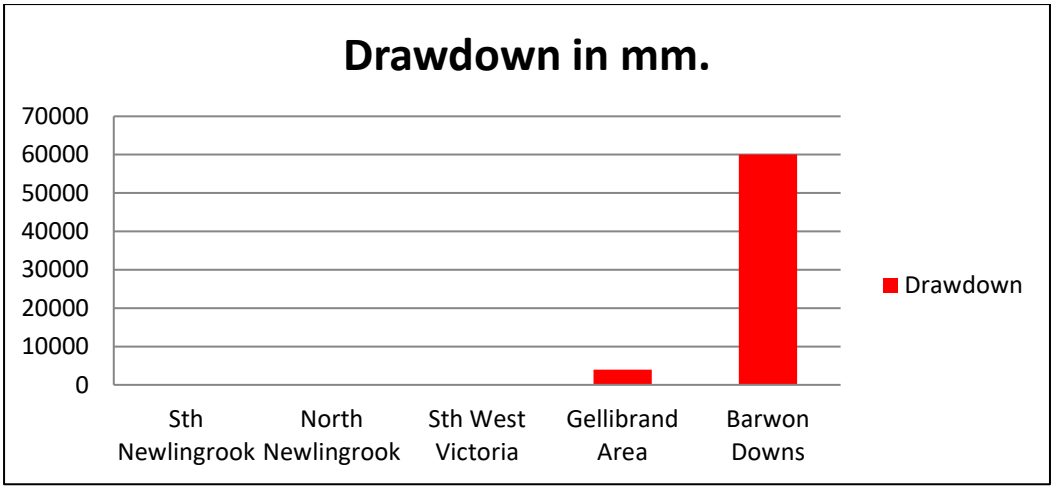
As stated above adjoining groundwater Dynamic Equilibrium Water Level Zones indicate that the zone in the Barwon Downs Borefield area of influence was way out of "whack."



As stated earlier, in 2010 SKM had this to say "***As anticipated, the Newlingrook South Zone has not experienced falling water levels and it is likely that climate change has less impact in this area. It is unlikely that the Newlingrook North zone presents slowly falling trends as a result of cli9mate change, because it has similar climate to that of the southern zone. Therefore, the trends of the Newlingrook North zone are possibly associated with the faster rate of decline in the Barwon Downs Graben.***"(31-Lower Tertiary Aquifer Groundwater Appraisal, SKM, 2010)

SKM in 2011 also stated in their "Climate Change Modelling for the Barwon Down Aquifers" report, "***Future groundwater responses are not expected to be significantly impacted by future climate assumptions.***"(32)

The Department of Sustainability and Environment in a 2006 report, "State Observation Bore Network Program, Regional Groundwater Monitoring Network review for Deep Aquifer System in the South West Victoria" that groundwater is declining at rates less than 10 centimetres a year.(3)



This data strongly indicates that the closer one got to the influence of the Barwon Downs Borefield drawdown the greater the impact. The further away from this impact the smaller the range of oscillation with the Dynamic Equilibrium Water Level Zone fluctuations.

The impact and affect on the Boundary Creek region has been evaluated and accepted as far back as 1991, and if, as stated in this article, "***...the creek's recent dryness had probably been caused by test groundwater pumping...***" with approximately 22,000 ML extracted between 1986 and 1990. During the Millennium Drought an average of 11000 ML per year was extracted.

(The total water extracted, being more than 125 000 ML by 2017.)

[file(6a)]
Colac Herald, Friday Jan 18, 1991 Page 3

Board accepts blame for dry creek

by Mary Dracup

The Geelong District Water Board has admitted responsibility for the low level of Boundary Creek over the last two summers.

A spokesman for the board said on Tuesday that the creek's recent dryness had probably been caused by test groundwater pumping at Geranganete between November 1988 and March 1990 and the board was monitoring the affect closely.

"The whole reason for the test pumping was to monitor the results. We have to monitor the recovery rate of the aquifer and try to get a long-term picture of the affects this kind of pumping has," the spokesman said.

He said it was still too early to say what the results of the pumping had been — it would not be until the end of 1992 that the board's investigations would be complete.

He said the board's test pumping was condoned by the Natural Resources and Environment Committee, which had recommended looking to groundwater for future water requirements after its inquiry in 1989.

Nevertheless, he said the board was conscious of problems such as Boundary Creek drying up in summer, and was trying to find ways to solve them.

"If this kind of affect was to happen because of pumping we would have to look at ways to get around it. It's not a question of going ahead at any cost."

Meanwhile, the spokesman said there would be no further test pumping until after the investigations were complete.

Barwon Water confirms impact of bore pumping

Barwon Water has confirmed that pumping groundwater from a Barwon Downs borefield has impacted the water flow to Boundary Creek.

The results come after water campaigner Malcolm Gardiner raised his concerns for more than 10 years about the effect that pumping the Barwon Downs borefield would have on the region's waterways.

Yeodene's Nellie Shalley has previously expressed her concerns to the *Colac Herald* about Boundary Creek, which flows through her property south-east of Colac, drying up in summer.

She said that she believed groundwater pumping at a borefield near her property had depleted the creek's flow.

A Barwon Water spokeswoman said the study was a comprehensive groundwater monitoring program that launched in 2013 to help inform Barwon Water's Barwon Downs borefield renewal application, which the corporation is due to submit in late 2017.

Barwon Water general manager strategy and partnerships Carl Bicknell said the data was a result of a major update to the groundwater model for the Barwon Downs area.

The study found that use of the borefield over the past 30 years was responsible for two thirds of the reduction in base flow from the aquifer into Boundary Creek, while the dry climate during the same time accounted for the remaining third.

The spokeswoman said the model showed the lower sections of Boundary Creek "would likely have" no-flow periods during summer regardless of groundwater pumping, but pumping had increased the frequency and duration of no-flow periods in lower reaches of Boundary Creek.

The data confirmed there was no predicted impact to vegetation outside the Boundary Creek catchment as a result of groundwater pumping.

Mr Bicknell said it had been known for some time that borefield pumping was connected to flows in Boundary Creek, but the level of interaction had not been fully understood.

"As a condition of our current groundwater licence we have released supplementary flows into Boundary Creek," he said.

"However, we know these flows have not always made their way to the lower reaches of the waterway.

"We now have results of a thorough scientific study that provides answers we can be confident in, allowing us to examine ways to restore flows that will compensate for the operation of the borefield."

The spokeswoman said the borefield was a "crucial" supplementary water source for Geelong, the Surf Coast, Bellarine Peninsula and parts of Golden Plains Shire when surface storages were low.

She said that in 2007, at the height of the worst drought on record, the borefield provided up to 70 per cent of the Geelong's daily water supplies.

Mr Bicknell said further technical studies were underway to assess the effect of a range of alternative borefield operating regimes on flows in Boundary Creek and measures to address the issue of acid water release from Big Swamp into Boundary Creek.

The outcomes of these studies, as well as planned community engagement in the coming months, will provide information for Barwon Water's licence application.

IMPACT: Nellie Shalley inspects a dry Boundary Creek in 2007.

Colac Herald. Wednesday. June 28. 2017

To those not knowing any better this 2017 article gives an impression that sound management decisions were being made and that it was important that the groundwater extraction licence be renewed. No mention is made of the 26 years since the "***Board accepts blame for dry creek***" in 1991, of the disastrous impacts from the groundwater extraction at the Barwon Downs Borefield. Surface water resources and receptors dependent on these resources have suffered enormously.[(6)(13)(15)(16)(17)(19)(20)]

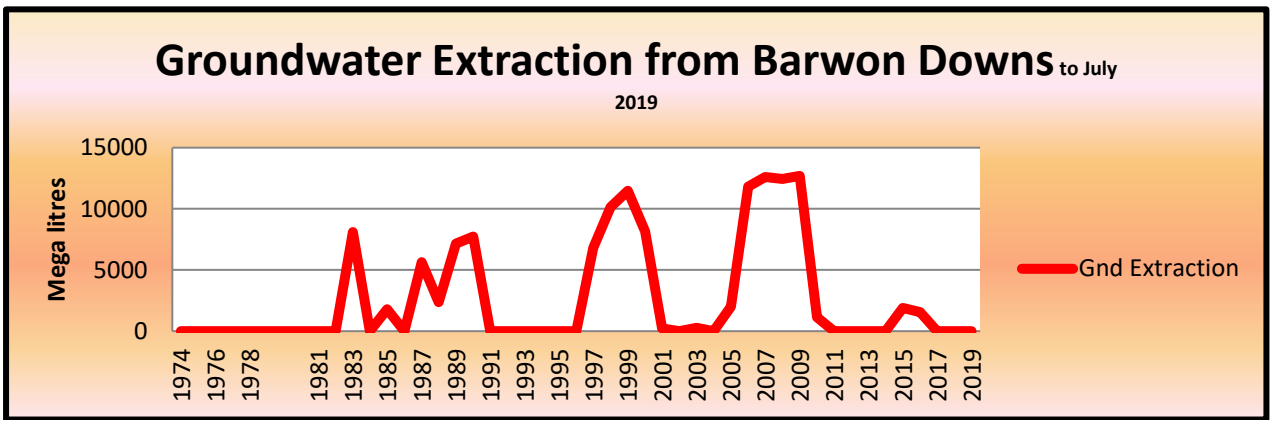
These observable short-term impacts are masked by "The Green Belt Illusion" (see page 21).

