DELWP

Assessment of Accuracy of Baseflow Studies
Latrobe, Thomson Macalister and Mitchell Rivers

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Executive summary

Background

The Department of Environment, Land, Water and Planning (DELWP) previously undertook two projects to fill information gaps on priority Groundwater Dependent Ecosystems (GDE) – baseflow dependent rivers and wetlands. These projects, completed by GHD (GHD 2013a; GHD 2013b), developed a methodology to:

- establish where groundwater interaction occurs with rivers and wetlands
- quantify the groundwater contribution to the waterway where interaction occurs
- identify associated high value environmental assets, and
- assess the risk to these environmental assets from groundwater extraction.

A discussion paper was prepared by GHD in 2012 to appraise methods for quantifying regional groundwater discharge to streams (as “baseflow”) throughout Victoria. The adopted baseflow estimation method involved digital baseflow filtering “trained” to environmental tracer data – primarily electrical conductivity.

A pilot project was undertaken by GHD in 2012/13 for characterising the baseflow contributions for five Victorian rivers (GHD, 2013a), including the lower Mitchell and lower Thomson-Macalister Rivers. This project was expanded in 2013 (GHD, 2013b) to a further eight Victorian rivers including the Latrobe River catchment, using the same method. As for the pilot method, the results were used to assess the risk of groundwater extraction to the environmental values that those rivers support.

A scientific review of both baseflow studies (GHD, 2013a; GHD, 2013b) made a number of recommendations to refine the method and quantification used to determine the risk of combined surface water and groundwater extractions to significant environmental values.

Project objectives

The **primary objective** of this project is to implement the recommendations from the scientific review of the method developed by GHD (GHD, 2013a; GHD, 2013b) to improve the accuracy and reliability of the baseflow estimates to three high value Gippsland river systems:

- Latrobe River (Latrobe River to Kilmany South)
- Thomson-Macalister River system (Thomson River from Cowwarr Weir to Bundalaguah; Macalister River from Lake Glenmaggie to the confluence with the Thomson River), and
- Mitchell River (Glenaladale to Rosehill).

The objective of this project is to improve understanding of the degree and nature of interaction between rivers and groundwater in the Gippsland region, and to help understand potential impacts of coal mining, coal seam gas developments and other water uses on water-dependent environmental assets. The outputs of the work will improve the accuracy of, and confidence in, estimates of the dependency of flows on groundwater and improve the technical basis on the likelihood of direct, indirect and cumulative impacts of water use on baseflows.

One of the key outcomes from this study is to provide a tiered framework for the application of the baseflow estimation method(s) most suitable for different types of reaches, such as losing, gaining and regulated reaches.

The project is to be completed in two stages:

- Stage 1**:** Review groundwater contributions to rivers
- Stage 2: Targeted ground-truthing of existing data (data verification)

This report documents the Stage 1 assessment.

Scope of Work

Following on from the work completed in 2013 (GHD, 2013a; GHD, 2013b), the scope of work for this project includes:

- Review of the previous work and technical reviewers' comments, identifying options for improving the accuracy of bulk and interstation baseflow estimates
- Review of the physical and water management characteristics of the three Gippsland rivers that may affect the applicability and accuracy of different baseflow methods
- Application of supporting methods to improve the accuracy of baseflow estimates, and
- Identify any data gaps, and provide recommendations for future monitoring, to be undertaken as part of Stage 2 of this project.

Previous Work

GHD previously estimated baseflow to the Latrobe River (GHD, 2013b), and the Mitchell and Thomson-Macalister Rivers (GHD, 2013a) using a digital filter "trained" (or calibrated) to baseflow estimates derived using the Electrical Conductivity (EC) mass balance method. "Baseflow" in this study, and those of GHD (2013a and 2013b), is explicitly defined as regional groundwater discharge to streams, as distinct from the other slow flow components comprising interflow, banks storage returns, and so on. Regional groundwater discharge is the component of stream flow of primary interest to this study, because this is the component that can be managed through groundwater licensing and usage regimes.

The tracer method is widely used for estimating the regional groundwater discharge component of stream flow (i.e. baseflow, as opposed to the quickflow, or runoff and interflow, component). This method uses a simple solute mass balance assessment between groundwater (baseflow) and surface water (runoff) end-members to estimate the proportion of each end member component of stream flow. The solute mass balance model is (after McCallum et al. 2010):

$$\frac{Q_G}{Q_T} = \frac{(c_T - c_S)}{(c_G - c_S)},$$

where Q_G is the groundwater-derived (baseflow) component of stream flow, Q_T is the total stream flow (i.e. runoff plus interflow plus baseflow), c_T is the tracer concentration in the stream, c_S is the runoff end member tracer concentration, c_G is the groundwater (baseflow) end member tracer concentration.

This method was used to generate continuous daily baseflow estimates based upon gauged flow records, using EC data used as an environmental tracer.

The application of the EC mass balance method and training of the digital filter is outlined in detail in GHD (2013a) and Section 2.1 of this report, and a summary is outlined as follows:

1. Verification of the suitability of the EC Mass Balance method: Daily records of stream flow and EC data (from a gauge for which baseflow is to be estimated) are compared against one another using scatter plots to assess whether or not the EC mass balance method is applicable given the assumptions of the method. This process tests whether or not surface water EC exhibits a log-linear declining trend with increasing stream flow rates. The assumption being tested is whether or not the two-reservoir mixing model between (more saline) groundwater and (less saline) surface water explains the bulk of the observed trends in stream flow and EC.
2. Estimate groundwater and surface water EC end members: An estimate was made of the groundwater EC end member using spatial averaging of observed groundwater EC at bores within each stream gauge's catchment, which was assumed to coincide with the surface water catchment unless the groundwater level data suggested otherwise. The runoff EC end member was estimated using the lowest recorded reliable stream flow EC.
3. Apply the EC mass balance method: The EC mass balance method was applied to the entire gauged flow and EC record. Baseflow estimates for days with no observed EC data could not be made, so this produced a discontinuous baseflow time series.
4. Apply the digital baseflow filter: The Eckhardt digital baseflow filter was "trained" (calibrated) to the baseflows estimated using the EC mass balance method. The objective function to be maximised during calibration of the Eckhardt filter against the EC mass balance estimates was the Nash-Sutcliffe coefficient. The calibrated digital baseflow filter was used to generate continuous daily baseflow estimates using gauged streamflow records.
5. Account for uncertainty in the groundwater and surface water EC end members and flow gauging error: Uncertainty ranges were assigned to the runoff and groundwater EC end members based on observed data ranges where possible (for example 95% confidence limits), or estimates otherwise. Uncertainty ranges were also defined for gauge records using published information where available, otherwise estimates were made.
6. Compute interstation baseflow time series: Baseflow estimate time series for upstream and downstream gauge pairs were subtracted from one another to estimate baseflow gains and losses along reaches (between gauges). A key limitation of this approach is that it compounds uncertainties of each of the upstream and downstream gauge baseflow estimates, and any conclusions regarding the gaining/losing nature of a given stream reach must be validated using multiple lines of evidence.

Technical reviewers comments

A summary of the recommendations from the independent review comments of Cartwright (2012 and 2013) and Costelloe (2012 and 2013) of the baseflow method developed by GHD (GHD 2013a; GHD 2013b) has been provided in Section 2 of this report. Recommended actions and justifications for inclusion in, or exclusion from, the current scope of works are also provided, and the areas investigated in this study (Section 4 of this report) are listed below.

1. EC mass balance method application:
    i) Define the groundwater end member EC using typical low flow EC
    ii) Remove periods (events) with poor flow and EC correlation from the EC mass balance application

    iii) Check and document that the defined runoff EC end member is representative of the highest flow periods

2. Digital baseflow filter application:
    i) Define Eckhardt filter parameter BFImax using the highest estimated baseflow index (BFI) from the baseflows estimated using the EC mass balance.
    ii) Optimise only the Eckhardt filter parameter Alpha during training of the digital filter.
3. Verification using independent data / methods:
    i) Estimate reach-scale baseflow gains using a reach-scale EC and flow mass balance.
    ii) To calibrate and provide evidence for inferences made regarding gaining/losing reaches as derived from the interstation baseflow analyses, assess the independent data including: detailed local studies, scatter plots of stream flow and EC from upstream versus downstream gauges, reach-scale flow balances, and observed gradients between groundwater levels and stream stages.

Baseflow characterisation

The physical and water management characteristics of the three Gippsland river catchments (Latrobe, Thomson-Macalister, and the Mitchell) were assessed in Section 3 of this report to provide a broad characterisation of the baseflow characteristics, as well as highlighting issues which may affect the accuracy of application of different baseflow methods. Physical catchment characteristics investigated include:

Surface water streamflow and EC:

- Streamflow and EC statistics are summarised, which provide an indication of the suitability of the application of the EC mass balance method, where the underlying assumption of the EC mass balance method is that low flows are largely supported by input from relatively saline groundwater, and therefore exhibit comparatively high surface water EC concentrations. The gauged period of record is also summarised to indicate whether there is sufficient data to apply baseflow separation techniques.
- Scatter plots of upstream versus downstream flow and EC data for overlapping periods have been developed. This analysis serves as a basic check for potential baseflow gains along each reach, with increasing downstream EC and flow indicative of potential baseflow gains.

Groundwater EC and hydrographic assessment:

- Groundwater EC statistics are presented for the total upstream groundwater catchment and the interstation catchment (useful in reach-scale mass balances). Groundwater EC is presented spatially, providing an indication of variability in EC across the catchment and the distribution of data available to characterise the groundwater EC.
- Hydrographic comparison of surface water levels along the reach and groundwater levels at nearby bores has been conducted (where possible) to provide an indication of the relative groundwater gradient. Higher groundwater levels relative to stream water levels indicate potential for baseflow gaining conditions.

Water management characteristics:

- The impacts of surface water management occurring within each river reach (including reservoirs, river diversions and returns, and drainage) on baseflow estimation are discussed, and presented spatially on maps.
- Groundwater extraction (non-mining licenced extractions, mining extractions, and stock and domestic) are presented spatially and summarised for the total upstream catchment and the interstation catchment. A large volume of groundwater extraction in the vicinity of assessed reaches could have the potential to reduce baseflow. It is noted that the baseflow estimation presented in this study reflects the groundwater discharge to streams, after depletion by groundwater extraction.

Other relevant baseflow investigations which have been conducted within the three river catchments were also reviewed as part of this assessment. Relevant authorities (DELWP, the East Gippsland CMA and West Gippsland CMA) were contacted to ensure that all the key baseflow investigations were reviewed, including:

- SAFE: Secure Allocations, Future Entitlement (DSE, 2012)
- Understanding connectivity within groundwater systems and between groundwater and rivers (Hoffman, 2011)
- East Gippsland and West Gippsland ecoMarkets groundwater models (GHD 2010a; GHD 2010b)

The baseflow characterisation was used to assess the usefulness and applicability of other potential baseflow estimation methods to enhance the digital filter method, for the various catchment characteristics. The key findings of the baseflow characterisation are discussed in Section 3 of this report, and are summarised below.

Latrobe River

Water management characteristics

There are a range of water management activities that are undertaken in the Latrobe River catchment that impact streamflow and stream EC, particularly in the lower reaches of the basin.

Reservoirs: The catchment has three major storages: Blue Rock Reservoir on the Tanjil River; Lake Narracan on the Latrobe River (at the confluence of the Tanjil River, Moe River and Narracan Creek); and Moondarra Reservoir on the Tyers River. Blue Rock is the largest storage and has a significant impact on the flow regime, with reduced flows in the wetter months and increased flows in the summer months as a result of releases to downstream water users. The smaller capacity of the Narracan and Moondarra storages relative to the catchments they impound, results in a less significant change in flow regime. The reservoirs also affect downstream EC by allowing for mixing of different salinity flows, resulting in a more uniform EC downstream of the reservoir.

Diversions: A number of water users divert from the Latrobe system, the most significant extraction in the Latrobe catchment is the diversion to power stations at Yallourn Weir (in the order of 227 ML/d). The diversions take a mix of baseflow and other flow components from the stream; therefore, these diversions do not have any impact on the application of the baseflow separation method at a single gauge location. Diversions do however have an effect on any interstation analysis of baseflow.

Drainage: There are a number of drains that convey water from the southern part of the Macalister Irrigation District to the lower Latrobe River. These collect relatively saline water from high water table areas and discharge to the river system. The discharge from these drains has an elevated EC, primarily as these drains are collecting groundwater from high water table areas. It is likely that a large proportion of the drain discharges is a mix of baseflow and other flow components; therefore, is considered a negligible issue for the baseflow analyses.

Industrial Water Returns: There are five major industrial water users that return water to the river: Energy Brix, Hazelwood Mine, Loy Yang Mine, Yallourn Mine, and Australian Paper Mill (APM). The saline industrial water returns affect the baseflow separation method by increasing the EC of streamflow (thereby resulting in a higher estimate of baseflow).

Treated Waste Water Returns: There are three significant wastewater treatment plants that discharge treated wastewater to the river: Warragul WWTP, Moe WWTP, and Morwell WWTP. The treated wastewater returns also affect the baseflow separation method by increasing the EC of streamflow, resulting in a higher estimate of baseflow. However, it is noted that part of the treated wastewater is made up of groundwater intercepted by the sewerage network. In effect, a proportion of these treated wastewater flows is baseflow that may have previously reached the river via a natural flow path.

Groundwater Management: The major groundwater extractions are from the three mines which operate in the Latrobe River catchment: Hazelwood Mine extracting an average of 14,200 ML/yr from the Morwell (M1 and M2) Formation; Loy Yang Mine extracting an average of 12,700 ML/yr from the Morwell (M2C) and Traralgon (T1) Formations; and Yallourn Mine extracting an average 320 ML/yr from the Morwell (M1A) Formation. While these mines extract significant volumes of groundwater, the groundwater extractions are from deep confined aquifers, and have minimal observable impact on groundwater levels in the unconfined aquifer. There are also groundwater extractions from stock and domestic bores, non-mining licenced groundwater extraction, concentrated in the upper reaches of the Moe River (Moe Groundwater Management Area), and the lower reaches of the Latrobe River (extractions from the Denison Water Supply Protection Area and the Rosedale Groundwater Management Area).

Physical characteristics:

The Latrobe River catchment has highly variable data availability, with very limited surface water EC data in the upper and middle catchment around Morwell, and adequate surface water EC data in the lower Latrobe River (between Scarnes Bridge and Rosedale). Interstation EC mass balance baseflow analysis is extremely limited in the upper Latrobe River (to Thoms Bridge) and the middle Latrobe River (between Thoms Bridge and Scarnes Bridge) due to insufficient stream EC data, where there are no concurrent stream EC and flow data for all upstream and downstream gauges. However, there is sufficient data to perform interstation EC mass balance baseflow analysis for two reaches on the lower Latrobe River (between Scarnes Bridge and Kilmany South).

Comparison of gauged stream flows and EC for corresponding upstream and downstream gauges along the Latrobe River suggest that stream EC increases down each gauged reach of the Latrobe River relatively consistently. This suggests that the river is largely baseflow-dependent. Caution must be taken with this inference however, given the relatively saline water returns from industrial water users.

The limited surface water EC data in the upper Latrobe River to Thoms Bridge suggests little contrast between the EC concentration during low and high flow periods. This is likely due to the EC-mixing effect on stored and subsequently released water from Blue Rock Reservoir, Moondarra Reservoir and Lake Narracan.

There is a high degree of spatial variability in the groundwater EC concentration across the Latrobe River catchment, transitioning from relatively fresh groundwater (25 – 750 uS/cm) in the north-west to more saline (> 1,500 uS/cm) in the south-east. There is also variability in the groundwater monitoring data, with a high density of groundwater monitoring data in the upper part of the catchment in the vicinity of the Moe River and Bear Creek, and in the lower part of the catchment at the base of the Latrobe River, with limited data throughout the rest of the catchment.

There are only two groundwater observation bores located sufficiently close to the Latrobe River to allow hydrographic comparison of groundwater and surface water levels. These bores are located near Moe in the upper Latrobe catchment (800 m north of the Moe Drain and 700 m west of the Latrobe River) and monitor the confined aquifers of the Yarragon Formation and underlying Thorpdale Volcanics/Childers Formation. Comparison of the groundwater levels to the adjacent Latrobe River water levels (estimated using LiDAR data), suggest a strong potential for baseflow discharge to the Latrobe River at this location from the confined aquifers. However, there is no suitable data for a similar analysis to be conducted on the middle and lower Latrobe River.

Local baseflow assessments

Findings from the Victorian Government’s Secure Allocation, Future Entitlement (SAFE) project indicate that the upper reaches of the Latrobe River, Morwell River and Traralgon Creek are gaining reaches, with moderate to high BFIs. The study indicated that Tyres River, Bear Creek and Billy Creek are also gaining reaches; however, with a low confidence rating given baseflow indices have not been estimated along these reaches. This study did not classify baseflow for the Tanjil River downstream of Blue Rock Lake, Latrobe River downstream of Lake Narracan, and Tyres River downstream of Moondarra Reservoir, given the impacts of regulation on these reaches. Given that these baseflow estimates comprise digital filter application, which is also part of the methodology applied in the current project, they do not serve any purpose in validating the baseflow estimates to be developed in the current project.

The modelled spatial baseflow gains and losses across the Latrobe River catchment, estimated for a wet (July 1978) and dry (April 1983) period, derived from the West Gippsland ecoMarkets Model (GHD, 2010) suggests generally baseflow gaining conditions along the Latrobe River.

Inferred baseflow condition for the Latrobe River catchment

The limited available earlier studies indicate that the Latrobe River can be classified as a primarily baseflow-gaining stream. However, it is noted that for much of the Latrobe catchment, this conclusion is primarily based on the ecoMarkets groundwater model, due to a lack of sufficient supporting information to inform the assessment of the SAFE project.

The gauged stream flow and EC data, and groundwater/surface water level analysis indicate baseflow gaining conditions along the Latrobe River. This conclusion is however of low confidence because:

- There is only one suitable groundwater level observation site located sufficiently close to the Latrobe River for inferring baseflow status on the basis of groundwater levels relative to stream water levels. This site is located near Moe (800 m north of the Moe Drain and 700 m west of the Latrobe River), and hence much of the lower Latrobe River possesses no suitable data for similar analysis, and
- Industrial water offtakes and return of more saline water between Thoms Bridge and Rosedale, primarily by the coal mines, make conclusions regarding baseflow status on the basis of observed stream EC increases difficult and prone to significant uncertainty.

Despite these limitations, the data analysed in this report, and the results of the ecoMarkets model, do tend to point towards dominantly baseflow-gaining conditions along the Latrobe River.

Thomson-Macalister River

Water management characteristics

There are a range of water management actions that are undertaken in the Thomson-Macalister River catchment that impact streamflow and stream EC, as discussed below.

Reservoirs: The catchment has two major storages: the Thomson Reservoir on the Thomson River; and Glenmaggie Reservoir on the Macalister River. These storages have a significant impact on the flow regime, and also affect downstream EC by allowing mixing of different salinity flows, resulting in a more uniform EC downstream of the reservoir. However, for this catchment, the EC upstream of the reservoirs is relatively low and not particularly variable with respect to flow or season, which results in a minor impact of the reservoirs on gauged stream EC.

Diversions: A number of water users divert from the streams: the most significant extraction on the Thomson River is at Cowwarr Weir (41 ML/d), while the most significant extraction on the Macalister River is at Maffra Weir (115 ML/d). The diversions take a mix of baseflow and other flow components from the stream; therefore, do not have any impact on the application of the baseflow separation method at a single gauge location. Diversions do however have an effect on interstation analysis of baseflow.

Drainage: There are a number of drains that convey water from the southern part of the Macalister Irrigation District to the Thomson and Macalister rivers. These collect relatively saline water from high water table areas and discharge to the river.

Groundwater Management: The groundwater extractions from stock and domestic bores and from non-mining licenced groundwater extraction are concentrated in the lower reaches of the Macalister River (Wa De Lock and Sale Groundwater Management Areas), and the lower reaches of the Thomson River (Denison Water Supply Protection Area and the Rosedale and Sale Groundwater Management Areas).

Physical characteristics

The Thomson-Macalister River catchment has highly variable data availability, with very limited surface water EC data upper reaches of the Thomson River (upstream of Heyfield) and in the upper reaches of Macalister River (upstream of Riverslea), but adequate surface water EC data in the lower Thomson and Macalister Rivers. Interstation EC mass balance baseflow analysis is extremely limited in the upper Thomson River (to Heyfield) due to insufficient stream EC data, with only three concurrent flow and surface water EC readings for all upstream and downstream gauges. However, there is sufficient data to perform interstation EC mass balance baseflow analysis for three reaches within the Thomson-Macalister River catchment: Thomson River between Heyfield and Wandocka, Macalister River between Glenmaggie and Riverslea (limited assessment), and the Lower Thomson-Macalister River from Wandocka to Bundalaguah, including Macalister River.

The surface water EC data suggests that there is very little contrast between gauged stream EC at low flows versus those at high flows for the majority of the Thomson-Macalister catchment, with the exception of the Thomson River at Bundalaguah and the Macalister River at Riverslea. These observations are likely largely due to the EC-homogenising effect on stored and subsequently released water from the Thomson Dam. The greater contrast in stream EC at high versus low flows at the two gauges furthest downstream along the Thomson and Macalister Rivers, suggests that the rivers may become more baseflow dependent further downstream, and that the effects of reservoir releases on the stream EC signature diminish with distance downstream.

Comparison of gauged stream flows and EC for corresponding upstream and downstream gauges indicates that stream EC consistently increases down each gauged reach of the Thomson-Macalister River, with the exception of the upper reach between Cowwarr Weir and Heyfield, for which there is too little data to make a firm conclusion. This suggests that the river is largely baseflow-dependent, except possibly in the reach between Cowwarr Weir and Heyfield.

There is a high degree of spatial variability of groundwater EC across the Thomson-Macalister catchment, which transitions from moderately fresh groundwater in the north (750 – 1,000 uS/cm), to more saline in the south (> 1,500 uS/cm). There is also a high density of groundwater monitoring data in the lower part of the catchment, with very limited data throughout the upper catchment.

Hydrographic comparison of surface water and groundwater levels at nearby bores was conducted along the Thomson River at Wandocka, Rainbow Creek, and the Macalister River between Glenmaggie and Riverslea. Analysis of the data indicate consistent baseflow gaining conditions around the Wandocka gauge, which is supported by the observed stream EC increases between Heyfield and Wandocka. The observed groundwater level and surface water level data at the Rainbow Creek gauge indicate consistent losing conditions, which is probably due to artificial maintenance of high stream water levels (above the watertable) via flow regulation. The analysis also indicates that at the upper end towards Lake Glenmaggie, and at the lower end towards Riverslea gauge, the Macalister River appears to be variably gaining/losing, although losing conditions appear to only occur periodically.

Local baseflow assessments

Findings from the Victorian Government’s Secure Allocation, Future Entitlement (SAFE) project have classified the Macalister River to its confluence with the Thomson River as a gaining reach (moderate confidence rating), primarily given that it is perennial with a moderate BFI (DSE, 2012). The Thomson River upstream of the Thomson Dam has been classified as baseflow gaining, given that it is unregulated and perennial, with a low confidence rating as no BFI has been estimate along this reach. The Thomson River downstream of Thomson Dam has not been classified, given that its flow becomes heavily regulated via controlled reservoir releases beyond this point.

The modelled spatial baseflow gains and losses across the Thomson-Macalister River catchment, estimated for a wet (July 1978) and dry (April 1983) period, derived from the West Gippsland ecoMarkets Model (GHD, 2010) suggests mixed baseflow conditions. The model indicates that the majority of the Thomson-Macalister catchment is baseflow gaining during wet periods, especially in the upper reaches, but also in the lower catchment. During a dry period (April 1983), the model results indicate that the upper reaches of the Thomson-Macalister catchment remain weakly baseflow-gaining, and the lower reaches of the Thomson and Macalister Rivers can become baseflow neutral to strongly baseflow-losing.

Summary of inferred baseflow condition for the Thomson-Macalister River

The limited available earlier studies indicate that the Thomson-Macalister River can be classified as a primarily baseflow-gaining stream, except periodically during dry periods. The surface water flow and EC data analysis indicate dominantly gaining baseflow conditions for the Thomson River downstream of Heyfield. This is primarily based on observed stream EC gains down this reach, which is in agreement with the historical issues with shallow saline watertable drainage from the Macalister Irrigation District. The groundwater level / surface water level analysis presented also supports this, with dominantly baseflow gaining conditions, except:

- In the lower Macalister River where the river appears to become locally losing during dry periods – around 9 km downstream of Lake Glenmaggie, and most likely at the Riverslea gauge. However, it should be noted that groundwater level data from the area between these two locations indicates consistent strongly baseflow-gaining conditions, even in dry periods, and
- Around Rainbow Creek near Heyfield, where artificial maintenance of elevated surface water levels relative to the regional watertable appears to result in persistent locally losing conditions. On the nearby main stem of the Thomson River in this area however, variable gaining/losing conditions appear to prevail, because of its greater depth of incision compared to Rainbow Creek.

Given that these are spatially and temporally-isolated exceptions, it is concluded that the Thomson-Macalister catchment can be classified as broadly baseflow-gaining for the purposes of this assessment.

Mitchell River

Water management characteristics

The Mitchell River is relatively un-impacted by water management activities, with no major on-stream storages, and diversions that are small relative to streamflow. The majority of the stock and domestic and licensed groundwater extractions are concentrated in the lower reaches of the Mitchell River (Wy Yung Water Supply Protection Area), where the majority of extractions are within 3 km of the river, along the alluvial floodplain. The large volumes of groundwater extraction along the Mitchell River between Glenaladale and Rosehill are likely to reduce baseflow to streams along this reach. The effect of this on the baseflow estimates presented in this project is that the estimated baseflows reflect the groundwater discharge to streams, after depletion by groundwater extraction.

Physical characterisation

The Mitchell River catchment has adequate surface water EC data at the assessed gauges (Glenaladale and Rosehill) to conduct interstation EC mass balance baseflow analysis. The surface water EC data suggest that there is sufficient contrast between stream EC at high flows versus that at low flows, which supports the application of the EC mass balance method for baseflow estimation at these gauges.

Comparison of gauged stream flows and EC for the corresponding upstream and downstream gauge indicates stream EC consistently increases down the Mitchell River. This suggests that the river is largely baseflow-dependent. Comparison of gauged upstream and downstream flow data indicate variably gaining/losing flow down the Mitchell River. This may be indicative of seasonal losses to bank storage as suggested in Hoffman (2011); however, the observed flow gains and losses are affected by known surface water and groundwater usage from this reach, in addition to ungauged tributary inflows near Rosehill.

There is a moderate degree of spatial variability in groundwater EC concentration across the Mitchell River catchment, which transitions from moderately fresh in the north (750 – 1,000 uS/cm) to moderately saline in the south (> 1,500 uS/cm). There is also a high density of groundwater monitoring data in the lower part of the catchment, with very limited data throughout the upper catchment.

There are two groundwater observation sites along the Mitchell River that are located sufficiently close to the river to assess potential baseflow gain/loss status. Comparison of groundwater levels from these bores with corresponding nearby river water levels (estimated using LiDAR elevations) indicate temporally gaining/losing conditions along the Mitchell River. Hofmann (2011) used a number of bore transects perpendicular to the river to assess groundwater level gradients with respect to the river. Hofmann's analysis indicated consistently flow-losing conditions in only one transect of the eight analysed. The other seven transects exhibited temporally and spatially variable gaining/losing conditions along the lower Mitchell River.

Local baseflow assessments

Findings from the Victorian Government's Secure Allocation, Future Entitlement (SAFE) project have classified the upper reach in the Mitchell River catchment as baseflow gaining with moderate to high BFI's (DSE, 2012). The lower Mitchell River (between Glenaladale and Riverslea) transitions between baseflow gaining and neutral – losing, based on findings from Hoffman (2011).

Hofmann (2011) estimated the baseflow contribution to the lower Mitchell River between Glenaladale and Riverslea using ^{222}Rn and Chloride (Cl) as tracers to define spatial and temporal variability of surface water / groundwater interactions. The results from this study shows that despite the reach locally varying between gaining and losing baseflow, on a net basis along the reach it gains baseflow. The results also indicate that "baseflow" estimated using ^{222}Rn results in approximately 2 to 5 times higher fluxes than the baseflow calculated using Cl, which was attributed to the ^{222}Rn estimates including bank storage returns as well as regional groundwater. For the purposes of validating the baseflow estimates of the current project, Hofmann's (2011) Cl mass balance results are the most applicable, because the objective of the project is to estimate the regional groundwater contribution to stream flows, not intermediate slow flow components such as bank storage returns.

The modelled spatial baseflow gains and losses across the Mitchell River catchment, estimated for a wet (August 1998) and dry (March 2004) period, derived from the East Gippsland ecoMarkets Model (GHD, 2010) suggests mixed baseflow conditions. The model results indicate that during the wet period, the majority of the upper reaches of the Mitchell River catchment are weakly baseflow gaining, and the lower reaches are baseflow neutral. During the dry period, the model results indicate that the majority of both upper and lower reaches of the Mitchell River are baseflow neutral.

Summary of inferred baseflow condition for the Mitchell River

The significant available earlier studies (primarily Hofmann, 2011) indicate that the Mitchell River can be classified as a primarily baseflow-gaining stream, except periodically in the lower catchment during periods of high surface water levels, when the river temporarily loses water to the adjacent and underlying alluvial aquifer. The surface water flow and EC data analysis also indicate dominantly gaining baseflow conditions, as do the groundwater level / surface water level analysis presented, although these show temporary losing stream flow conditions. It is therefore concluded that the Mitchell River catchment can be classified as broadly baseflow-gaining for the purposes of this assessment.

Improving the accuracy of baseflow estimates

The recommended adjustments to the baseflow assessment method suggested from the independent technical reviewers comments were tested in Section 4 of this report. For this purpose, the Mitchell River was selected as a case study, because changes to baseflow estimate reliability could be tested against the independent baseflow estimates derived by Hofmann (2011). In contrast, there was no suitable independent data for comparison for either the Thomson-Macalister or Latrobe Rivers. Two supporting methods for estimating baseflow which were tested as part of this study include:

- Reach scale EC mass balance, and
- Sellinger (1996) rating curve baseflow estimation method.

The suggested changes to the existing baseflow estimation method which were tested as part of this study include:

- Constraining the interstation baseflow analysis
- Defining groundwater end member EC using gauged stream EC at lowest flows
- Eckhardt Filter parameters, and
- Removing periods of poor (non-linear) flow-EC relationships from individual gauge-based EC mass balances.

Based on the outcomes of the testing, the changes to the baseflow method that are considered suitable and valuable for improving the accuracy and/or reliability of the baseflow estimates have been applied to the Mitchell, Thomson Macalister and Latrobe Rivers.

Testing other methods and data

Reach scale EC mass balance

It is possible to use an EC mass balance between the upstream and downstream gauges of a given reach to more reliably estimate baseflow gains. The principal behind the reach scale EC mass balance approach is identical to that used to estimate baseflow at a single gauge, except that the runoff end member EC is replaced by the EC at the upstream end of the reach and the groundwater end member EC is replaced by the groundwater concentration within the area thought to be contributing baseflow to the reach.

Application of the reach scale EC mass balance on the Mitchell River produces baseflow estimates that are very similar to Hofmann's (2011) estimates derived using chloride as a tracer. In contrast to this evidence for baseflow gaining conditions along the lower Mitchell River, the interstation baseflow analysis for this reach by GHD (2013a) concluded variable but on average losing conditions. The reason for this difference regarding gaining/losing conditions appears to be the uncertainty in the groundwater end member EC used in the GHD (2013a) baseflow estimates for the upstream and downstream gauges.

Based on this comparison, it is concluded that the recommendations of Cartwright (2013) and Costelloe (2013) to validate the interstation baseflow estimates using alternative methods, particularly the reach-scale EC mass balance, is a valuable addition to the methods applied by GHD (2013a and 2013b).

The fact that similar baseflow estimates can be made using the (widely available) gauged flow and EC data at two upstream gauges, as was made using detailed field sampling and analysis by Hofmann (2011), highlights that the reach-scale EC mass balance method as recommended by Cartwright (2013) and Costelloe (2013) is an efficient and cost effective means of estimating baseflow discharge to stream reaches. However, the method is only applicable to stream reaches with corresponding upstream and downstream gauges, which have flow and EC data for the same days, and results are impacted in reaches where the EC is artificially increased and ungauged tributaries are unaccounted for.

Sellinger (1996) rating curve baseflow estimation method

The “rating curve” method of Sellinger (1996) for estimating baseflow contributions to stream flow was considered for application in this project. However, given that the primary objective of this project is the estimation of regional groundwater discharge to streams, rather than intermediate flow components such as bank storage returns and interflow, the Sellinger (1996) rating curve method is not regarded as applicable to the current study.

Testing suggested changes to existing method

Constraining interstation baseflow analyses

Interstation baseflow gain and loss assessments derived by GHD (2013a and 2013b) (i.e. by subtracting individual gauge-based baseflow time series estimated for downstream gauges from those estimated for upstream gauges), may be constrained through use of the reach-scale baseflow gains estimated using the reach-scale EC mass balance method. That is, the reach-scale baseflow gains estimated using the reach-scale EC mass balance could be used to inform adjustment of the groundwater EC end member value at the upstream and/or downstream gauge, so that subtraction of the baseflow time series from the upstream and downstream gauges results in similar baseflow gains as estimated using the reach-scale EC mass balance. This approach also serves to improve the reliability of the baseflow time series derived for the upstream and/or downstream gauges.

The automated calibration software PEST (Doherty, 2010) was used to calibrate the interstation baseflow gains through adjustment of the groundwater EC end members for the upstream and downstream gauge pairs.

The calibration for the test case on the Mitchell River catchment was of variable quality. During low flow periods, the calibration is of poorest quality, which is likely due to flow gauging errors being of a similar order to (or larger than) the baseflow gains. However, the calibration of the baseflow estimates derived for individual flow gauges to reach-scale baseflow gains, derived via an EC mass balance, is considered of great value to improving the reliability of the interstation baseflow gains and losses derived through subtracting downstream filtered baseflow time series from those of upstream gauges.

Defining groundwater end member EC using gauged stream EC at lowest flows

Based on analysis in the Mitchell River, it is recommended that the groundwater EC end member is *not* defined using the lowest recorded stream EC, unless there is no other information to support this parameter, and the stream is unregulated. In the case of streams in which flow is regulated through reservoir releases, this approach should certainly not be taken, because in these cases the lowest recorded stream EC will almost always reflect a mixture of all flow components (runoff, baseflow, interflow and bank storage) that have been mixed within the reservoir over time prior to release. Therefore, this approach has not been applied in to the Latrobe and Thomson-Macalister catchments.

Eckhardt Filter parameters

Changing the Eckhardt filter's Alpha and BFImax parameters to reflect observed stream flow recession rates and the EC-estimated maximum BFI is not considered suitable for the current study, which aims to estimate the regional groundwater discharge component within stream flows, rather than flow components such as interflow and bank storage returns. As such Eckhardt filter's Alpha and BFImax parameters were calibrated to achieve a best fit to the EC derived baseflow estimates.

Removing periods of poor (non-linear) flow-EC relationships from individual gauge-based EC mass balances

Although stream flow-EC relationships are often non-linear, EC remains a conservative tracer of groundwater (baseflow) input to stream flow, assuming that there are no other significant sources of salts, which is the case for the Gippsland rivers analysed in this study. An exception to this applies for those Latrobe River reaches affected by saline industrial water returns. It is therefore concluded that this proposed change to the method is not warranted. It has therefore not been applied in the current study, nor is it recommended for future application of the method, except in catchments in which there are significant contributions to stream EC from sources other than groundwater.

Revised baseflow estimates

Based on the outcomes of testing the recommended refinements to the baseflow method to the Mitchell River catchment, the changes to the baseflow method that are considered suitable and valuable for improving the accuracy and/or reliability of the baseflow estimates have been applied to the Mitchell, Thomson-Macalister and Latrobe Rivers.

The most significant improvement to the method is the use of reach scale EC mass balances to estimate interstation baseflow gains, used in conjunction with the existing method to constrain the estimate of groundwater end member EC at the upstream and downstream gauges. Application of these two additions to the method results in an estimate of baseflow at each gauge that is in agreement with the interstation baseflow gains. In addition to these refinements to the baseflow estimation method, the Eckhardt filter's Alpha and BFImax parameters were calibrated to achieve a best fit to the EC-derived baseflow estimates. The other changes to the methodology which were tested on the Mitchell River catchment were found to not significantly improve the estimation of baseflow from regional groundwater, and therefore have not been applied to the Mitchell, Thomson-Macalister or Latrobe Rivers. The baseflow time-series were re-derived for all assessed gauges in the Mitchell, Thomson-Macalister and Latrobe Rivers, applying the changes to the method noted above, and also extending the surface water flow and EC data from the 2013 studies (GHD 2013a, GHD, 2013b).