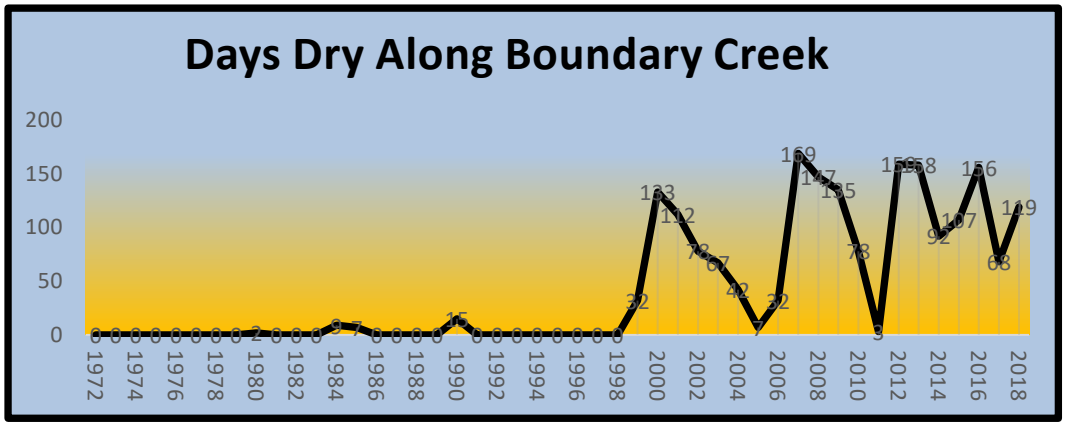
The Relevance of this to the Boundary Creek Region.

Having a basic understanding of flowpaths; vertical leakage; natural variation in the Dynamic Equilibrium Water Level Zone; the capacity of aquifer discharge to buffer the impact from drought; the observable amount of water table drop that has taken place in zones not directly impacted from massive groundwater extraction, and, the influence an inappropriate definition of sustainability can

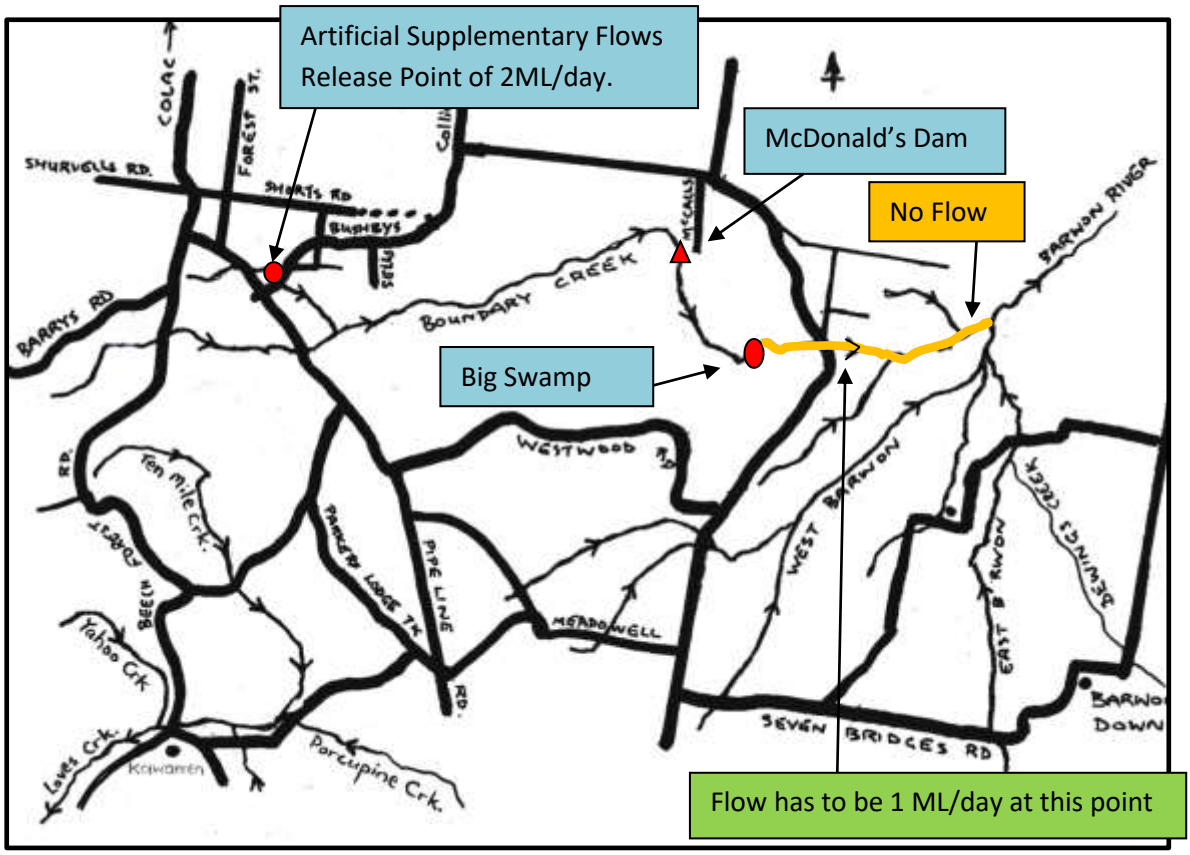
have on management decisions, some understanding of the dynamics taking place within the Big Swamp can be gained.

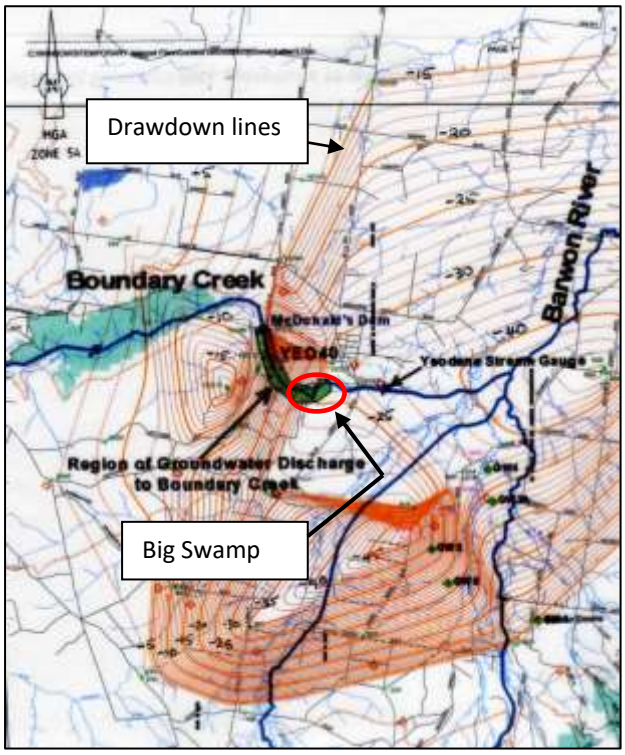
To start with, local history tells us that along the middle and lower reach of Boundary Creek below McDonald's Dam, the creek had never dried up from 1912 to 1984; other than during the construction of McDonald's Dam in the late 1970s when there were some days when the building of this dam disrupted flows. This period was followed by extensive groundwater extraction providing up to 50% of Geelong's water supply through the 1982-83 drought.





However, as the amount of extraction has increased so have the days of no flow down Boundary Creek. Even 7 years after pumping was suspended Boundary Creek does not flow during summer months and well into the winter period, until there is sufficient rainfall. When rain stops so do the flows down Boundary Creek despite a 2 ML a day release of Artificial Supplementary Flows taken out of the Otway to Colac Pipeline(see release point of these flows page30). These flows do not pass the Big Swamp. The water is sucked down into the depleted aquifer below the swamp wetlands.