Latrobe River Catchment

The revised method for applying the reach-scale EC mass balance was applied at the following gauges within the Latrobe River catchment:

- Latrobe River between Scarnes Bridge and Rosedale, applying a groundwater end member EC of 3,151 (1,133 – 8,765) uS/cm, and
- Latrobe River between Rosedale and Kilmany South, applying a groundwater end member EC of 1,561 (688 – 3,541) uS/cm.

The automated calibration software PEST (Doherty, 2010) was used to calibrate the interstation baseflow gains. A relatively good calibration was achieved for both interstation pairs; however, it is noted that the calibration of the interstation baseflow gains to the reach-scale EC mass balance estimates at low flows was relatively poor for the Latrobe River from Scarnes Bridge to Rosedale. This is likely due to flow gauging inaccuracies being of similar order of magnitude to the baseflow discharge rate.

The baseflow time-series were re-derived for all assessed gauges in the Latrobe River catchment. The primary differences between the estimates generated in the current study and the previous study (GHD, 2013b) are due to the revisions to the groundwater end member EC, which has been calibrated in the interstation analysis. Discussions of the primary differences between the baseflow estimates generated in GHD (2013b) and the current study for each gauge are presented in Section 4.4.1 of this report.

Thomson-Macalister River Catchment

The revised method for applying the reach-scale EC mass balance was applied at the following gauge pairs within the Thomson-Macalister catchment:

- Thomson River between Heyfield and Wandocka, applying a groundwater end member EC of 1,444 (758 – 2,750) uS/cm,
- Macalister River between Glenmaggie and Riverslea, applying a groundwater end member EC of 1,129 (384 – 3,319) uS/cm, and
- Lower Thomson-Macalister River from Wandocka to Bundalaguah including Macalister River, applying a groundwater end member EC of 965 (394 – 2,366) uS/cm.

The automated calibration software PEST (Doherty, 2010) was used to calibrate the interstation baseflow gains. A relatively good calibration was achieved for all three interstation pairs at high flows; however, it is noted that the calibration of the interstation baseflow gains to the reach-scale EC mass balance estimates at low flows was relatively poor for the all three gauge pairs. Similar to the Latrobe River, this is likely due to flow gauging inaccuracies being of a similar order of magnitude to the baseflow discharge rate. Additionally, calibration of the interstation baseflow gains on the Macalister River between Glenmaggie and Riverslea is very limited, with only eight concurrent recordings of EC to derive the reach-scale mass balance estimates.

The baseflow time-series were re-derived for all assessed gauges in the Thomson-Macalister River catchment. Similar to the Latrobe River catchment, the primary differences between the estimates generated in current study and the previous study (GHD, 2013a) are due to the revisions to the groundwater end member EC, which has been calibrated in the interstation analysis. Discussions of the primary differences between the baseflow estimates generated in GHD (2013a) and the current study for each gauge are presented in Section 4.4.2 of this report.

Data gaps

Findings from the catchment characterisation and the application of the recommended changes and additions to the baseflow assessment method have highlighted a number of data gaps which increase the uncertainty of baseflow estimates. The key data gaps include:

- Surface water streamflow and EC – gaps in concurrent flow and EC gauging data between upstream and downstream sites which reduce the ability to implement interstation analyses
- Groundwater EC – limited groundwater monitoring bores in upland catchments to derive groundwater EC end members

- Surface Water Management – gaps in the surface water management data, in particular river diversions and returns, and
- Independent baseflow studies – limited relevant independent baseflow studies to assess the effects of the recommended changes and additions to the baseflow assessment method on the reliability of the baseflow estimates.

The table below summarises the data available for the interstation reaches in the Latrobe, Thomson-Macalister and Mitchell River catchments. The findings indicate that there are no concurrent surface water flow and EC recordings for the Latrobe River upstream of Thoms Bridge, and the Latrobe River between Thoms Bridge and Scarnes Bridge. Additionally, there is limited data available for the Thomson River between Cowwarr Weir and Heyfield, and the Macalister River between Glenmaggie and Riverslea.

Additionally, the Mitchell River between Glenaladale and Rosehill is the only assessed reach with an independent data set suitable for assessing the reliability of the EC mass balance method of baseflow estimation: those of Hofmann (2011). Therefore, it is recommended that monitoring investigations conducted as part of Stage 2 are focused on providing additional data for the Latrobe or Thomson-Macalister River catchments.

Interstation Section	Interstation Gauge Pairs	Period of concurrent flow and SW EC readings	Count of concurrent flow and SW EC readings	Count of GW EC Boreholes
Latrobe River upstream of Thoms Bridge	226216, 226021, 226408, 226005	NA	0	174
Latrobe River between Thoms Bridge and Scarnes Bridge	226005, 226007, 226415, 226033	NA	0	13
Latrobe River between Scarnes Bridge and Rosedale	226033, 226228	7/01/1997 - 5/05/2013	194	53
Latrobe River between Rosedale and Kilmany South	226228, 226227	18/05/1977 - 3/12/2014	222	93
Thomson River between Cowwarr Weir and Heyfield	225231, 225200, 225236	17/10/2007 8/04/2010	3	12
Thomson River between Heyfield and Wandocka	225200, 225236, 225212	10/08/2005 5/09/2012	73	10
Lower Thomson-Macalister River from Wandocka to Bundalaguah including Macalister River	225212, 225232, 225247	13/07/2005 22/05/2014	93	43
Macalister River between Glenmaggie and Riverslea	225204, 225247	5/03/2007 4/04/2012	9	69
Mitchell River between Glenaladale and Rosehill	224203, 224217	11/01/1977 15/12/2014	82	54

Recommendations for Stage 2

To address the data gaps identified requires a concerted monitoring campaign with a relatively high capital and operating cost over a number of years (5-10 years). With this in mind, the recommendations for Stage 2 are focussed on activities that can be undertaken within the time and budget available (in the order of $50,000), and can achieve an improvement in the baseflow separation accuracy or uncertainty. While highly localised studies and field data do not broadly inform the regional-scale conceptualisation and analysis of groundwater-surface water interactions, they do provide a valuable basis for constraining the estimates, and thereby improving the confidence of more broad-scale approaches.

It is recommended that the targeted sites for field assessment be discussed between the relevant authorities (CMA's, SRW and DELWP) in a workshop, to prioritise the field assessments on reaches which will deliver most value to the project, while meeting the requirements of the Gippsland CMAs and the Bioregional Assessment Program.

Flow and EC accretion profiling

This activity involves undertaking instantaneous streamflow gauging and EC sampling at a series of sites along a river reach. This allows a mass balance to be undertaken on each section and for the specific sections where groundwater enters the stream to be identified and baseflow quantified. It is expected that four to five sites would be sampled within a River reach in two sampling expeditions to capture spring and summer baseflow contributions. This data and analysis allows for a more detailed verification of the baseflow estimates derived from the baseflow separation method. However, it is acknowledged that this method only provides a snapshot in time of the baseflow processes, and these results may not be representative of average or typical conditions.

Installation of EC sensors, flow gauges and data loggers

This activity involves the installation of EC sensors, pressure sensors, and data loggers to allow for collection of these data at sites where no data is currently collected. This allows a single gauge baseflow separation to be undertaken for a site that currently has no estimate of baseflow. If the installation of sensors is done such that new interstation pairs can be analysed, this would permit a reach scale mass balance to be undertaken for a reach that currently has no estimate. Preliminary inquiries indicate that the cost of this option is greater than the flow and EC accretion profiling, and it is therefore likely this option would be applied at comparatively fewer locations. The main benefit of this activity is the collection of data that permits baseflow estimates to be made at sites that currently have no estimate of baseflow. A limitation of this method is that the relatively short period of data collection (up to 6 months) may not be representative of the full range of streamflow/baseflow conditions.

Sampling of groundwater EC in private bores

To improve the best estimate of groundwater end member EC, one potential option is to sample private groundwater bores in targeted locations to improve the distribution of EC data points that contribute to the groundwater end member EC. A sampling campaign would target bores in reaches and areas that have no or very limited groundwater EC data and private bores exist that could be sampled.

While it is expected that this approach could deliver a more robust best estimate of groundwater EC and as a consequence, a more refined estimate of the interstation baseflow gains; it is anticipated that the large variance in groundwater EC will not be reduced, and as such, the uncertainty of the groundwater end member EC will remain high. Therefore, this activity would be of limited value. Additionally, the outcome of this activity is dependent on access to private bores, with the cost of acquiring this data dependent on the cooperation of landholders. Given these limitations, the success of groundwater investigations in improving groundwater estimates is uncertain, and likely to be costly.

Conclusions

This study conducted an assessment into improving the accuracy of baseflow estimates for the Latrobe, Thomson-Macalister and Mitchell River catchments, building on work undertaken in prior studies (GHD 2013a; GHD, 2013b). One key outcome from this study was the broad characterisation of the physical and water management characteristics of the three Gippsland catchments which highlights the suitability and limitations of estimating baseflow in different areas of the catchments. In addition, other lines of evidence were compiled to provide an independent characterisation of baseflow within the catchments. These included developing reach scale scatter plots of stream flow and EC readings, hydrographic comparison of surface water levels along the reach and groundwater levels at nearby bores, and a thorough a literature review of external independent baseflow studies in the area.

The recommended adjustments to the baseflow assessment method suggested from the independent technical reviewers comments of the previous studies (GHD 2013a, GHD 2013b) were tested using the Mitchell River as a case study. The most significant improvement to the method is the use of a reach scale EC mass balance to estimate interstation baseflow gains, used in conjunction with the existing method to constrain the estimate of groundwater end member EC at the upstream and downstream gauges.

The refined method applied in this study utilises groundwater tracer data in two different ways to constrain digitally filtered baseflow time series estimates:

1. An EC mass balance on individual gauged flow and EC data, which produces baseflow time series estimates for the entire area upstream of the gauge; and
2. A reach-scale EC mass balance, utilising flow and EC data at upstream/downstream gauge pairs to estimate baseflow gains within specific river reaches. The reach-scale baseflow gains can then be used to further constrain the individual gauged baseflow time series estimates at the upstream and downstream gauges.

The two EC mass balance data sets are used to calibrate a digital baseflow filter for individual flow gauges, which produces a calibration-constrained continuous daily time series of baseflow estimates for the entire period of available stream flow gauging. This allows for assessment of both seasonal and inter-annual baseflow behaviour. It also allows for temporal expansion of reach-scale baseflow gains estimated using the reach-scale EC mass balance, by subtracting two (upstream and downstream) filtered (calibrated) baseflow time series from one another.

The two EC mass balance methods can estimate baseflows to both regulated and unregulated rivers, which traditional digital baseflow filter methods cannot. In rivers regulated by reservoirs, baseflow estimates for gauges located below the reservoir will be limited in their estimation of seasonal baseflow variability, due to the flow- and EC-homogenising effect of reservoir storage and subsequent release. However, the long term average estimated baseflow gains to the reservoir catchment are unaffected by reservoir regulation because EC is a conservative groundwater (baseflow) tracer. Similarly, for reaches downstream of reservoirs that are gauged by upstream/downstream pairs, baseflow gains to those reaches estimated using a reach-scale EC mass balance are entirely unaffected by river regulation from upstream reservoirs.

The baseflow separation method is most uncertain when applied to upland catchments that have very limited groundwater EC data available. These catchments are relatively undeveloped and new data would be difficult to generate; however given that the lack of development, it is perhaps less important to reduce the uncertainty of these estimates. While the upland EC end members and baseflow estimates are likely to remain uncertain, it is also likely that they remain relatively unchanged. It is also unlikely that groundwater management actions can have a significant effect (except for forestry and fire management which can have a significant impact on baseflow).

In contrast, the lower reaches of the rivers have a larger amount of useful water information and the majority of water use. Applying reach scale mass balances to improve the estimate of interstation baseflow allows for a more reliable estimate of baseflow in the reaches where groundwater management actions can have a significant impact.

The monitoring to be undertaken as part of Stage 2 is focussed on activities that can be undertaken within the time and available budget (around $50,000), and can achieve an improvement in the baseflow estimation accuracy or uncertainty. While highly localised studies and field data do not broadly inform the regional-scale conceptualisation and analysis of groundwater-surface water interactions, they do provide a valuable basis for constraining the estimates and thereby improving the confidence of more broad-scale approaches. Potential monitoring programs for Stage 2 include flow and EC accretion profiling, installation of EC sensors, flow gauges and data loggers and sampling of groundwater EC in private bores.

The targeted sites for field assessment will be discussed between the relevant authorities (CMA’s, SRW and DELWP) in a workshop at commencement of Stage 2, to prioritise the field assessments on reaches which will deliver most value to the project, while meeting the requirements of the Gippsland CMA and the Bioregional Assessment Program.

One of the objectives of this project is the quantification of the potential risk of coal seam gas and coal mining development to groundwater-surface water interactions and groundwater-dependent environmental values of the Gippsland’s rivers. Initial findings from this study and others indicate that the potential effect of depressurisation of aquifers by the Latrobe Valley coal mines on shallow groundwater levels (and therefore groundwater-surface water interactions), is relatively insignificant in the (shallow) Yallourn Formation. Findings indicate that groundwater levels in the (shallow) Yallourn Formation around the three Latrobe Valley mines have not been significantly depressurised, whereas depressurisation increases significantly in the deeper formations. A review of potential methods, such as simple analytical tools that can be used to inform the timing and magnitude of coal seam gas extraction impacts on baseflow, will be conducted in Stage 2 of this project, which could be applied to provide additional evidence to confirm these conclusions.

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1. Introduction

1.1 Project background

The Department of Environment, Land, Water and Planning (DELWP) previously undertook two projects to fill information gaps on priority Groundwater Dependent Ecosystems (GDE) – baseflow dependent rivers and wetlands. These projects, completed by GHD, developed a methodology to:

- establish where groundwater interaction occurs with rivers and wetlands;
- quantify the groundwater contribution to the waterway where interaction occurs;
- identify associated high value environmental assets; and
- assess the risk to these environmental assets from groundwater extraction.

A discussion paper was prepared by GHD in 2012 to appraise methods for quantifying regional groundwater discharge to streams (as “baseflow”) throughout Victoria. This paper formed the basis of a workshop to decide which method would best be suited to quantifying groundwater-surface water interactions for high-risk baseflow-dependent waterways throughout Victoria. The adopted baseflow estimation method involved digital baseflow filtering “trained” to environmental tracer data – primarily electrical conductivity. A series of recommendations for trialling and implementing the recommended method were provided at the end of the discussion paper.

A pilot project was undertaken by GHD in 2012 - 2013 for five Victorian rivers (GHD, 2013a). The year-long pilot established an innovative method that characterised groundwater contributions to the upper Loddon, upper Moorabool, lower Ovens, lower Mitchell and lower Thomson-Macalister Rivers. These results were used to assess the risk of groundwater extraction to the environmental values that those rivers support.

This project was expanded in 2013 (GHD, 2013b) to a further eight Victorian rivers using the same method. Rivers assessed were the Latrobe, Barwon, Gellibrand, Glenelg, Hopkins, Yea, Seven Creeks and Deep Creek. As for the pilot method, the results were used to assess the risk of groundwater extraction to the environmental values that those rivers support.

The results from these projects were incorporated into a state-wide tool (Victorian Water Asset Register – VWAR) that flags areas where environmental values are potentially at risk from groundwater extraction (both current and future). This will assist waterway and environmental managers to manage risks to high priority GDEs.

A scientific review of both baseflow studies (GHD, 2013a; GHD, 2013b) made a number of recommendations to refine the method and quantification used to determine the risk of combined surface water and groundwater extractions to significant environmental values. These recommendations are reviewed and incorporated into this current project.

GHD, in partnership with Groundwater Logic, has been contracted by DELWP to assess the accuracy of baseflow estimates for the Latrobe, Thomson-Macalister and Mitchell River catchments.

1.2 Project objectives

The **primary objective** of this project is to improve the accuracy and reliability of the baseflow estimates along the Latrobe, Thomson-Macalister and Mitchell Rivers.

The objective of this project is to improve understanding of the degree and nature of interaction between rivers and groundwater in the Gippsland region, and to help understand potential impacts of coal mining, coal seam gas developments and other water uses on water-dependent environmental assets. The outputs of the work will improve the accuracy of, and confidence in, analysis of the dependency of flows on groundwater and improve technical basis on the likelihood of direct, indirect and cumulative impacts of water use on baseflows.

The scope of this project is to implement the recommendations from the scientific review of the method developed by GHD (GHD, 2013a; GHD, 2013b) for characterising groundwater contributions to rivers.

One of the key outcomes from this study is to provide a tiered framework for the application of the baseflow estimation method(s) most suitable for difference classes of reaches, such as losing reaches, gaining reaches and regulated reaches.

The project will apply the refined method to three high value Gippsland river systems (Figure 1):

- Latrobe River (Latrobe River to Kilmany South);
- Thomson-Macalister River system (Thomson River from Cowwarr Weir to Bundalaguah; Macalister River from Lake Glenmaggie to the confluence with the Thomson River); and
- Mitchell River (Glenaladale to Rosehill).

The project is to be completed in two stages:

- Stage 1**:** Review groundwater contributions to rivers
- Stage 2: Targeted ground-truthing of existing data (data verification)

This report documents Stage 1 assessment.

1.3 Project scope

Following on from the work completed in 2013 (GHD, 2013a; GHD, 2013b), the scope of work for this project includes:

- Review of the previous work and technical reviewers' comments, identifying options for improving the accuracy of bulk and interstation baseflow estimates
- Review of the physical and water management characteristics of the three Gippsland rivers that may affect the applicability and accuracy of different baseflow methods
- Application of supporting methods to improve the accuracy of baseflow estimates, and
- Identify any data gaps, and provide recommendations for future monitoring, to be undertaken in part as Stage 2 of this project.

1.4 Limitations

This report: has been prepared by GHD for DELWP and *may only be used and relied on by DELWP for the purpose agreed between GHD and the DELWP as set out section 1.2 of this report.*

GHD otherwise disclaims responsibility to any person other than DELWP arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

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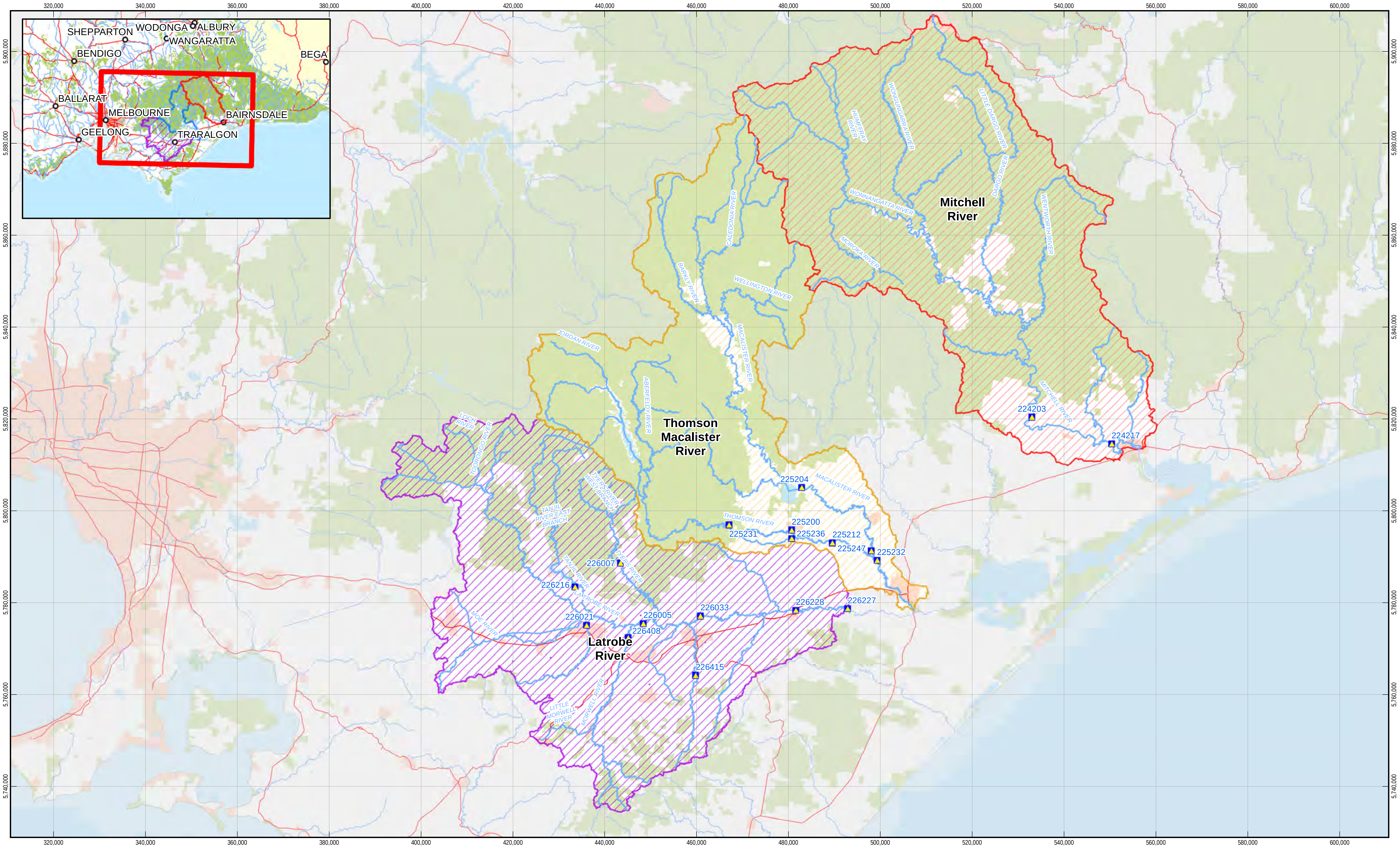

Paper Size A3

0 4 8 16 24 32

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

—	Major Water Course
▨	Latrobe River
▨	Mitchell River
▨	Thomson Macalister River
▲	Surface Water Gauges (Assessed)

Department of Environment, Land, Water & Planning
Gippsland River Baseflow Assessment

Job Number	31-32709
Revision	0
Date	27 May 2015

Catchment Overview
Baseflow Catchments

Figure 1

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Data source: DEWLP, VICMaps, 2015; GHD, Baseflow Catchments, 2015; DELWP, WMIS Surface and Groundwater Data, 2015. Created by: adrummond

2. Previous work and technical review comments

2.1 Previous baseflow estimates for the Mitchell, Thomson-Macalister and Latrobe Rivers

GHD previously estimated baseflow[1] to the Latrobe River (GHD, 2013b), and the Mitchell and Thomson-Macalister Rivers (GHD, 2013a) using a digital filter “trained” (or calibrated) to baseflow estimates derived using the Electrical Conductivity (EC) mass balance method. This method was used to generate continuous daily baseflow estimates based upon gauged flow records, using EC data used as an environmental tracer.

The tracer method is widely used for estimating the regional groundwater discharge component of stream flow (i.e. baseflow, as opposed to the quickflow, or runoff and interflow, component). This method uses a simple solute mass balance assessment between groundwater (baseflow) and surface water (runoff) end-members to estimate the proportion of each end member component of stream flow. The solute mass balance model is (after McCallum et al. 2010):

$$\frac{Q_G}{Q_T} = \frac{(c_T - c_S)}{(c_G - c_S)},$$

where Q_G is the groundwater-derived (baseflow) component of stream flow, Q_T is the total stream flow (i.e. runoff plus interflow plus baseflow), c_T is the tracer concentration in the stream, c_S is the runoff end member tracer concentration, c_G is the groundwater (baseflow) end member tracer concentration.

As Cartwright (2013) reiterated, the ideal situation for which the methodology applies is:

- Availability of continuous EC data over the same monitoring period as the discharge data;
- Groundwater has a significantly higher EC than surface water;
- Groundwater EC values vary little within the catchment or any variation is regular and well constrained; and
- The river is largely gaining (neither the chemical mass balance technique or the digital filters are applicable to losing rivers).

Not all catchments in the earlier studies met all of these requirements. The independent technical reviewers of the earlier studies therefore made a range of suggestions for addressing or at least identifying some of the issues and limitations arising from situations where application of the EC mass balance method is not ideal. This is addressed to the extent possible in the current study.

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[1] “Baseflow” in this study, and those of GHD (2013a and 2013b), is explicitly defined as regional groundwater discharge to streams, as distinct from the other slow flow components comprising interflow, banks storage returns, and so on. True regional groundwater discharge is the component of stream flows of interest to this study, because this is the component that can be managed through groundwater licensing and usage regimes.

The application of the EC mass balance method and training of the digital filter is outlined in detail in GHD (2013a), and a summary is outlined as follows:

- Daily records of stream flow and EC data (from a gauge for which baseflow is to be estimated) are compared against one another using scatter plots to assess whether or not the EC mass balance method is applicable given the assumptions of the method. This process tests whether or not surface water EC exhibits a log-linear declining trend with increasing stream flow rates. The assumption being tested is whether or not the two-reservoir mixing model between (more saline) groundwater and (less saline) surface water explains the bulk of the observed trends in stream flow and EC. In some cases:
    - The contrast between groundwater and surface water salinity may not be large enough to distinguish between stream flows dominated by groundwater discharge (i.e. baseflow-dominated), and those dominated by surface runoff; and/or
    - Groundwater-surface water interactions may be complicated by mixing of waters from more than two reservoirs, such as input from interflow and/or bank storage. These complications can result in complicated relationships between stream flow and EC (see GHD (2013a) for details), which may in turn result in uncertainties in baseflow estimates derived using the simple two-reservoir EC mass balance method, and/or an inability of the method to distinguish between regional groundwater discharge to streams, which is the focus of this Project, as well as more local scale shallow storage and discharge processes via interflow and/or bank storage.
- In the previous studies and independent reviews, it was recognised that little could be done in cases where the flow-EC relationship was not well defined, specifically in terms of the objective of providing bulk estimates of continuous baseflow time series for each gauge analysed. In recognition of the variability in the suitability of each gauge for use with the EC mass balance method, the relative degrees of noise in the relationship between observed stream flow and EC were used to assign confidence ratings to each gauge's baseflow estimates (GHD, 2013a and 2013b). A summary discussion of these with reference to the Gippsland rivers of interest to the current Project follows:
    - The upstream gauges on the Thomson River were assigned a very low confidence rating on the above basis, and only the most downstream gauge at Bundalaguah was assigned a confidence rating of "moderate" (GHD, 2013a; Figure 6). The Macalister River gauges were also assigned a "low" confidence rating for similar reasons; the Mitchell River was however assigned a moderate to high confidence ranking (GHD, 2013a; Figure 6). Many of the Latrobe River (and tributary) gauges were assigned a "low" confidence rating, although these ratings tended to increase in the downstream direction (GHD, 2013b; Figure 2).
    - These confidence ratings were defined on a bulk basis in light of the entire flow-EC data set; however for most gauges, there are often periods where the relationship between flow and EC is significantly better than is indicated by the bulk statistics (see Appendix F of GHD (2013a) and Appendix B of GHD (2013b)), and hence the mass balance method may be applied to those events. The digital filter may then be trained to those more reliable data periods, whilst ignoring the less reliable periods. This was a core recommendation of the review by Cartwright (2012). The only gauge along the three rivers where there are no events with a reasonable flow-EC relationship is the Thomson River u/s of Cowwarr Weir (GHD, 2013a). The Latrobe River at Scarnes Bridge also exhibits only very limited events with only a poor-moderate relationship between stream flow and EC (GHD, 2013b).

- An estimate was made of the groundwater EC end member using spatial averaging of observed groundwater EC at bores within each stream gauge's catchment, which was assumed to coincide with the surface water catchment unless the groundwater level data suggested otherwise. ECs were log-averaged, because spatial groundwater EC data tend to exhibit a log-normal distribution, at least in the rivers in which the method has been applied to date in GHD (2013a and 2013b).
- The runoff EC end member was estimated using the lowest recorded reliable stream flow EC.
- Uncertainty ranges were assigned to the runoff and groundwater EC end members based on observed data ranges where possible (for example 95% confidence limits), or estimates otherwise. Uncertainty ranges were also defined for gauge records using published information where available, otherwise estimates were made.
- The EC mass balance method was applied to the entire gauged flow and EC record. Baseflow estimates for days with no observed EC data could not be made, so this produced a discontinuous baseflow time series.
- The Eckhardt digital baseflow filter was "trained" (calibrated) to the baseflows estimated using the EC mass balance method; in the previous studies, both the alpha and BFImax parameters were estimated using the automated technique of Excel's Solver add-in. The objective function to be maximised during calibration of the Eckhardt filter against the EC mass balance estimates was the Nash-Sutcliffe coefficient.
- Baseflow estimate time series for upstream and downstream gauge pairs were subtracted from one another to estimate baseflow gains and losses along reaches (between gauges). As noted by the independent reviewers of the previous studies, this can be severely compromised by the compounding uncertainties of each of the upstream and downstream gauge baseflow estimates, and any conclusions regarding the gaining/losing nature of a given stream reach must be validated using multiple lines of evidence. This is discussed further in the following section.

2.2 Previous Independent Review Comments and Suggestions

A summary of previous independent review comments of Cartwright (2012 and 2013) and Costelloe (2012 and 2013) are provided in Table 1 below. Recommended actions and justifications for inclusion in or exclusion from the current scope of works are also provided. Several recommendations in Table 1 overlap with one another either wholly or partly; therefore further below, Table 2 summarises a defined scope of work for subsequent components of this project.

Table 1 Cartwright (2012, 2013) and Costelloe (2012, 2013) Review Comments Summary

Index	Reviewer	Comment	Response / Action	Address in Current Scope?	Priority
1	Cartwright (2012)	If there are periods of time where the observed EC vs. discharge data deviate from the predicted trends then either the data should not be used or alternatively another EC vs. discharge trend should be constructed for those specific periods. The methodology to identify when these periods of mismatch are (calculating correlation coefficients over time) is appropriate.	Clarification: We did not infill the EC data using the flow-EC regression. We used the EC data on days it was available to do the mass balance, and estimate a baseflow rate for those days. The filter was then trained to those estimates, and therefore the filter estimates the baseflow rates for the days where no EC data exist. Action: It is a good idea to remove the EC data from the EC-derived baseflow estimates to which the filter is trained. This may avoid spurious baseflow estimates, and more reliable calibration of the digital filter. This is particularly relevant to the upper Latrobe and Thomson-Macalister Rivers where the relationship between flow and EC is generally poor when assessed in bulk, but is often good on an event by event basis.	Yes	High
2	Cartwright (2012)	Catchments where the approach works less well is where the groundwater is of very low salinity. In such cases there is no strong relationship between EC and discharge. Rivers such as this are poor choices for a chemical mass balance approach to determining baseflow as the relative errors increase as the groundwater composition approaches that of the river water (Cook, 2012).	Action: Compare low flow EC vs regional groundwater EC. Document this, noting any potential issues, and adjust the assessment confidence ratings accordingly.	Yes	Low
3	Cartwright (2013)	The application of an “untrained” digital filter, such as the Nathan & McMahon filter or the Eckhardt filter with its default parameters, in combination with a chemical mass balance (or the filter trained using the chemical mass balance) may provide this complementary information. The simple application of a filter represents little additional effort and may provide more useful information (for example the water balance in the river is a function of all components of the baseflow not just the groundwater input).	Whilst this may provide additional potentially useful information for comparatively little effort, the objective of the project is to estimate regional discharge to streams, not the other slow flow components. Given the limited budget and timeframe, it is recommended that this be assessed if desired in later studies.	Maybe (if time and budget permits)	Low

Index	Reviewer	Comment	Response / Action	Address in Current Scope?	Priority
4	Cartwright (2013)	An alternative and potentially easier way of constraining the groundwater end member is to use the highest EC concentrations recorded during the low flow periods when the river is most likely to be fed mainly or entirely by groundwater inflows	Action: Assess the effect of defining the groundwater end member EC using gauged EC at low flows on the baseflow estimates and their uncertainty. This is a good simplifying idea, based on a sound and generally accepted assumption (e.g. see Gonzales, 2009). Uncertainty of the groundwater end member could be defined using confidence limits of the observed stream EC during lowest flow periods. Note: This could be an issue in regulated reaches, for example due to mine and/or reservoir discharges. Correction of observed stream EC using EC of artificial discharge may be required.	Yes	High
5	Cartwright (2013)	While the interstation analysis is a good idea, it needs more rigorous checking, for example: Does the EC of the river increase along reaches that are predicted to be predominantly losing (in theory it should not) → plot XY EC of upstream/downstream gauge pairs Does the river discharge at low summer flow conditions when there is little surface runoff decline along the suspected losing reaches → plot XY flow of upstream/downstream gauge pairs Are there considerable no flow periods on the putative losing reaches (especially at times when adjacent dominantly gaining reaches are flowing)	Action: Validate interstation analyses using the methods suggested to the left.	Yes	High
6	Cartwright (2013)	The datasets which this study uses are not always ideal. In some cases the EC data were collected over a relatively short time period. If the EC record represents one set of flow conditions (e.g., collected mainly during drought or high rainfall years), it may introduce uncertainties into the analysis. Groundwater-surface water interaction varies between drought and high rainfall periods as rainfall-runoff relationships differ and water table elevations vary. It would be good to see an analysis using one of the longer records that addresses this. It should be possible to carry out an analysis using parts of a record from a single gauge and assess how well the prediction of baseflow using the data from the drought years agrees with that using the data from the high-rainfall years.	Whilst this would expand the assessment of uncertainty, it will not improve the reliability or accuracy of the estimates made, which is the objective of the current Project.	No	N/A
7	Costelloe, (2012)	Use a runoff EC end member (cs) value equal to that of the freshest measured peak runoff rather than that of rainfall (as indicated in McCallum et al., 2010).	Action: As described to left. See also Comment/Action #13 below.	Yes	Address via Action #13

Index	Reviewer	Comment	Response / Action	Address in Current Scope?	Priority
8	Costelloe, (2012)	The EC – discharge graphs in Appendix F (GHD, 2013a) show that at most sites this relationship involves considerable scatter. Often a given EC value corresponds to discharge values that vary over an order of magnitude. This would seem to challenge some of the assumptions of the solute mass balance. The variability in the EC-discharge relationship does not carry through to the estimation of baseflow using the solute mass balance because of its simplifying assumptions and use of two stable end-members. A more robust understanding of the EC-discharge behaviour over a range of stream types would be in the long-term interests in applying the mass balance approach and may require a review of scientific studies in this area.	Action: The call for scientific studies into processes affecting the stream flow-EC relationship is valuable, but beyond scope, given that detailed academic studies are yet to resolve this question. However, this comment is addressed at least in part in response to #1 above (i.e. through removing periods of poor flow and EC correlation from the analysis).	No	N/A
9	Costelloe, (2012)	The use of EC records from immediately upstream and downstream of the major storages (where available) would seem to be the best way to get around the issue of surface storage releases.	Action: This is addressed via comment/action #10 below.	Yes (see Action #10)	Address via Action #10
10	Costelloe, (2012)	The method used to do the EC mass balance at each gauging station was most suitable for the most upstream gauge. The application of the same method (particularly the estimation of the runoff EC parameter) for downstream gauges has its pros and cons. The method used partially accounts for in-reach runoff and also provides a time-series of baseflow that allows for the analysis of gaining or losing behaviour moving downstream. However, I would like to see the downstream gauge analysis also include the use of the upstream daily measured EC to define the EC runoff parameter (cs). This method does not account for the effects of in-reach runoff (i.e. the in-reach runoff is assumed to have the same EC as the upstream gauged flow) but does allow for an independent check on whether groundwater discharge is occurring within the reach being investigated. The use of the upstream EC data has the advantage of providing a temporally varying input to the baseflow analysis but the appropriate averaging period for the upstream EC end-member would need to be analysed. For instance, if the flow time from the upstream to downstream gauges is more than a day then the upstream end-member would probably need to be averaged over a similar time period, or lagged, to account for the mixing effects within the reach.	Action: Assess the effects on the baseflow estimates and their uncertainties of using upstream gauged daily stream EC as a time-varying runoff EC end member. Also assess potential conceptual issues with using this approach. I.e. this approach becomes a reach-scale EC mass balance approach, rather than an approach that assesses baseflow to the entire catchment area upstream of each gauge. On discussion with Ian Cartwright, this task could also be expanded for use in adjusting the downstream gauge baseflow estimate; through calibration of baseflow gains along reaches between gauges estimated via the interstation baseflow analyses of GHD (2013a and 2013b) against the gains estimated using the reach-scale EC mass balance. This would provide another line of evidence for the baseflow gain/loss inferences made, in addition those outlined in Action #5.	Yes	High

Index	Reviewer	Comment	Response / Action	Address in Current Scope?	Priority
11	Costelloe, (2012)	Attempt to use the EC-derived baseflow time-series to fix the Eckhardt BFImax parameter and only optimise the alpha parameter.	*Action:* Assess the effects on the baseflow estimates of fixing the Eckhardt filter BFImax parameter to the maximum BFI estimated using the EC mass balance, whilst optimising the alpha parameter. A comparison of previous BFImax parameters (GHD, 2013a and 2013b) versus those revised using this approach will be made. See also Action #16 below.	Yes	Address via Action #16
12	Costelloe, (2012)	More effort needs to be put in determining the EC uncertainty during events compared to during low flow periods. For instance, could errors in the assumptions of the EC mass balance method during events (e.g. hysteresis) result in unrealistically 'flashy' baseflow estimates in comparison to smaller uncertainties during low flow periods?	*Action:* Address via Cartwright's (2012) suggestion of excluding EC-derived baseflow estimates from periods when the flow-EC regression is poor (see #1 above). Also addressed via Action #14 below.	Yes	Address via Action #1 and #14
13	Costelloe (2013)	It would be useful to identify the discharge percentile when the cs term was measured for each catchment in order to assess its representativeness (i.e. the lower the discharge exceedance percentile the more likely the cs term represents only runoff). For catchments with no EC measurements during high flows and relatively high cs values, it would be worth testing the uncertainty range of the groundwater discharge using an arbitrary low EC value (i.e. 100-200) to determine what effect a possible overestimation of cs has on the groundwater discharge estimate.	*Action:* Document the discharge percentile at which the runoff end member EC was defined for each gauge, and consider revising this end member as required where it is not considered reflective of runoff-dominated events. Note: As quantified in all previous investigations, the runoff end member contributes by far the least to baseflow estimate uncertainty, and hence this action is not expected to significantly reduce uncertainty.	Yes	Medium

Index	Reviewer	Comment	Response / Action	Address in Current Scope?	Priority
14	Costelloe (2013)	The mixing model is, of course, just a model and its effectiveness should be tested against observed data. This could be done by using the uncertainty range of the parameter values (cG and cS, as have been produced in the study) to produce the envelope of groundwater discharge (QG) time-series. These data could then be used to solve for the modelled cT term and compare the distribution of modelled cT – Q relationship against observed cT – Q to determine if the modelled uncertainty ranges captures most of the observed scatter in the QT - cT relationship. The question is whether the model captures the bulk of the groundwater discharge and rest of the scatter is noise due to other processes that are peripheral to the major concerns of water resource management. Given the very high variability shown in the observed the QT - cT relationship (Appendix B; GHD (2013b)) it is arguable whether a simple two end-member model captures all the processes occurring. However, it hopefully captures the bulk of the processes and provides reliable estimates of regional groundwater discharge to streams. If the modelled cT – Q relationship has a small range compared to the observed cT – Q relationship then this would argue for the use of independent datasets (e.g. detailed tracer studies), where available, to determine if the EC mass balance approach is capturing the dominant groundwater discharge processes.	*Action:* On discussion with Ian Cartwright, a slightly modified more appropriate approach is to validate the baseflow time series estimated using the digital filter by withholding a portion (the “validation period”) of the EC data from the baseflow estimates from the filter training data set, and then using the filtered baseflow time series from the “validation period” to back-calculate a stream EC. This back-calculated EC is then compared to the observed EC to assess whether the digital filter (and the end member uncertainties) captures most of the observed stream EC scatter.	Maybe, if time permits	Medium-Low

Index	Reviewer	Comment	Response / Action	Address in Current Scope?	Priority
15	Costelloe (2013)	Some of the reasons put forward to explain unusual EC-discharge relationships should also be tested by further analysis. For instance, the ‘boomerang’ behaviour at low flows at some gauges was attributed to first flows flushing saline pre-event water or fresher groundwater contributing relatively more at low flows. The former mechanism could be tested by separating the Q-EC plots according to whether the EC data were measured on a rising or falling limb. The latter mechanism could be tested using water table or hydrologic gradient analysis to determine if groundwater in some reaches ceases to contribute at low flow levels (presumably in summer) due to gradient reversals between the river and groundwater. The mechanisms behind the ‘boomerang’ behaviour do need to be established as this pattern challenges the underlying assumption of the mass balance approach. The use of groundwater gradient data would also be useful for testing whether reaches showing higher BFI patterns in winter-spring and lower in summer-autumn are consistent with the groundwater fluctuations. Alternatively, this pattern could be a function of winter-spring interflow fluxes being classified as regional groundwater fluxes by the EC mass balance approach.	This particular issue does not affect the three Gippsland rivers of the current Project. However, Comment/Action #1 above addresses some of these concerns in a broad sense.	No	N/A

Index	Reviewer	Comment	Response / Action	Address in Current Scope?	Priority
16	Costelloe (2013)	The application of the Eckhardt baseflow filter can produce baseflow estimates greater than the total streamflow at low flows. Typically, the alpha parameter is determined by plotting discharge at time-step k (Qk) against discharge from the next time step (Qk+1) during recession periods and then the BFImax parameter is adjusted to match estimates from tracer data but also to minimize periods where the estimated baseflow is greater than total flow. The GHD (2013b) report does not provide any detail on the application of the Eckhardt baseflow filter and my notes indicate that the application was not explained in detail in the GHD (2013a) report. For instance, it wasn't clear if both parameters were optimized by calibrating the filter derived baseflow estimate against the mass balance baseflow estimate or if the ranges of both parameters were constrained by complementary analysis (e.g. BFImax by the mass balance approach and alpha by the recession slope approach) and if minimizing periods of baseflow estimate greater than total streamflow was used as an additional criterion to limit acceptable parameter sets. I would favour a combination of the latter two approaches as optimizing the alpha value through calibration could lead to values that are not consistent with observed recession slopes. That would seem to contravene the physical basis of the Eckhardt filter equation albeit produce baseflow estimates which match the mass balance estimates.	*Action:* Calculate the Eckhardt BFImax parameter using the EC mass balance baseflow estimates. Calculate the potential range of the alpha parameter using recession slope analysis of the flow record as described to the left; this observed range can then be used to define upper and lower alpha parameter limits for calibration. Cartwright's (2013) recommendation to use the gauged EC at lowest stream flows for the groundwater end member EC will avoid periods of filtered baseflow exceeding total gauged flow altogether (Action #4). *Note:* These actions may not be possible to implement effectively for heavily regulated streams, or for streams in which the EC mass balance assessment is compromised by poor stream flow-EC relationships, and/or minimal contrast between groundwater EC and stream EC.	Yes, where data allow)	High

Index	Reviewer	Comment	Response / Action	Address in Current Scope?	Priority
17	Costelloe (2013)	The use of the EC mass balance method to estimate baseflow time-series at individual gauging stations has been used to determine changes between net losing and gaining behaviour in the rivers. This is a very useful exercise but the use of these findings in water resource studies of these catchments should be treated with caution unless supported by overall water balance studies and hydrometric data (i.e. time-varying gradients between river stage and groundwater). I think that the use of the EC mass balance data will make a very useful contribution to our understanding of water resources in these catchments but comparison with other datasets will provide greater confidence in the data or may identify unexpected uncertainties in these datasets. It should be noted though, that water balance approaches are commonly dominated by the uncertainty around the gauged estimates (typically 10-15%) and in the ungauged surface inflows. The size of these uncertainties can be significantly larger than the groundwater discharge (or losses to groundwater) in many river systems. Therefore, the wider the range of approaches that can be used to estimate or constrain components of the water balance, the greater the confidence in the understanding of the system.	*Action:* Include other lines of evidence to test the conclusions of the interstation baseflow analysis. These should include the upstream/downstream stream flow and EC comparisons outlined in Comment/Action #5 above, reach-scale mass balance assessment to identify potentially losing reaches, and analysis of time varying gradients between groundwater and streams (where available data make this possible). See also Comment/Action #10 above.	Yes	High
18	Costelloe (2013)	The analysis of the baseflow estimates relative to the Environmental Water Demand (EWD) components would give important insights into when the size of the uncertainty ranges around the groundwater discharge estimates begin to impede their usefulness in water resource management. At some point, highly uncertain estimates may not provide useful information when making water resource decisions and this can be a flag for when additional, independent data are required. Conversely, if the analysis finds that groundwater discharge behaviour during low flows is of greatest importance for EWD consideration, then less weight can be attributed to the uncertainty range at high flows.	Given that the current and previous method of assessing EWDs did not directly use the estimated baseflow time series quantities (see GHD, 2013a), this suggestion is of no value to the current objectives. To explain this further, the EWD assessment method (GHD, 2013a) makes the simplifying assumption that 100% of estimated groundwater usage depletes stream flows, and that the temporal pattern of this depletion is proportional to the estimated time series of BFIs. That is, the filtered baseflow time series is used only to define the temporal pattern of groundwater usage depletion of stream flows; the quantity of depletion is defined as 100% of the estimated groundwater use.	No	N/A

2.3 Recommended scope of work

Based on the summary of previous review comments provided by Cartwright (2012 and 2013) and Costelloe (2012 and 2013), and a detailed planning discussion with Ian Cartwright, the following scope of work is recommended for this project, considering the project objectives and time and budget constraints.

Table 2 Proposed scope of work

Sub-Task	Action	Comments/ Actions Addressed (Table 1 reference)	Priority	Report Section
EC mass balance method application	Define the groundwater end member EC using typical low flow EC. This may require correction for the effects of surface storage releases. This task addresses the reviewers' criticisms that baseflow estimates made using the groundwater end member EC estimated using regional groundwater quality data may result in baseflow estimates exceeding total gauged flow.	4, 16	High	4.3.2
	Remove periods (events) with poor flow and EC correlation from the EC mass balance application. This task addresses several of both reviewers' recommendations regarding factors complicating or clouding the application of the EC mass balance method, such as interflow and bank storage returns.	1, 11, 12, 15	High	4.3.4
	Check and document that the defined runoff EC end member is representative of the highest flow periods. Make an estimate using more comprehensive nearby gauge EC data if required. Also check that the difference between groundwater EC and surface water EC are sufficient for application of the method, and if not note the resultant uncertainties.	2, 7, 13	High	3.2.1, 3.3.1, 3.4.1, Appendix E
Digital baseflow filter application	Define Eckhardt filter parameter BFImax using the highest estimated baseflow index (BFI) from the baseflows estimated using the EC mass balance. Do not optimise this parameter during training of the digital filter.	11, 16	High	4.3.3
	Optimise only the Eckhardt filter parameter Alpha during training of the digital filter. The upper and lower bounds of the Alpha parameter should be defined using recession curve analysis of the gauged stream flow hydrograph.	16	High	4.3.3
	If time and budget permits, validate the baseflow time series estimated using the digital filter by withholding a portion (the validation period) of the EC data from the baseflow estimates from the filter training data set, and then using the filtered baseflow time series from the validation period to back-calculate a stream EC. This back-calculated EC is then compared to the observed EC to assess whether the digital filter (and the end member uncertainty) captures most of the observed stream EC scatter.	14	Low	Not completed
	If time and budget permits, apply the untrained digital filter using "default" recommended parameters from the literature, and calculate the difference between this time series and that of the filter trained to the EC mass balance. The objective here is to provide an estimate of the other slow stream flow components: interflow, bank storage and irrigation returns. These components are distinct from the regional groundwater discharge (baseflow). Given that regional groundwater discharge is the key objective of this project, it is worth noting that the output of this task (and estimate of other slow stream flow components) is considered of secondary interest at this stage.	3	Low	Not completed
Verification using independent data / methods	Estimate reach-scale baseflow gains using a reach-scale EC and flow mass balance. Note that this does not identify losses to groundwater, only gains. Use estimated baseflow gains to verify / constrain the individual gauge-based baseflow EC mass balance and inter-station baseflow gain and loss assessment. Test these results against Monash University's baseflow gain estimates made using radon as a tracer on the lower Mitchell.	5, 10, 17	High	4.2.2

Sub-Task	Action	Comments/ Actions Addressed (Table 1 reference)	Priority	Report Section
	To calibrate and provide evidence for inferences made regarding gaining/losing reaches as derived from the interstation baseflow analyses, assess the following independent data (where available/possible): • Detailed local studies, such as the environmental tracer studies on the lower Mitchell by Monash University; • Scatter plots of stream flow and EC from upstream versus downstream gauges (as per Cartwright, 2013); • Reach-scale flow balances (noting the often large uncertainties with this method); • Observed gradients between groundwater levels and stream stages.	5, 10, 17	High	3.2.1, 3.3.1, 3.4.1, 4.3.1.
	If time and budget permits, test baseflow time series estimated using the digital filter trained to the EC mass balance against baseflow estimates made using the “rating curve method” of Sellinger (1996), which accounts for groundwater levels relative to stream stage heights in a simple manner.	5, 17	Low	4.2.3

3. Catchment characterisation

3.1 Introduction

This section assesses the physical and water management characteristics of the three Gippsland river catchments (Latrobe, Thomson-Macalister, and the Mitchell) to provide a broad characterisation of the baseflow characteristics, as well as highlighting issues which may affect the accuracy of application of different baseflow methods. Physical catchment characteristics investigated include:

- Surface water streamflow and EC:
    - Streamflow and EC statistics are summarised, which provide an indication of the suitability of the application of the EC mass balance method, where the underlying assumption of the EC mass balance method is that low flows are largely supported by input from relatively saline groundwater, and therefore exhibit comparatively high surface water EC concentrations. The gauged period of record is also summarised to indicate whether there is sufficient data to apply baseflow separation techniques.
    - Scatter plots of upstream versus downstream flow and EC data for overlapping periods have been developed. This analysis serves as a basic check for potential baseflow gains along each reach, with increasing downstream EC and flow indicative of potential baseflow gains.
- Groundwater EC and hydrographic assessment:
    - Groundwater EC statistics are presented for the total upstream groundwater catchment and the interstation catchment (useful in reach-scale mass balances). Groundwater EC is presented spatially, providing an indication of variability in EC across the catchment and the distribution of data available to characterise the groundwater EC.
    - Hydrographic comparison of surface water levels along the reach and groundwater levels at nearby bores was conducted (where possible) to provide an indication of the relative groundwater gradient. Higher groundwater levels relative to stream water levels indicate potential for baseflow gaining conditions.
- Water management characteristics:
    - The impacts of surface water management occurring within each river reach (including reservoirs, river diversions and returns, and drainage) on baseflow estimation were discussed, and presented spatially on maps.
    - Groundwater extraction (non-mining licenced extractions, mining extractions, and stock and domestic) was presented spatially and summarised for the total upstream catchment and the interstation catchment. A large volume of groundwater extraction in vicinity of assessed reaches could have the potential to reduce baseflow. It is noted that the baseflow estimation presented in this study reflects the groundwater discharge to streams, after depletion by groundwater extraction.

Other relevant baseflow investigations which have been conducted within the three river catchments were also reviewed as part of this assessment. Relevant authorities (DELWP, the East Gippsland CMA and West Gippsland CMA) were contacted to ensure that all the key baseflow investigations were reviewed, including:

- SAFE: Secure Allocations, Future Entitlement (DSE, 2012): Key surface water – groundwater interaction datasets collated in the SAFE project which were reviewed as part of this study include BFI estimates derived in SKM (2002) and SKM (2012), and a baseflow classification database for major streams across Victoria.
- Understanding connectivity within groundwater systems and between groundwater and rivers (Hoffman, 2011): This study estimated the baseflow contribution to the lower Mitchell River using ^{222}Rn and Chloride (Cl) as tracers to define spatial and temporal variability of surface water / groundwater interactions.
- East Gippsland and West Gippsland ecoMarkets groundwater models (GHD 2010a; GHD 2010b): model results of baseflow during dry and wet periods have been presented spatially, and discussed.

Key findings from the baseflow characterisation are presented, and have been used to assess the usefulness and applicability of other potential baseflow estimation methods to enhance the digital filter method, for the various catchment characteristics.

3.2 Latrobe River

Baseflow was previously assessed at the following nine gauges with the Latrobe River catchment (GHD 2013b):

- Latrobe River at Thoms Bridge (226005)
- Tyers River at Browns (226007)
- Narracan Creek at Moe (226021)
- Latrobe River at Scarnes Bridge (226033)
- Tanjil River at Tanjil South (226216)
- Latrobe River at Kilmany South (226227)
- Latrobe River at Rosedale (Main Stream) (226228)
- Morwell River at Yallourn (226408)
- Traralgon Creek at Traralgon South (SEC) (226415)

3.2.1 Physical characteristics

Surface Water

Table 3 presents a summary of the gauged flow data for the assessed gauges within the Latrobe River catchment.

Table 3 Latrobe River Flow Data Summary

Gauge	Start Date	End Date	Count of readings	Mean flow (ML/day)	Median flow (ML/day)	95%ile flow (ML/day)	5%ile flow (ML/day)
226005	17/01/1962	3/02/2015	19,333	1,526	931	4,637	317
226007	18/08/1961	16/02/2015	16,538	255	170	680	60
226021	27/06/1996	3/02/2015	6,793	73	47	216	12

Gauge	Start Date	End Date	Count of readings	Mean flow (ML/day)	Median flow (ML/day)	95%ile flow (ML/day)	5%ile flow (ML/day)
226033	21/12/1996	12/05/2013	5,977	1,223	741	3,480	359
226216	2/04/1955	18/02/2015	21,873	375	305	932	93
226227	17/12/1976	8/02/2015	7,549	1,553	892	5,343	350
226228	2/12/1936	8/02/2015	28,515	2,135	1,330	7,019	415
226408	31/08/2001	3/02/2015	4,553	237	143	750	36
226415	2/07/1997	23/02/2015	6,415	54	24	191	2

Table 4 and Figure 2 present a summary of the surface water EC data for the assessed gauges within the Latrobe River catchment. As was identified by GHD (2013b), for the upper Latrobe River to Thoms Bridge (gauges 226007, 226216, 226005, and 226408), it is clear that there are often very few EC gauging's, and the limited data suggests little contrast between low and high flow EC. Occasionally for these gauges, the low flow EC can be slightly fresher than the high flow EC, which is counterintuitive to the underlying assumption of the EC mass balance method that low flows are largely supported by input from relatively saline groundwater. These observations are likely due to the EC-homogenising effect on stored and subsequently released water from Blue Rock Reservoir, Moondarra Reservoir and Lake Narracan.

The issue may also be compounded by too small a contrast between groundwater EC and stream EC at higher stream flows; however, this is not supported by the data presented in Table 6 (groundwater EC interstation analysis). Therefore, this observation may be indicative of no or very little baseflow gain along these reaches. As indicated, this assessment is hampered by the dominant effect of reservoir release on gauged stream ECs.

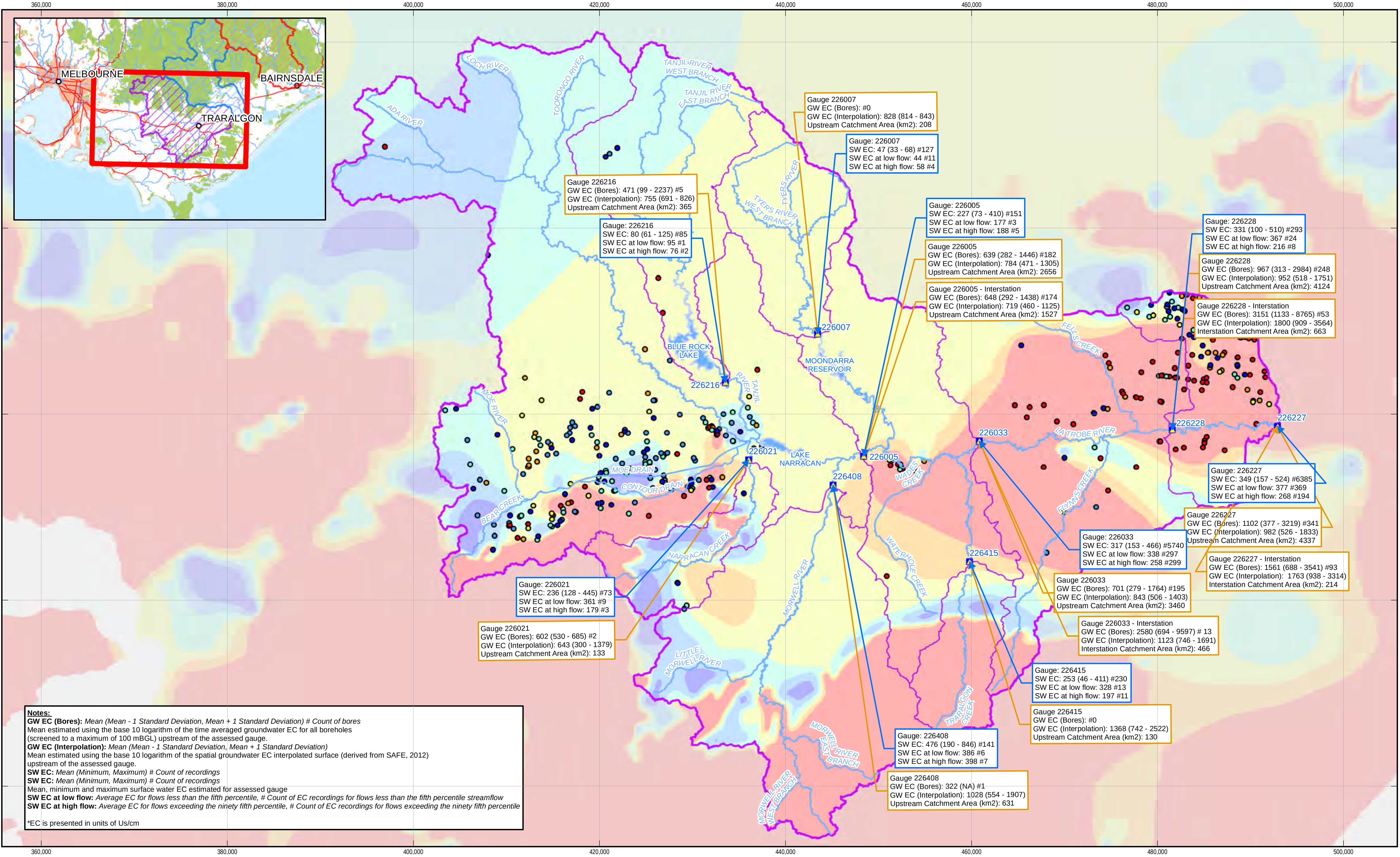
Hence, based on analysis of the surface water EC data, these streams are not good candidates for the EC mass balance method. However, as was recommended by Cartwright (2012) and proposed in Table 2, periods of the gauged records where there is a poor correlation between stream flow and EC should be removed from the analysis. It may be however that there are no (or very limited) reliable periods of corresponding flow and EC data, and hence the baseflow analyses for these gauges are likely to remain at a very low level of confidence. This is further assessed and discussed in Section 4.

A further issue associated with the scarcity of stream EC data, and the lack of contrast between high and low flow EC in the upper Latrobe catchment gauges (to Thoms Bridge), is that interstation EC mass balance baseflow analysis (as proposed in Table 2) is at best of only limited value for this river reach. At worst, it is impossible, due to insufficient stream EC data for the Latrobe River and its tributaries along this reach.

Table 4 Latrobe River Surface Water EC Data Summary

Gauge ID	Start Date	End Date	Count of EC readings	Mean EC [uS/cm] (Min - Max)	Average low flow EC [uS/cm] (count)	Average high flow EC [uS/cm] (count)
226408	17/01/1991	2/12/2014	141	476 (190 - 846)	386 (6)	398 (7)
226415	2/12/2002	26/06/2007	230	253 (46 - 411)	328 (13)	197 (11)
226005	11/01/1990	18/10/2004	151	227 (73 - 410)	177 (3)	188 (5)
226007	29/07/2003	16/12/2014	127	47 (33 - 68)	44 (11)	59 (4)
226021	12/10/2005	7/02/2012	73	236 (128 - 445)	361 (9)	179 (3)

Gauge ID	Start Date	End Date	Count of EC readings	Mean EC [uS/cm] (Min - Max)	Average low flow EC [uS/cm] (count)	Average high flow EC [uS/cm] (count)
226033	16/12/1996	12/05/2013	5,740	317 (153 - 467)	338 (297)	258 (299)
226216	11/01/1990	4/09/2012	85	80 (61 - 125)	95 (1)	77 (2)
226227	20/12/1996	10/03/2015	6,385	349 (157 - 524)	377 (369)	268 (194)
226228	2/01/1990	3/12/2014	293	331 (100 - 510)	367 (24)	216 (8)



Gauge 226007
GW EC (Bores): #0
GW EC (Interpolation): 828 (814 - 843)
Upstream Catchment Area (km2): 208

Gauge: 226007
SW EC: 47 (33 - 68) #127
SW EC at low flow: 44 #11
SW EC at high flow: 58 #4

Gauge 226216
GW EC (Bores): 471 (99 - 2237) #5
GW EC (Interpolation): 755 (691 - 826)
Upstream Catchment Area (km2): 365

Gauge: 226216
SW EC: 80 (61 - 125) #85
SW EC at low flow: 95 #1
SW EC at high flow: 76 #2

Gauge: 226005
SW EC: 227 (73 - 410) #151
SW EC at low flow: 177 #3
SW EC at high flow: 188 #5

Gauge 226005
GW EC (Bores): 639 (282 - 1446) #182
GW EC (Interpolation): 784 (471 - 1305)
Upstream Catchment Area (km2): 2656

Gauge 226005 - Interstation
GW EC (Bores): 648 (292 - 1438) #174
GW EC (Interpolation): 719 (460 - 1125)
Upstream Catchment Area (km2): 1527

Gauge: 226228
SW EC: 331 (100 - 510) #293
SW EC at low flow: 367 #24
SW EC at high flow: 216 #8

Gauge 226228
GW EC (Bores): 967 (313 - 2984) #248
GW EC (Interpolation): 952 (518 - 1751)
Upstream Catchment Area (km2): 4124

Gauge 226228 - Interstation
GW EC (Bores): 3151 (1133 - 8765) #53
GW EC (Interpolation): 1800 (909 - 3564)
Interstation Catchment Area (km2): 663

Gauge: 226227
SW EC: 349 (157 - 524) #6385
SW EC at low flow: 377 #369
SW EC at high flow: 268 #194

Gauge 226227
GW EC (Bores): 1102 (377 - 3219) #341
GW EC (Interpolation): 982 (526 - 1833)
Upstream Catchment Area (km2): 4337

Gauge: 226033
SW EC: 317 (153 - 466) #5740
SW EC at low flow: 338 #297
SW EC at high flow: 258 #299

Gauge 226227 - Interstation
GW EC (Bores): 1561 (688 - 3541) #93
GW EC (Interpolation): 1763 (938 - 3314)
Interstation Catchment Area (km2): 214

Gauge 226033
GW EC (Bores): 701 (279 - 1764) #195
GW EC (Interpolation): 843 (506 - 1403)
Upstream Catchment Area (km2): 3460

Gauge 226033 - Interstation
GW EC (Bores): 2580 (694 - 9597) # 13
GW EC (Interpolation): 1123 (746 - 1691)
Interstation Catchment Area (km2): 466

Gauge: 226021
SW EC: 236 (128 - 445) #73
SW EC at low flow: 361 #9
SW EC at high flow: 179 #3

Gauge 226021
GW EC (Bores): 602 (530 - 685) #2
GW EC (Interpolation): 643 (300 - 1379)
Upstream Catchment Area (km2): 133

Gauge: 226415
SW EC: 253 (46 - 411) #230
SW EC at low flow: 328 #13
SW EC at high flow: 197 #11

Gauge 226415
GW EC (Bores): #0
GW EC (Interpolation): 1368 (742 - 2522)
Upstream Catchment Area (km2): 130

Gauge: 226408
SW EC: 476 (190 - 846) #141
SW EC at low flow: 386 #6
SW EC at high flow: 398 #7

Gauge 226408
GW EC (Bores): 322 (NA) #1
GW EC (Interpolation): 1028 (554 - 1907)
Upstream Catchment Area (km2): 631

Notes:
GW EC (Bores): *Mean (Mean - 1 Standard Deviation, Mean + 1 Standard Deviation) # Count of bores*
Mean estimated using the base 10 logarithm of the time averaged groundwater EC for all boreholes
(screened to a maximum of 100 mBGL) upstream of the assessed gauge.
GW EC (Interpolation): *Mean (Mean - 1 Standard Deviation, Mean + 1 Standard Deviation)*
Mean estimated using the base 10 logarithm of the spatial groundwater EC interpolated surface (derived from SAFE, 2012)
upstream of the assessed gauge.
SW EC: *Mean (Minimum, Maximum) # Count of recordings*
SW EC: *Mean (Minimum, Maximum) # Count of recordings*
Mean, minimum and maximum surface water EC estimated for assessed gauge
SW EC at low flow: *Average EC for flows less than the fifth percentile, # Count of EC recordings for flows less than the fifth percentile streamflow*
SW EC at high flow: *Average EC for flows exceeding the ninety fifth percentile, # Count of EC recordings for flows exceeding the ninety fifth percentile*

*EC is presented in units of Us/cm

Paper Size A3

0 2 4 8 12 16
Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

Average GW EC

●	< 250
●	251 - 500
●	501 - 750
●	751 - 1000
●	1001 - 1500
●	> 1500
▲	Surface Water Gauges (Assessed)

■	Major Water Area
—	Major Watercourse
☐	Latrobe River Catchment
☐	Assessed sub-catchments

GW EC (Us/cm)

■	< 250
■	251 - 500
■	501 - 750
■	751 - 1,000
■	1,001 - 1,500
■	> 1500

Department of Environment, Land, Water & Planning
Gippsland River Baseflow Assessment

Job Number	31-32709
Revision	0
Date	27 May 2015

Latrobe River
EC Analysis

Figure 2

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Data source: DEWLP, VICMaps, 2015; GHD, Baseflow Catchments, 2015; DELWP, WMIS Surface and Groundwater Data, 2015. GHD, Groundwater EC Interpoalted Surface, 2013. Created by: adrummond

Comparison of gauged stream flows and EC for corresponding upstream and downstream gauges along the Latrobe River is presented in Figure 3. This is presented via scatter plots of upstream versus downstream flow and EC for each reach of the Latrobe River, as recommended by Cartwright (2013) and proposed in Table 2). It serves as a basic check for potential baseflow gains along each reach, with increasing downstream EC and flow indicative of potential groundwater inputs.

Where flows into a reach are contributed from more than one stream (i.e. from tributaries), the upstream gauged EC data were calculated as flow-weighted values, to account for the differing rates of flow from the tributaries, and hence the differing relative EC input to the reach.

Flow data were assessed for the effect of travel times greater than one day down each reach. There is no evidence of significant time lags down the Rosedale to Kilmany South reach; however, there is an apparent 1-day time lag between Thoms Bridge and Scarnes Bridge, and between Scarnes Bridge and Rosedale. The data presented in Figure 3 were therefore adjusted accordingly, unless otherwise specified in the figure.

Figure 3 shows that stream EC increases down each gauged reach of the Latrobe River relatively consistently. This suggests that the river is largely baseflow-dependent. Caution must be taken with this inference however, given the relatively saline water returns from industrial water users (primarily the power generators, shown in Figure 6).

Data for the upper gauged reach between Thoms Bridge and Scarnes Bridge are compromised by ungauged EC inputs from Traralgon Creek and the Tyers River, in addition to Wades Creek, which flows through Morwell. Data for this reach is too limited to make a firm conclusion regarding baseflow dependency; however, the limited data available suggests that the river may alternate between gaining and losing conditions along this reach. It should be noted that the relatively saline industrial water returns from industrial water users along this reach are likely to contribute to the observed EC increases (Table 9 and Table 10).

In the upper reaches between Thoms Bridge and Rosedale, Figure 3 shows relatively consistent flow losses, although there are also periods of flow gain. These observed flow losses may be due to industrial and other water offtakes (Figure 6). The observed flow losses are inconsistent with the observed EC gains along these upper reaches, which may suggest either (or a combination) of:

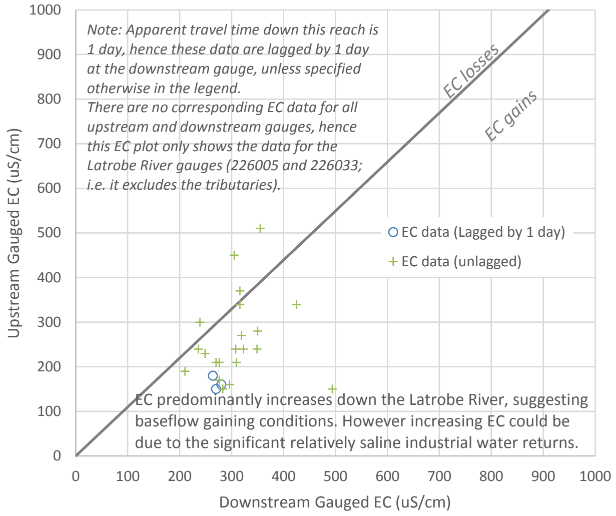
- Gauged stream flows and EC may be significantly affected by water offtakes and return of more saline industrial water; and/or
- Baseflow gains along this reach. It is possible and likely in places for flows to decrease along a river reach, despite receiving relatively saline baseflows which contribute to observed EC increases; this can occur through flow losses to water users and/or bank storage for instance – flow loss does not necessarily mean that a river is baseflow-losing.

The Victorian government's REALM model of the Latrobe River catchment represents the catchment surface water balance in some detail, including inflows, regulation and diversions. It indicates no net loss of surface water from the stream channel to groundwater once diversions are accounted for. This supports the above inference that the river is dominantly baseflow-gaining, and that the observed flow losses are likely due to diversions from the river.

The issues with saline industrial water returns noted above are likely to pose less of an issue to baseflow assessment using a reach-scale EC mass balance for the Latrobe River between Scarnes Bridge and Rosedale. This is because there are significantly less industrial water returns to this reach (only returns from Loy Yang power station affect it).

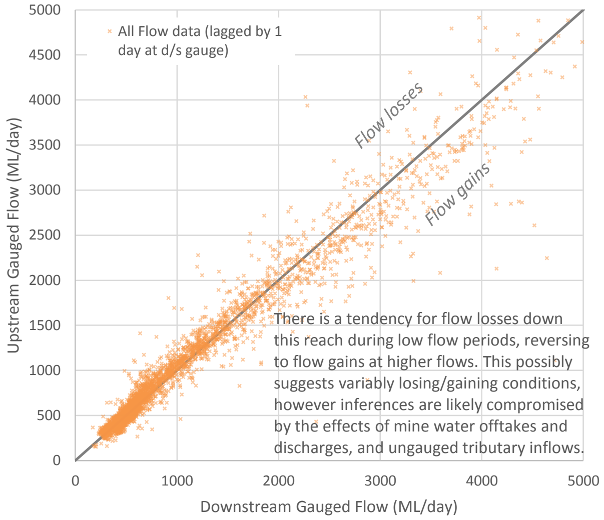
In the lower-most reach between Rosedale and Kilmany South, the flow data suggests dominantly baseflow-gaining conditions, as do the corresponding EC data.

Latrobe River Thoms Bridge (gauges 226005/226007/226415) to Scarnes Bridge (gauge 226033)



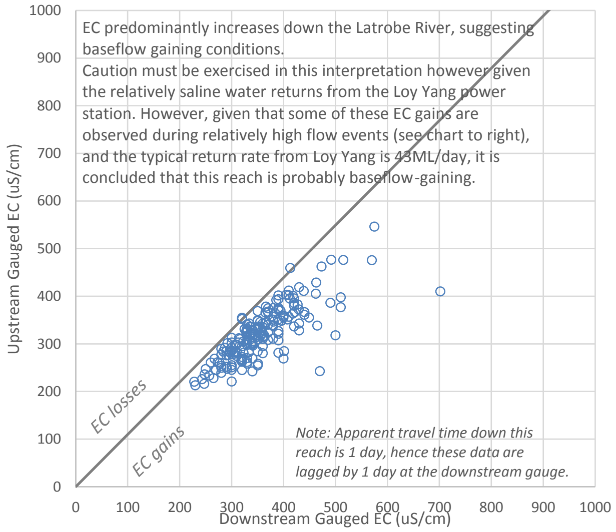
Note: Apparent travel time down this reach is 1 day, hence these data are lagged by 1 day at the downstream gauge, unless specified otherwise in the legend.
There are no corresponding EC data for all upstream and downstream gauges, hence this EC plot only shows the data for the Latrobe River gauges (226005 and 226033; i.e. it excludes the tributaries).

EC predominantly increases down the Latrobe River, suggesting baseflow gaining conditions. However increasing EC could be due to the significant relatively saline industrial water returns.



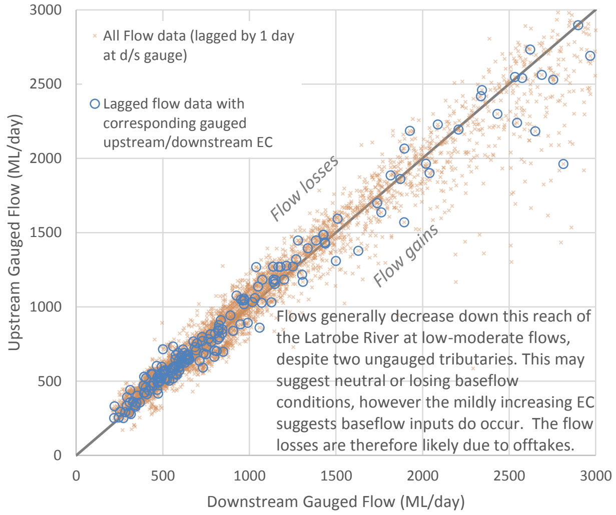
There is a tendency for flow losses down this reach during low flow periods, reversing to flow gains at higher flows. This possibly suggests variably losing/gaining conditions, however inferences are likely compromised by the effects of mine water offtakes and discharges, and ungauged tributary inflows.