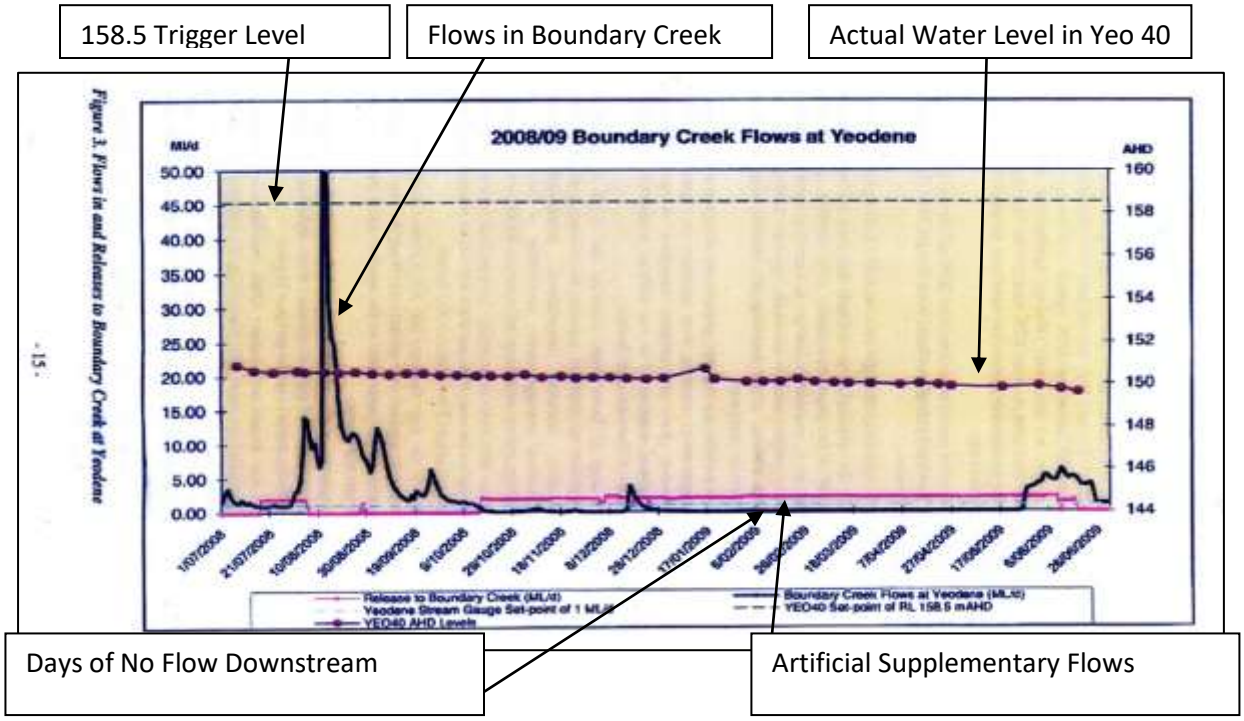




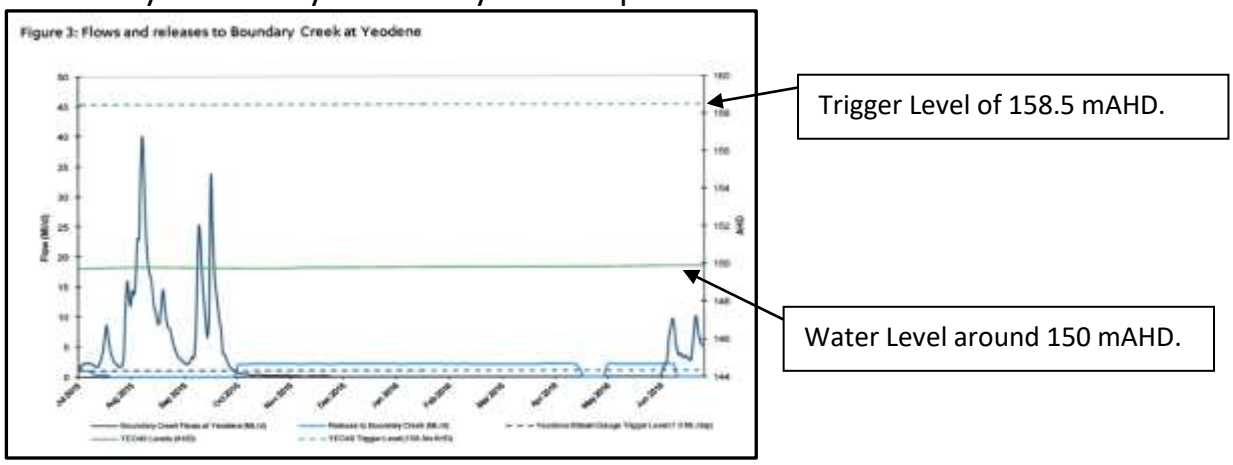
When the 2004 extraction licence was under review SKM provided this map showing where the LTA was discharging into Boundary Creek. The lower end of this included the Big Swamp. I have overlain the red line drawdown figures from the 2007 Barwon Downs Borefield report indicating that in the area of the Big Swamp there were drawdowns of the water table by 20 to 30 metres.

Since the 1990s, discharge from the aquifer has ceased; Boundary Creek does not flow unless there is significant rainfall, and when there is no rain the 2 ML/day Artificial Supplementary Flow release disappears into the Big Swamp. These Artificial Supplementary Flows were introduced in 2004 as part of the Licence extraction conditions with the intention of providing environmental and Stock and

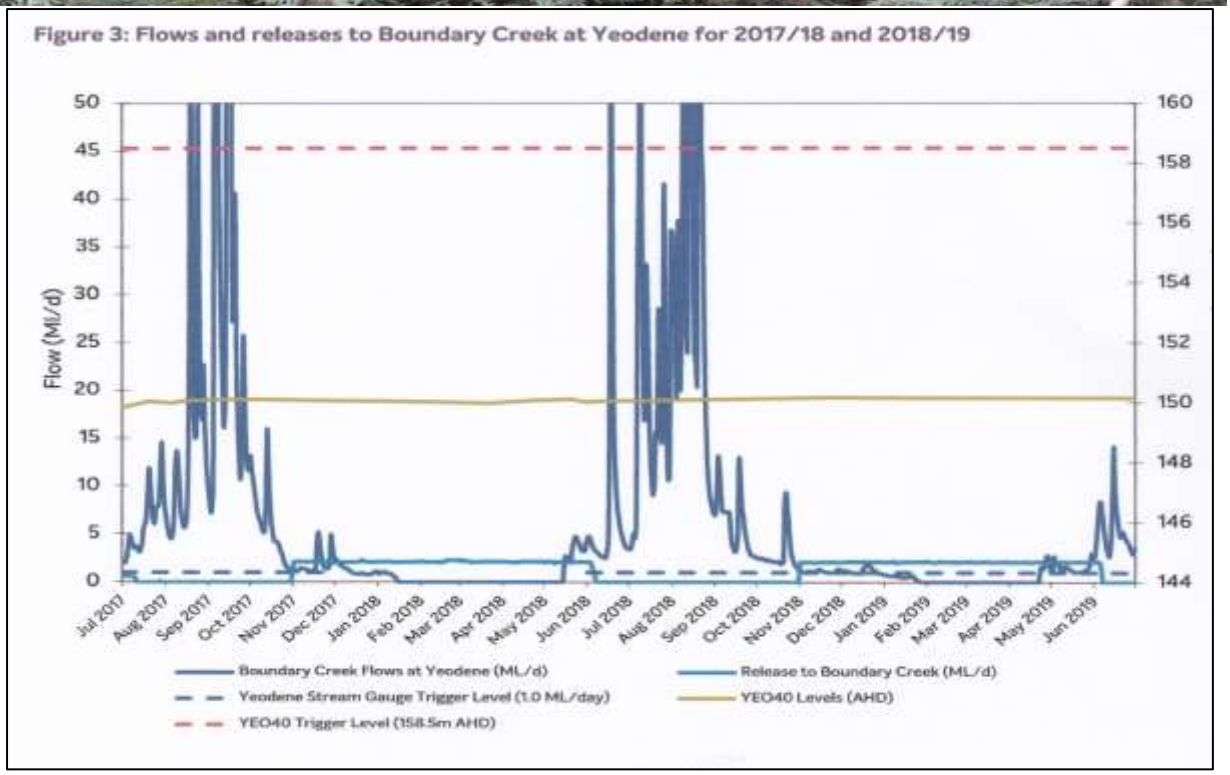
Domestic flows in Boundary Creek. The water level trigger demanding release of these flows was set at 158.5 mAHD in the Yeo 40 observation bore. The logic being that SKM had determined that the flows in Boundary Creek would stop when the water level dropped to 158 mAHD. A half metre tolerance was allowed. The water level in Yeo 40 progressively dropped further and further below this trigger level up to 2017.



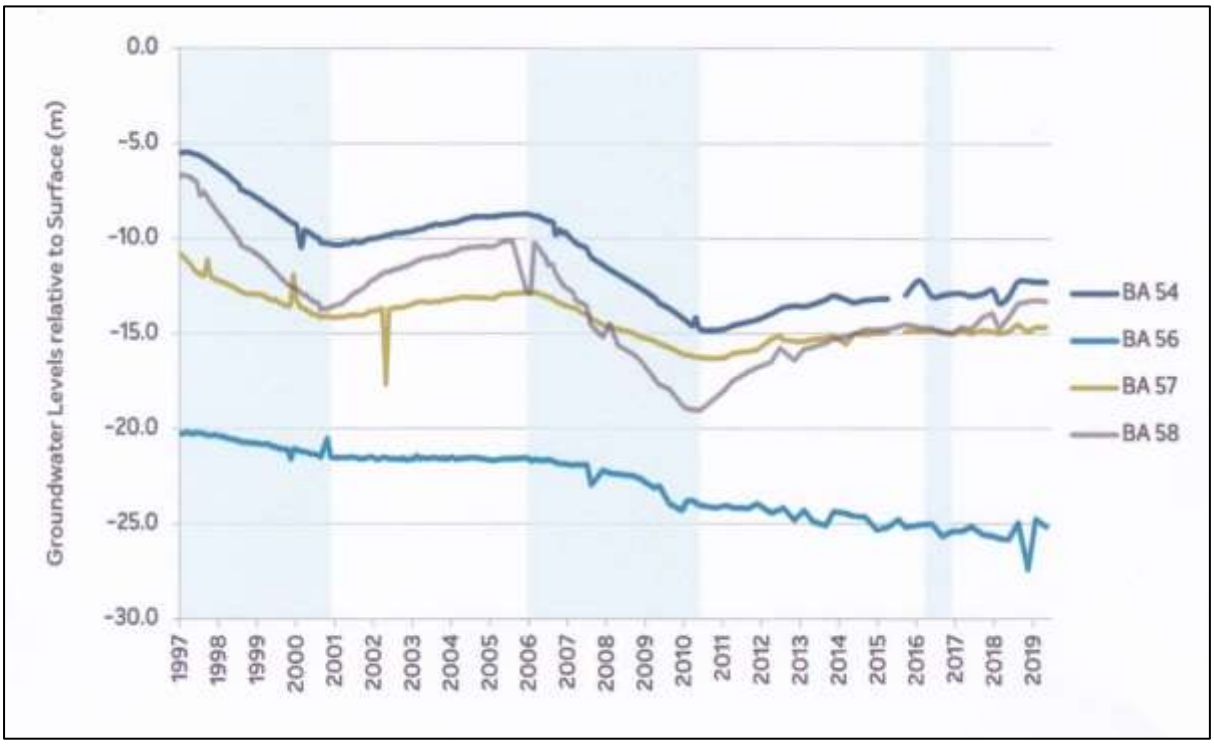
This chart above, is representative of each of the charts found in the yearly Barwon Downs Borefield reports. Even after 6 years of no pumping the 2015-2016 report below, shows a similar pattern. The water table has been drawn down way below any natural Dynamic Equilibrium Water level Zone.



On page 32 the top chart show that the water level in Yeo 40 has recovered very little if any, since major pumping finished in 2010. This chart have been taken from last and final Gerangamete Borefield report (2018-2019). Barwon Water let its licence lapse in 2019.