Latrobe River at Scarnes Bridge (gauge 226033) to Rosedale (gauge 226228)



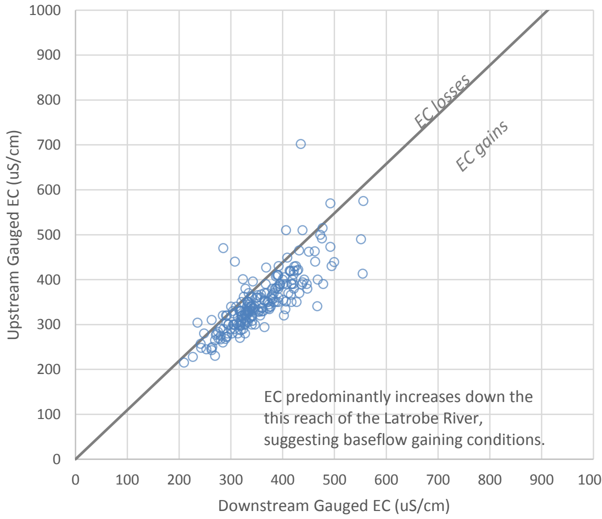
EC predominantly increases down the Latrobe River, suggesting baseflow gaining conditions.
Caution must be exercised in this interpretation however given the relatively saline water returns from the Loy Yang power station. However, given that some of these EC gains are observed during relatively high flow events (see chart to right), and the typical return rate from Loy Yang is 43ML/day, it is concluded that this reach is probably baseflow-gaining.

Note: Apparent travel time down this reach is 1 day, hence these data are lagged by 1 day at the downstream gauge.

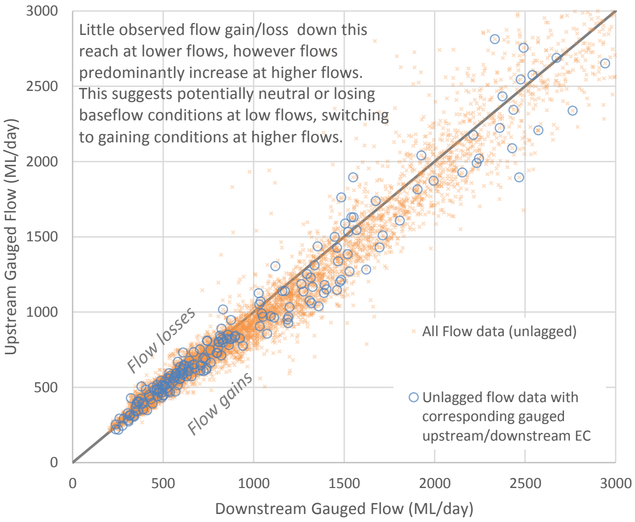


Flows generally decrease down this reach of the Latrobe River at low-moderate flows, despite two ungauged tributaries. This may suggest neutral or losing baseflow conditions, however the mildly increasing EC suggests baseflow inputs do occur. The flow losses are therefore likely due to offtakes.

Latrobe River Rosedale (gauge 226228) to Kilmany South (gauge 226227)



EC predominantly increases down the this reach of the Latrobe River, suggesting baseflow gaining conditions.



Little observed flow gain/loss down this reach at lower flows, however flows predominantly increase at higher flows.
This suggests potentially neutral or losing baseflow conditions at low flows, switching to gaining conditions at higher flows.

NOTE: No evidence of significant time lags for flow down the Rosedale to Kilmany South river reach, however there is an apparent 1-day time lag in flows between Thoms Bridge and Scarnes Bridge, and between Scarnes Bridge and Rosedale.

Figure 3 Latrobe River - Comparison of Gauged Upstream/Downstream Stream Flow and EC Data

Groundwater EC

Figure 2 illustrates the spatial variability in the groundwater EC concentration across the Latrobe River catchment. It transitions from relatively fresh groundwater (25 – 750 uS/cm) in the north-west and saline (> 1500 uS/cm) in the south-east. The groundwater EC surface presented in Figure 2 was derived from the watertable salinity map (mg/L TDS) generated for Victoria as part of the SAFE project (SKM, 2012), and converted to EC using the equation below ($R^2 = 0.96$), which was derived using state-wide groundwater EC and TDS data from DELWP's Water Management Information System (WMIS).

$$Log\ (EC) = 0.9936 \times Log\ (TDS) + 0.2426$$

Figure 2 also presents the spatial distribution of time-averaged groundwater EC concentration at boreholes, where it should be noted that most bores possess only one or two EC readings. Figure 2 highlights that there is a high density of groundwater monitoring data in the upper part of the catchment in the vicinity of the Moe River and Bear Creek, and in the lower part of the catchment at the base of the Latrobe River, with limited data throughout the rest of the catchment.

Figure 2 and Table 5 summarise the spatially averaged mean groundwater EC and the range (plus and minus one standard deviation from the mean), calculated for the interpolated groundwater EC surface and the time-average groundwater EC borehole estimates, for the total upstream catchment at each assessed gauge. Table 6 presents the groundwater EC statistics for the catchment area between each downstream gauge and its upstream counterpart (i.e. the interstation catchment), which will be useful for reach-scale mass balances used for estimating baseflow gains along specific river reaches.

Table 5 Latrobe River - Groundwater EC Data Summary (total upstream catchment)

Gauge ID	Catchment Area (km^2)	GW EC [uS/cm] - Interpolated: Mean (Mean +/- 1 Standard Deviation)	GW EC [uS/cm] - Boreholes: Mean (Mean +/- 1 Standard Deviation)	Count of boreholes
226007	208	828 (814 - 843)	NA	0
226216	365	755 (691 - 826)	471 (99 - 2237)	5
226227	4,337	982 (526 - 1833)	1102 (377 - 3219)	341
226005	2,656	784 (471 - 1305)	639 (282 - 1446)	182
226033	3,460	843 (506 - 1403)	701 (279 - 1764)	195
226228	4,124	952 (518 - 1751)	967 (313 - 2984)	248
226021	133	643 (300 - 1379)	602 (530 - 685)	2
226408	631	1028 (554 - 1907)	322 (NA)	1
226415	130	1368 (742 - 2522)	NA	0

Table 6 Latrobe River - Groundwater EC Data Summary (interstation catchment)

Gauge ID	Catchment Area (km^2)	GW EC - Interpolated: Mean (Mean +/- 1 Standard Deviation)	GW EC - Boreholes: Mean (Mean +/- 1 Standard Deviation)	Count of boreholes
226227	214	1763 (938 - 3314)	1561 (688 - 3541)	93
226005	1,527	719 (460 - 1125)	648 (292 - 1438)	174
226033	466	1123 (746 - 1691)	2580 (694 - 9597)	13
226228	663	1800 (909 - 3564)	3151 (1133 - 8765)	53

Groundwater Levels

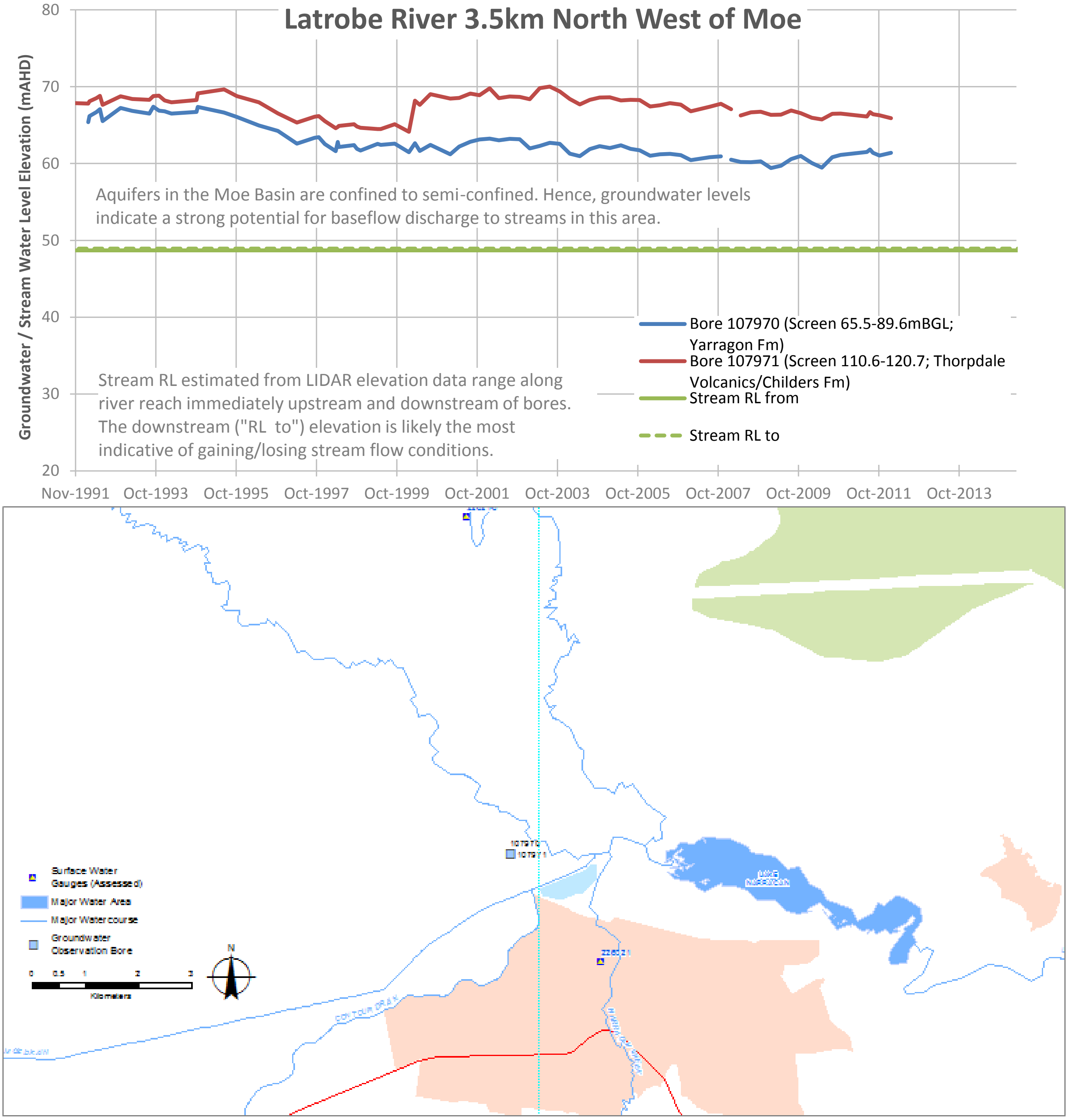
There are only two groundwater observation bores located sufficiently close to the Latrobe River to allow hydrographic comparison of groundwater and surface water levels. These bores are 107970 and 107971, located near Moe in the upper Latrobe catchment, located 800 m north of the Moe Drain and 700 m west of the Latrobe River. They monitor the confined aquifers of the Yarragon Formation and underlying Thorpdale Volcanics/Childers Formation. The data are compared to adjacent Latrobe River water levels (estimated using LiDAR data), in Figure 4.

The data suggest a strong potential for baseflow discharge to the Latrobe River at this location from the confined aquifers. This is probably the case throughout much of the upper catchment area around Moe (“the Moe Basin”), where groundwater flow eastward into the main Latrobe Valley is restricted by a narrowing of the sedimentary basin to the east of Moe, as was discussed by GHD (2010a). Findings from Jacobs SKM (2014) also suggest that baseflow provides a significant proportion of stream flow in the upland sections of the Latrobe and Tanjil River systems that drain the Victorian Uplands where basement outcrops. While the contribution of baseflow to the Moe Drain were not considered in Jacobs SKM (2014), the study did note that the average stream flow in the drain increases from 131 ML/day at Darnum to 281 ML/day at east of Trafalgar. Jacobs SKM (2014) also inferred that while runoff and inputs from Shady creek (which remains ungauged) are likely to contribute a portion of stream flow through this stretch, the significant increase in stream flow through the section suggests some baseflow inputs.

There are no suitable groundwater level data (i.e. observation bores located sufficiently close to the Latrobe River) further to the east, in the main Latrobe Valley between Moe and Sale. Hence hydrometric assessment of potential gaining/losing behaviour of the river in this area cannot be made.

With regard to the potential effect of depressurisation of aquifers by the Latrobe Valley coal mines on shallow groundwater levels (and therefore groundwater-surface water interactions), the typical effect of depressurisation by the coal mines on deeper versus shallower formations is shown in Figure 5. This shows that groundwater levels in the (shallow) Yallourn Formation around the three Latrobe Valley mines have not been significantly depressurised, whereas depressurisation increases significantly in the deeper formations.

Therefore, it is considered unlikely that the Latrobe River loses water via leakage down to the underlying aquifers as a result of the coal mine depressurisation; however, it is likely that the depressurisation and associated large areal groundwater drawdown extent are likely to have historically reduced baseflows to the Latrobe River and surrounding streams via enhanced downward groundwater gradients and baseflow capture. It is likely that this effect will continue in the long-term given the confined nature of the deep aquifers. Baseflow effects are likely delayed over long time frames as a result, and attenuated to some degree due to drawdown-related reductions in other groundwater discharge components, such as offshore groundwater flow to the east. These conclusions are supported by the numerical modelling of GHD (2010a), the results of which in terms of modelled baseflow gain and loss, are discussed in Section 3.2.3 and presented in Appendix A.



Aquifers in the Moe Basin are confined to semi-confined. Hence, groundwater levels indicate a strong potential for baseflow discharge to streams in this area.

Stream RL estimated from LIDAR elevation data range along river reach immediately upstream and downstream of bores. The downstream ("RL to") elevation is likely the most indicative of gaining/losing stream flow conditions.

Figure 4 Latrobe River - Groundwater and surface water level analysis

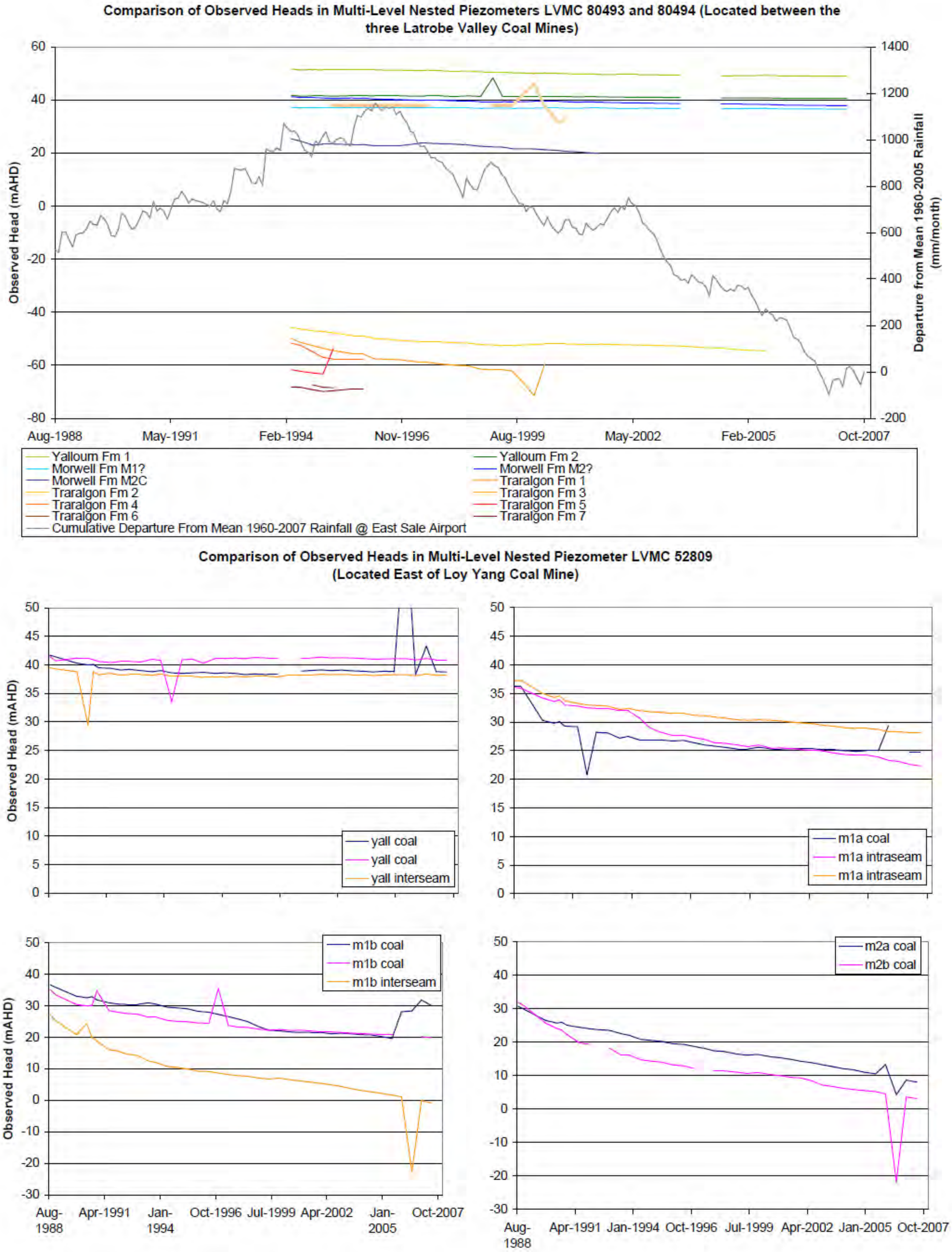


Figure 5 Nested Hydrographs in the Latrobe Valley (from GHD, 2010a)

3.2.2 Water management characteristics

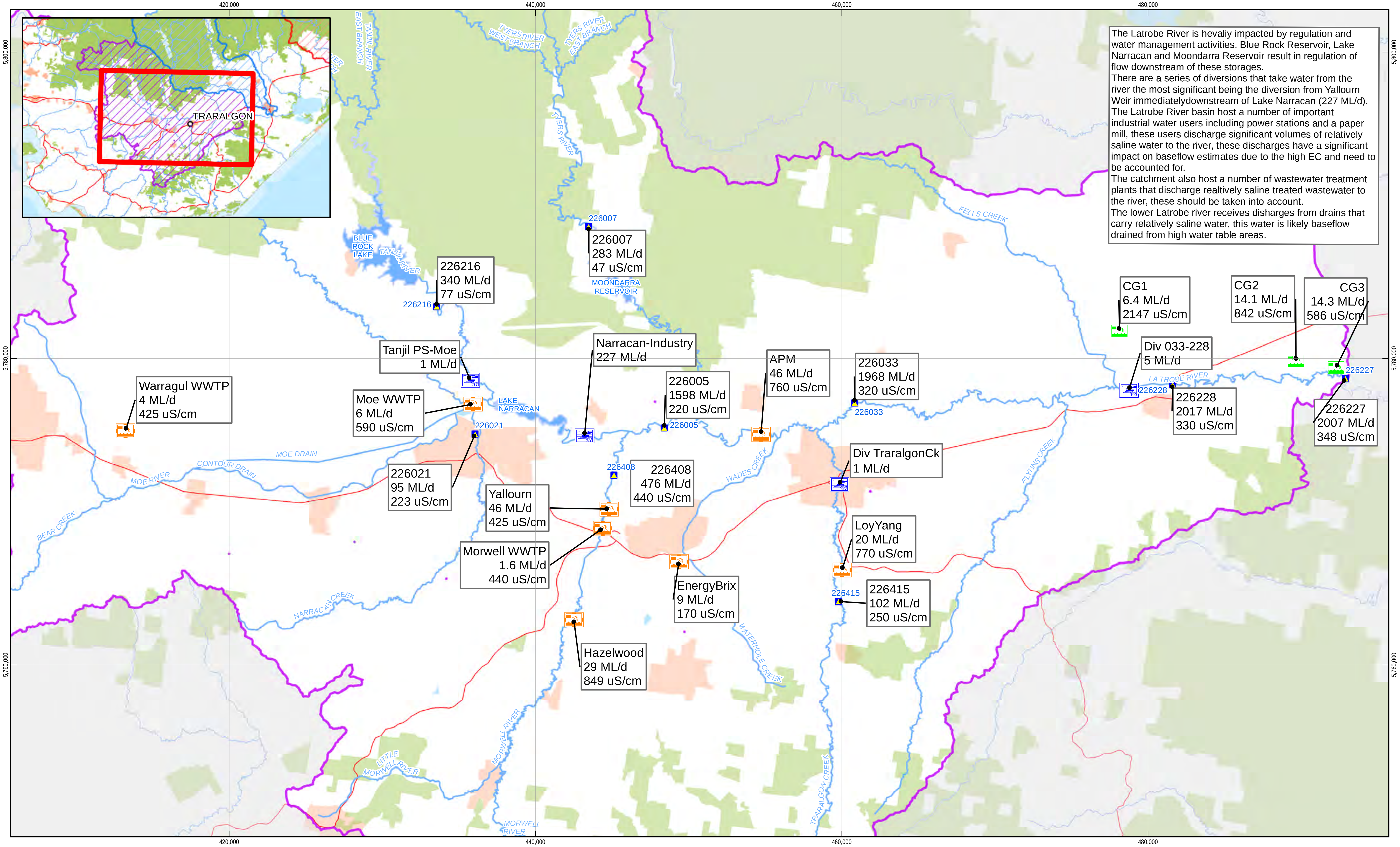
There are a range of water management actions that are undertaken in the Latrobe River catchment that impact streamflow and stream EC, particularly in the lower reaches of the basin. These actions are illustrated in Figure 6, and discussed below.

Reservoirs

The catchment has three major storages: Blue Rock Reservoir on the Tanjil River; Lake Narracan on the Latrobe River (at the confluence of the Tanjil River, Moe River and Narracan Creek); and Moondarra Reservoir on the Tyers River. Blue Rock is the largest storage and has a significant impact on the flow regime, with reduced flows in the wetter months and increased flows in the summer months as a result of releases to downstream water users. The smaller capacity of the Narracan and Moondarra storages relative to the catchments they impound, results in a less significant change in flow regime. Figure 7, Figure 8, and Figure 9 illustrate the effect of each storage on the flow regime. The reservoirs also affect downstream EC by allowing for mixing of different salinity flows, resulting in a more uniform EC downstream of the reservoir. However, for this catchment, the EC upstream of Blue Rock and Moondarra are relatively low and not particularly variable with respect to flow or season. In the case of Lake Narracan the storage is relatively small compared to the river flows, resulting in a minor impact on downstream EC.

Diversions

A number of water users divert from the Latrobe system. The most significant extraction in the Latrobe catchment is the diversion to power stations at Yallourn Weir (227 ML/d). The diversions take a mix of baseflow and other flow components from the stream; therefore, these diversions do not have any impact on the application of the baseflow separation method at a single gauge location. Diversions do however have an effect on any interstation analysis of baseflow and need to be taken into account.



The Latrobe River is hevaliy impacted by regulation and water management activities. Blue Rock Reservoir, Lake Narracan and Moondarra Reservoir result in regulation of flow downstream of these storages.

There are a series of diversions that take water from the river the most significant being the diversion from Yallourn Weir immediatelydownstream of Lake Narracan (227 ML/d).

The Latrobe River basin host a number of important industrial water users including power stations and a paper mill, these users discharge significant volumes of relatively saline water to the river, these discharges have a significant impact on baseflow estimates due to the high EC and need to be accounted for.

The catchment also host a number of wastewater treatment plants that discharge realtively saline treated wastewater to the river, these should be taken into account.

The lower Latrobe river receives disharges from drains that carry relatively saline water, this water is likely baseflow drained from high water table areas.

Paper Size A3

0 1 2 4 6 8

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

- ▲ Surface Water Gauges (Assessed)
- 🟦 Major Water Area
- — Major Watercourse
- ▭ Latrobe River Catchment
- Drains
- Industry Returns
- Offtakes
- ▲ SW Gauges

State Government Victoria

GHD

Department of Environment, Land, Water & Planning
Gippsland River Baseflow Assessment

Job Number	31-32709
Revision	0
Date	27 May 2015

Latrobe River
Water Management

Figure 6

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Data source: DEWLP, VICMaps, 2015; GHD, Baseflow Catchments, 2015; DELWP, WMIS Surface and Groundwater Data, 2015; SRW, Drain Data, 2015; DELWP, REALM Model results, 2015; EPA, Industrial Discharge Data, 2013-14. Created by: adrummond

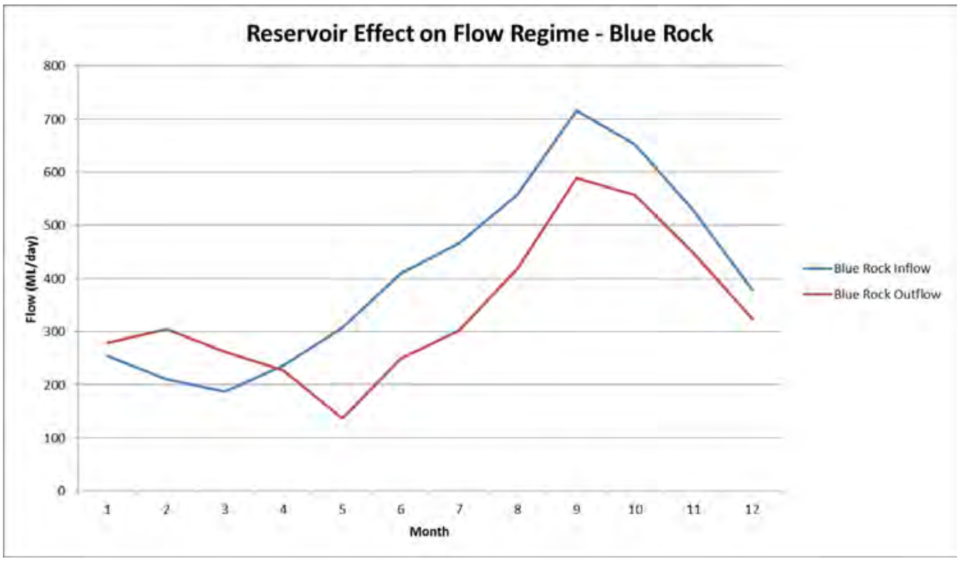


Figure 7 Reservoir effect on flow regime - Blue Rock

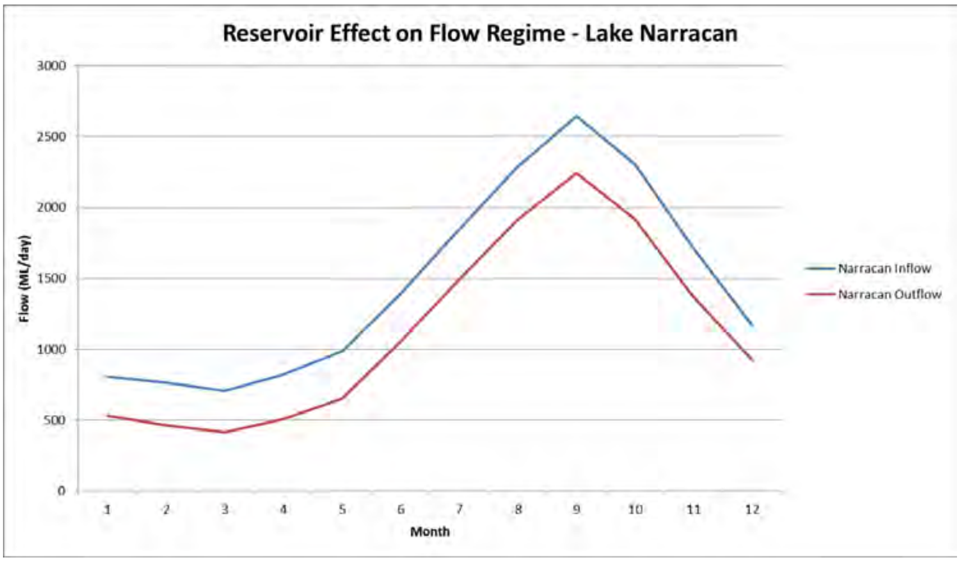


Figure 8 Reservoir effect on flow regime –Lake Narracan

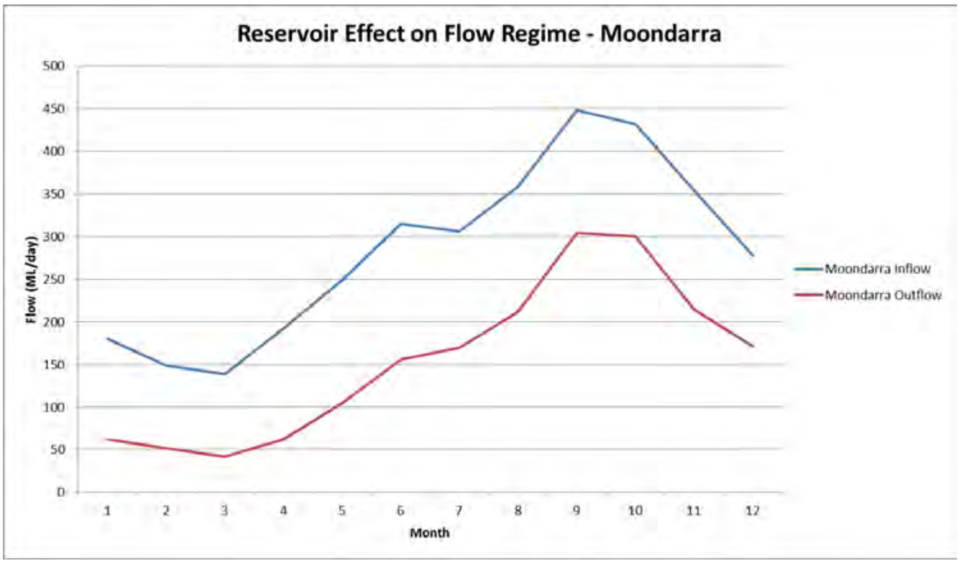


Figure 9 Reservoir effect on flow regime – Moondarra

Drainage

There are a number of drains that convey water from the southern part of the Macalister Irrigation District to the lower Latrobe River. These collect relatively saline water from high water table areas and discharge to the river system. Southern Rural Water operates meters that measure flow and EC for the major drains, summarised in Table 7 and Table 8.

The discharge from these drains has an elevated EC, primarily as these drains are collecting groundwater from high water table areas. Therefore, it is possible to consider these drain discharges as a mix of baseflow and other flow components, in the same way that streamflow is treated.

It is possible that EC in these drains is elevated for other reasons, (for example fertilizer loading) and this could have an impact on the accuracy of the baseflow estimates. However, it is likely that at least some, if not most of this input will also be derived from groundwater, due to leaching of fertilisers down to the watertable. This is therefore considered a negligible issue for the baseflow analyses, and estimation of its effect would be tenuous at best.

Table 7 Latrobe Drain Flow Data Summary

Drain	Gauge	Start Date	End Date	Count of readings	Mean flow (ML/day)	Median flow (ML/day)	95%ile flow (ML/day)	5%ile flow (ML/day)
Central Gippsland 1	225735	8/08/2001	22/11/2013	4,246	6.4	4.3	0.3	19.2
Central Gippsland 2	225729	30/07/1999	31/12/2013	5,149	14.1	8.2	1.1	37.5
Central Gippsland 3	225709	23/07/1997	31/12/2013	6,116	14.6	9.8	1.0	39.2

Table 8 Latrobe Drain EC Data Summary

Drain	Gauge ID	Start Date	End Date	Count of EC readings	Mean EC [uS/cm] (Min - Max)	95%ile EC [uS/cm]	5%ile EC [uS/cm]
Central Gippsland 1	225735	8/08/2001	15/04/2013	4,021	2718 (29 - 9150)	444	6,267
Central Gippsland 2	225729	30/07/1999	4/10/2011	3,762	1208 (44 - 4073)	415	2,980
Central Gippsland 3	225709	23/08/1997	2/10/2011	4,885	947 (46 - 2954)	297	2,530

Industrial Water Returns

There are five major industrial water users that return water to the river, detailed in Table 9 and Table 10. The industrial water returns affect the baseflow separation method by increasing the EC of streamflow (thereby resulting in a higher estimate of baseflow), and effort should be made to account for this.

Table 9 Latrobe Return Flow Data Summary

Return	Start Date	End Date	Count of readings	Mean flow (ML/day)	Median flow (ML/day)	95%ile flow (ML/day)	5%ile flow (ML/day)
Energy Brix	1/07/2003	1/10/2012	112	9.1	9.0	5.9	13.4
Hazelwood	31/01/1987	31/10/2012	310	29.9	17.4	0	96.1
Loy Yang	18/10/2001	11/02/2013	529	54.6	43.3	21.1	128.6
Yallourn	2/01/2008	8/06/2012	1,620	44.5	49.4	0	80.9
APM	1/01/2008	1/06/2012	54	47.1	46.3	37.7	58.1

Table 10 Latrobe Return EC Data Summary

Return	Start Date	End Date	Count of EC readings	Mean EC [uS/cm] (Min - Max)	Median EC [uS/cm]	95%ile EC [uS/cm]	5%ile EC [uS/cm]
Energy Brix	2/07/2012	24/06/2013	52	206 (100 - 930)	170	120	380
Hazelwood	10/01/1989	17/06/2013	1,242	858 (1 - 2000)	849	250	1,799
Loy Yang	18/10/2001	11/02/2013	529	769 (220 - 1200)	770	610	960
Yallourn	NA	NA	NA	NA	425	NA	NA
APM	NA	NA	NA	NA	760	NA	NA

Note 1 – Hazelwood return EC estimated based on mass balance of upstream and downstream monitoring sites, this resulted in unreasonable results and levels were capped at 2000 uS/cm

Note 2 – Yallourn and APM EC values extracted from EPA licence annual report (2012/13 and 2013/14)

Treated Wastewater Returns

There are three significant wastewater treatment plants that discharge treated wastewater to the river, as shown in Table 11 and Table 12. The treated wastewater returns also affect the baseflow separation method by increasing the EC of streamflow, resulting in a higher estimate of baseflow. However, it is noted that part of the treated wastewater is made up of groundwater intercepted by the sewerage network. In effect, a proportion of these treated wastewater flows is baseflow that may have previously reached the river via a natural flow path. Reliable accounting for these effects is not considered possible in this study.

Table 11 Latrobe Wastewater Flow Data Summary

Return	Mean flow (ML/day)	Median flow (ML/day)	95%ile flow (ML/day)	5%ile flow (ML/day)
Warragul WWTP	4.5	4.4	3.2	7.0
Moe WWTP	6.0	5.7	4.1	9.3
Morwell WWTP	1.7	1.6	1.1	2.6

Note 1 – Based on monthly data from April 2013 to March 2015

Table 12 Latrobe Wastewater EC Data Summary

Return	Mean EC (Min - Max)	Median EC [uS/cm]	95%ile EC [uS/cm]	5%ile EC [uS/cm]
Warragul WWTP	424 (313 - 507)	425	325	507
Moe WWTP	570 (418 - 720)	590	422	715
Morwell WWTP	451 (358 - 600)	440	362	588

Note 1 – Based on monthly data from April 2013 to March 2015

Groundwater Management

Figure 10 summarises the groundwater extractions from stock and domestic bores, non-mining licenced groundwater extraction, and licenced mining extractions across the Latrobe River catchment, for both the catchment portion between flow gauges (“interstation catchments”), and the total upstream catchments to each gauge. The following notes should be considered when interpreting the groundwater extraction data presented in Figure 10:

- Stock and domestic bore extractions were assumed to be 2 ML/yr;
- Non-mining licenced groundwater extraction volumes are presented from the 2009-2010 full licenced entitlement volume; and
- The mine extraction volume is the average annual groundwater use over the period 2004 – 2014, collated from the Latrobe Valley Groundwater Annual Reports (GHD, 2014), and aggregates pumping across all licenced aquifers.