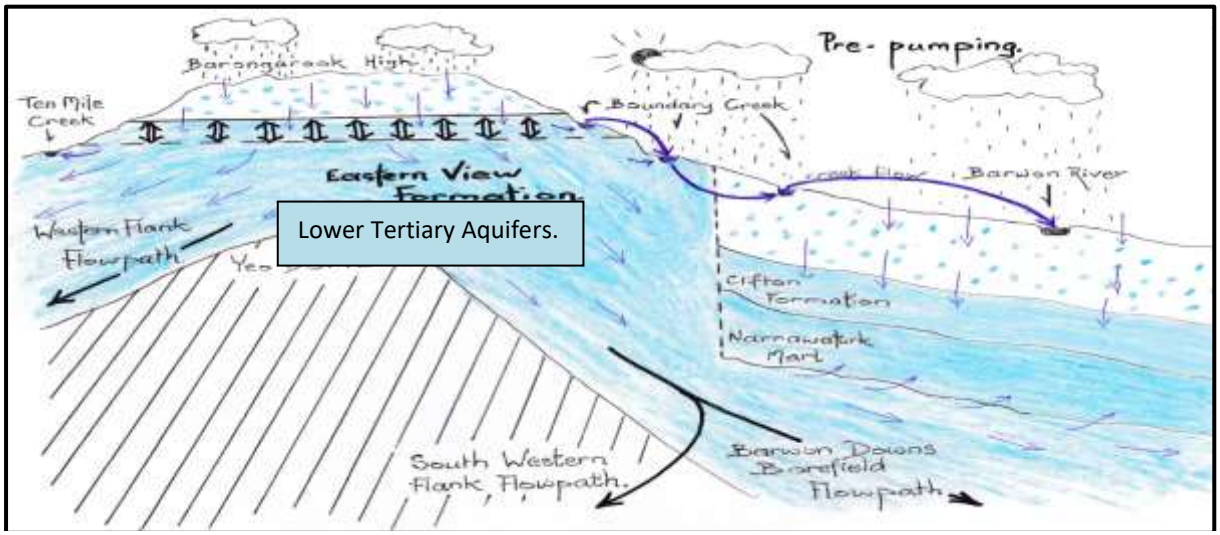


The groundwater level in Yeo 40 is still around 8m below the trigger level and around 10m below pre 1980 levels of 160m (AHD).



The Blue shaded areas indicate periods of groundwater extraction. Taken from the 2018-2019 report.

This chart shows 4 hydrographs of bores in the Dilwyn Aquifer. Recovery back to the 1997 water levels is still well down.



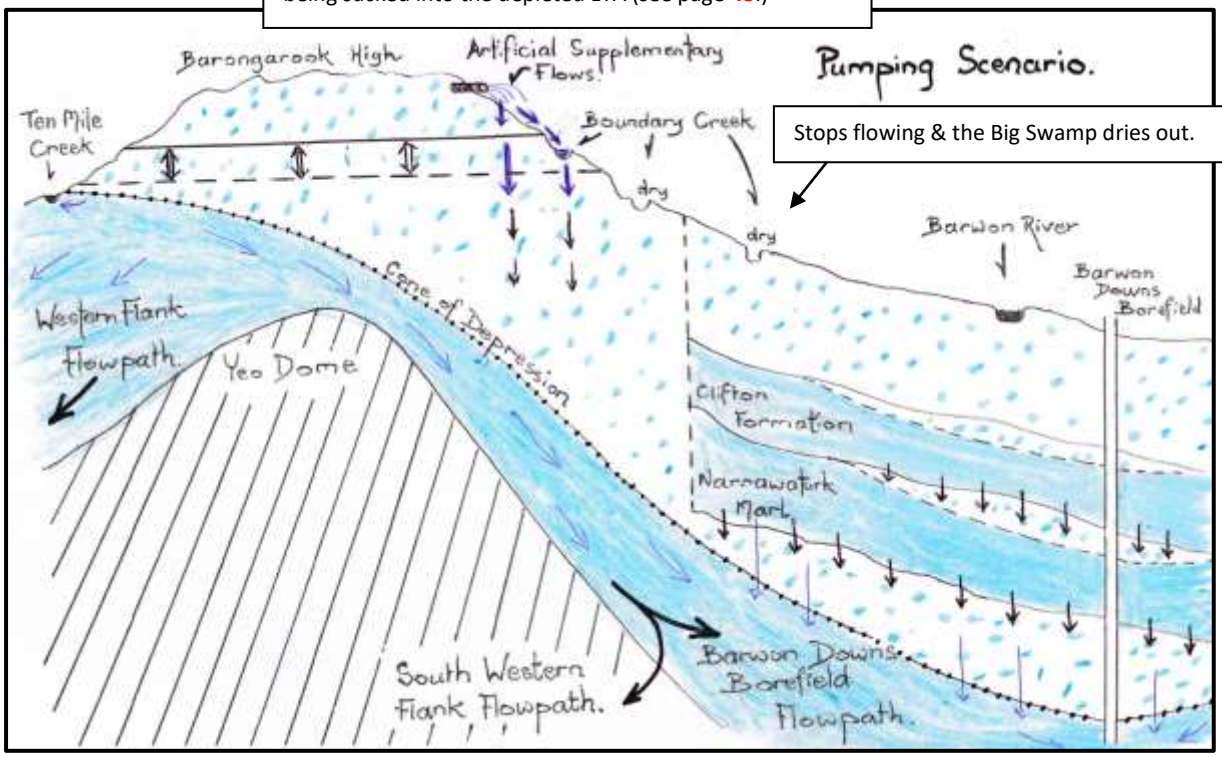
Conceptual Diagram

This cross section shows the Lower Tertiary Aquifers under natural conditions pre groundwater extraction. During normal weather patterns, the Dynamic Equilibrium Water Level Zone (DEWLZ) would oscillate up and down within a range whereby the top end of Boundary Creek would stop flowing in summer but remain moist, and the lower reaches of Boundary Creek would continue to flow all year, every year. These lower reaches of Boundary Creek, including the wetlands of the Big Swamp, were always below the lowest level of the DEWLZ and as a result continually received discharge from the overflowing Lower Tertiary Aquifers.

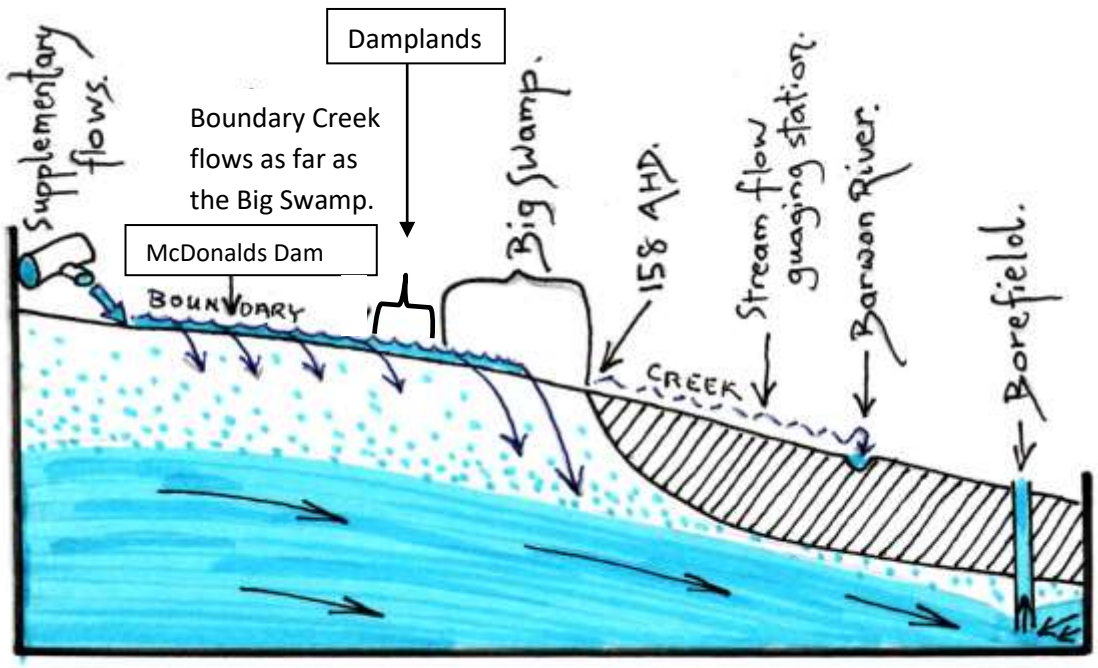
Under these conditions the Narawaturk Marl would have water driven up into it (upward Vertical Leakage) from the pressurised Lower Tertiary Aquifers. In turn water would be forced up into the bottom of the Clifton aquifer formation. During rainfall events infiltration across the system would come from above (downward Vertical leakage).

The functioning of this system would have evolved over eons of time and ecosystems would have adapted to this natural rhythm, reaching a relatively stable equilibrium in time with water levels in the oscillating Dynamic Equilibrium Water Level Zone. However, if water extraction from the Lower Tertiary Aquifers is greater than the recharging capacity of the system then changes would take place with the DEWLZ dropping to unprecedented levels. The greater the difference between recharge and extraction the greater the changes the impact would be. Dropping the water level tens of metres below the Big Swamp has shown how devastating these changes can be. However by SKM's definition, the Lower Tertiary Aquifers were being managed sustainably – if water can be extracted from the LTAs then the pumping regime is sustainable.

Artificial Supplementary Flows sustain the top end of Boundary Creek but the flows never pass the Big Swamp, being sucked into the depleted LTA (see page **43**.)



The conceptual cross sections on this page show what is taking place when an aquifer system is drawn down faster than the natural processes can recharge the system.



Impacts on a Falling Water Level in the DEWLZ in the Barongarook High Area.
In the Barongarook High area the groundwater extraction caused…

- the water table level to fall way below the Dynamic Equilibrium Water Level Zone;
- Boundary Creek to stop running;
- the Big Swamp Wetland to dry up;
- water from the Narawaturk Marl begin to vertically leak downwards to fill the dewatered space in the Lower Tertiary Aquifers (LTA), and
- the Clifton Formation aquifer begin to leak downwards to fill the leaking Narawaturk Marl.