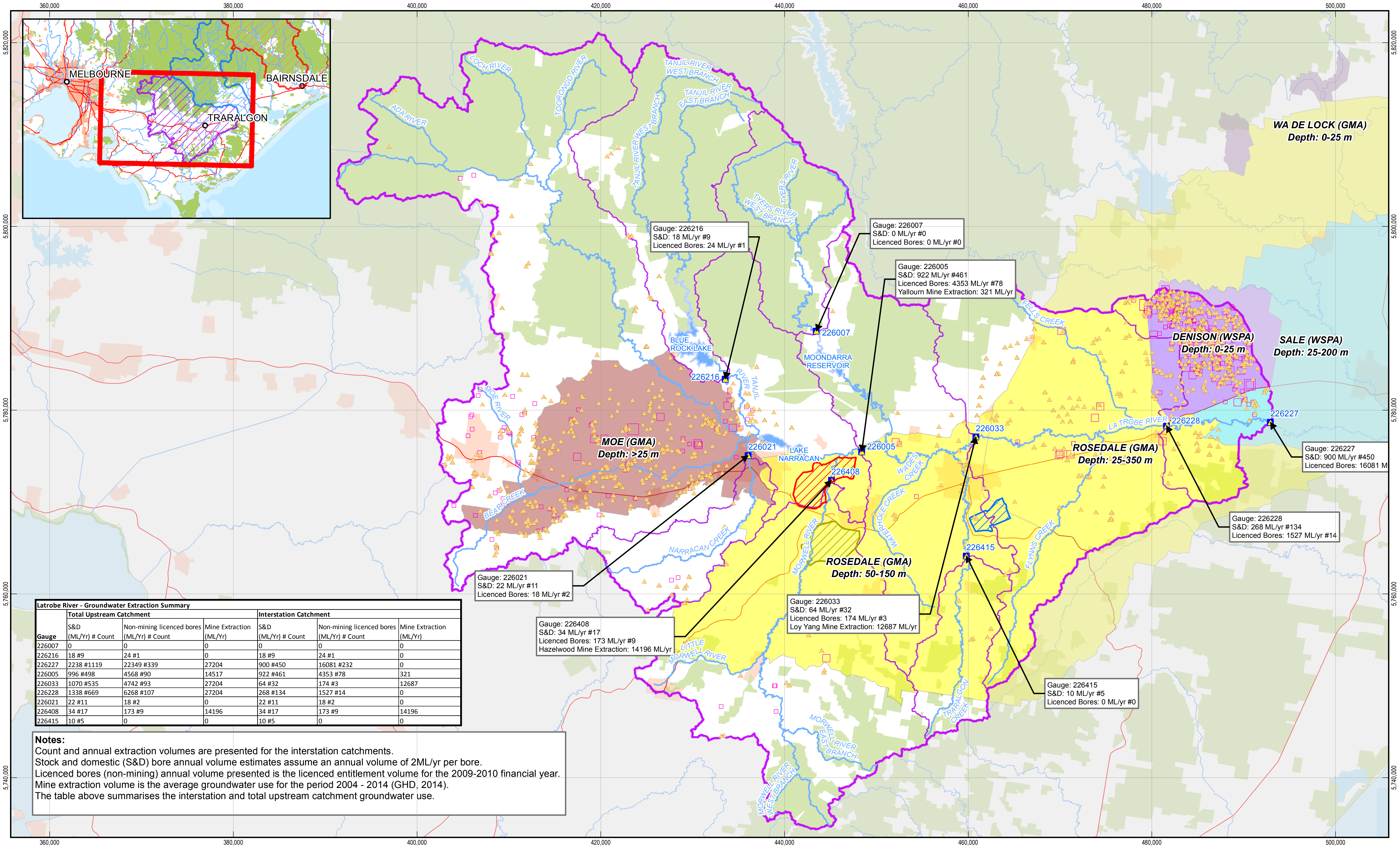
The figure highlights that the majority of the stock and domestic and non-mining licenced groundwater extractions are concentrated in the upper reaches of the Moe River (Moe Groundwater Management Area), and the lower reaches of the Latrobe River (extractions from the Denison Water Supply Protection Area and the Rosedale Groundwater Management Area). The large volumes of groundwater extraction in these catchments potentially reduce groundwater discharge (baseflow) to the Moe River and the lower Latrobe River. The effect of this on the baseflow estimates presented in this project is that the estimated baseflows reflect the groundwater discharge to streams, after depletion by groundwater extraction. This was discussed in detail by GHD (2013a), and is incorporated into the assessment of risks to environmental flows in this project.

The upper reaches of the Tanjil River, Traralgon Creek, Narracan Creek and Tyers River have minimal groundwater extraction; therefore, it is expected that baseflow in these catchments are not influenced by pumping.

Three mines operate in the Latrobe River catchment:

- Hazelwood Mine: extracting an average of 14,200 ML/yr from the Morwell (M1 and M2) Formation;
- Yallourn Mine: extracting an average 320 ML/yr from the Morwell (M1A) Formation; and
- Loy Yang Mine: extracting an average of 12,700 ML/yr from the Morwell (M2C) and Traralgon (T1) Formations.

While these mines extract significant volumes of groundwater, the groundwater extractions are from deep confined aquifers, and have minimal observable impact on groundwater levels in the unconfined aquifer, as discussed in Section 3.2.1 and shown in Figure 5.



Latrobe River - Groundwater Extraction Summary

Gauge	Total Upstream Catchment S&D (ML/Yr) # Count	Total Upstream Catchment Non-mining licenced bores (ML/Yr) # Count	Total Upstream Catchment Mine Extraction (ML/Yr)	Interstation Catchment S&D (ML/Yr) # Count	Interstation Catchment Non-mining licenced bores (ML/Yr) # Count	Interstation Catchment Mine Extraction (ML/Yr)
226007	0	0	0	0	0	0
226216	18 #9	24 #1	0	18 #9	24 #1	0
226227	2238 #1119	22349 #339	27204	900 #450	16081 #232	0
226005	996 #498	4568 #90	14517	922 #461	4353 #78	321
226033	1070 #535	4742 #93	27204	64 #32	174 #3	12687
226228	1338 #669	6268 #107	27204	268 #134	1527 #14	0
226021	22 #11	18 #2	0	22 #11	18 #2	0
226408	34 #17	173 #9	14196	34 #17	173 #9	14196
226415	10 #5	0	0	10 #5	0	0

Notes:

Count and annual extraction volumes are presented for the interstation catchments.
Stock and domestic (S&D) bore annual volume estimates assume an annual volume of 2ML/yr per bore.
Licenced bores (non-mining) annual volume presented is the licenced entitlement volume for the 2009-2010 financial year.
Mine extraction volume is the average groundwater use for the period 2004 - 2014 (GHD, 2014).
The table above summarises the interstation and total upstream catchment groundwater use.

Paper Size A3

0 2 4 8 12 16

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

- ▲ Stock and Domestic Bore

Licensed Bore Entitlement (ML/yr)

- □ < 100
- □ 101 - 350
- □ 351 - 1500
- □ > 1501
- ▲ Surface Water Gauges (Assessed)
- ■ Major water area
- — Major Water Course
- □ Latrobe River Catchment
- □ Assessed sub-catchments
- ▨ Yallourn Mine
- ▨ Loy Yang Mine
- ▨ Hazelwood Mine

GMU

- ■ DENISON
- ■ MOE
- ■ ROSEDALE
- ■ SALE
- ■ WA DE LOCK

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Latrobe River Groundwater Extraction

Figure 10

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Data source: DEWLP, VICMaps, 2015; GHD, Baseflow Catchments, 2015; DELWP, WMIS Surface and Groundwater Data, 2015. SRW, Licenced GW Use Volume (2010). GHD, Mine Use Volume (2014). Created by: adrummond

3.2.3 Local baseflow assessments

SAFE

Figure 11 presents a summary of the known baseflow investigations conducted across the Latrobe River catchment, collated as part of the Victorian Government's Secure Allocation, Future Entitlement (SAFE) project. The upper reaches of the Latrobe River, Morwell River and Traralgon Creek have been classified as gaining reaches with a moderate level of confidence, and baseflow indices (BFIs) have been estimated for these perennial reaches (SKM, 2002; SKM, 2012). The BFI estimates for the Latrobe River catchment derived by SKM (2012) by applying the Lyne Hollick digital filter method with a filter parameter value of 0.98, are relatively high (0.7 – 0.8), indicating that around 75% of the streamflow in these unregulated reaches is comprised of baseflow. Comparatively, the BFI estimates derived in SKM (2002), which applied the same digital filter method but with a filter parameter value of 0.925, derived relatively lower BFI estimates for Traralgon Creek, Waterhole Creek and Morwell River, with BFI ranging from 0.34 – 0.48.

The upper reaches of Tyers River, Bear Creek and Billy Creek have also been classified as gaining reaches, given they are unregulated and perennial, with a low confidence rating given baseflow indices have not been estimated along these reaches. This study did not classify baseflow for the Tanjil River downstream of Blue Rock Lake, Latrobe River downstream of Lake Narracan, and Tyres River downstream of Moondarra Reservoir, given the impacts of regulation on these reaches.

Given that these baseflow estimates comprise digital filter application, which is also part of the methodology applied in the current project, they do not serve any purpose in validating the baseflow estimates to be developed in the current project.

ecoMarkets

Appendix A presents the modelled spatial baseflow gains and losses across the Latrobe River catchment, estimated for a wet (July 1978) and dry (April 1983) period, derived from the West Gippsland ecoMarkets Model (GHD, 2010). The model results indicate that the upper reaches of the Latrobe River catchment, and the Latrobe River downstream of the confluence with Tyers River are predominantly baseflow gaining during a wet period; and the lower reaches of the Morwell River and Traralgon Creek are baseflow neutral. During dry periods, the model indicates that the upper reaches of the Latrobe River catchment, and the lower stem of the Latrobe River, are generally weakly baseflow gaining; and the mid to lower reaches of the Latrobe River catchment are generally baseflow neutral. In summary, the ecoMarkets modelling suggests generally baseflow gaining conditions along the Latrobe River, despite the long-term depressurisation effects of the coal mines and power stations.

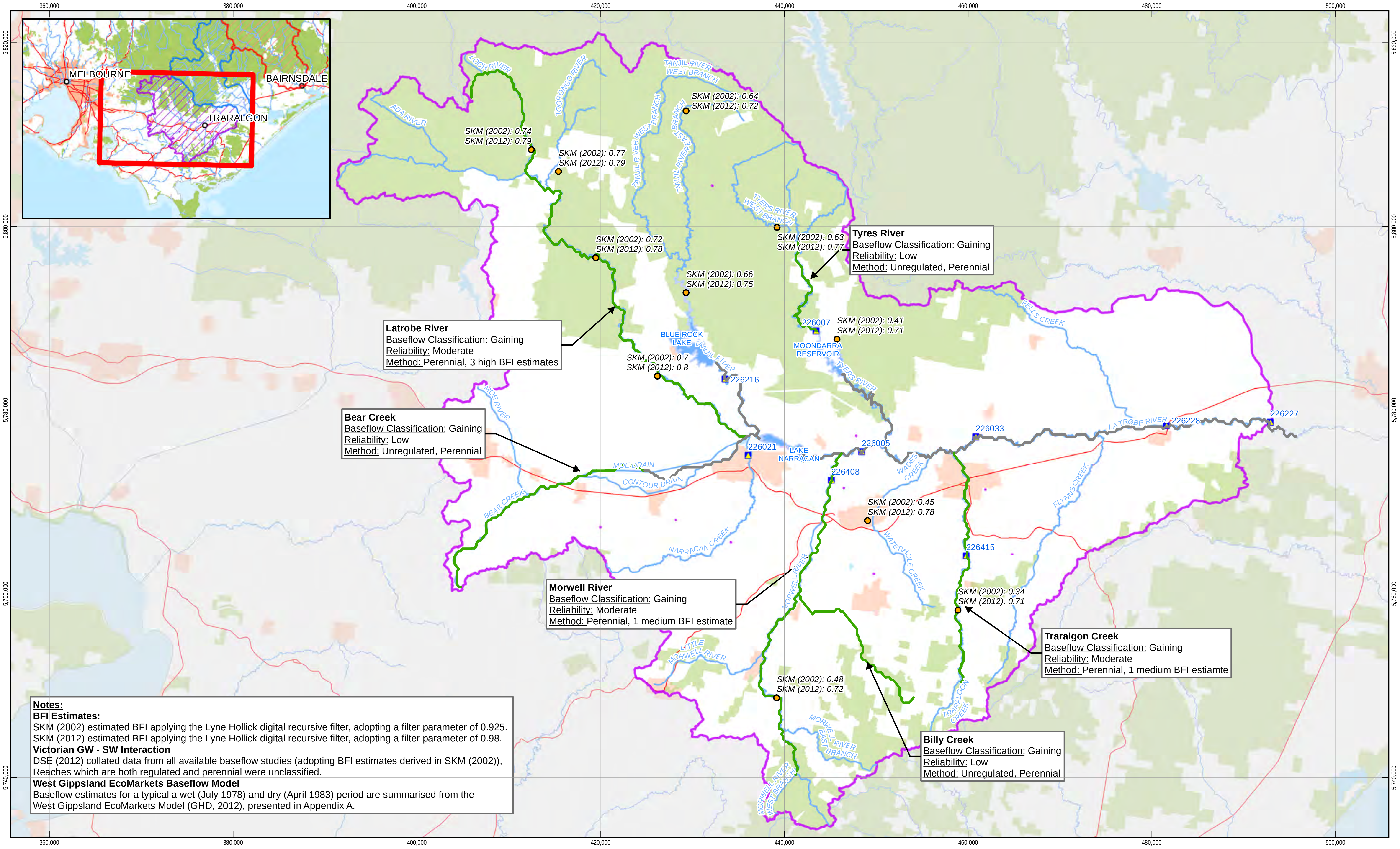
3.2.4 Summary of Inferred Baseflow Condition for the Latrobe River

The limited available earlier studies indicate that the Latrobe River can be classified as a primarily baseflow-gaining stream. However, it is noted that for much of the Latrobe catchment, this conclusion is primarily based on the ecoMarkets groundwater model, due to a lack of sufficient supporting information to inform the assessment of the SAFE project (Figure 11). The reason for the lower Latrobe River's baseflow gaining/losing condition being unclassified in the SAFE project is the significant effects of flow regulation by the three reservoirs, which precludes reliable application of the digital filter method used in that assessment.

The gauged stream flow and EC data, and groundwater/surface water level analysis presented in Section 3.2.1 indicate baseflow gaining conditions along the Latrobe River. This conclusion is however of low confidence because:

- There is only one suitable groundwater level observation site located sufficiently close to the Latrobe River for inferring baseflow status on the basis of groundwater levels relative to stream water levels. This site is located near Moe (800 m north the Moe Drain and 700 m west the Latrobe River), and hence much of the lower Latrobe River possesses no suitable data for similar analysis; and
- Industrial water offtakes and return of more saline water between Thoms Bridge and Rosedale, primarily by the coal mines, makes conclusions regarding baseflow status on the basis of observed stream EC increases difficult and prone to significant uncertainty.

Despite these limitations, the data analysed in this report, and the results of the ecoMarkets model, do tend to point towards dominantly baseflow-gaining conditions along the Latrobe River.



Tyres River
Baseflow Classification: Gaining
Reliability: Low
Method: Unregulated, Perennial

Latrobe River
Baseflow Classification: Gaining
Reliability: Moderate
Method: Perennial, 3 high BFI estimates

Bear Creek
Baseflow Classification: Gaining
Reliability: Low
Method: Unregulated, Perennial

Morwell River
Baseflow Classification: Gaining
Reliability: Moderate
Method: Perennial, 1 medium BFI estimate

Traralgon Creek
Baseflow Classification: Gaining
Reliability: Moderate
Method: Perennial, 1 medium BFI estiamte

Billy Creek
Baseflow Classification: Gaining
Reliability: Low
Method: Unregulated, Perennial

Notes:

BFI Estimates:
SKM (2002) estimated BFI applying the Lyne Hollick digital recursive filter, adopting a filter parameter of 0.925.
SKM (2012) estimated BFI applying the Lyne Hollick digital recursive filter, adopting a filter parameter of 0.98.

Victorian GW - SW Interaction
DSE (2012) collated data from all available baseflow studies (adopting BFI estimates derived in SKM (2002)), Reaches which are both regulated and perennial were unclassified.

West Gippsland EcoMarkets Baseflow Model
Baseflow estimates for a typical a wet (July 1978) and dry (April 1983) period are summarised from the West Gippsland EcoMarkets Model (GHD, 2012), presented in Appendix A.

Paper Size A3
0 2 4 8 12 16
Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

● BFI Estimates

Baseflow Classification
━ Gaining
━ Neutral - Losing

━ Unclassified
▲ Surface Water Gauges (Assessed)
■ Major Water Area
━ Major Watercourse

□ Latrobe River Catchment

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Revision 0
Date 27 May 2015

Latrobe River
SAFE Baseflow Studies

Figure 11

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Data source: DEWLP, VICMaps, 2015; GHD, Baseflow Catchments, 2015; DELWP, SAFE Datasets, 2012. Created by: adrummond

3.3 Thomson-Macalister River

Baseflow was previously assessed at the following seven gauges within the Thomson-Macalister River catchment (GHD, 2013a):

- Thomson River at Heyfield (225200)
- Macalister River at Lake Glenmaggie (Tail Gauge) (225204)
- Thomson River at Wandocka (225212)
- Thomson River U/S of Cowwarr Weir (225231)
- Thomson River at Bundalaguah (225232)
- Rainbow Creek at Heyfield (225236)
- Macalister River at Riverslea (225247)

3.3.1 Physical characteristics

Surface Water

Table 13 presents a summary of the gauged flow data for the assessed streamflow gauges within the Thomson-Macalister River catchment.

Table 13 Thomson-Macalister River Flow Data Summary

Gauge	Start Date	End Date	Count of readings	Mean flow (ML/day)	Median flow (ML/day)	95%ile flow (ML/day)	5%ile flow (ML/day)
225200	1/05/1992	1/03/2015	8266	215	137	584	45
225204	29/03/1960	11/02/2015	20004	881	223	4652	28
225212	30/03/1963	28/01/2015	17957	645	252	2237	77
225231	2/04/1976	8/02/2015	14367	587	323	1659	159
225232	4/11/1976	8/02/2015	11449	1082	333	4104	117
225236	10/04/1992	3/02/2015	8121	144	63	399	26
225247	12/01/2001	12/02/2015	4700	339	105	1825	25

Table 14 and Figure 12 present a summary of the surface water EC data for the assessed gauges within the Thomson-Macalister River catchment. For all gauges except 225232 (Thomson River at Bundalaguah) and 225247 (Macalister River at Riverslea), the bulk statistics suggest that there is very little contrast between gauged stream EC at low flows versus those at high flows. Occasionally for these gauges, the low flow EC can be slightly fresher than the high flow EC, which is counterintuitive to the underlying assumption of the EC mass balance method that low flows are largely supported by input from relatively saline groundwater. These observations are likely largely due to the EC-homogenising effect on stored and subsequently released water from the Thomson Dam. However, they could also result from, or be compounded by:

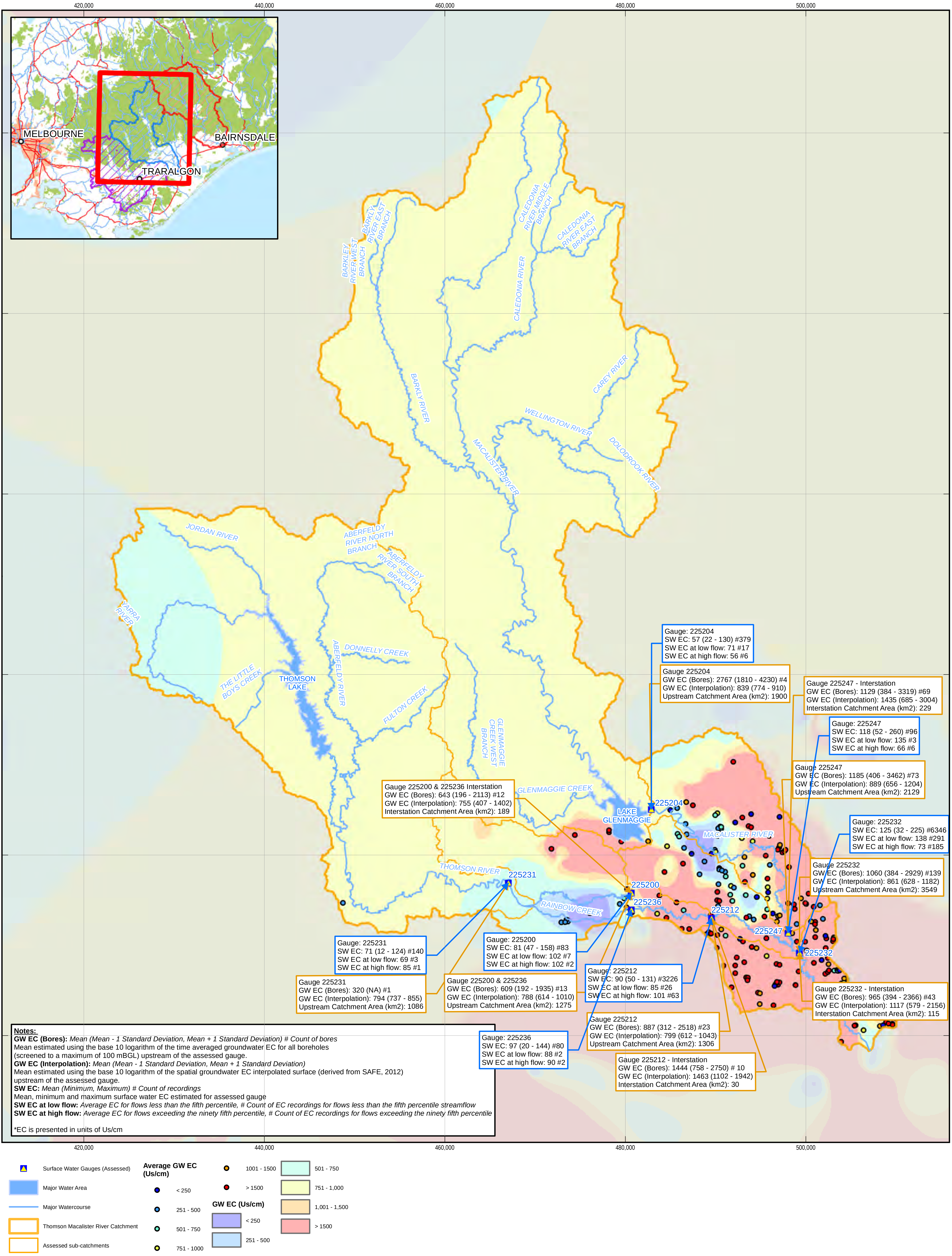
- Too small a contrast between groundwater EC and stream EC at higher stream flows, although this is not supported by the extensive groundwater data in this area (Table 16); and/or
- No or very little baseflow gain along the Thomson River between Cowwarr and Wandocka.

The greater contrast in stream EC at high versus low flows at the two gauges furthest downstream along the Thomson and Macalister Rivers (225232 and 225247), suggests that the rivers may become more baseflow dependent further downstream, and that the effects of reservoir releases on the stream EC signature diminish with distance downstream.

Given the minimal, and at times counterintuitive, contrast between stream EC at high versus low flows for the Thomson River gauges upstream of Wandocka, the upstream gauges are not good candidates for the EC mass balance method. However, as was recommended by Cartwright (2012) and proposed in Table 2, periods of the gauged records where there is a poor correlation between stream flow and EC should be removed from the analysis. However, it may be that there are no (or very limited) reliable periods of corresponding flow and EC data, and hence the baseflow analyses for these gauges are likely to remain at a very low level of confidence. This is further assessed and discussed in Section 4.

Table 14 Thomson-Macalister River Surface Water EC Data Summary

Gauge ID	Start Date	End Date	Count of EC readings	Mean EC [uS/cm] (Min - Max)	Average low flow [EC uS/cm] (count)	Average high flow [EC uS/cm] (count)
225200	25/01/2005	5/09/2012	83	81 (47 - 158)	102 (7)	103 (2)
225204	11/01/1990	4/12/2014	379	57 (22 - 130)	71 (17)	56 (6)
225212	9/01/1991	30/07/2014	3,226	90 (50 - 131)	85 (26)	101 (63)
225231	5/12/2002	29/12/2014	140	71 (12 - 124)	69 (3)	85 (1)
225232	20/12/1996	22/03/2015	6,346	125 (33 - 225)	138 (291)	73 (185)
225236	13/07/2005	5/09/2012	80	97 (20 - 144)	88 (2)	90 (2)
225247	16/12/1996	23/12/2014	96	118 (52 - 260)	135 (3)	66 (6)



Gauge: 225204
SW EC: 57 (22 - 130) #379
SW EC at low flow: 71 #17
SW EC at high flow: 56 #6

Gauge 225204
GW EC (Bores): 2767 (1810 - 4230) #4
GW EC (Interpolation): 839 (774 - 910)
Upstream Catchment Area (km2): 1900

Gauge 225247 - Interstation
GW EC (Bores): 1129 (384 - 3319) #69
GW EC (Interpolation): 1435 (685 - 3004)
Interstation Catchment Area (km2): 229

Gauge: 225247
SW EC: 118 (52 - 260) #96
SW EC at low flow: 135 #3
SW EC at high flow: 66 #6

Gauge 225247
GW EC (Bores): 1185 (406 - 3462) #73
GW EC (Interpolation): 889 (656 - 1204)
Upstream Catchment Area (km2): 2129

Gauge 225200 & 225236 Interstation
GW EC (Bores): 643 (196 - 2113) #12
GW EC (Interpolation): 755 (407 - 1402)
Interstation Catchment Area (km2): 189

Gauge: 225232
SW EC: 125 (32 - 225) #6346
SW EC at low flow: 138 #291
SW EC at high flow: 73 #185

Gauge 225232
GW EC (Bores): 1060 (384 - 2929) #139
GW EC (Interpolation): 861 (628 - 1182)
Upstream Catchment Area (km2): 3549

Gauge: 225231
SW EC: 71 (12 - 124) #140
SW EC at low flow: 69 #3
SW EC at high flow: 85 #1

Gauge: 225200
SW EC: 81 (47 - 158) #83
SW EC at low flow: 102 #7
SW EC at high flow: 102 #2

Gauge: 225212
SW EC: 90 (50 - 131) #3226
SW EC at low flow: 85 #26
SW EC at high flow: 101 #63

Gauge 225232 - Interstation
GW EC (Bores): 965 (394 - 2366) #43
GW EC (Interpolation): 1117 (579 - 2156)
Interstation Catchment Area (km2): 115

Gauge 225231
GW EC (Bores): 320 (NA) #1
GW EC (Interpolation): 794 (737 - 855)
Upstream Catchment Area (km2): 1086

Gauge 225200 & 225236
GW EC (Bores): 609 (192 - 1935) #13
GW EC (Interpolation): 788 (614 - 1010)
Upstream Catchment Area (km2): 1275

Gauge 225212
GW EC (Bores): 887 (312 - 2518) #23
GW EC (Interpolation): 799 (612 - 1043)
Upstream Catchment Area (km2): 1306

Gauge: 225236
SW EC: 97 (20 - 144) #80
SW EC at low flow: 88 #2
SW EC at high flow: 90 #2

Gauge 225212 - Interstation
GW EC (Bores): 1444 (758 - 2750) # 10
GW EC (Interpolation): 1463 (1102 - 1942)
Interstation Catchment Area (km2): 30

Notes:

GW EC (Bores): *Mean (Mean - 1 Standard Deviation, Mean + 1 Standard Deviation) # Count of bores*
Mean estimated using the base 10 logarithm of the time averaged groundwater EC for all boreholes (screened to a maximum of 100 mBGL) upstream of the assessed gauge.
GW EC (Interpolation): *Mean (Mean - 1 Standard Deviation, Mean + 1 Standard Deviation)*
Mean estimated using the base 10 logarithm of the spatial groundwater EC interpolated surface (derived from SAFE, 2012) upstream of the assessed gauge.
SW EC: *Mean (Minimum, Maximum) # Count of recordings*
Mean, minimum and maximum surface water EC estimated for assessed gauge
SW EC at low flow: *Average EC for flows less than the fifth percentile, # Count of EC recordings for flows less than the fifth percentile streamflow*
SW EC at high flow: *Average EC for flows exceeding the ninety fifth percentile, # Count of EC recordings for flows exceeding the ninety fifth percentile*

*EC is presented in units of Us/cm

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

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Thomson-Macalister River
EC Analysis

Figure 12

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Data source: DEWLP, VICMaps, 2015; GHD, Baseflow Catchments, 2015; DELWP, WMIS Surface and Groundwater Data, 2015. GHD, Groundwater EC Interpoalted Surface, 2013. Created by: adrummond

Comparison of gauged stream flows and EC for corresponding upstream and downstream gauges along the Thomson-Macalister River are presented in Figure 13. This is presented via scatter plots of upstream versus downstream flow and EC for each gauged reach, as recommended by Cartwright (2013) and proposed in Table 2. It serves as a basic check for potential baseflow gains along each reach, with increasing downstream EC and flow indicative of potential groundwater inputs.

Where flows into a reach are contributed from more than one stream (i.e. from tributaries), the upstream gauged EC data were calculated as flow-weighted values, to account for the differing rates of flow from the tributaries, and hence the differing relative EC input to the reach.

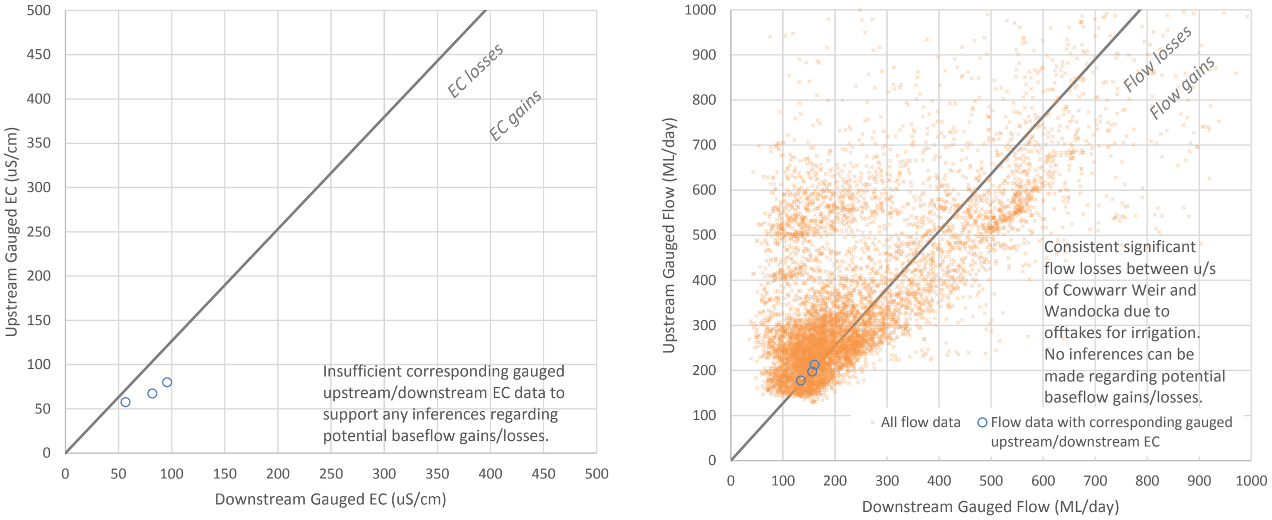
Flow data were assessed for the effect of travel times greater than one day down each reach; however, there is no evidence of significant time lags and therefore no adjustment has been made.

Figure 13 shows that stream EC consistently increases down each gauged reach of the Thomson-Macalister River, with the exception of the upper reach between Cowwarr Weir and Heyfield, for which there is too little data to make a firm conclusion. This suggests that the river is largely baseflow-dependent, except possibly in the reach between Cowwarr Weir and Heyfield. This is in agreement with the known historical saline shallow watertable issues in the Macalister Irrigation District (MID); a network of drains is used to manage this issue, with the saline drainage being returned to the river (see Section 3.2.2, Figure 18, Table 17 and Table 18). These drain returns can be primarily classified as regional groundwater, and therefore as baseflow for the purposes of this study.

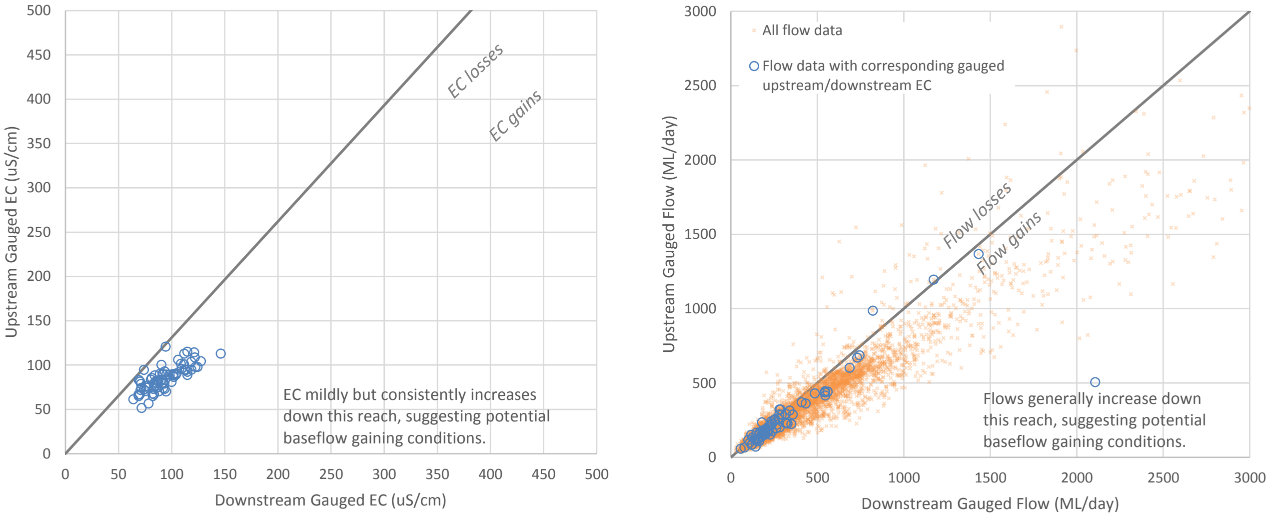
Comparison of the gauged upstream and downstream flow data in Figure 13 indicate significant systematic flow losses due to irrigation offtakes in the reach upstream of Heyfield. Further downstream towards Wandocka, both the flow and EC data indicate flow- and baseflow-gaining conditions. In the lower-most reach between Wandocka and Bundalaguah, the EC data suggest dominantly baseflow-gaining conditions, despite the flow data indicating that this reach variably gains/losses flow, probably to bank storage and/or water offtakes.

The Victorian government’s REALM model of the Thomson-Macalister catchment accounts for the surface water balance in some detail, including inflows, regulation and diversions. It indicates no net loss of surface water from the stream channel to groundwater once diversions are accounted for. This supports the above inference that the river is dominantly baseflow-gaining, and that the observed flow losses are likely due to the large diversions from the river.

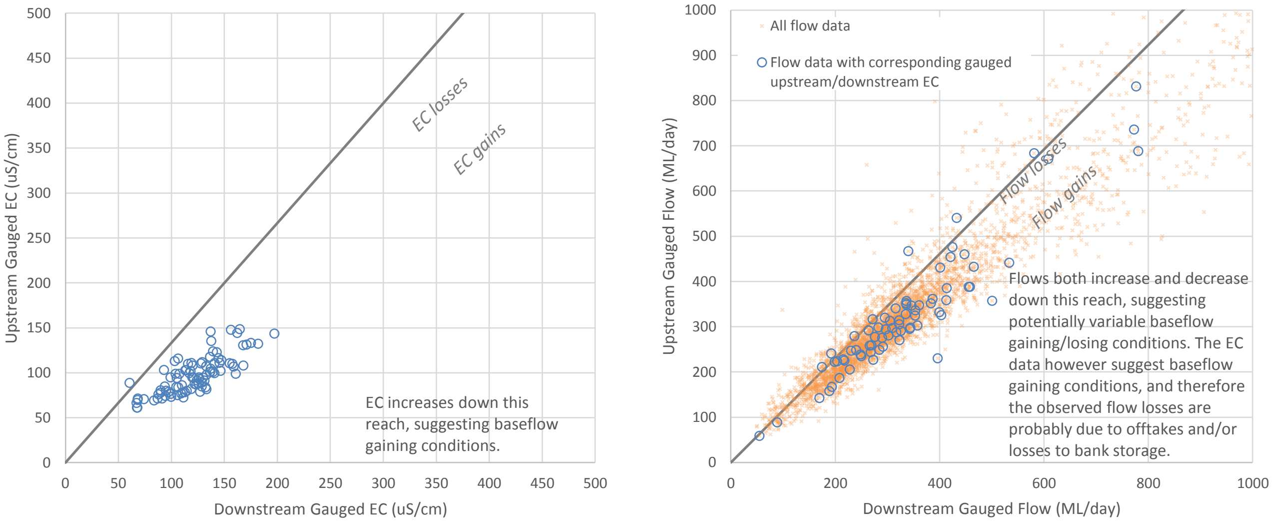
Thomson River u/s Cowwarr Weir (gauge 225231) to Heyfield (gauges 225200/225236)



Thomson River Heyfield (gauges 225200/225236) to Wandocka (gauge 225212)



Thomson River Wandocka (gauges 225212/225247) to Bundalaguah (gauge 225232)



NOTE: No evidence of significant time lags for flow down these river reaches.

Figure 13 Thomson-Macalister River - Comparison of Gauged Upstream/Downstream Stream Flow and EC Data

Groundwater EC

Figure 12 illustrates the spatial variability of groundwater EC across the Thomson-Macalister catchment, which transitions from moderately fresh groundwater in the north (750 – 1,000 uS/cm), to more saline in the south (> 1,500 uS/cm). Figure 12 highlights that there is a high density of groundwater monitoring data in the lower part of the catchment, with very limited data throughout the upper catchment.