Failure to Accept this Process.
The following statement is taken from Barwon Water's Draft Version 1 "*Boundary Creek, Big Swamp and surrounding environment – remediation and Environment Protection Plan*," table at Barwon Water Remediation Workshop Group meeting number 10 (12-12-2019). It clearly shows a lack of understanding how the Big Swamp wetlands have remained saturated from an upward vertical leakage (gradient) from below.

> "***Is the pressure in the regional groundwater system (the LTA) maintaining an upwards gradient to keep overlying local alluvial systems/aquifers saturated?***"

Pre groundwater extraction the LTA pressure maintained a flow in Boundary Creek and a saturated state within the Big Swamp. The pressure head being 10 metres at least, above the Big Swamp. Data going back decades supports the fact that this cannot be disputed.

The Cone of Depression Spreads.
As the cone of depression spreads and the depleted aquifer begins to fill, water from further and further out is sucked into the void. By the end of 2019 it was accepted that the surface area being impacted covered an area of at least 480 km^2.

Artificial Supplementary Flows Disappear.
The LTA pressure water level was drawn down way below the Big Swamp. The Artificial Supplementary Water being released into the Barongarook High area failed to maintain flows in Boundary Creek. Water released completely disappears into the dewatered Lower Tertiary Aquifers, flowing no further than the Big Swamp wetlands. These drawdowns are massive when compared with

the 20cm oscillation[31] in the Newlingrook Groundwater Management Area, and the 10cm per year lowering of the DEWLZ oscillation as describe by GHD.[4]

Impact Denied.

Despite all of these things Jacobs and Barwon Water denied any direct connection between the Big Swamp Wetland and the Lower Tertiary Aquifer but did concede, "***Available information suggests that Yeodene (Big) Swamp is a groundwater discharge site.***" This would also suggest that when the Lower Tertiary Aquifers are full and these aquifers are discharging that there is a direct connection. The following pages examine this connection.

Perched Aquifer (Alluvial Aquifer) and the Big Swamp wetland.

The 2016 Jacob report[26] also suggests that after years of groundwater extraction that the Big Swamp Wetland now sits on a perched swamp and that a thick alluvial aquifer is underlain by the Narrawarturk Marl aquitard or MTD separating it from the Lower Tertiary Aquifers. "***The lithological logs for TB 1a and TB 2c indicate there is a perched aquifer in the alluvial deposits which is hydrologically buffered from the underlying regional LTA.***" But is this the case? Pre groundwater extraction data does not agree with this notion.

The Jacobs discussion supporting this case of the Big Swamp Wetland sitting on a perched swamp starts in the upper reaches of Boundary Creek where Jacobs states "***Groundwater levels in this part of the catchment have not been influenced significantly by groundwater extraction from the Barwon Downs borefield. This suggests that the nature of groundwater surface water interaction has also not changed significantly over time.***"[26] This seems a rather difficult statement to justify when it is considered that since 2004 during summer and dry periods the majority if not all of the flow in this upper reach of Boundary creek is from the Artificial Supplementary Flows released out of the Otway to Colac Pipeline. The implication of these artificial flows places a great deal of doubt on the veracity of the above statement. In 2009 SKM[32] found that surface water in the hydrological sensitive areas did not match up with the drawdown observable in Lower Tertiary Aquifers bores found in the same area.

"***It was observed during the inspection of the quadrant that water was present at sites 1, 2 and 3 indicating that the water table at these sites is currently at ground level, which appears to contradict the observation bore and groundwater elevation map data. At sites 1 and 2 the presence of water is most probably due to supplementary flow in Boundary Creek from the Colac pipeline, which is likely to have maintained the water table at the***

surface in the immediate vicinity of the creek channel."[32] The Artificial Supplementary Flows maintained this continuous surface flow as well as maintaining an artificially boosted water table in the upper reaches of Boundary Creek. At a subsurface lower level the drawdown from the Barwon Downs Borefield was dropping the natural water table pressure. The Artificial Supplementary Flows were masking the borefield extraction impact.

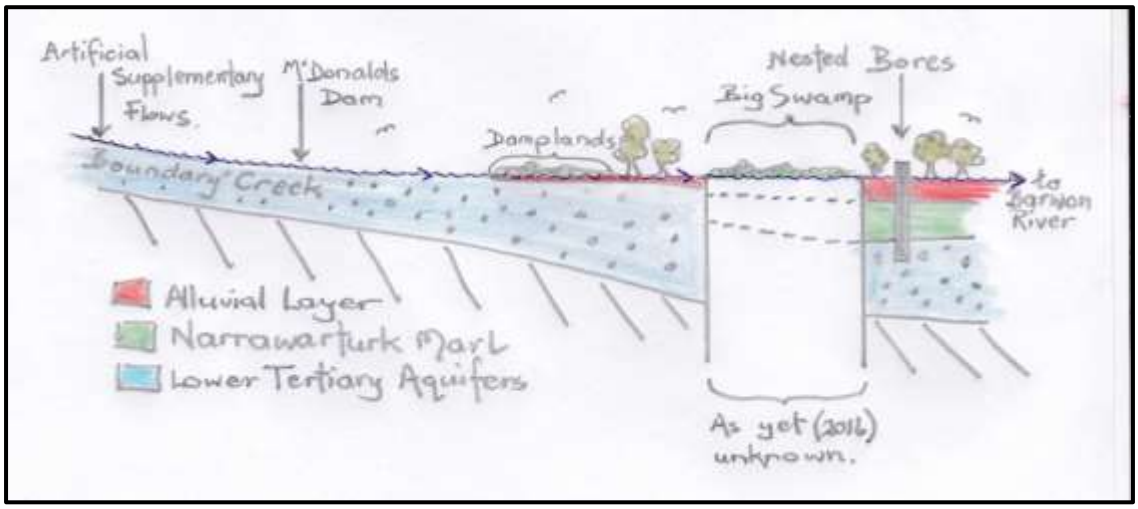
The Middle Reaches of Boundary Creek.

These artificial supplementary waters then flowed down Boundary Creek and through McDonalds Dam and into the Damplands above the Big Swamp Wetland. "***The damplands shallow alluvial aquifer is thought to be supported by rainfall and surface water flow in Boundary Creek.***"[26] but not accepted by Barwon Water as being supported by groundwater discharge from the LTA. This may have been the case when the 2016 report was compiled but pre groundwater extraction data tells a different story. The 2016 Jacobs report states "***The water levels in bore 109130 suggest that the creek was historically gaining in this location and is now losing.***"[26]

(see page **41** for hydrograph of Observation Bore 109130)

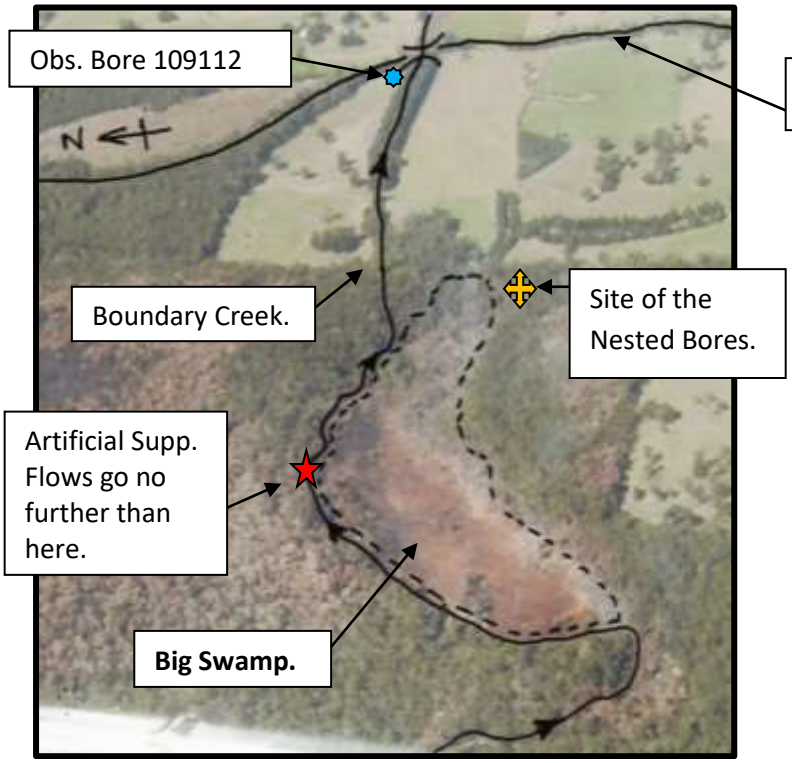
Once again no mention is made of the Artificial Supplementary Flows buffering and maintaining flows in this reach of Boundary Creek during dry periods. How it was established that the Damplands sits on a shallow alluvial aquifer was not explained especially when there are no observation bores in the Damplands.(See page **36** for the site of the Damplands)

The Jacobs 2016 report continues, " ***In contrast there is a thick alluvial aquifer at Yeodene (Big) Swamp, which is underlain by MTD...***" How this statement can be substantiated is also a mystery. New nested observation bores were drilled in recent times at the bottom end of the Big Swamp Wetland but not in the swamp itself (see page **40**).



A profile of what lies under the Big Swamp Wetland has never been researched. Whether the swamp sits on and has direct contact with the LTA or has a layer of Narrawarturk Marl aquitard (MTD) below the surface, is also not known. The Jacobs 2016 report states "***Downstream of Yeodene (Big) Swamp (Reach 3) the watertable lies within the shallow alluvial aquifer and is close to the surface***."[26] Above and below the Big Swamp Wetland Jacobs states there are shallow alluvial aquifers but the swamp itself sits on a thick alluvial aquifer underlain by MTD. No explanation is given how these statements have been arrived at or why the alluvial layer thickens under the Big Swamp.

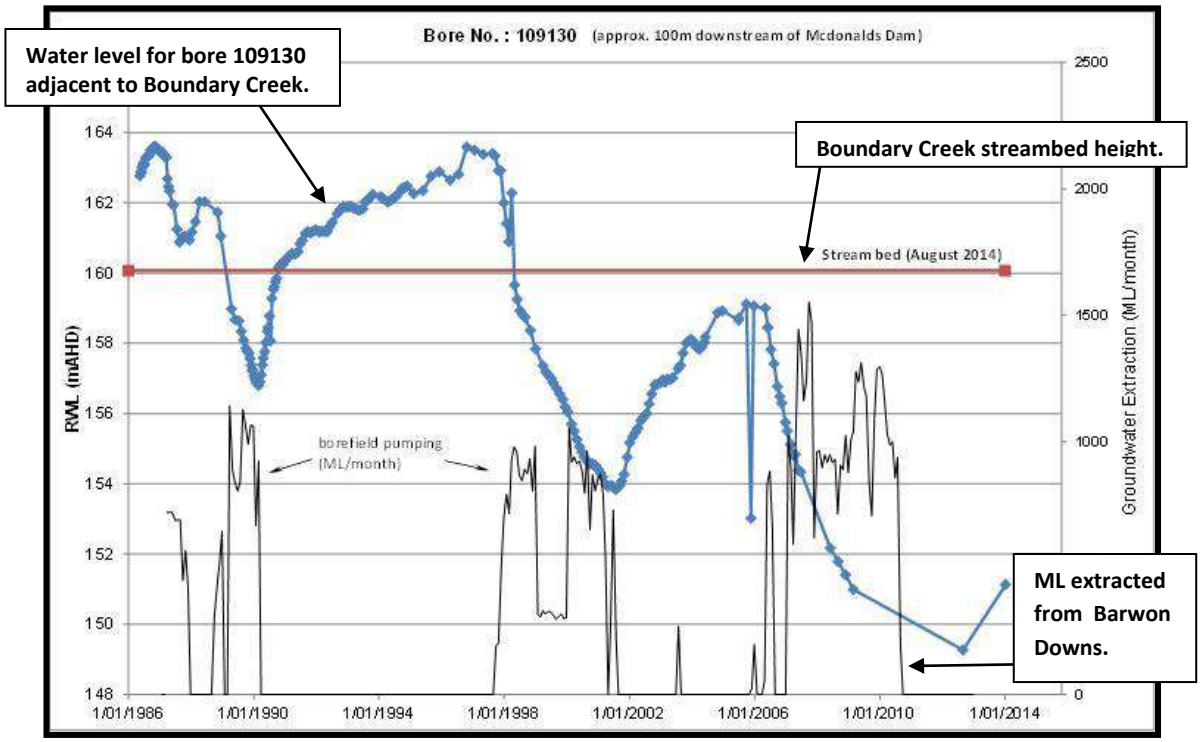
To further justify that the Big Swamp sits over an alluvial aquifer and has no direct interaction with the LTA, the data gained from the nested bores drilled in 2014 has been used. "***The lithological logs for Bores TB1a and TB2c indicate that there is a perched aquifer in the alluvial deposits which is hydrologically buffered from the underlying regional LTA.***"[26]



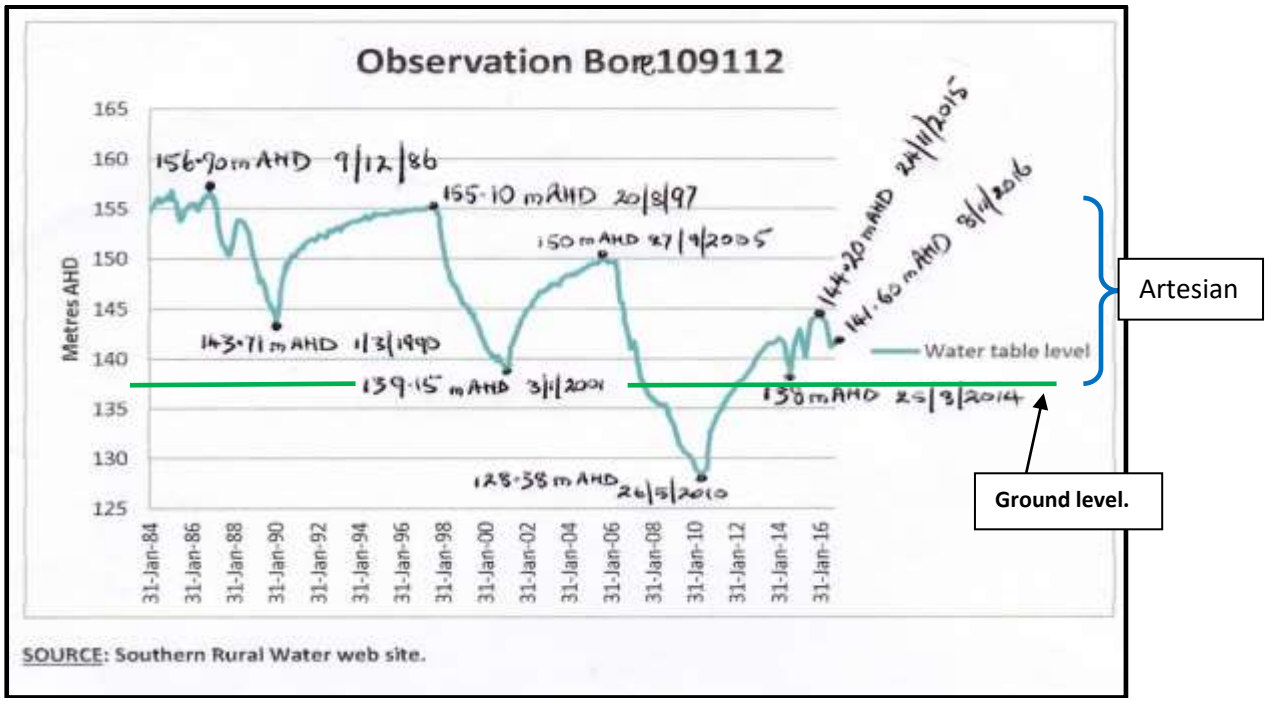
"***The bores monitor three different hydrogeological units beneath Yeodene (Big) Swamp...***"[26]
These 3 nested observation bores drilled in 2014-15 are outside the perimeter of the Big Swamp and as there are no bores located within the swamp itself, what actually exists under the Big Swamp is based on conjecture and guess work. The depth of the peat; the connectivity with the LTA and other land formation below the swamp is unknown. The data collected from these bores has then been used to justify the argument that an alluvial aquifer and aquitard in the Big Swamp have been reacting solely to rainfall and climate conditions. This may be the case since 2014 but the impact from 30 years of extraction pre 2014 should be taken into account. The Jacobs' report at least concedes that, "***Downstream of McDonalds Dam (Reach 2) groundwater levels have been***

heavily influenced by extraction from the borefield with drawdown in the LTA ranging between 15 and 20 metres below pre-pumping groundwater levels."

"... the drawdown in the LTA was around 20 m in this area of the aquifer and while groundwater levels have recovered since 2010, the water level remains lower than pre-pumping levels."(26)



Source. R. Evans presentation to Barwon Downs Groundwater Community Reference Group 2015.

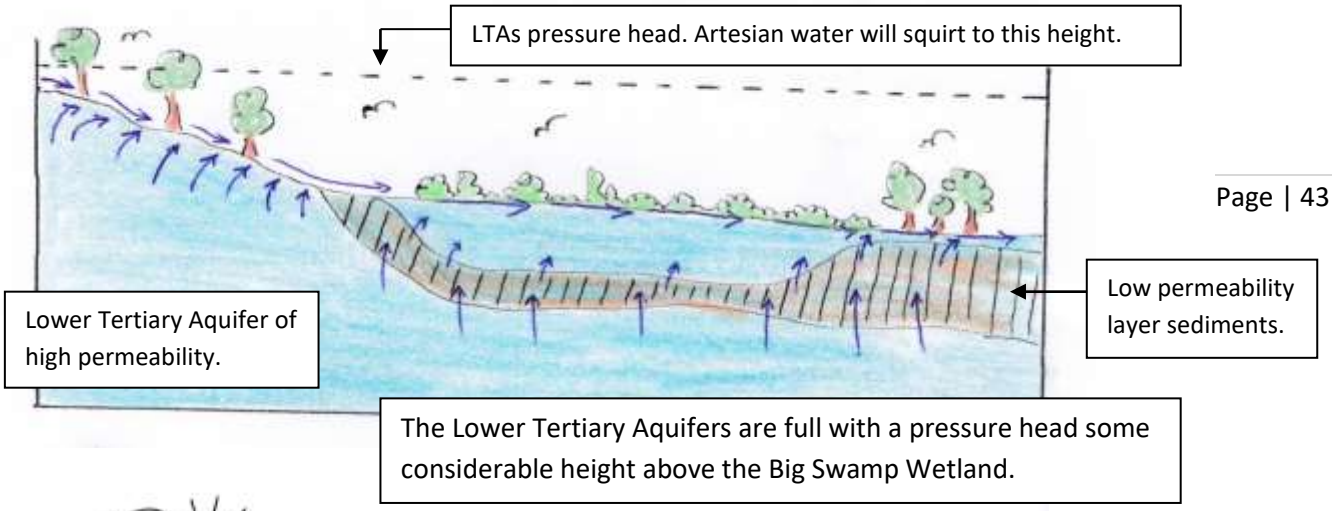


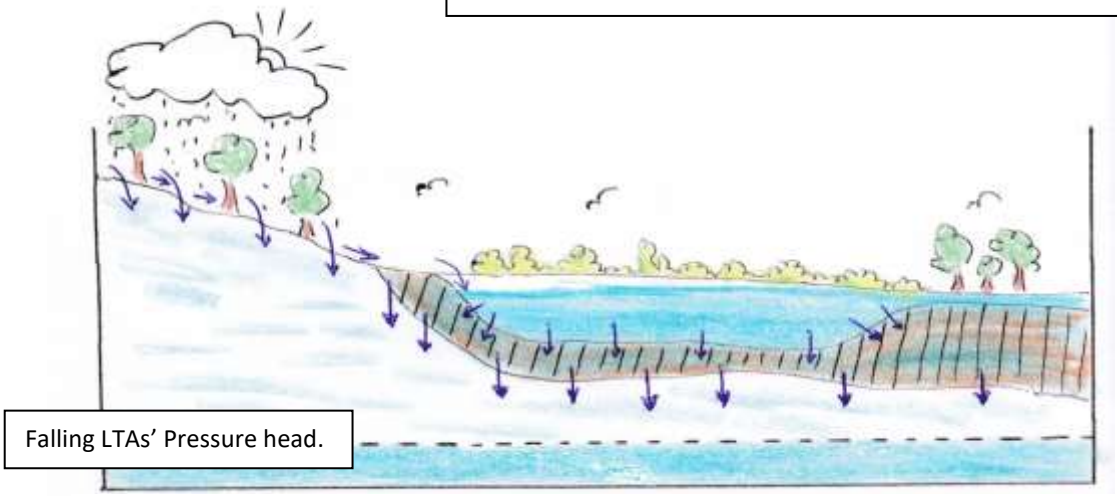
The data from this hydrograph of Bore 109112 (see page 40 for location) has been used in the conceptual drawing on page 43).