Table 15 and Table 16 summarise the spatially averaged mean groundwater EC and the range (plus and minus one standard deviation from the mean), calculated using the interpolated groundwater EC surface and the time-average groundwater EC borehole estimates, for the total upstream catchment at each assessed gauge. Table 16 presents the groundwater EC statistics for the catchment area between each downstream gauge and its upstream counterpart (i.e. the interstation catchment), which will be useful for reach-scale mass balances, used for estimating baseflow gains along specific river reaches.

Table 15 Thomson-Macalister River - Groundwater EC Data Summary (total upstream catchment)

Gauge ID	Catchment Area (km^2)	GW EC [uS/cm] - Interpolated: Mean (Mean +/- 1 Standard Deviation)	GW EC [uS/cm] - Boreholes: Mean (Mean +/- 1 Standard Deviation)	Count of boreholes
225204	1,900	839 (774 - 910)	2,767 (1810 - 4230)	4
225231	1,086	794 (737 - 855)	320 (NA)	1
225247	2,129	889 (656 - 1204)	1,185 (406 - 3462)	73
225200	1,275	788 (614 - 1010)	609 (192 - 1935)	13
225232	3,549	861 (628 - 1182)	1,060 (384 - 2929)	139
225212	1,306	799 (612 - 1043)	887 (312 - 2518)	23

Table 16 Thomson-Macalister River - Groundwater EC Data Summary (interstation catchment)

Gauge ID	Catchment Area (km^2)	GW EC - Interpolated: Mean (Mean +/- 1 Standard Deviation)	GW EC - Boreholes: Mean (Mean +/- 1 Standard Deviation)	Count of boreholes
225212	30	1,463 (1102 - 1942)	1,444 (758 - 2750)	10
225200	189	755 (407 - 1402)	643 (196 - 2113)	12
225247	229	1,435 (685 - 3004)	1,129 (384 - 3319)	69
225232	115	1,117 (579 - 2156)	965 (394 - 2366)	43

Groundwater Levels

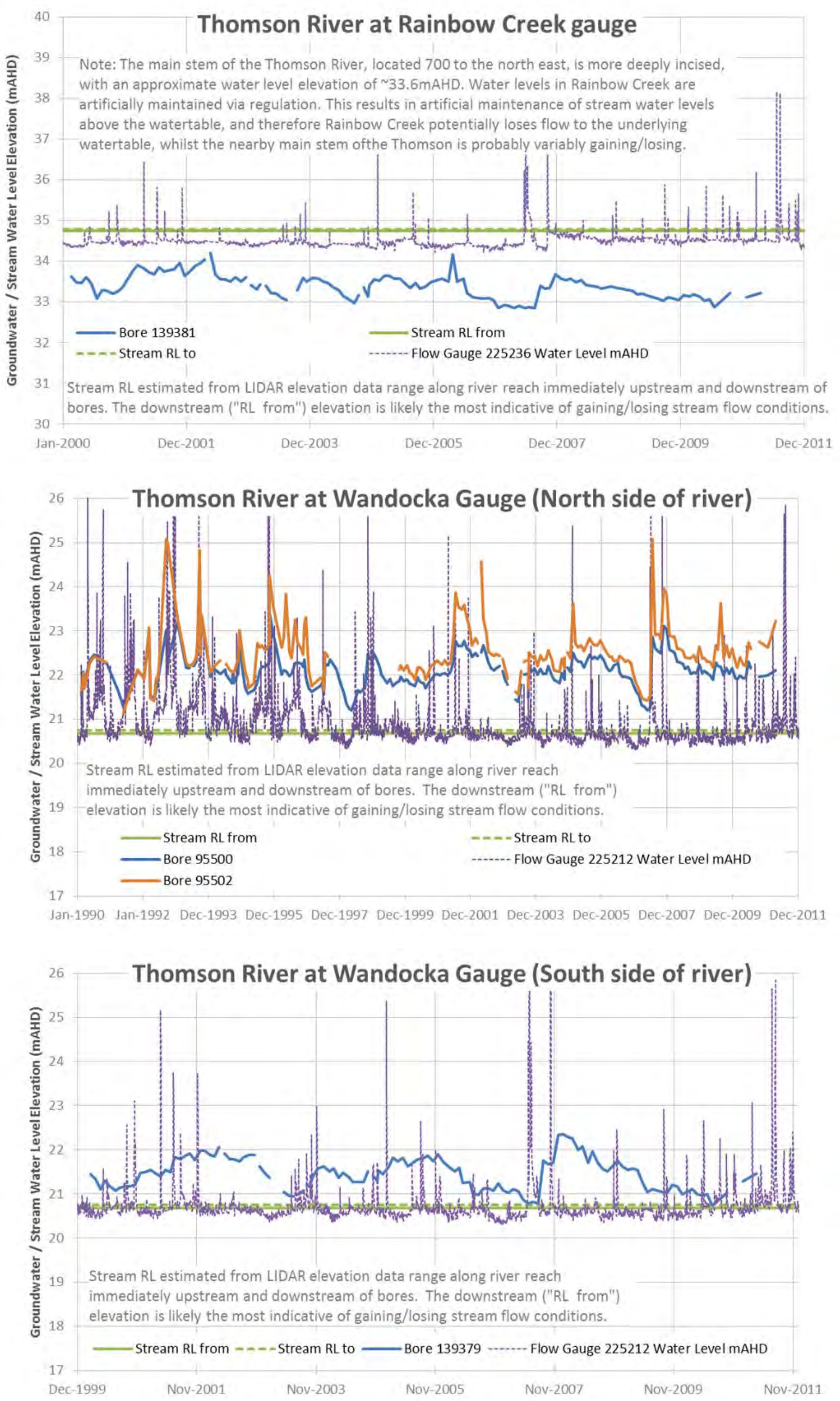
There are three groundwater observation bore locations along the Thomson River which are sufficiently close to the river to allow assessment of potential baseflow gaining or losing conditions. Two of these are located on either side of the river at the Wandocka gauge (225212), and the third is located at the Rainbow Creek gauge (225236). Time series of groundwater versus surface water levels at each of these sites are presented in Figure 14. These data indicate consistent baseflow gaining conditions around the Wandocka gauge, which is supported by the observed stream EC increases between Heyfield and Wandocka (Figure 13). The numerical modelling of GHD (2010a), the results of which (discussed in Section 3.2.3 and presented in Appendix A) support this conclusion based upon the modelled wet period baseflow gains, but contradicts the conclusion based upon the modelled 1983 dry period, in which the model simulates baseflow losses upstream of Wandocka. This could however have been a short-term response of the model to the extreme dry climate experienced at that time.

The observed groundwater level and surface water level data at the Rainbow Creek gauge (Figure 13) indicate consistent losing conditions, which is probably due to artificial maintenance of high stream water levels (above the watertable) via flow regulation. Local anecdotal experience from the West Gippsland CMA also suggests that the Thomson River is predominantly losing from Cowwarr Weir to some distance downstream of Heyfield (Anthony Goode, Personal Communication, 2015). The main stem of the Thomson River, located 700 m to the north east, is more deeply incised than Rainbow Creek, with an approximate water level elevation of ~33.6 mAHD (estimated using LiDAR data). It is noted there is moderately dense vegetation along the river banks and water within the river at the time of survey (based on inspection of high quality aerial imagery), which reduces the accuracy of the LiDAR survey.

Comparison of this approximate water level elevation with groundwater levels in bore 139381 (at Rainbow Creek; Figure 13) suggests that the nearby main stem of the Thomson may be variably gaining/losing, given that groundwater levels vary between approximately 33 and 34 mAHD. This latter conclusion is tentative however, given the 700 m distance between bore 139381 and the main stem of the Thomson.

These conclusions regarding Rainbow Creek and the Thomson River are generally supported by the numerical modelling of GHD (2010a) (Section 3.2.3 and Appendix A). This modelling indicates strongly losing conditions along Rainbow Creek during dry periods and variable gaining/losing conditions during wet periods. Along the Thomson River near Rainbow Creek, the model suggests variable gaining/losing conditions even during dry periods and gaining conditions in wet periods.

Comparison of groundwater levels with approximated surface water levels has also been made at four locations along the Macalister River (Figure 15). It should be noted that surface water levels have been estimated using LiDAR data, because there is only one gauge with a co-located groundwater observation bore (Riverlsea), although this has no recorded gauge zero elevation on DELWP’s WMIS database. Despite this limitation, the data suggest dominantly baseflow-gaining conditions down the Macalister River. At the upper end towards Lake Glenmaggie, and at the lower end towards Riverslea gauge, the river appears to be variably gaining/losing, although losing conditions appear to only occur periodically. This is supported by the observed stream EC increases on the Thomson River between Wandocka and Bundalaguah, into which the Macalister River flows (Figure 13). The modelling of GHD (2010) (Section 3.2.3 and Appendix A) generally supports these inferences for the modelled dry and wet periods, although the model suggests variably gaining/losing conditions during dry periods in the lower Macalister River.



Thomson River at Rainbow Creek gauge

Note: The main stem of the Thomson River, located 700 to the north east, is more deeply incised, with an approximate water level elevation of ~33.6mAHD. Water levels in Rainbow Creek are artificially maintained via regulation. This results in artificial maintenance of stream water levels above the watertable, and therefore Rainbow Creek potentially loses flow to the underlying watertable, whilst the nearby main stem ofthe Thomson is probably variably gaining/losing.

Stream RL estimated from LIDAR elevation data range along river reach immediately upstream and downstream of bores. The downstream ("RL from") elevation is likely the most indicative of gaining/losing stream flow conditions.

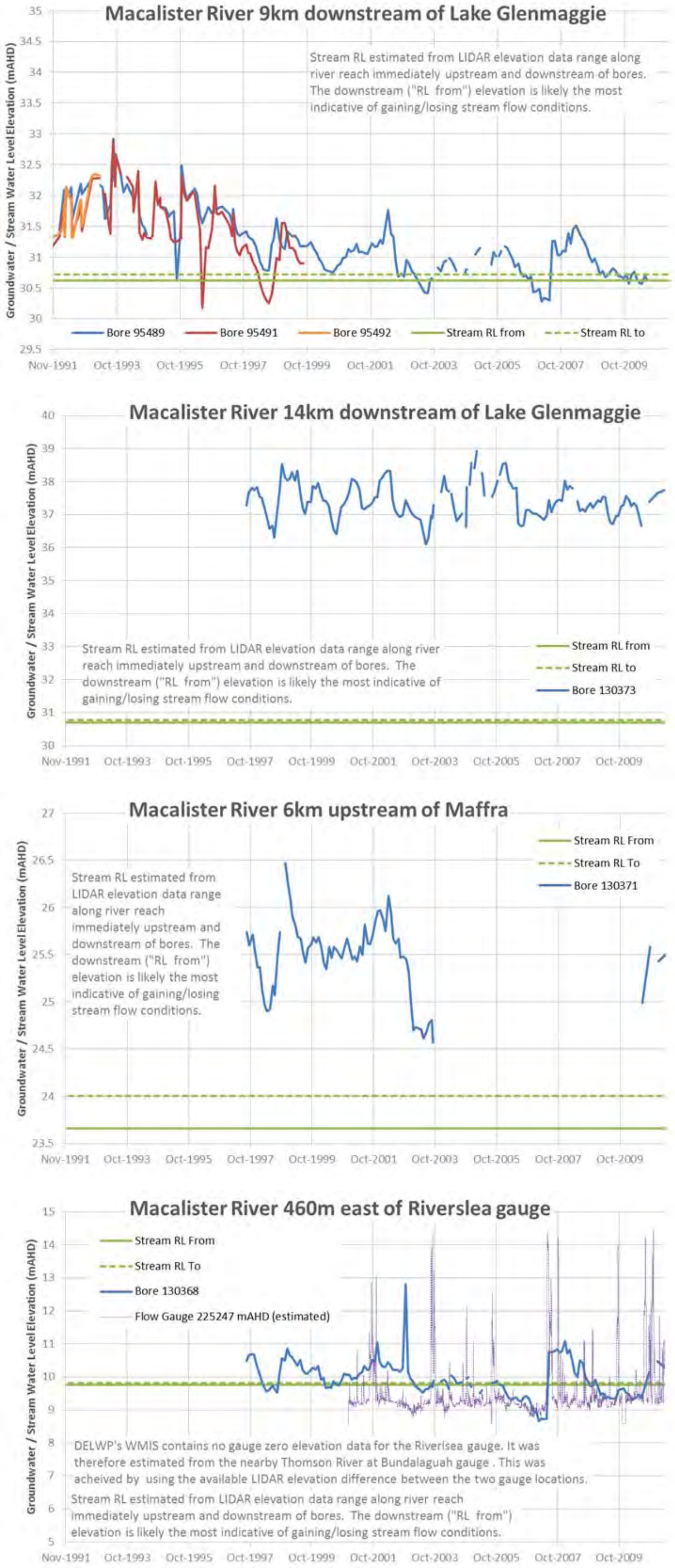
Thomson River at Wandocka Gauge (North side of river)

Stream RL estimated from LIDAR elevation data range along river reach immediately upstream and downstream of bores. The downstream ("RL from") elevation is likely the most indicative of gaining/losing stream flow conditions.

Thomson River at Wandocka Gauge (South side of river)

Stream RL estimated from LIDAR elevation data range along river reach immediately upstream and downstream of bores. The downstream ("RL from") elevation is likely the most indicative of gaining/losing stream flow conditions.

Figure 14 Thomson River Groundwater & Surface Water Level Hydrographs



Stream RL estimated from LIDAR elevation data range along river reach immediately upstream and downstream of bores. The downstream ("RL from") elevation is likely the most indicative of gaining/losing stream flow conditions.

Stream RL estimated from LIDAR elevation data range along river reach immediately upstream and downstream of bores. The downstream ("RL from") elevation is likely the most indicative of gaining/losing stream flow conditions.

Stream RL estimated from LIDAR elevation data range along river reach immediately upstream and downstream of bores. The downstream ("RL from") elevation is likely the most indicative of gaining/losing stream flow conditions.

DELWP's WMIS contains no gauge zero elevation data for the Riverlsea gauge. It was therefore estimated from the nearby Thomson River at Bundalaguah gauge . This was acheived by using the available LIDAR elevation difference between the two gauge locations.

Stream RL estimated from LIDAR elevation data range along river reach immediately upstream and downstream of bores. The downstream ("RL from") elevation is likely the most indicative of gaining/losing stream flow conditions.

Figure 15 Macalister River Groundwater & Surface Water Level Hydrographs

3.3.2 Water management characteristics

There are a range of water management actions that are undertaken in the Thomson-Macalister River catchment that impact streamflow and stream EC. These actions are illustrated in Figure 18 and discussed below.

Reservoirs

The catchment has two major storages: the Thomson Reservoir on the Thomson River; and Glenmaggie Reservoir on the Macalister River. These storages have a significant impact on the flow regime. Figure 16 and Figure 17 illustrate the effect of each storage on the flow regime. The reservoirs also affect downstream EC by allowing mixing of different salinity flows, resulting in a more uniform EC downstream of the reservoir. However, for this catchment, the EC upstream of the reservoirs is relatively low and not particularly variable with respect to flow or season, which results in a minor impact of the reservoirs on gauged stream EC.

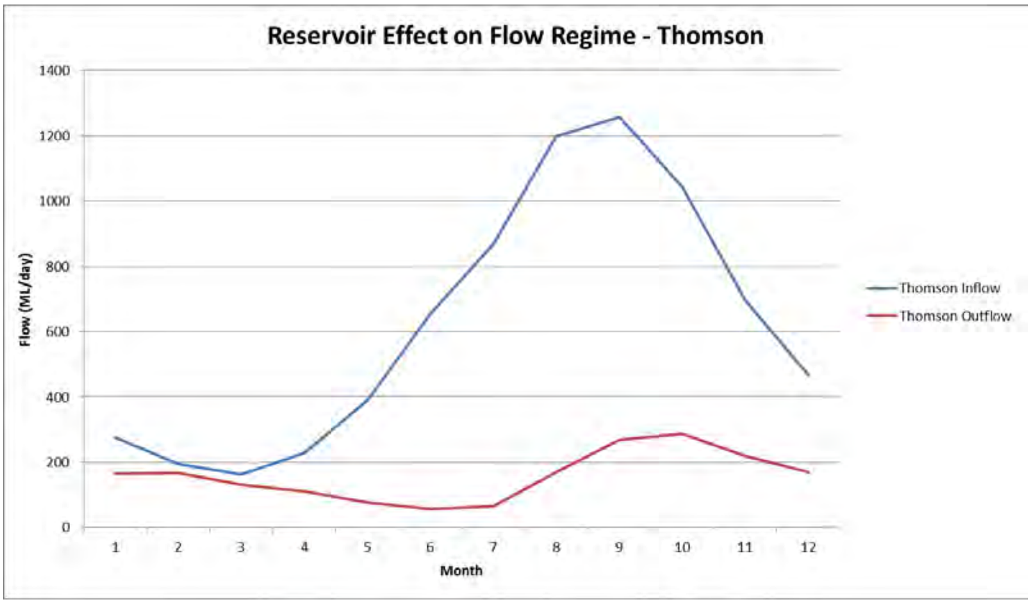


Figure 16 Reservoir effect on flow regime - Thomson

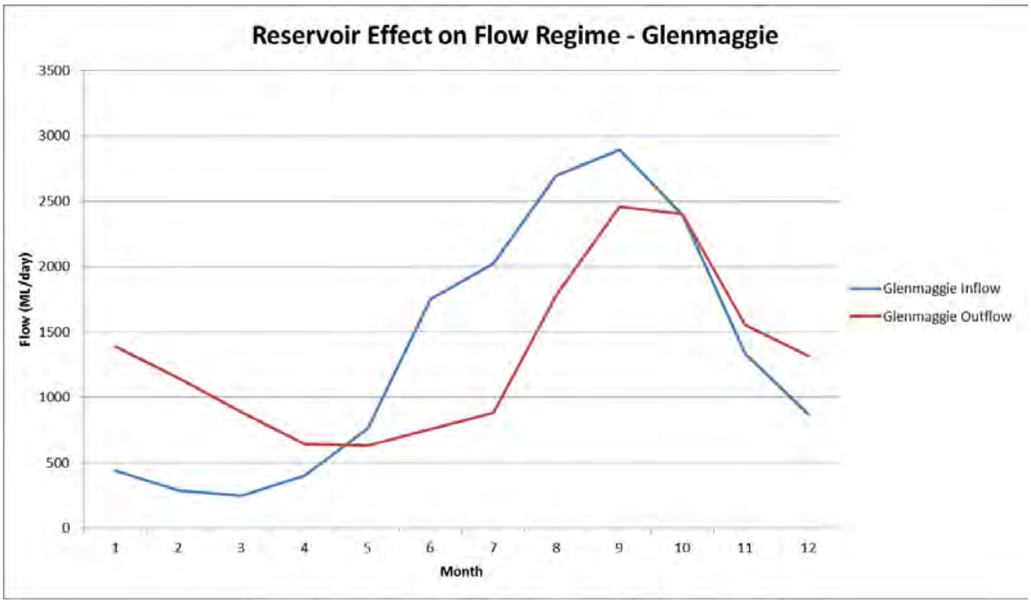
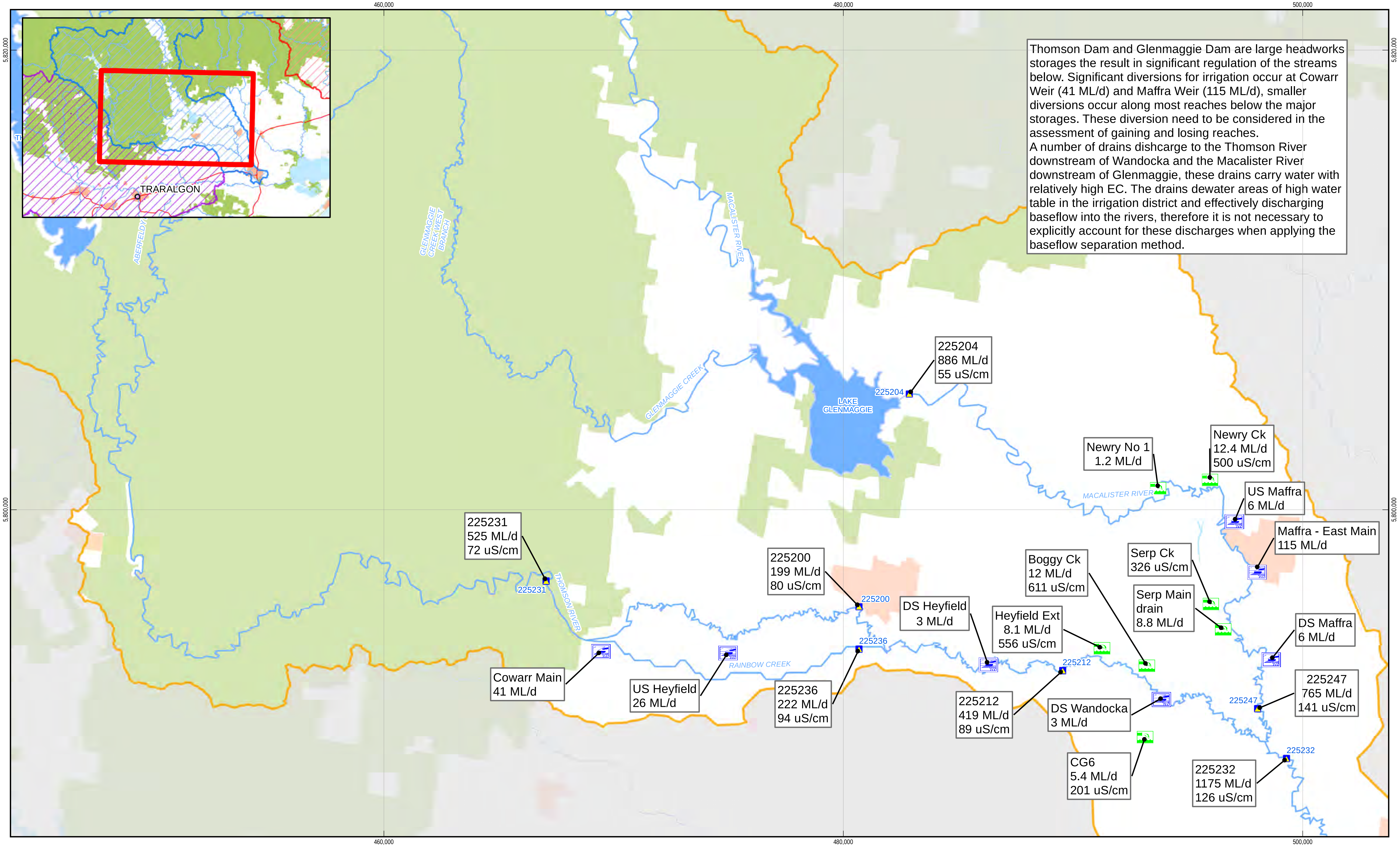


Figure 17 Reservoir effect on flow regime –Glenmaggie



Thomson Dam and Glenmaggie Dam are large headworks storages the result in significant regulation of the streams below. Significant diversions for irrigation occur at Cowarr Weir (41 ML/d) and Maffra Weir (115 ML/d), smaller diversions occur along most reaches below the major storages. These diversion need to be considered in the assessment of gaining and losing reaches.
A number of drains dishcarge to the Thomson River downstream of Wandocka and the Macalister River downstream of Glenmaggie, these drains carry water with relatively high EC. The drains dewater areas of high water table in the irrigation district and effectively discharging baseflow into the rivers, therefore it is not necessary to explicitly account for these discharges when applying the baseflow separation method.

Paper Size A3

0 0.5 1 2 3 4

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

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▲	Surface Water Gauges (Assessed)	▭	Thomson Macalister River Catchment
🟦	Major Water Area		
—	Major Watercourse	🟩	Drains
		🟧	Industry Returns
	Offtakes	▲	SW Gauges

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Job Number 31-32709
Revision 0
Date 27 May 2015

State Government Victoria

GHD

Thomson-Macalister River Water Management

Figure 18

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Data source: DEWLP, VICMaps, 2015; GHD, Baseflow Catchments, 2015; DELWP, WMIS Surface and Groundwater Data, 2015; SRW, Drain Data, 2015; DELWP, REALM Model results, 2015; EPA, Industrial Discharge Data, 2013-14. Created by: adrummond

Diversions

A number of water users divert from the streams: the most significant extraction on the Thomson River is at Cowwarr Weir (41 ML/d), while the most significant extraction on the Macalister River is at Maffra Weir (115 ML/d).

The diversions take a mix of baseflow and other flow components from the stream; therefore, do not have any impact on the application of the baseflow separation method at a single gauge location. Diversions do however have an effect on any interstation analysis of baseflow, and need to be taken into account.

Drainage

There are a number of drains that convey water from the southern part of the Macalister Irrigation District to the Thomson and Macalister rivers. These collect relatively saline water from high water table areas and discharge to the river. Southern Rural Water operates meters that measure flow and EC for the major drains and these are summarised in Table 17 and Table 18.

The discharge from these drains has an elevated EC in large part because these drains are collecting groundwater from high water table areas. It is therefore possible to consider these drain discharges as a mix of baseflow and other flow components in the same way that streamflow is treated.

It is possible that EC in these drains is elevated for other reasons, (for example fertilizer loading, and this could have an impact on the accuracy of the baseflow estimates. However, it is likely that at least some, if not most of this input will also be derived from groundwater, due to leaching of fertilisers down to the watertable. This is therefore considered a negligible issue for the baseflow analyses, and estimation of its effect would be tenuous at best.

Table 17 Thomson-Macalister Drain Flow Data Summary

Drain	Gauge	Start Date	End Date	Count of readings	Mean flow ML/day	Median flow ML/day	95%ile flow ML/day	5%ile flow ML/day
Central Gippsland 4	225725	24/06/2000	31/12/2013	4,746	11.7	8.4	0.3	27.6
Lake Wellington Main Drain	225730	22/08/1997	31/12/2013	5,833	17.0	7.8	1.0	61.3
Serpentine Creek/Main Drain	225244 / 225250	24/06/2000	31/12/2013	4,838	8.8	4.7	0.3	25.5
Newry Creek	225245	18/02/2000	31/12/2013	4,733	12.4	5.8	0.0	40.8
Nuntin	225251	6/10/2001	31/12/2013	4,135	5.5	4.1	0.0	14.8
Central Gippsland 6	225734	8/08/2001	31/12/2013	4,508	5.4	2.4	0.1	16.8
Bundalaguah	225732	3/08/2001	31/12/2013	4,353	5.0	1.3	0.0	17.7
Heyfield Extension	225733	9/08/2001	31/12/2013	4,123	8.1	1.9	0.2	30.8
Boggy Creek	225248	9/08/2001	30/06/2013	3,863	12.0	8.4	0.0	39.3
Lake Wellington 1	225745	1/07/2004	31/12/2013	3,363	4.1	2.0	0.1	16.1
Newry 1	225746	1/07/2004	31/12/2013	3,086	1.2	0.6	0.0	4.2

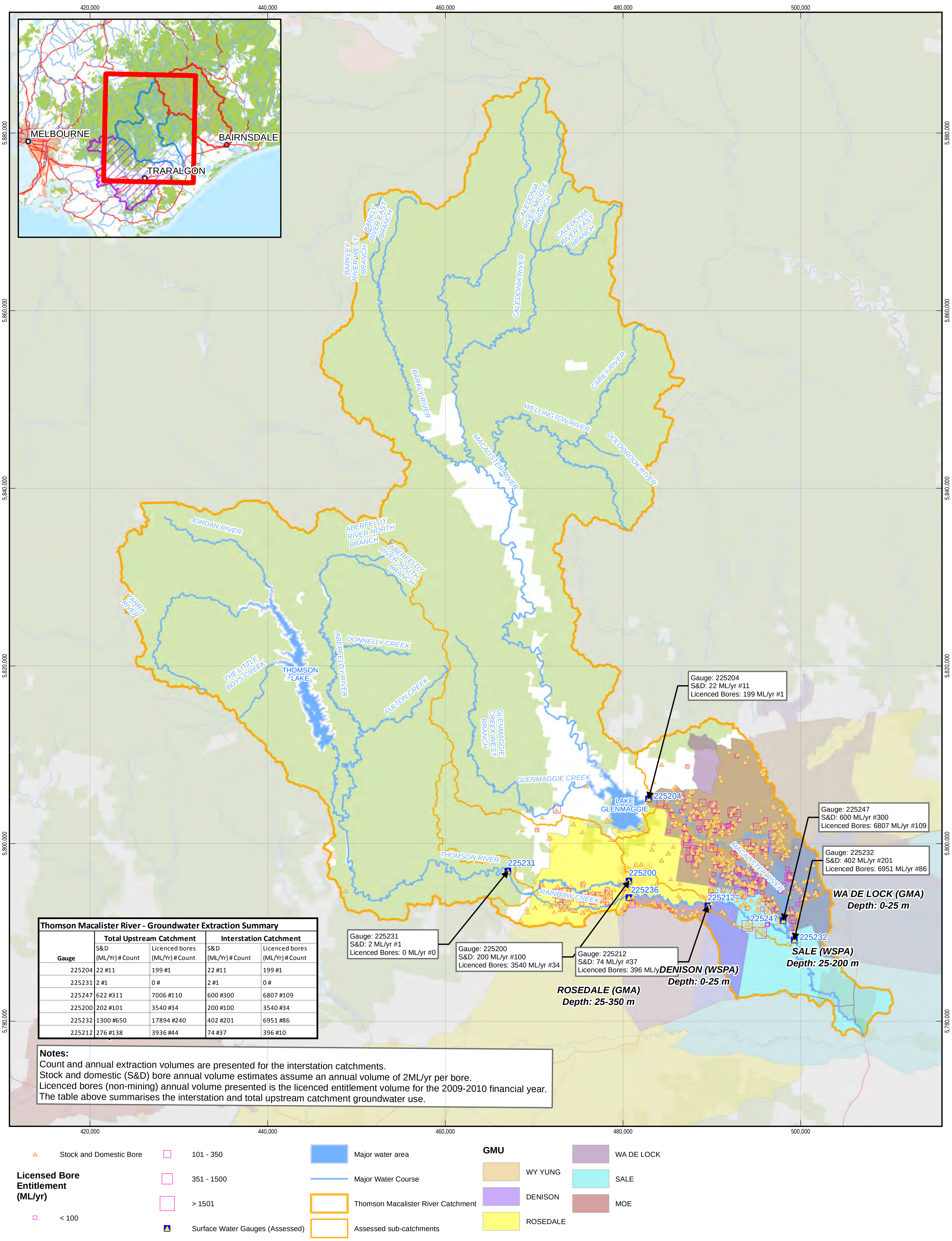
Table 18 Thomson-Macalister Drain EC Data Summary

Drain	Gauge ID	Start Date	End Date	Count of EC readings	Mean EC [uS/cm] (Min - Max)	95%ile EC [uS/cm]	5%ile EC [uS/cm]
Central Gippsland 4	225725	8/09/2000	4/10/2011	3,852	2,024 (24 – 8,060)	429	5,282
Lake Wellington Main Drain	225730	22/08/1997	31/12/2013	5,833	17.0	340.0	7,458.8
Serpentine Creek/Main Drain	225244/ 225250	24/06/2000	3/10/2011	3,883	374 (30 - 945)	199	677
Newry Creek	225245	19/02/2000	3/10/2011	3,722	551 (22 – 1,975)	241	1,026
Nuntin	225251	6/10/2001	4/10/2011	2,985	684 (18 – 1,805)	336	1,287
Central Gippsland 6	225734	8/08/2001	3/07/2006	1,765	431 (2 – 4,598)	75	1,980
Bundalaguah	225732	3/08/2001	1/10/2011	3,385	673 (56 – 3,202)	306	1,268
Heyfield Extension	225733	9/08/2001	3/10/2011	3,443	1278 (27 – 5,949)	156	4,554
Boggy Creek	225248	9/08/2001	3/10/2011	3,252	645 (67 – 2,381)	372	1,048
Lake Wellington 1	225745	26/02/2004	10/09/2014	3,711	1850 (24 – 6,858)	266	4,594

Groundwater Management

Figure 19 summarises the groundwater extractions from stock and domestic bores, and licensed groundwater extractions across the Thomson-Macalister River catchment. Extractions are summarised for both the interstation catchment and the total upstream catchment.

The figure highlights that the majority of the stock and domestic and licensed groundwater extractions are concentrated in the lower reaches of the Macalister River (Wa De Lock and Sale Groundwater Management Areas), and the lower reaches of the Thomson River (Denison Water Supply Protection Area and the Rosedale and Sale Groundwater Management Areas). The large volumes of groundwater extraction in these catchments likely reduce baseflow to streams along these reaches. The effect of this on the baseflow estimates presented in this project is that the estimated baseflows reflect the groundwater discharge to streams, after depletion by groundwater extraction. This was discussed in detail by GHD (2013a), and is incorporated into the assessment of risks to environmental flows in GHD (2013a). The upper reaches of the Macalister and Thomson Rivers have minimal groundwater extraction; therefore, it is expected that baseflow in these catchments are not influenced by pumping.



Gauge: 225204
S&D: 22 ML/yr #11
Licenced Bores: 199 ML/yr #1

Gauge: 225247
S&D: 600 ML/yr #300
Licenced Bores: 6807 ML/yr #109

Gauge: 225232
S&D: 402 ML/yr #201
Licenced Bores: 6951 ML/yr #86

Gauge: 225231
S&D: 2 ML/yr #1
Licenced Bores: 0 ML/yr #0

Gauge: 225200
S&D: 200 ML/yr #100
Licenced Bores: 3540 ML/yr #34

Gauge: 225212
S&D: 74 ML/yr #37
Licenced Bores: 396 ML/y

Thomson Macalister River - Groundwater Extraction Summary

Gauge	Total Upstream Catchment		Interstation Catchment	
	S&D (ML/Yr) # Count	Licenced bores (ML/Yr) # Count	S&D (ML/Yr) # Count	Licenced bores (ML/Yr) # Count
225204	22 #11	199 #1	22 #11	199 #1
225231	2 #1	0 #	2 #1	0 #
225247	622 #311	7006 #110	600 #300	6807 #109
225200	202 #101	3540 #34	200 #100	3540 #34
225232	1300 #650	17894 #240	402 #201	6951 #86
225212	276 #138	3936 #44	74 #37	396 #10

Notes:
Count and annual extraction volumes are presented for the interstation catchments.
Stock and domestic (S&D) bore annual volume estimates assume an annual volume of 2ML/yr per bore.
Licenced bores (non-mining) annual volume presented is the licenced entitlement volume for the 2009-2010 financial year.
The table above summarises the interstation and total upstream catchment groundwater use.