The Big Swamp Wetland was a Natural Discharge Point.
Gathering together the historical and present day data clearly shows that the Big Swamp Wetland was a natural discharge point of groundwater due to the effect of upward hydraulic influence (leakage) from the Lower Tertiary Aquifers. An observation bore drilled into the LTA underneath the Big Swamp pre groundwater extraction would have squirted water metres into the air above the wetland level.
This pressure would have been doing three things.
Maintaining Year Round Flow.
1.Maintaining an overflow discharge from the LTA through springs and those other outlets where the Artificial Supplementary Flows disappear into.
Keeping the Wetland Saturated.
2. Keeping any hydrogeological unit (alluvial aquifer/aquitard) in Boundary Creek and the Big Swamp region, saturated from upward vertical leakage.
Preventing the Creation of Perched Swamps.
3. Preventing the creation of hydrologically separated perched water tables or wetlands.

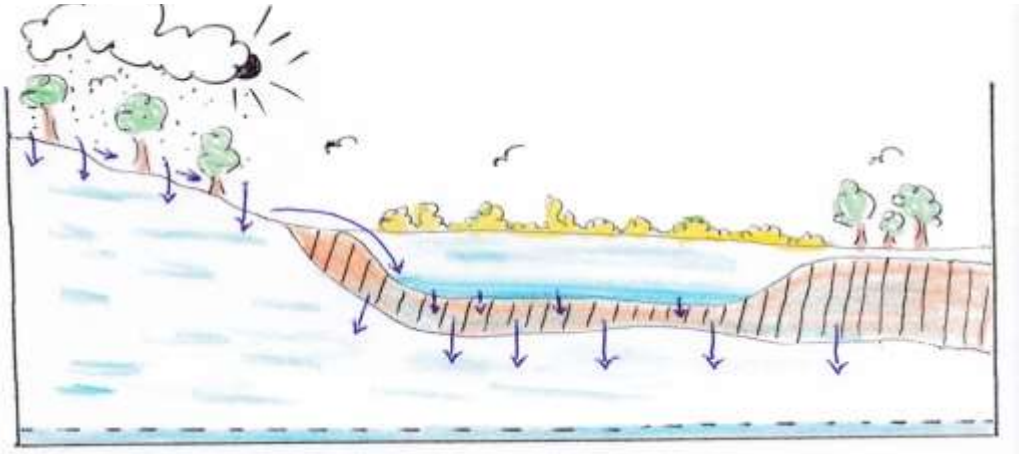
Perched Swamp Creation.
The creation of perched water tables is best described through statements made in the SKM, Barwon Downs Flora Study, 2009.[30]
"***The aquifer pumped by the Barwon Downs borefield is known to be heterogeneous in nature (i.e. comprises layers of high and low permeability sediments (Dudding 1991) and, as such ,has the potential to form perched water tables.***" (see concept illustrations, page **43**)
Perched water tables would only occur in the Big Swamp Wetland if the artesian pressure head in this area was reduced below the subsurface allowing the creation of a perched swamp.
"***It is not known whether leakage of the supplementary flow into the LTA is sufficient to maintain the water table at the surface and keep it connected to the regional water table, or that a perched water table (i.e. disconnected to the regional water table) immediately adjacent to the creek channel has formed.***"
Data clearly indicates that if the LTAs or regional water table is lowered enough, the potential to create perched water tables is a reality.

The following figures on page 43 show how this is possible.

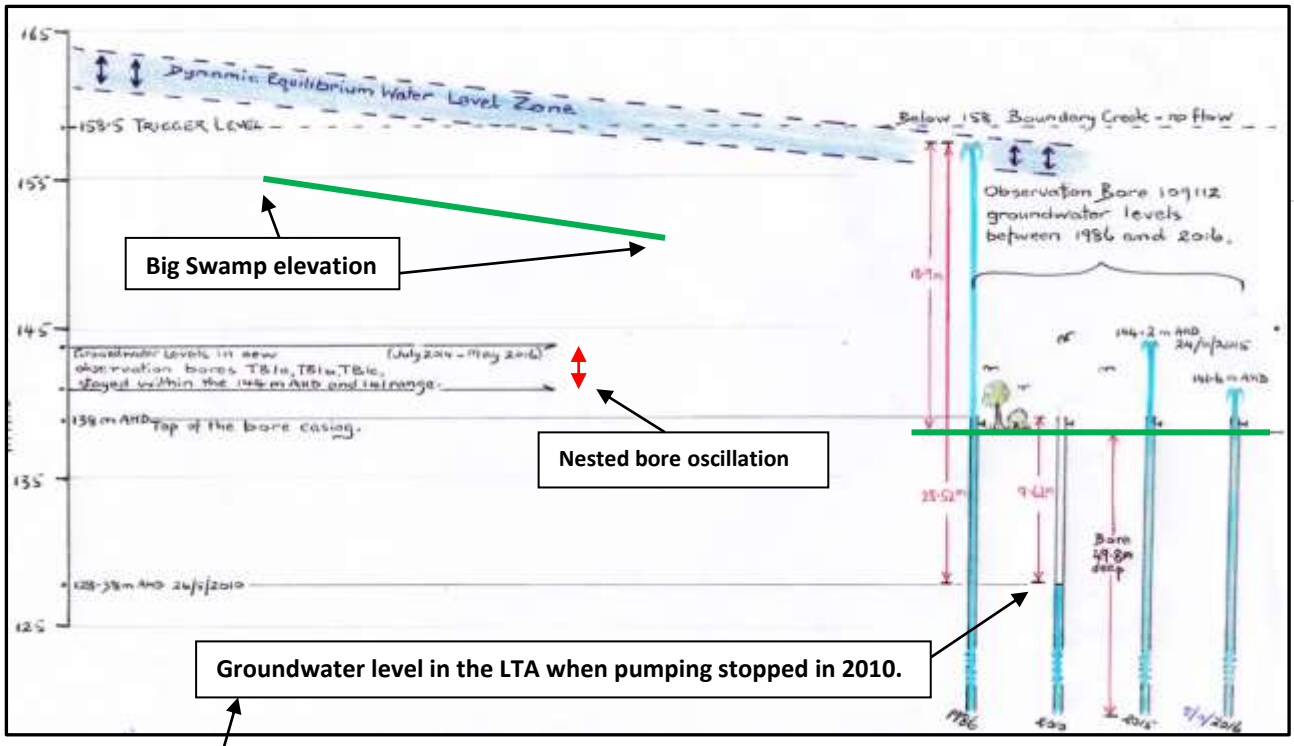




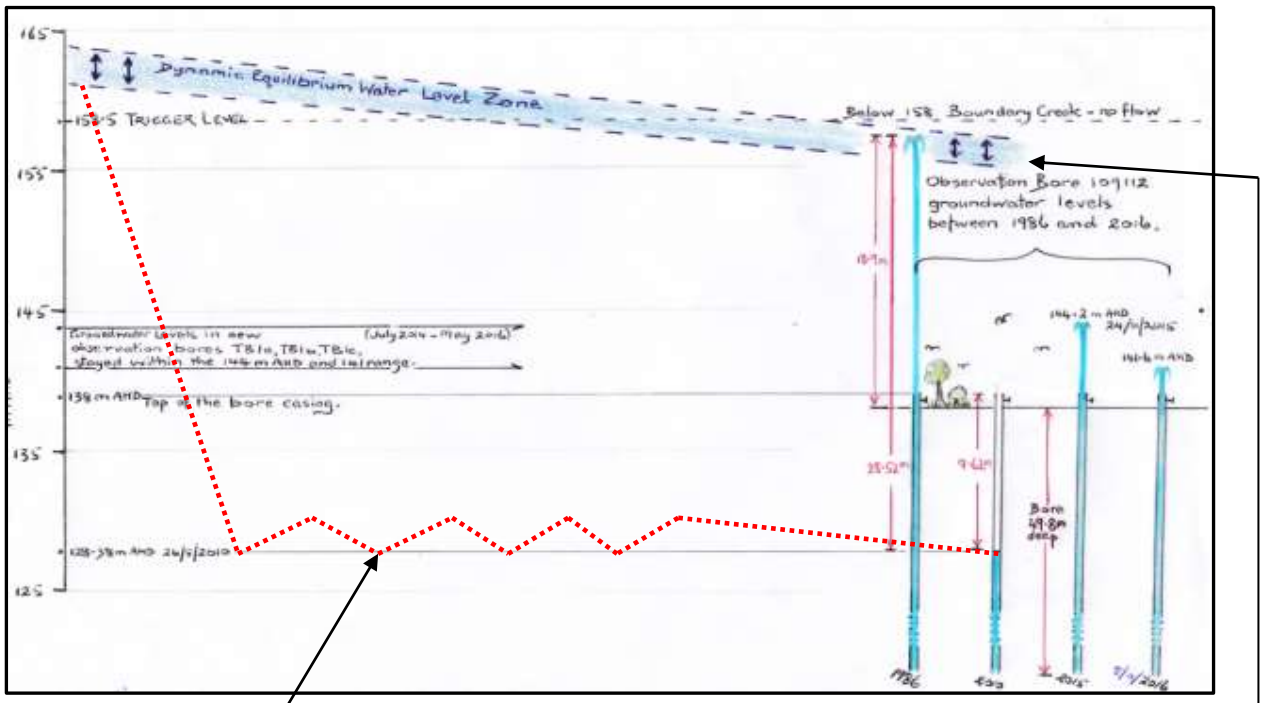
The extraction of groundwater lowers the water table pressure head and the low permeability layer creates a perched swamp.