Paper Size A3
0 1.5 3 6 9 12
Kilometers
Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

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Gippsland River Baseflow Assessment

Job Number	31-32709
Revision	0
Date	24 Apr 2015

Thomson Macalister River Groundwater Extraction

Figure 19

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Data source: DEWLP, VICMaps, 2015; GHD, Baseflow Catchments, 2015; DELWP, WMIS Surface and Groundwater Data, 2015. SRW, Licenced GW Use Volume (2010). GHD, Mine Use Volume (2014). Created by: adrummond

3.3.3 Local baseflow assessments

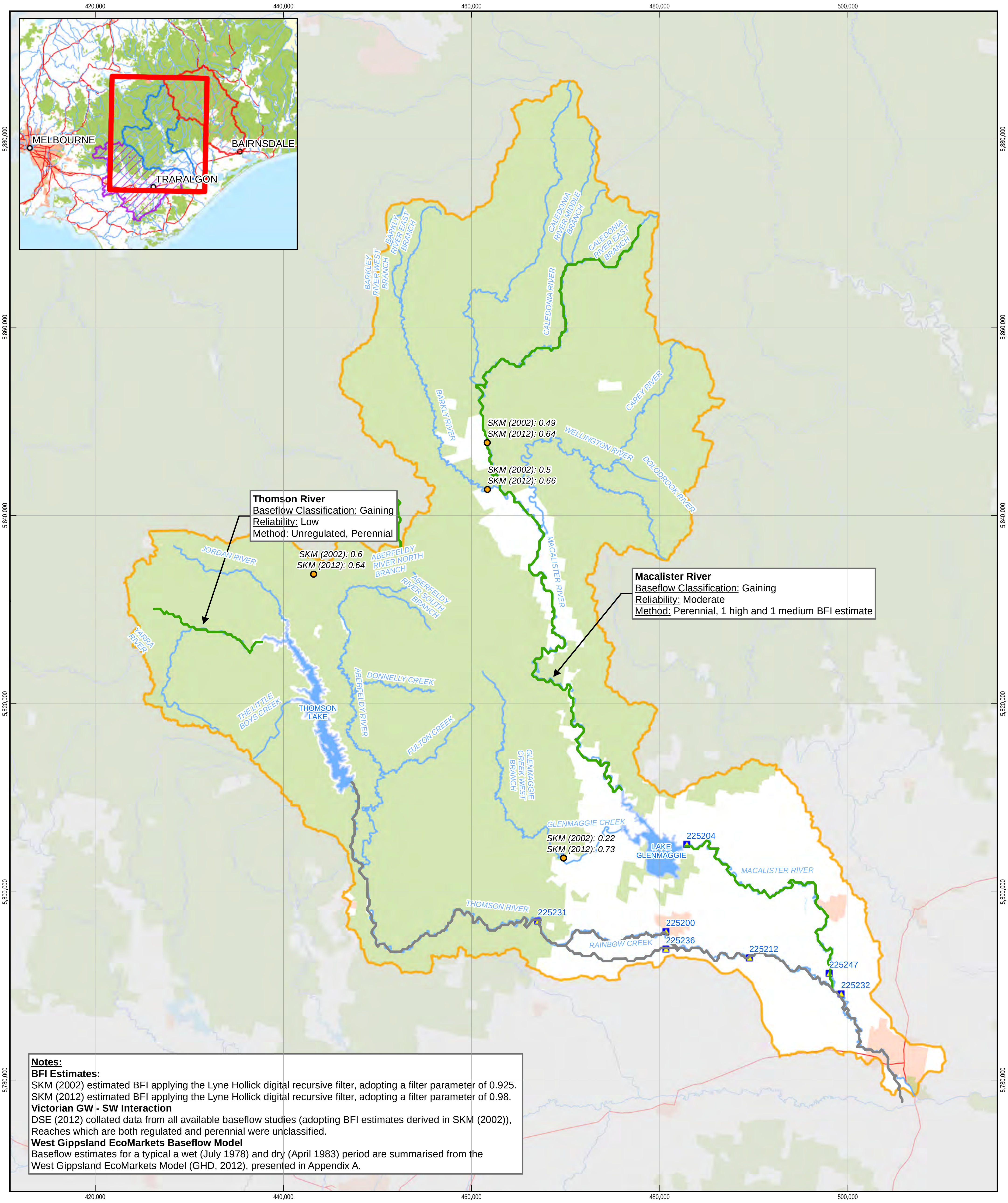
SAFE

Figure 20 presents a summary of the numerous baseflow investigations conducted across the Thomson-Macalister River catchment, collated as part of the SAFE project. The Macalister River to its confluence with the Thomson River has been classified as a gaining reach (moderate confidence rating), primarily given that it is perennial. SKM (2012) estimated one baseflow index in the catchment's upper reaches on the Macalister River, using the Lyne and Hollick (1979) digital filter. SKM (2012) indicates that the BFI estimate for the Macalister River and Barkly River is relatively high (0.64 – 0.66), compared to the moderate BFI estimate (0.49 – 0.50) derived in SKM (2002).

The Thomson River upstream of the Thomson Dam has been classified as baseflow gaining, given that it is unregulated and perennial, although no baseflow estimates were derived for this reach by SKM (2012). The Thomson River downstream of Thomson Dam has not been classified, given that its flow becomes heavily regulated via controlled reservoir releases beyond this point.

ecoMarkets

Appendix A presents spatial baseflow gains and losses across the Thomson-Macalister River catchment for wet (July 1978) and dry (April 1983) periods, based on numerical modelling of the West Gippsland ecoMarkets Model (GHD, 2010a). The model indicates that the majority of the Thomson-Macalister catchment is baseflow gaining during wet periods, especially in the upper reaches, but also in the lower catchment. During a dry period (April 1983), the model results indicate that the upper reaches of the Thomson-Macalister catchment remain weakly baseflow-gaining, and the lower reaches of the Thomson and Macalister Rivers can become baseflow neutral to strongly baseflow-losing.



Thomson River
Baseflow Classification: Gaining
Reliability: Low
Method: Unregulated, Perennial

Macalister River
Baseflow Classification: Gaining
Reliability: Moderate
Method: Perennial, 1 high and 1 medium BFI estimate

Notes:
BFI Estimates:
SKM (2002) estimated BFI applying the Lyne Hollick digital recursive filter, adopting a filter parameter of 0.925.
SKM (2012) estimated BFI applying the Lyne Hollick digital recursive filter, adopting a filter parameter of 0.98.
Victorian GW - SW Interaction
DSE (2012) collated data from all available baseflow studies (adopting BFI estimates derived in SKM (2002)),
Reaches which are both regulated and perennial were unclassified.
West Gippsland EcoMarkets Baseflow Model
Baseflow estimates for a typical a wet (July 1978) and dry (April 1983) period are summarised from the
West Gippsland EcoMarkets Model (GHD, 2012), presented in Appendix A.

● BFI Estimates

Baseflow Classification

— Gaining

— Neutral - Losing

— Unclassified

▲ Surface Water Gauges (Assessed)

🟦 Major Water Area

— Major Watercourse

☐ Thomson Macalister River Catchment

Paper Size A3
0 1.5 3 6 9 12
Kilometers
Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

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GHD

State Government Victoria

Department of Environment, Land, Water & Planning
Gippsland River Baseflow Assessment

Job Number	31-32709
Revision	0
Date	27 May 2015

Thomson-Macalister River
SAFE Baseflow Studies

Figure 20

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Data source: DEWLP, VICMaps, 2015; GHD, Baseflow Catchments, 2015; DELWP, SAFE Datasets, 2012. Created by: adrummond

3.3.4 Summary of inferred baseflow condition for the Thomson-Macalister River

The limited available earlier studies indicate that the Thomson-Macalister River can be classified as a primarily baseflow-gaining stream, except periodically during dry periods. The surface water flow and EC data analysed in Section 3.3.1 indicate dominantly gaining baseflow conditions for the Thomson River downstream of Heyfield. This is primarily based on observed stream EC gains down this reach, which is in agreement with the historical issues with shallow saline watertable drainage from the Macalister Irrigation District. The groundwater level / surface water level analysis presented in Section 3.3.1 also supports this, with dominantly baseflow gaining conditions, except:

- In the lower Macalister River where the river appears to become locally losing during dry periods – around 9 km downstream of Lake Glenmaggie, and most likely at the Riverslea gauge. However, it should be noted that groundwater level data from the area between these two locations indicates consistent strongly baseflow-gaining conditions, even in dry periods, and
- Around Rainbow Creek near Heyfield, where artificial maintenance of elevated surface water levels relative to the regional watertable appears to result in persistent locally losing conditions. On the nearby main stem of the Thomson River in this area however, variable gaining/losing conditions appear to prevail, because of its greater depth of incision compared to Rainbow Creek.

Given that these are spatially and temporally-isolated exceptions, it is concluded that the Thomson-Macalister catchment can be classified as broadly baseflow-gaining for the purposes of this assessment.

3.4 Mitchell River

Baseflow was previously assessed at the following two gauges within the Mitchell River catchment (GHD, 2013a):

- Mitchell River at Glenaladale (224203), and
- Mitchell River at Rosehill (224217).

3.4.1 Physical characteristics

Surface Water

Table 19 presents a summary of the gauged flow data for the assessed surface water gauges within the Mitchell River catchment.

Table 20 and Figure 21 present a summary of the surface water EC data for the assessed gauges within the Mitchell River catchment.

Table 19 Mitchell River Flow Data Summary

Gauge	Start Date	End Date	Count of readings	Mean flow (ML/day)	Median flow (ML/day)	95%ile flow (ML/day)	5%ile flow (ML/day)
224203	8/08/1937	26/01/2015	28,296	2,338	1,153	7,905	96
224217	30/10/1976	22/02/2015	5,140	1,975	1,052	6,348	41

Table 20 Mitchell River Surface Water EC Data Summary

Gauge ID	Start Date	End Date	Count of EC readings	Mean EC [uS/cm] (Min - Max)	Average low flow EC [uS/cm] (count)	Average high flow EC [uS/cm] (count)
224203	9/01/1990	15/12/2014	290	62 (15 - 140)	87 (23)	39 (3)
224217	8/04/2003	29/12/2014	527	89 (9 - 312)	241 (27)	47 (23)

The bulk statistics presented in Table 20 suggest that there is sufficient contrast between stream EC at high flows versus that at low flows, which supports the application of the EC mass balance method for baseflow estimation at these gauges.

Comparison of gauged stream flows and EC for corresponding upstream and downstream gauges along the Mitchell River are presented in Figure 22. This is presented via scatter plots of upstream versus downstream flow and EC for each gauged reach, as recommended by Cartwright (2013) and proposed in Table 2. It serves as a basic check for potential baseflow gains along each reach, with increasing downstream EC and flow indicative of potential groundwater inputs.

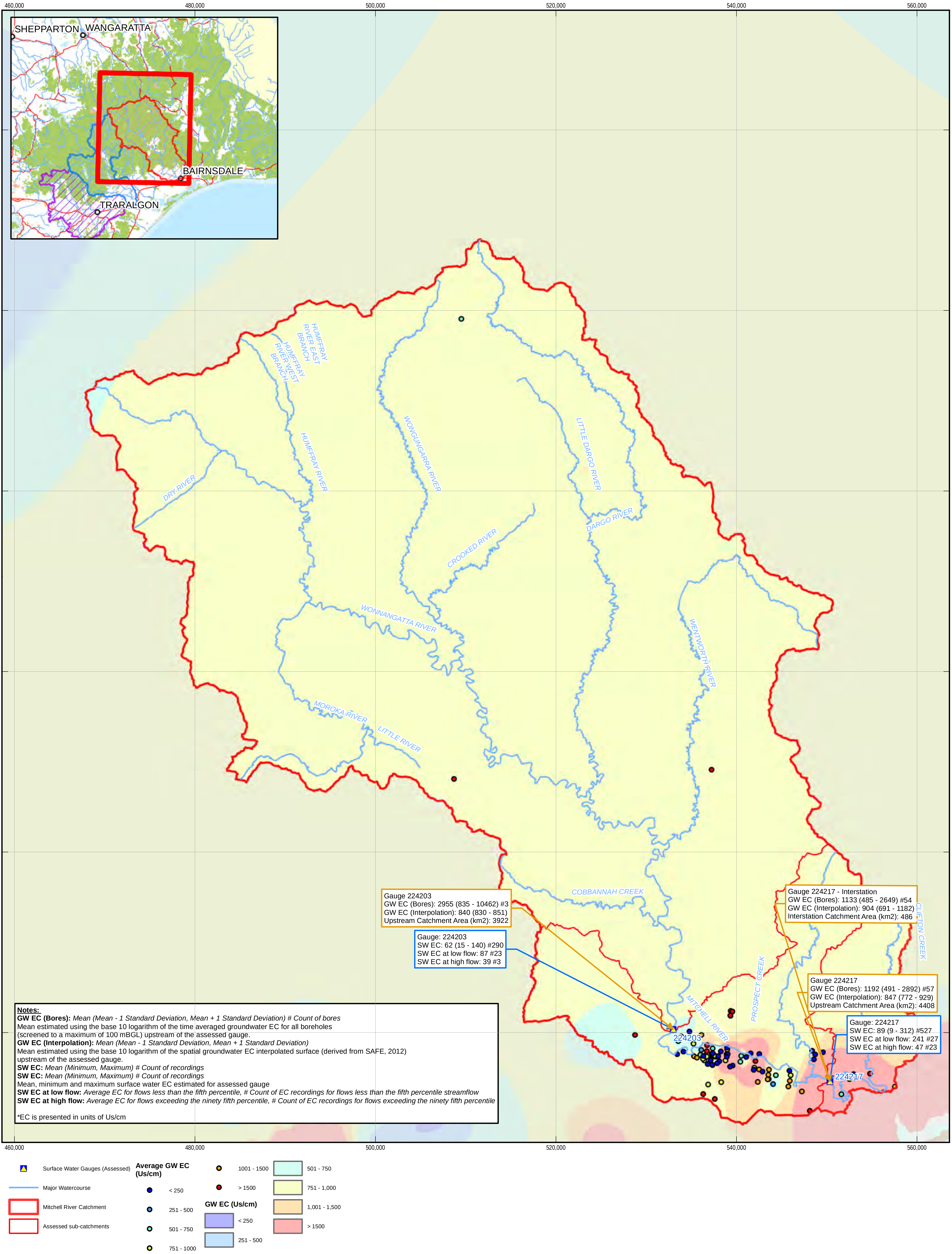
Flow data were assessed for the effect of travel times greater than one day down each reach. There is no evidence of significant time lags and therefore no adjustment has been made.

Figure 22 shows that stream EC consistently increases down the Mitchell River. This suggests that the river is largely baseflow-dependent. Comparison of gauged upstream and downstream flow data in Figure 22 indicate variably gaining/losing flow down the Mitchell River. This may be indicative of seasonal losses to bank storage, which were identified by Hofmann (2011) using radon and chloride mass balances (see Section 3.4.3). However, the observed flow gains and losses are affected by known surface water and groundwater usage from this reach (Figure 24 and Figure 25), in addition to ungauged tributary inflows near Rosehill. Surface water diversions will need to be taken into account for more reliable interstation baseflow analysis.

The Victorian government's REALM model of the Mitchell River catchment accounts for all surface water balance components, including inflows and diversions. It indicates a net loss of surface water from the stream channel along its length, even once diversions are accounted for. This conflicts with the above inference that the river is dominantly baseflow-gaining, but this water loss from the REALM model may reflect Hofmann's (2011) observation that there are significant periodic / seasonal losses of river water to bank storage. It is noted however that the REALM model's loss along the Mitchell River between Glenaladale and Rosehill is defined as a 20% loss for flows below 100 ML/day, which is in disagreement with flow losses being to bank storage – because bank storage losses typically occur at higher flows (Hofmann, 2011). There may be other reasons for the observed stream flow losses, for example:

- Stream depletion by groundwater pumping along the Mitchell River flats;
- Evapotranspiration of surface water, although Hofmann (2011) notes that this component of the reach-scale water balance is typically negligible;
- Flow gauging errors; and/or
- Unaccounted for surface water diversions.

Despite the unexplained flow losses, at this stage it is concluded that the Mitchell River can be classified as a primarily baseflow-gaining stream, based on the detailed work of Hofmann (2011), and supported by the observed stream EC increases down the river, and the numerical modelling of GHD (2010).



Gauge 224203
GW EC (Bores): 2955 (835 - 10462) #3
GW EC (Interpolation): 840 (830 - 851)
Upstream Catchment Area (km2): 3922

Gauge: 224203
SW EC: 62 (15 - 140) #290
SW EC at low flow: 87 #23
SW EC at high flow: 39 #3

Gauge 224217 - Interstation
GW EC (Bores): 1133 (485 - 2649) #54
GW EC (Interpolation): 904 (691 - 1182)
Interstation Catchment Area (km2): 486

Gauge 224217
GW EC (Bores): 1192 (491 - 2892) #57
GW EC (Interpolation): 847 (772 - 929)
Upstream Catchment Area (km2): 4408

Gauge: 224217
SW EC: 89 (9 - 312) #527
SW EC at low flow: 241 #27
SW EC at high flow: 47 #23

Notes:
GW EC (Bores): *Mean (Mean - 1 Standard Deviation, Mean + 1 Standard Deviation) # Count of bores*
Mean estimated using the base 10 logarithm of the time averaged groundwater EC for all boreholes
(screened to a maximum of 100 mBGL) upstream of the assessed gauge.
GW EC (Interpolation): *Mean (Mean - 1 Standard Deviation, Mean + 1 Standard Deviation)*
Mean estimated using the base 10 logarithm of the spatial groundwater EC interpolated surface (derived from SAFE, 2012)
upstream of the assessed gauge.
SW EC: *Mean (Minimum, Maximum) # Count of recordings*
SW EC: *Mean (Minimum, Maximum) # Count of recordings*
Mean, minimum and maximum surface water EC estimated for assessed gauge
SW EC at low flow: *Average EC for flows less than the fifth percentile, # Count of EC recordings for flows less than the fifth percentile streamflow*
SW EC at high flow: *Average EC for flows exceeding the ninety fifth percentile, # Count of EC recordings for flows exceeding the ninety fifth percentile*

*EC is presented in units of Us/cm

Paper Size A3
0 1.5 3 6 9 12
Kilometers
Map Projection: Lambert Conformal Conic
Horizontal Datum: GDA 1994
Grid: GDA 1994 VICGRID94

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Gippsland River Baseflow Assessment

Mitchell River
EC Analysis

Job Number	31-32709
Revision	0
Date	27 May 2015

Figure 21

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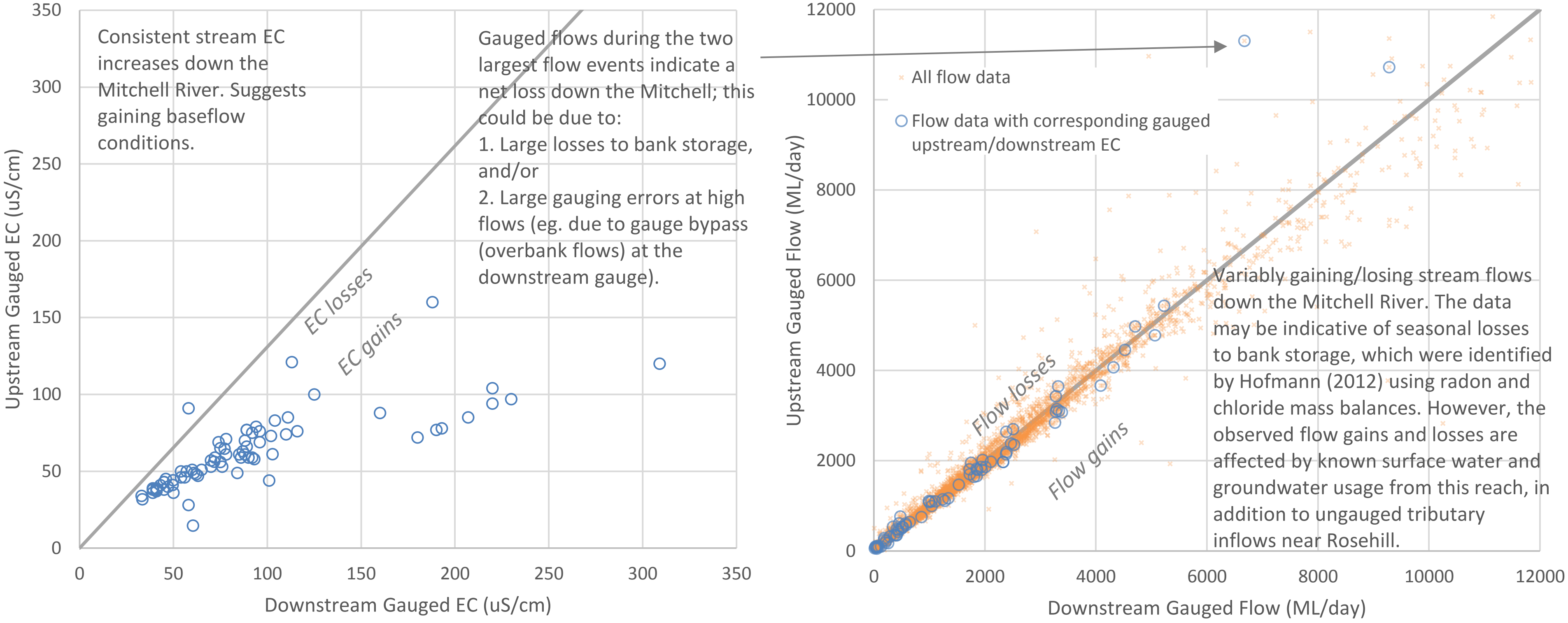
Data source: DEWLP, VICMaps, 2015; GHD, Baseflow Catchments, 2015; DELWP, WMIS Surface and Groundwater Data, 2015. GHD, Groundwater EC Interpoalted Surface, 2013. Created by: adrummond

Mitchell River Glenaladale (gauge 224203) to Rosehill (gauge 224217)



Consistent stream EC increases down the Mitchell River. Suggests gaining baseflow conditions.

Gauged flows during the two largest flow events indicate a net loss down the Mitchell; this could be due to:

1. Large losses to bank storage, and/or
2. Large gauging errors at high flows (eg. due to gauge bypass (overbank flows) at the downstream gauge).

Variably gaining/losing stream flows down the Mitchell River. The data may be indicative of seasonal losses to bank storage, which were identified by Hofmann (2012) using radon and chloride mass balances. However, the observed flow gains and losses are affected by known surface water and groundwater usage from this reach, in addition to ungauged tributary inflows near Rosehill.

NOTE: No evidence of significant time lags for flow down this river reach.

Figure 22 Mitchell River - Comparison of Gauged Upstream/Downstream Stream Flow and EC Data

Groundwater EC

Figure 21 and Table 21 summarise the spatially averaged mean groundwater EC and the range (plus and minus one standard deviation from the mean), for the total upstream catchment at each assessed gauge. These averaged data were calculated using the interpolated groundwater EC surface, and the time-averaged groundwater EC at each borehole. Table 22 presents the groundwater EC statistics for the catchment area between each downstream gauge and its upstream counterpart (i.e. the interstation catchment), which will be useful for reach-scale mass balances for estimating baseflow gains along specific river reaches.

Figure 21 illustrates the spatial variability in groundwater EC concentration across the Mitchell River catchment. EC transitions from moderately fresh in the north (750 – 1,000 uS/cm) to moderately saline in the south (> 1,500 uS/cm). Figure 21 highlights that there is a high density of groundwater monitoring data in the lower part of the catchment, with very limited data throughout the rest of the catchment, and that there is significant spatial variability in groundwater EC. These two factors resulted in large uncertainties in the earlier baseflow assessments made using the EC mass balance method for the Mitchell River (GHD, 2013a). However, the revised approach for this project to defining the groundwater end member using gauged EC at low flows (Cartwright, 2013 and Table 2) may address this issue.

Table 21 Mitchell River - Groundwater EC Data Summary (total upstream catchment)

Gauge ID	Catchment Area (km^2)	GW EC [uS/cm] - Interpolated: Mean (Mean +/- 1 Standard Deviation)	GW EC [uS/cm] - Boreholes: Mean (Mean +/- 1 Standard Deviation)	Count of boreholes
224203	3,922	840 (830 - 851)	2,955 (835 - 10462)	3
224217	4,408	847 (772 - 929)	1,192 (491 - 2892)	57

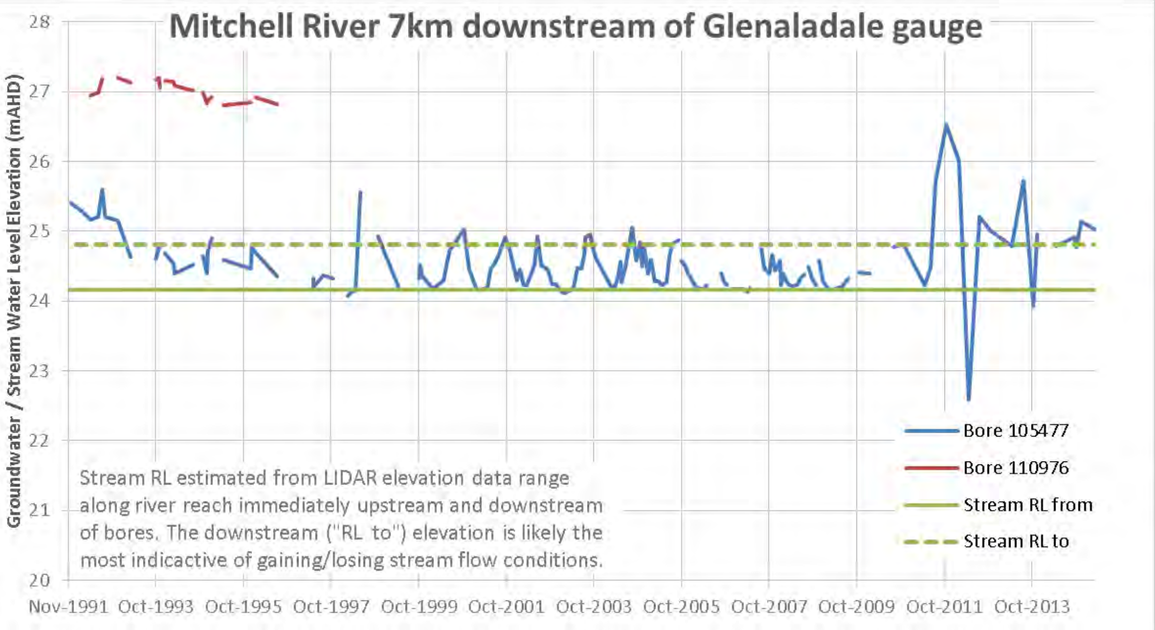
Table 22 Mitchell River - Groundwater EC Data Summary (interstation catchment)

Gauge ID	Catchment Area (km^2)	GW EC - Interpolated: Mean (Mean +/- 1 Standard Deviation)	GW EC - Boreholes: Mean (Mean +/- 1 Standard Deviation)	Count of boreholes
224217	486	904 (691 – 1182)	1,133 (485 – 2,649)	54

Groundwater Levels

There are two groundwater observation sites along the Mitchell River that are located sufficiently close to the river to assess potential baseflow gain/loss status. Comparison of groundwater levels from these bores with corresponding nearby river water levels (estimated using LiDAR elevations) are presented in Figure 23. These data indicate temporally gaining/losing conditions along the Mitchell River. It is noted there is moderately dense vegetation along the river banks and water within the river at the time of survey (based on inspection of high quality aerial imagery), which reduces the accuracy of the LiDAR survey.

Hofmann (2011) used a number of bore transects perpendicular to the river to assess groundwater level gradients with respect to the river. Hofmann's analysis indicated consistently flow-losing conditions in only one transect of the eight analysed. The other seven transects exhibited temporally and spatially variable gaining/losing conditions along the lower Mitchell River. Hofmann (2011) noted flow-losing conditions tended to occur during periods of high stream flow, although this was often followed by subsequent groundwater drainage back towards the river. Hofmann's conclusions are in agreement with the inferences made using the hydrographs in Figure 23.



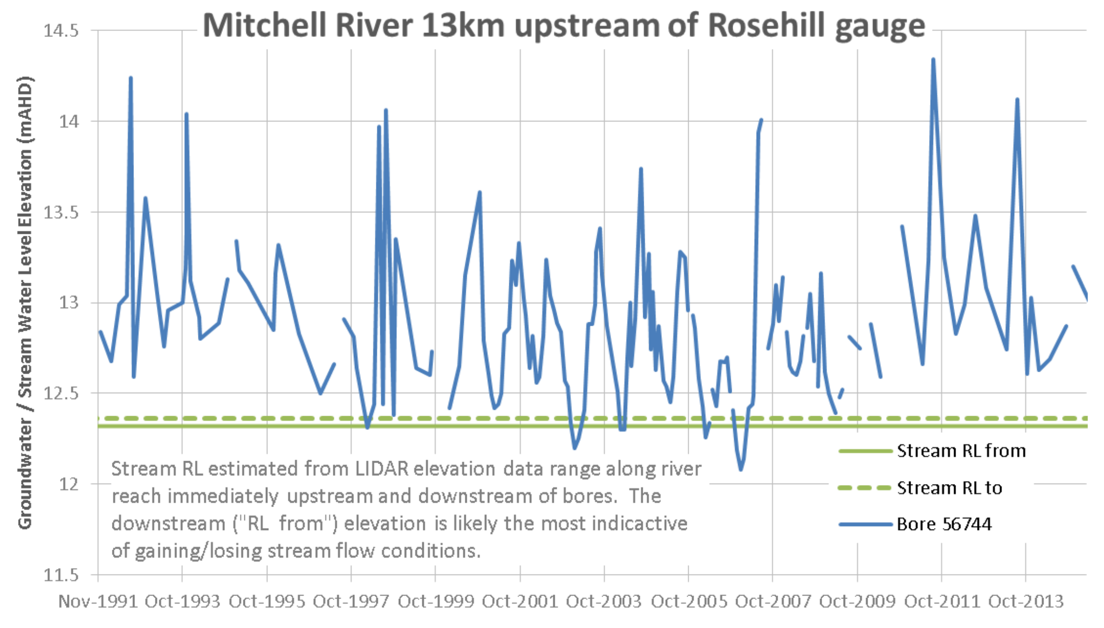
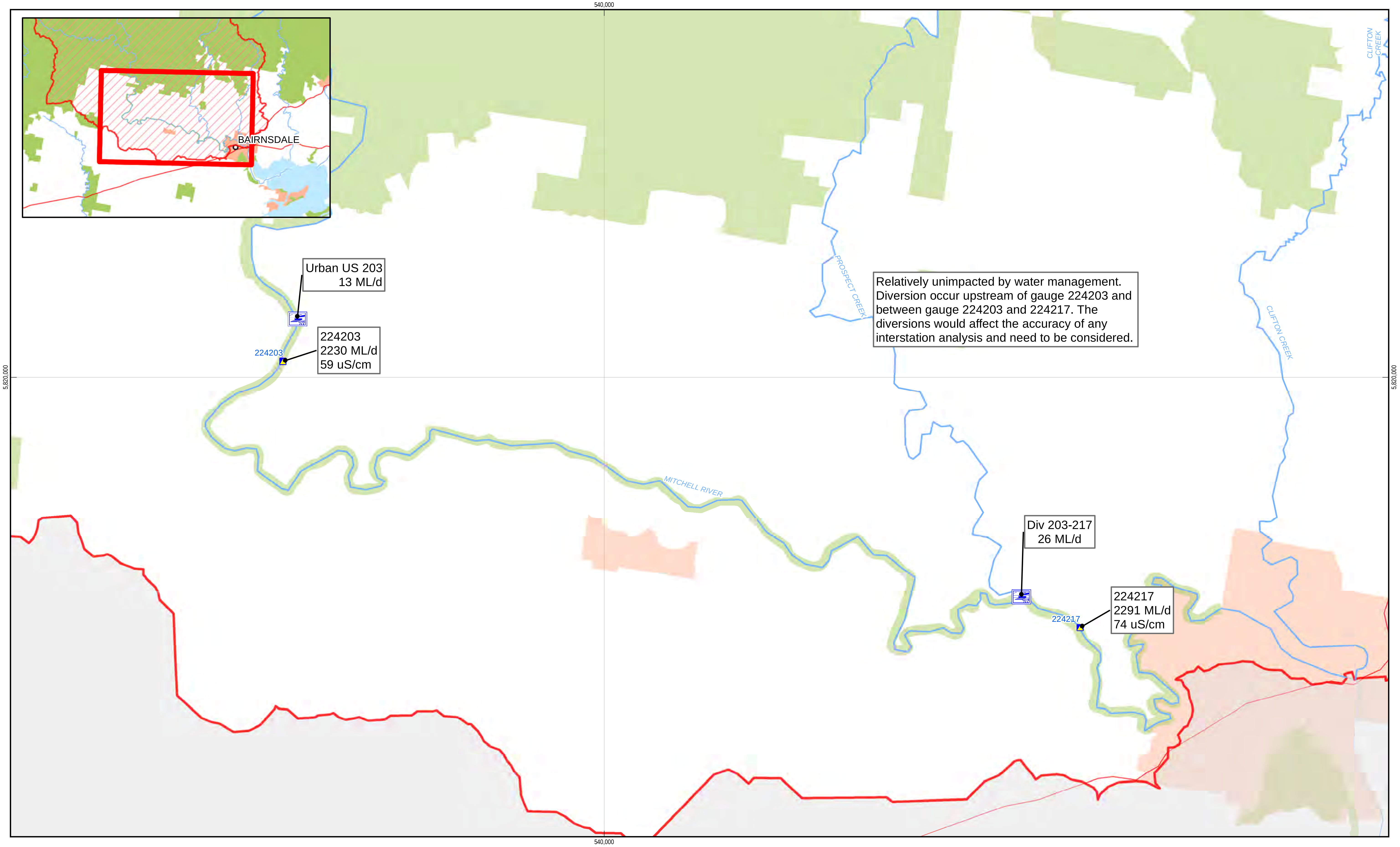


Figure 23 Mitchell River Groundwater & Surface Water Level Hydrographs

3.4.2 Water management characteristics

Figure 24 provides an illustrative summary of the water management characteristics of the Mitchell River. This river is relatively un-impacted by water management activities, with no major on-stream storages, and diversions are small relative to streamflow. Diversions do however have an impact on any interstation analysis of baseflow and need to be taken into account.



Urban US 203
13 ML/d

224203
2230 ML/d
59 uS/cm

Relatively unimpacted by water management. Diversion occur upstream of gauge 224203 and between gauge 224203 and 224217. The diversions would affect the accuracy of any interstation analysis and need to be considered.

Div 203-217
26 ML/d

224217
2291 ML/d
74 uS/cm

Paper Size A3
0 0.5 1 2 3
Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

▲ Surface Water Gauges (Assessed)
Major Watercourse
Mitchell River Catchment
Drains
Industry Returns
Offtakes
▲ SW Gauges

Department of Environment, Land, Water & Planning
Gippsland River Baseflow Assessment

Job Number	31-32709
Revision	0
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Mitchell River
Water Management

Figure 24

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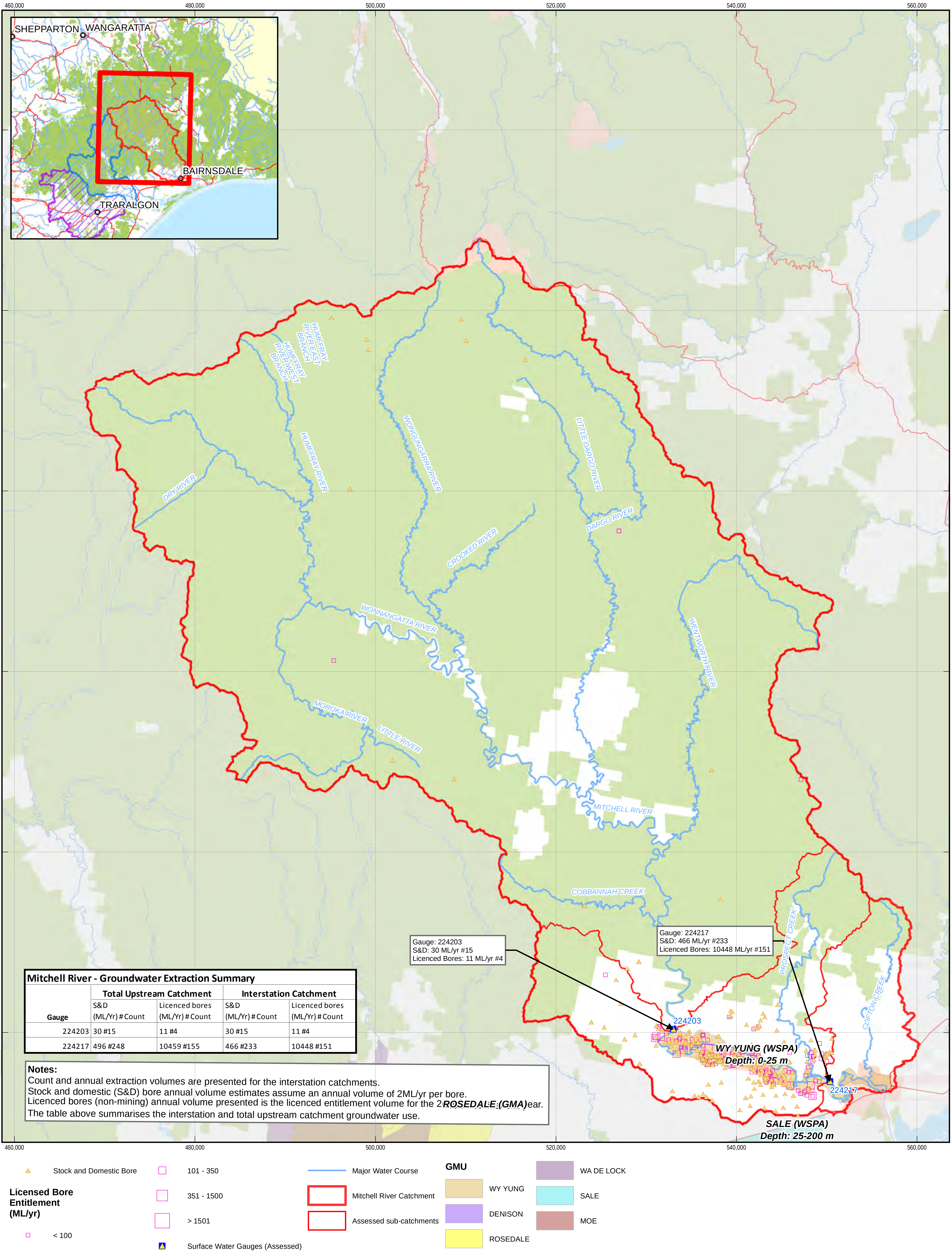
Data source: DEWLP, VICMaps, 2015; GHD, Baseflow Catchments, 2015; DELWP, WMIS Surface and Groundwater Data, 2015; SRW, Drain Data, 2015; DELWP, REALM Model results, 2015; EPA, Industrial Discharge Data, 2013-14. Created by: adrummond

Groundwater Management

Figure 25 summarises the groundwater extractions from stock and domestic bores, and licensed groundwater extractions across the Mitchell River catchment. Extractions are summarised for both the interstation catchment and the total upstream catchment.