The low permeability layer will leak downwards moving water into the depleted aquifers below and the perched swamp will start to dry out.



The groundwater table under the influence of the Lower Tertiary Aquifers was lowered from an 18 m artesian level to approximately 10 metres below groundwater level (also see page **45**).



Groundwater extraction from the Barwon Downs Borefield dropped the lower level of the Dynamic Equilibrium Water Level Zone way below the Big Swamp and has not returned to its original oscillating zone pre pumping(see page 33).

The **blue line** indicates how high the artesian water would squirt into the air at this observation bore 109112 pre groundwater extraction.

The **red line** indicates how far down the observation bore was drawn down below ground level .

Water table level in observation bore 109112 in 2010, approximately 10 m below ground level.

With all of this in mind it is difficult to understand why this statement requires the words "...***most likely...***" to be included. "***It is most likely that there was historically an upward gradient from the LTA through the aquitard to the alluvial aquifer at the Yeodene (Big) Swamp.***"[25] It is just as difficult to understand why this next statement was not a definite statement by not including the word "***...suggests...***" "***Available information suggests that the Yeodene (Big) Swamp is a groundwater discharge site.***" And, perhaps it should read "***...was a discharge site pre groundwater extraction.***"[25]

Creation of Actual Acid Sulfate Soils.

Because groundwater extraction volumes exceeded the natural recharge ability, the top end of the Big Swamp began to dry out. The drying peat turned Potential Acid Sulfate Soils (PASS) to Actual Acid Sulfate Soils (AASS) and as the water levels were dropped further and further the more PASS was converted to AASS. By the time the nested observation bores were drilled outside the bottom end perimeter of the Big Swamp in 2014, the upward vertical leakage had been reversed and the pressure from the LTA into the Big Swamp no longer existed.

The Big Swamp Wetland No Longer Saturated.

The wetlands had changed from a gaining groundwater swamp to one losing water to the depleted water table below. As this happened any hydrogeological units below and around Boundary Creek and the Big Swamp Wetland changed from being under the influence of the Lower Tertiary Aquifers upward vertical leakage, to being under the influence of rainfall, artificial supplementary flows and climate conditions.

Before Groundwater Extraction.

Significantly in the pre groundwater extraction period there would have been little to no natural variability in the water levels of the Big Swamp Wetland, and the lowest level would have been buffered from any rainfall and climate conditions by the natural upward discharge out of the hydrogeological units below. Not until the water level dropped below the level of the Big Swamp would rainfall and climate conditions have any significant impact on the wetlands or the water levels in the nested bores area. As in adjoining catchments, not under the influence of the Barwon Downs Borefield, impacts in the Boundary Creek area should not have taken place (see page 26).

Upward Movement of Water.

In a Jacob's report 2017[25] it discusses this very fact that groundwater will vertically leak upwards. The report also mentions that discharge from the aquifer will move in another three ways.

"***Groundwater discharges from the aquifer via vertical flow to the overlaying MTD, baseflow to rivers and small amounts to ET and lateral groundwater flow.***"

"***The MTD is recharged from rainfall and from the underlying LTA...***" (see the conceptual drawing depicting this LTA upward groundwater movement at the top of page **43**).

Oscillating Water Tables Levels Since Groundwater Extraction.

The upward and downward oscillation of the water levels taking place in alluvial aquifers and aquitard levels below and around the Big Swamp is a recent phenomenon and is reflected in the data being collected from the nested bores drilled in 2014. Under pre groundwater extraction conditions there would have been little to no oscillation. These hydrogeological units would have been saturated from the LTA's upward pressure just as Farmar-Bowers stated in 1986. "***Current water tables appear to be quite stable and there is little movement between seasons or years. (J. Leonard Pers.Com.)***"[5] The lower level of the Dynamic Equilibrium Water Level Zone would have been much higher than the Big Swamp Wetland, much higher up in the Barongarook High profile.

The Buffering Capacity of the LTAs Upward Gradient Pressure.

Water levels in the Big Swamp wetlands pre 1982 would have varied very little. Whatever hydrogeological units exist beneath the swamp would have remained saturated and the wetlands of the Big Swamp would always be under water. This buffering capacity of the aquifer during dry periods is one reason why groundwater was chosen as a water source for the Geelong system. "***The borefield is a critical back up source for Barwon Water because it is buffered from climate variability due to the depth and large storage capacity of the aquifer.***"[27] In a handout given at the 21 November 2017 Colac Otway Performing Arts Centre Barwon Water Workshop on the renewal of the Barwon Downs Borefield extraction licence, this same sentiment was repeated. "***In confined lower aquifers, the lack of correlation between the groundwater level and the rainfall pattern shows that these aquifers do not react to rainfall or short – term climate variations.***"[2]

Where the LAT outcrops and becomes an unconfined aquifer groundwater levels mimic the rainfall pattern in the Dynamic Equilibrium Water Level Zone. However, the oscillation in this zone had developed over eons and has

oscillated in a similar pattern through many droughts and floods up until extensive groundwater commenced in 1982-83. Since then things slowly began to change. The bottom level of the Dynamic Equilibrium Water Level Zone began to drop to unprecedented levels. As the extraction increased so did the speed of the change. There is data going back at least three decades clearly demonstrating the impact the Barwon Downs Borefield has had on the Big Swamp Wetland and Boundary Creek flows as the water table has been lowered.

Little recognition of historical local knowledge and data was used in the modelling of the 2019 Barwon Downs Borefield groundwater extraction renewal process and 12,000 ML/year extraction application. The modelling input was dominated by data collected since 2014. This presented an extremely skewed and inaccurate accounting of the impacts from the Barwon Downs Borefield.

Application Withdrawn.
Early in 2019 just months before the Barwon Downs Borefield groundwater extraction expired, Barwon Water withdrew its application. The licence has lapsed.

Where to From Here?

1. **Monitor the Remediation Program.**
   Barwon Water have made a commitment to remediate the Big Swamp Wetland and surrounding region. The progress being made with this needs to be monitored.
2. **Before Any Groundwater Extraction Resumes.**
   - Evaluate and comprehensively document impacts that have already taken place. Include impacts on Groundwater Dependent Ecosystems, Acid Sulfate Soils, Barongarook Creek, Boomerang Swamp, Big swamp, Loves Creek, Gellibrand River, Barwon River and Stock & Domestic water supply.
   - Evaluate impacts on subterranean ecosystems found within the cone of depression influence. This must include impact ***ALL*** layers above the Lower Tertiary Aquifers.
   - Review, analyse and evaluate Jacobs' work, findings and predictions conducted as part of the most recent Monitoring Program.
   - Monitor how the aquifers recover.
   - Do not resume extraction until the Lower Tertiary Aquifers recover to pre 1980 levels.
   - Better determine the time frame for full recovery.
   - Use observable and verifiable data to better validate model assumptions, predictions, likelihoods and maybes.

- Ensure that the Australian National definition of sustainability be the definition adopted by all resource management mangers.
- Collect data that will enable an ACCURATE determination of what the sustainable groundwater extraction level per year is.

3. ***Educate* the public regarding the interconnection of surface and groundwater ecosystems.** Simply making data and documentation available is not education.
4. Actively pursue the activity of recycling waste water up to a publicly accepted drinking water standard.
5. **Reinstate Stock & Domestic water supply back to farmers impacted from the Barwon Downs Borefield groundwater extraction.**
6. **Re-visit the modernisation of the antiquated and wasteful method of transferring water** from the upper Barwon River system to Geelong.
7. **Re-visit and enshrine the zero level and 99% reduction of groundwater extraction in the Gellibrand and Gerangamete Groundwater Management Areas respectively, in much stronger legislation than presently exists.**

CONCLUSION.

In 1984 John Leonard, involved in much of the early work and investigation of groundwater resources in the Barwon Downs and Gellibrand River Catchment areas, came to these conclusions.

"***Creation of a cone of depression in the potentiometric surface in the Gerangamete area will distort the present flow pattern and absorb the northeasterly and southwesterly components of recharge from the Yeodene recharge avenue.***"(29)

If only John was aware of all the impacts that were to take place as a result of the huge cone of depression created by the Barwon Downs Borefield, it is not beyond the realm of possibilities that he would have been horrified. However, as recently as February 2012 Barwon Water continued to maintain that groundwater extraction had not caused any long term surface water impacts by stating that "***...water table drawdown occurs during pumping, but no long-term environmental impacts have been linked to borefield operation.***"
(Barwon Water, February 2012:Water Supply Demand Strategy 2012-2062, Draft.)

And…
"*No evidence was found that declining groundwater levels caused by groundwater extraction at Barwon downs had a negative impact on vegetation health in the catchment.*"
(Jacobs 2016)

Every Otway Water Book is a testament to how wrong these statements are.
These books can be found at **www.otwaywater.com.au**

Otway Water Book 35 provides insight into understanding how ignoring the hydrology of the Gerangamete and Gellibrand Management Areas has contributed to extraordinary impacts.

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