The figure highlights that the majority of the stock and domestic and licensed groundwater extractions are concentrated in the lower reaches of the Mitchell River (Wy Yung Water Supply Protection Area), where the majority of extractions are within 3 km of the river, along the alluvial floodplain. The large volumes of groundwater extraction along the Mitchell River between Glenaladale and Rosehill are likely to reduce baseflow to streams along this reach. The effect of this on the baseflow estimates presented in this project is that the estimated baseflows reflect the groundwater discharge to streams, after depletion by groundwater extraction. This was discussed in detail by GHD (2013a), and is incorporated into the assessment of risks to environmental flows in GHD (2013a).

There is minimal groundwater extraction in the upper reaches of the Mitchell River (upstream of Glenaladale); therefore, it is expected that baseflow in these catchments are not influenced by pumping.



Gauge: 224203
S&D: 30 ML/yr #15
Licenced Bores: 11 ML/yr #4

Gauge: 224217
S&D: 466 ML/yr #233
Licenced Bores: 10448 ML/yr #151

Mitchell River - Groundwater Extraction Summary

	Total Upstream Catchment		Interstation Catchment	
Gauge	S&D (ML/Yr) # Count	Licenced bores (ML/Yr) # Count	S&D (ML/Yr) # Count	Licenced bores (ML/Yr) # Count
224203	30 #15	11 #4	30 #15	11 #4
224217	496 #248	10459 #155	466 #233	10448 #151

Notes:
Count and annual extraction volumes are presented for the interstation catchments.
Stock and domestic (S&D) bore annual volume estimates assume an annual volume of 2ML/yr per bore.
Licenced bores (non-mining) annual volume presented is the licenced entitlement volume for the 2[illegible]ear.
The table above summarises the interstation and total upstream catchment groundwater use.

Paper Size A3
0 1.5 3 6 9 12
Kilometers
Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

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Gippsland River Baseflow Assessment

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Revision	0
Date	24 Apr 2015

Mitchell River
Groundwater Extraction

Figure 25

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Data source: DEWLP, VICMaps, 2015; GHD, Baseflow Catchments, 2015; DELWP, WMIS Surface and Groundwater Data, 2015. SRW, Licenced GW Use Volume (2010). GHD, Mine Use Volume (2014). Created by: adrummond

3.4.3 Local baseflow assessments

SAFE / Hofmann (2011)

Figure 27 presents a summary of the numerous baseflow investigations conducted across the Mitchell River catchment, collated as part of the SAFE project. The lower Mitchell River (between Glenaladale and Rosehill) is classified as transitioning between baseflow gaining and losing (with a high confidence rating), based on chemical baseflow separation analysis for 14 sampling locations, reported in Hofmann (2011). Hofmann (2011) estimated the baseflow contribution to the lower Mitchell River using ^{222}Rn and Chloride (Cl) as tracers to define spatial and temporal variability of surface water / groundwater interactions. The results of the Cl mass balance were significantly different to those of the ^{222}Rn mass balance. Hofmann (2011) attributed this difference to the two techniques measuring different components of stream flow: regional groundwater discharge (measured by the Cl mass balance); versus bank storage return flows (measured by the ^{222}Rn mass balance).

Figure 26 summarises the total baseflow contribution estimated by Hofmann (2011) during four sampling events for the entire reach between Glenaladale and Rosehill. This shows that despite the reach locally varying between gaining and losing baseflow, on a net basis along the reach it gains baseflow. Hofmann's (2011) results also indicate that the largest baseflow contributions relative to total stream flow occurred in February 2009, which corresponds to the end of the prolonged drought (1997 – 2009). The results also indicate that "baseflow" estimated using ^{222}Rn results in approximately 2 to 5 times higher fluxes than the baseflow calculated using Cl, which was attributed to the ^{222}Rn estimates including bank storage returns as well as regional groundwater.

For the purposes of validating the baseflow estimates of the current project, Hofmann's (2011) Cl mass balance results are the most applicable, because the objective of the project is to estimate the regional groundwater contribution to stream flows, not intermediate slow flow components such as bank storage returns. Refer to Section 4 for the results of this validation.

Table 23 Results from chemical baseflow calculations using ^{222}Rn and Cl- for the Mitchell River (adapted from Table 3.6 of Hofmann (2011)

Sample Date	Discharge (m3/day)	Baseflow flux Rn (m3/d)	Baseflow flux Rn (%)	Baseflow flux Cl (m3/d)	Baseflow flux Cl (%)
Feb – 2009	88,761	37,360	42.09	5,341	6.02
Apr – 2010	396,820	40,600	10.23	8,333	2.10
Sep – 2010	4,870,742	201,613	4.14	112,330	2.31
Oct – 2010	1,332,224	41,824	3.14	15,507	1.16

SAFE / SKM (2002 and 2012)

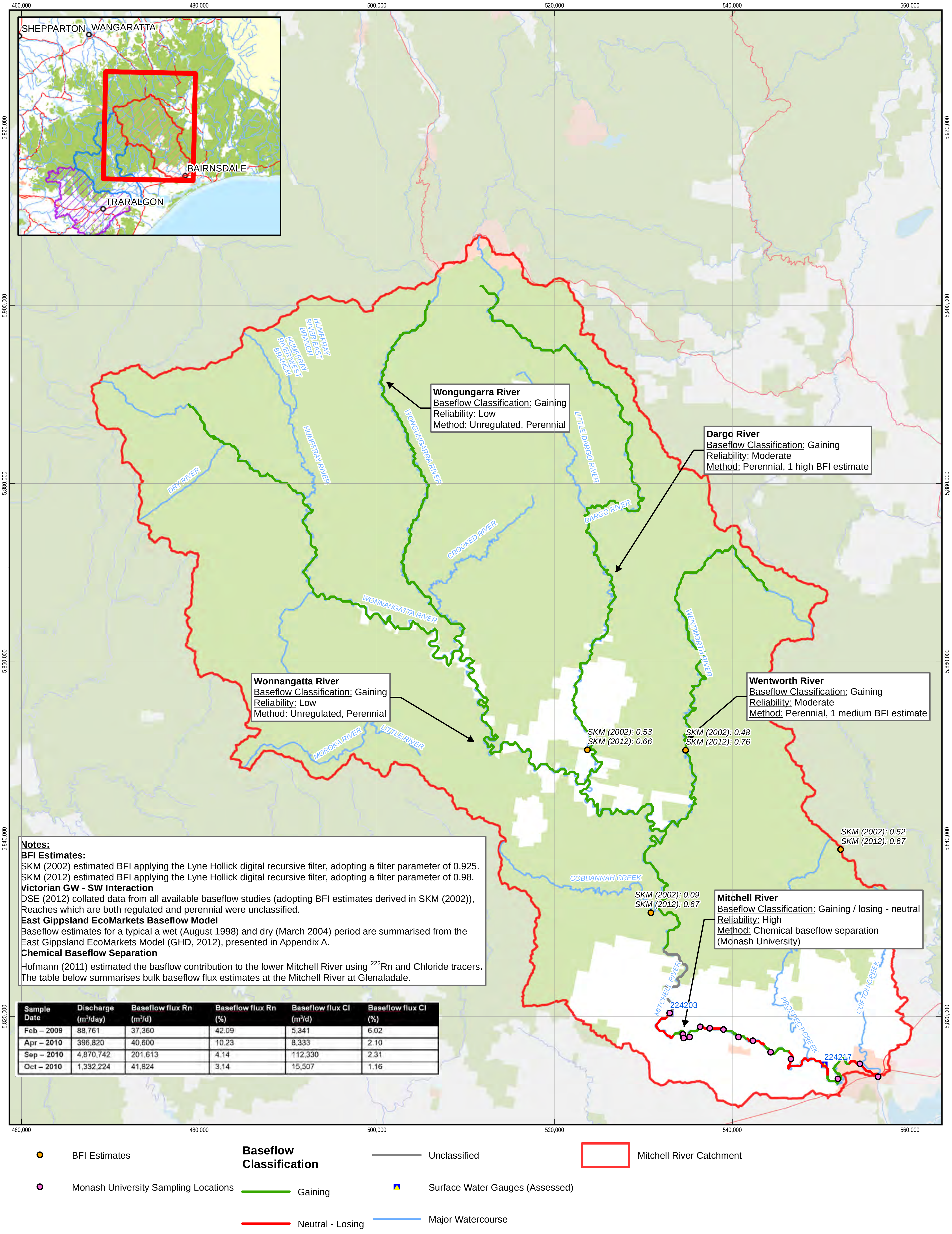
The results of baseflow analyses for the Mitchell River by SKM (2002 and 2012) are also presented in Figure 27. These analyses comprised application of the Lyne and Hollick (1979) digital filter to unregulated streams, with the filter not calibrated to tracer data. The Dargo and Wentworth Rivers were classified as baseflow gaining with a moderate confidence rating, primarily because these reaches are perennial upland streams. SKM (2012) indicated that the BFI estimate for the Dargo and Wentworth Rivers are moderate to high (0.66 – 0.76), compared to the moderate BFI estimate (0.48 – 0.53) derived in SKM (2002). The Wonnangatta and Wongungarra Rivers were also classified as baseflow gaining but with a low confidence rating.

ecoMarkets

Appendix A presents the modelled spatial baseflow gains and losses across the Mitchell River catchment, estimated for a wet (August 1998) and dry (March 2004) period. These were derived from the numerical model of East Gippsland developed for the ecoMarkets project (GHD, 2010b). The model results indicate that during the wet period, the majority of the upper reaches of the Mitchell River catchment are weakly baseflow gaining, and the lower reaches are baseflow neutral. During the dry period, the model results indicate that the majority of both upper and lower reaches of the Mitchell River are baseflow neutral.

3.4.4 Summary of Inferred Baseflow Condition for the Mitchell River

The significant available earlier studies (primarily Hofmann, 2011) indicate that the Mitchell River can be classified as a primarily baseflow-gaining stream, except periodically in the lower catchment during periods of high surface water levels, when the river temporarily loses water to the adjacent and underlying alluvial aquifer. The surface water flow and EC data analysed in Section 3.4.1 also indicate dominantly gaining baseflow conditions, as do the groundwater level / surface water level analysis presented in Section 3.4.1, although these show temporary losing stream flow conditions. It is therefore concluded that the Mitchell River catchment can be classified as broadly baseflow-gaining for the purposes of this assessment.



Wongungarra River
Baseflow Classification: Gaining
Reliability: Low
Method: Unregulated, Perennial

Dargo River
Baseflow Classification: Gaining
Reliability: Moderate
Method: Perennial, 1 high BFI estimate

Wonnangatta River
Baseflow Classification: Gaining
Reliability: Low
Method: Unregulated, Perennial

Wentworth River
Baseflow Classification: Gaining
Reliability: Moderate
Method: Perennial, 1 medium BFI estimate

Mitchell River
Baseflow Classification: Gaining / losing - neutral
Reliability: High
Method: Chemical baseflow separation (Monash University)

Notes:

BFI Estimates:

SKM (2002) estimated BFI applying the Lyne Hollick digital recursive filter, adopting a filter parameter of 0.925.
SKM (2012) estimated BFI applying the Lyne Hollick digital recursive filter, adopting a filter parameter of 0.98.

Victorian GW - SW Interaction

DSE (2012) collated data from all available baseflow studies (adopting BFI estimates derived in SKM (2002)), Reaches which are both regulated and perennial were unclassified.

East Gippsland EcoMarkets Baseflow Model

Baseflow estimates for a typical a wet (August 1998) and dry (March 2004) period are summarised from the East Gippsland EcoMarkets Model (GHD, 2012), presented in Appendix A.

Chemical Baseflow Separation

Hofmann (2011) estimated the basflow contribution to the lower Mitchell River using ^{222}Rn and Chloride tracers. The table below summarises bulk baseflow flux estimates at the Mitchell River at Glenaladale.

Sample Date	Discharge (m^3/day)	Baseflow flux Rn (m^3/d)	Baseflow flux Rn (%)	Baseflow flux Cl (m^3/d)	Baseflow flux Cl (%)
Feb – 2009	88,761	37,360	42.09	5,341	6.02
Apr – 2010	396,820	40,600	10.23	8,333	2.10
Sep – 2010	4,870,742	201,613	4.14	112,330	2.31
Oct – 2010	1,332,224	41,824	3.14	15,507	1.16

Map Projection: Lambert Conformal Conic
Horizontal Datum: GDA 1994
Grid: GDA 1994 VICGRID94

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Mitchell River
SAFE Baseflow Studies

Figure 26

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Data source: DEWLP, VICMaps, 2015; GHD, Baseflow Catchments, 2015; DELWP, SAFE Datasets, 2012. Created by: adrummond

3.5 Recommendations for improving baseflow estimates

Based upon the above characterisation of each of the three rivers, and the proposed scope of works in Table 2, a range of limitations have been identified, and corresponding recommendations made with the objective of improving the earlier baseflow estimates of GHD (2013a and 2013b) where possible. These limitations and recommendations are outlined below.

Hydrographic analysis indicated that Rainbow Creek near Heyfield appears to result in persistent locally losing conditions, where artificial maintenance of elevated surface water levels relative to the regional watertable. On the nearby main stem of the Thomson River in this area however, variable gaining/losing conditions appear to prevail, because of its greater depth of incision compared to Rainbow Creek. However, there is very limited available data with only three con-current flow and surface water EC recordings to conduct addition interstation assessment of this reach in Stage 1 of this study. Given that these are spatially and temporally-isolated exceptions, it is concluded that the Thomson-Macalister catchment can be classified as broadly baseflow-gaining for the purposes of this assessment. Consequently, it is noted that there are no consistently net losing stream reaches identified through the analysis and review presented above. Hence, there is no identified need to develop methods to estimate flow losses in this study. The EC mass balance method may be applied to the three Gippsland Rivers, but with due consideration of the limitations.

3.5.1 Latrobe River: Limitations of the EC Mass Balance and Digital Filter Method

The key limitations of estimating baseflow to the Latrobe River using the EC mass balance and subsequent digital filter arise from the following:

- Insufficient suitable groundwater level data in the main Latrobe Valley (east of Moe) to assess whether or not the Latrobe River gains or loses flow to the underlying groundwater system. The gauged stream EC data however, suggest typically gaining conditions, although this is a tentative conclusion given the complications arising from saline industrial water returns.
- Analysis of baseflows between Thoms Bridge and Scarnes Bridge is rendered impossible by a total lack of gauged EC data from corresponding time periods at all upstream gauges. As a compromise, this analysis would need to utilise only data from the two Latrobe River gauges (i.e. ignoring inputs from tributaries). However, even this compromise results in very few useable EC records for the analysis: only 3 days, if considering the one-day time lag for flow down this reach. Analysis of baseflow to this reach is also hampered by the significant industrial water offtakes and returns of more saline water to the river (discussed below). It is recommended that reach-scale baseflow mass balance assessment is not conducted for this reach.
- Significant diversions for industrial water supply (primarily for the power stations at Yallourn Weir) and their subsequent return to the river, which has a higher EC than the diverted water.
  - Effort should be made to account for this in the interstation baseflow analysis between Scarnes Bridge and Rosedale, where possible. This will be highly uncertain because diversions will inevitably need to be estimated where no data are available. Assessment will be made of the value of the interstation baseflow gain/loss assessment in light of these uncertainties.
  - Interstation mass balance assessment of the Latrobe River between Thoms Bridge and Scarnes Bridge is effectively impossible due to the lack of suitable gauged stream EC data, as noted above.

  - Effort should be made to account for the saline industrial water returns in the individual gauge baseflow analyses (as opposed to interstation, or reach-scale, baseflow analyses) for the Latrobe River at Scarnes Bridge gauge and Latrobe River at Rosedale gauge, through correction of the flow and EC record, where data on industrial water returns cater for this.
- For the Latrobe River upstream of Thoms Bridge, the lack of contrast between gauged stream EC at high versus low flows suggests that there may be insufficient contrast between groundwater and surface water EC for use in the EC mass balance method for estimating the proportion of baseflow inputs to the river. This is probably compounded by the significant regulation of river flows by the three reservoirs.
  - The baseflow estimates for these gauges will therefore remain at a level of very low confidence, and the value of revision of the earlier baseflow estimates (GHD, 2013b) should be questioned for this study.
  - Greater value would be gained through targeted sampling for environmental tracers (e.g. radon and major ions) along these river reaches, with subsequent reach-scale mass balance assessment of potential baseflow gains.
- The effect of releases from Blue Rock Reservoir on the Tanjil River artificially increase flow rates during summer. This, in addition to the reservoir's homogenising effect on gauged EC, compromises the reliability of the baseflow analysis at the Tanjil River gauge (226216), with lesser effects to the analysis of gauges located further downstream.

3.5.2 Thomson-Macalister River: Limitations of the EC Mass Balance and Digital Filter Method

Based upon the above characterisation of the Thomson-Macalister catchment, the key limitations of the EC mass balance method of baseflow estimation, and subsequent digital filter application are:

- A baseflow time series should not be estimated for the Rainbow Creek at Heyfield gauge, given that this creek appears to be a consistently losing stream. This gauge should however be used as input to baseflow estimation between Cowwarr and Heyfield using an reach-scale EC mass balance, given that a significant proportion of flow down this reach passes along Rainbow Creek.
- Given the minimal, and at times counterintuitive, contrast between stream EC at high versus low flows for the Thomson River gauges upstream of Wandocka, the upstream gauges are not good candidates for the EC mass balance method. There is however, a strong contrast between local groundwater EC and stream EC, and hence any baseflow inputs to these river reaches from local groundwater should be identifiable via mass balance. Furthermore, several of the measures proposed in Table 2 may address this to some degree, although the baseflow analyses for these gauges may remain at a low level of confidence. These measures include:
  - Removal of periods of poor correlation between stream flow and EC; and
  - Baseflow to the reach between Heyfield and Wandocka may be estimated using a reach-scale EC mass balance; this will not however be possible for the reach between Cowwarr and Heyfield due to insufficient stream EC data.

- Interstation (reach-scale) baseflow gain/loss assessment (conducted by subtracting the downstream filtered baseflow time series from the upstream series) will need to account for the significant surface water diversions along the Thomson-Macalister where possible. This will be highly uncertain because diversions will inevitably need to be estimated where no data are available. Assessment will be made of the value of the interstation baseflow gain/loss assessment in light of these uncertainties.

3.5.3 Mitchell River: Limitations of the EC Mass Balance and Digital Filter Method

The only identified limitations of the method to the Mitchell River is that surface water diversions, although considered a minor component of stream flow, should be taken into account where possible for more reliable interstation baseflow analysis along this river. This will be highly uncertain because diversions will inevitably need to be estimated where no data are available. Assessment will be made of the value of the interstation baseflow gain/loss assessment in light of these uncertainties.

The reach-scale baseflow mass balance to be conducted on the lower Mitchell River in this study should make use of the results of the detailed study of Hofmann (2011). This can be achieved through calibration of the reach-scale EC mass balance to Hofmann’s (2011) baseflow estimates derived using Cl as a tracer.

4. Improving the accuracy of the baseflow estimates

4.1 Introduction

This section of the report aims to test the effects of the recommended changes and additions to the baseflow assessment method (Table 2 and Section 3.5) on the reliability of the baseflow estimates. For this purpose, the Mitchell River has been selected as a case study, because changes to baseflow estimate reliability can be tested against the independent baseflow estimates derived by Hofmann (2011). In contrast, there are no suitable independent data for comparison for either the Thomson-Macalister or Latrobe Rivers. Two supporting methods for estimating baseflow which were tested are documented in Section 4.2, and listed below:

- Reach scale EC mass balance (Section 4.2.2)
- Sellinger (1996) rating curve baseflow estimation method (Section 4.2.3)

The suggested changes to the existing baseflow estimation method which were tested are discussed in Section 4.3, and are summarised below:

- Constraining the interstation baseflow analysis (Section 4.3.1)
- Defining groundwater end member EC using gauged stream EC at lowest flows (Section 4.3.2)
- Eckhardt Filter parameters (Section 4.3.3)
- Removing periods of poor (non-linear) flow-EC relationships from individual gauge-based EC mass balances (Section 4.3.4)

Based on the outcomes of the testing, the changes to the baseflow method that are considered suitable and valuable for improving the accuracy and/or reliability of the baseflow estimates have been applied to the Mitchell, Thomson-Macalister and Latrobe Rivers. This task is documented in Section 4.4.

4.2 Testing other methods and data

4.2.1 Independent data sets

Only one independent data set was identified (through the investigations described in Section 3 of this report) that are suitable for assessing the reliability of the EC mass balance method of baseflow estimation: those of Hofmann (2011). Hofmann (2011) sampled surface water and groundwater at a number of locations along the lower Mitchell River between Glenaladale and Bairnsdale for major ions and radon (^{222}Rn). Field sampling was conducted four times over the 2009-2010 period. As Hofmann (2011) noted, radon (and other radionuclides) are useful in estimating baseflow to streams because they originate from minerals that form the matrix of the aquifer, and from soil and suspended matter in rivers and on river beds. Of the major ions, chloride is particularly useful for the same purpose because it is a conservative tracer – it is typically not removed in any way from water along its flow path.

Hofmann (2011) undertook reach-scale mass balances based on chloride and radon data from four sampling times to estimate baseflow to the reach. Interestingly, the baseflow estimates derived using the radon mass balance were consistently higher than those of the chloride-based analysis. Hofmann attributed the 2-5 times higher radon-based baseflow estimates to the fact that radon concentrations are increased as stream water interacts over short time frames with soils and sediments in, on and around the immediate stream channel, whereas chloride does not. Chloride equilibrates over much longer time frames, and is therefore not appreciably affected (increased) by short-term interactions between water and sediments in and around the stream channel, such as during bank storage residence times, and during interflow migration through shallow soils and sediments towards streams.

Hofmann (2011) summarised his conclusions as follows: "*^{222}Rn in combination with other tracers has the potential to indicate short- to medium-term reservoir contributions to rivers, in time scales ranging from weeks to months. The 2 to 5 times higher amounts of baseflow calculated using ^{222}Rn indicate that bank storage and bank return flow are the major reservoirs contributing to the baseflow component, and it shows that regional groundwater has little influence on the total discharge. At high river flow, as occurs during the winter season, baseflow contribution to the river is in general low and reflects only a small fraction of summer or dry season baseflow. Baseflow contributions from long-term (regional groundwater) and short- to medium-term reservoirs (e.g. bank storage), decrease equally during high river level and may cease entirely during the actual flood events.*"

It is important to note that Hofmann's definition of 'baseflow' for his thesis includes flow from the intermediate stores, including bank storage returns and interflow, whereas the definition of baseflow for this study does not – it comprises only the regional groundwater discharge component of stream flow. Hence Hofmann's Cl-based baseflow estimates are most applicable for comparison to the baseflow estimates of this project, which are derived using EC.

4.2.2 Reach-scale EC mass balance

For the purposes of comparison of Hofmann's (2011) baseflow estimates with those derived using the EC mass balance method proposed in this study, it is necessary to introduce a revised method of application of the EC mass balance that was applied by GHD (2013a and 2013b). This method was identified as being of potential value to this project in Table 2 and Section 3.5.

Background

Hofmann's study collected geochemical tracers for baseflow identification at a number of sampling locations down the lower Mitchell River, between Glenaladale and Bairnsdale. Using the tracer data collected at each of these locations, in conjunction with gauged flows at the upstream (Glenaladale) end of the reach, and the downstream (Rosehill) end, he developed tracer mass balances for the gauged flows across the reach, which were used to estimate the proportion of baseflow. These point-scale baseflow estimates were then aggregated across the entire reach to develop an estimate of the total baseflow flux to the entire reach.

In contrast to this approach, the EC mass balance as applied in the earlier studies of GHD (2013a and 2013b; discussed in Section 2.1) were only conducted at each stream flow gauge location (where flow and EC data were available). The Eckhardt digital filter was then calibrated to the results of the EC mass balance to produce a continuous estimate of baseflow fluxes for every day of each gauged record – these baseflow estimates represent baseflow to the entire catchment upstream of the gauge; as opposed to specific reaches of a river.

Subsequently, GHD used these gauge-based baseflow time series to estimate the total baseflow flux to (or from) reaches with an upstream and a downstream gauge by subtracting the two baseflow time series from one another. This was used to estimate baseflow gains and losses down each gauged stream reach. However, as GHD (2013a and 2013b), and the independent technical reviews of Cartwright (2013) and Costelloe (2013) pointed out, this approach is prone to significant uncertainties. In some cases, these uncertainties were such that an overall assessment of gaining ***or*** losing baseflow could be made for the same reach, depending on the parameters used in the mass balance. The key uncertainties affecting the reliability of the interstation baseflow analysis of GHD (2013a and 2013b) include:

- Baseflow fluxes being less than flow gauging accuracy;
- The effect of surface water diversions from within the analysed reach, a proportion of which would comprise baseflow. Therefore, these diversions contribute to the estimated “baseflow losses” along the reach – which are obviously not physically losses from surface water to groundwater, but are simply losses from the interstation baseflow balance;
- High sensitivity of the baseflows estimated using the EC mass balance to small changes in the groundwater end member EC; and
- Compounding effects of the uncertainties and resulting errors in the baseflow estimates of the upstream and downstream gauges.

Reach-scale EC mass balance method

In response to these issues, Costelloe (2013) and Cartwright (2013) both recommended validating the conclusions of the interstation baseflow assessments using other data and lines of evidence where possible (Section 2.2). As the reviewers pointed out, it is possible to use an EC mass balance between the upstream and downstream gauges of a given reach to more reliably estimate baseflow gains[2] - the results of which are then directly comparable to the more detailed reach-scale mass balance studies of Hofmann (2011). The principal behind this approach, and therefore the form of the mass balance equation, is identical to that used to estimate baseflow at a single gauge, as is detailed in Section 2.1, except that the runoff end member EC is replaced by the EC at the upstream end of the reach. The resulting equation for this reach-scale EC mass balance for estimating baseflow fluxes to a given reach is:

$$\frac{Q_{G\,reach}}{Q_{T\,reach}} = \frac{(c_{Sd} - c_{Su})}{(c_{G\,reach} - c_{Su})}$$

Where: $Q_{G\,reach}$ is the groundwater-derived (baseflow) component of stream flow from within the reach only, excluding baseflow inputs from further upstream; $Q_{T\,reach}$ is the average stream flow across the reach (i.e. of upstream and downstream gauged flows); c_{Sd} is the tracer concentration in the stream at the downstream end of the reach, c_{Su} is the tracer concentration in the stream at the upstream end, $c_{G\,reach}$ is the groundwater (baseflow) end member tracer concentration within the area thought to be contributing baseflow to the reach.

Other terms can be added to the right hand side of the equation, such as the increase in stream EC across the reach due to evaporative concentration. However, as noted by Hofmann (2011), the effect of evaporation on gauged stream EC is negligible compared to baseflow fluxes. Evaporation of water from the stream reach has therefore been ignored for the purposes of this study.

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[2] It should be noted that this method cannot identify baseflow losses (i.e. leakage from the stream to the underlying groundwater system), because gauged stream EC is unaffected by such losses.

In the case being tested here, for the lower Mitchell River, the groundwater EC end member ($c_{G\ reach}$) was defined using the average groundwater EC within the interstation catchment, as detailed in Table 22 (1,133 uS/cm). Uncertainty analysis of the estimated baseflow gains to the reach were assessed using the standard deviation from Table 22 (485 – 2,649 uS/cm). Hofmann (2011) defined his groundwater Cl and ^{222}Rn end member concentrations using a similar approach.

Results and comparison with Hofmann's (2011) baseflow estimates

Figure 28 presents the baseflow estimates derived using the reach-scale EC mass balance method for the lower Mitchell River, compared to those estimates of Hofmann (2011). It is clear that the EC mass balance produces baseflow estimates that are very similar to Hofmann's (2011) estimates derived using chloride as a tracer, but are significantly lower than those derived using ^{222}Rn. This is sensible given that EC is effectively a proxy for total dissolved solids, of which Cl is a major component in most Australian waters. Further, as has been discussed, Hofmann (2011) noted that the ^{222}Rn-based baseflow estimates also include water from short-term subsurface reservoirs, such as from interflow and bank storage (i.e. they include stream flow components other than regional groundwater discharge, which are not the objective of this project's baseflow estimations).

In contrast to this evidence for baseflow gaining conditions along the lower Mitchell River, the interstation baseflow analysis for this reach by GHD (2013a) concluded variable but on average losing conditions. The reason for this difference regarding gaining/losing conditions appears to be the uncertainty in the groundwater end member EC used in the GHD (2013a) baseflow estimates for the upstream and downstream gauges. Testing for the current study shows that a small change in this end member value applied for the upstream gauge can result in the method used in GHD (2013a) estimating a baseflow gain across this reach.

Recommendation

Based on this comparison, it is concluded that the recommendations of Cartwright (2013) and Costelloe (2013) to validate the interstation baseflow estimates using alternative methods, particularly the reach-scale EC mass balance, is a valuable addition to the methods applied by GHD (2013a and 2013b). Reach-scale mass balance estimates have been derived for the Latrobe and Thomson-Macalister catchments, and are documented in Section 4.4.

Benefits and limitations of the reach-scale EC mass balance method

The fact that similar baseflow estimates can be made using the widely available gauged flow and EC data at two upstream gauges, as was made using detailed field sampling and analysis by Hofmann (2011), highlights that the reach-scale EC mass balance method as recommended by Cartwright (2013) and Costelloe (2013) is an efficient and cost effective means of estimating baseflow discharge to stream reaches.

Notwithstanding the value of the reach-scale EC mass balance in validating baseflow gains and losses, the following limitations have been identified:

- It is only applicable to stream reaches with corresponding upstream and downstream gauges, which possess flow and EC data for the same days;
- In stream reaches in which EC is artificially increased (such as due to the saline industrial water returns along the Latrobe River), the resulting artificial gauged EC increase must be accounted for in the reach-scale EC mass balance. This may not be possible and/or reliable without detailed records of discharge rates and EC. Failure to account for this may result in over-estimation of reach-scale baseflow gains; and

- Similar effects may occur due to ungauged tributary inflows to an analysed stream reach. If the runoff (and more importantly the groundwater EC) controlling EC inputs from ungauged tributaries differ significantly from those of the (gauged) main stream reach along which reach-scale baseflow gains are being assessed, then baseflow gains may be over- or under-estimated. If however, the groundwater and runoff EC end members of the ungauged tributaries are similar to those defined for the main stream channel, then this limitation should not affect the baseflow estimates. In these cases, it should be noted that the estimated baseflow gains may discharge to the catchment anywhere within either the main stream channel, and/or the ungauged tributaries. That is, the spatial location of the estimated baseflow gains within the catchment of the main stream channel and the ungauged tributaries is unknown.

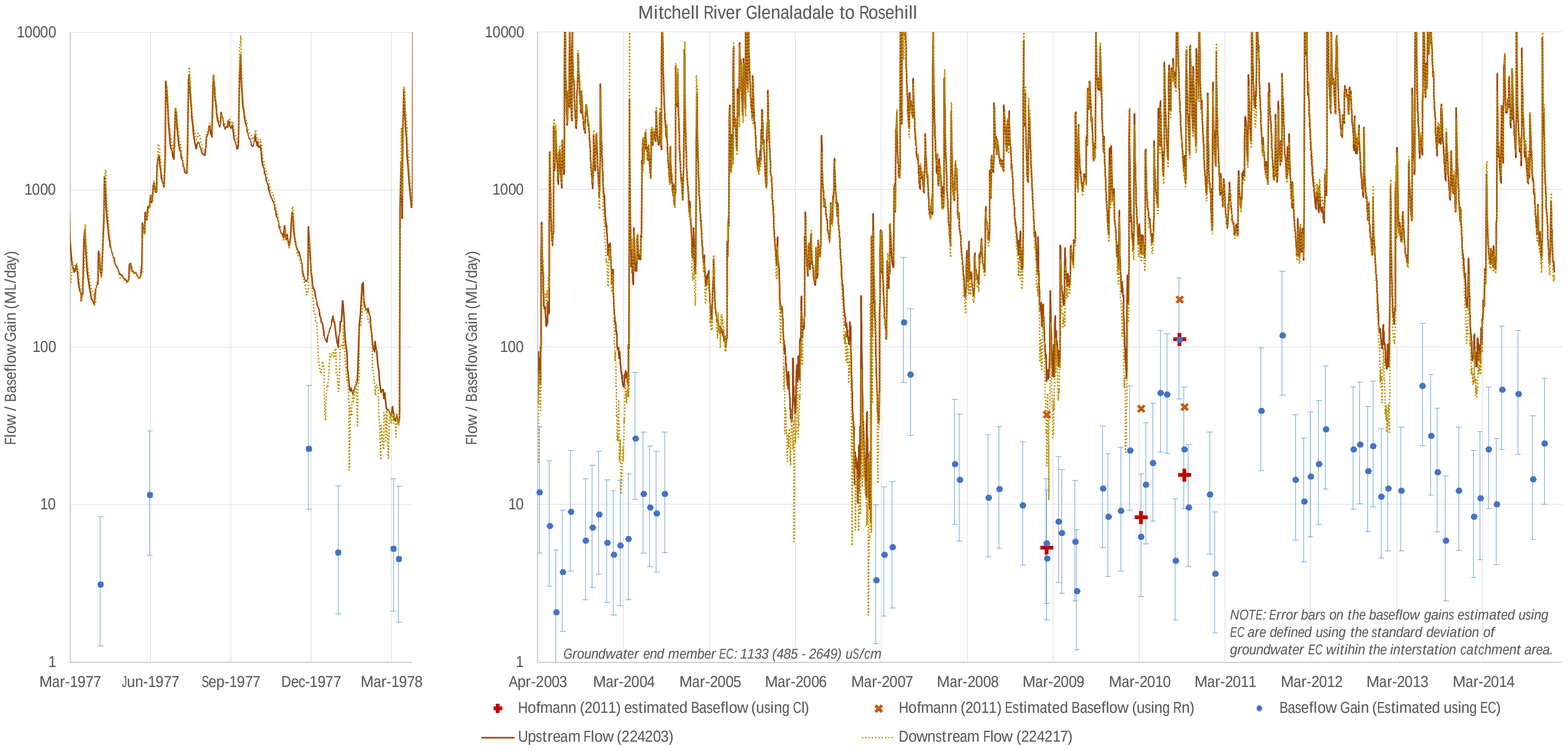


Figure **2т** Reach-Scale Baseflow Gain Estimates for the Lower Mitchell River

4.2.3 Sellinger (1996) rating curve baseflow estimation method

The “rating curve” method of Sellinger (1996) for estimating baseflow contributions to stream flow was considered for application in this project. The method is outlined by Sellinger (1996) as follows:

“*The method used in this report requires creating a rating curve from groundwater elevations and discharge measurements (Heath and Trainer, 1968). This method requires two assumptions: (1) that groundwater discharge is proportional to groundwater levels, and (2) that the entire flow from a stream is composed of groundwater discharge during fair weather periods. Simply, baseflows are separated from streamflows by identifying consecutive days of no precipitation then selecting the latter portion of these rainless days as baseflow*”.

As such, Sellinger’s method had a broader definition of what constitutes baseflow than has been adopted for this project. This project’s primary objective is the estimation of regional groundwater discharge to streams, with flows during low flow periods comprised of significant components of bank storage returns and interflow. This is almost certainly the case for the Mitchell River, but also probably the Latrobe (GHD, 2013b) and Thomson-Macalister (GHD, 2013a).

Recommendation

Given that the primary objective of this project is the estimation of regional groundwater discharge to streams, rather than intermediate flow components such as bank storage returns and interflow, the Sellinger (1996) rating curve method is not regarded as applicable to the current study.

4.3 Testing suggested changes to existing method

4.3.1 Constraining interstation baseflow analyses

As was recommended by the reviewers of the earlier studies, other lines of evidence should be used to validate the conclusions of the interstation baseflow gain and loss analyses of GHD (2013a and 2013b), and improve their reliability. This is one of the objectives of the current study.

Interstation baseflow gain and loss assessments derived by GHD (2013a and 2013b) (i.e. by subtracting individual gauge-based baseflow time series estimated for downstream gauges from those estimated for upstream gauges), may be constrained through use of the reach-scale baseflow gains estimated using the reach-scale EC mass balance method presented in Section 4.2.2. That is, the reach-scale baseflow gains estimated using the reach-scale EC mass balance could be used to inform adjustment of the groundwater EC end member value at the upstream and/or downstream gauge, so that subtraction of the baseflow time series from the upstream and downstream gauges results in similar baseflow gains as estimated using the reach-scale EC mass balance. This approach also serves to improve the reliability of the baseflow time series derived for the upstream and/or downstream gauges.

This method improvement was tested on the Mitchell River gauges, because the independent detailed studies of Hofmann (2011) provide confidence in the baseflow gains estimated using the reach-scale EC mass balance (Section 4.2.2).

The automated calibration software PEST (Doherty, 2010) was used to calibrate the interstation baseflow gains. Calibration was achieved through adjustment of the groundwater EC end members for the upstream (Glenadale) and downstream (Rosehill) gauges. Groundwater EC values were allowed to vary between 300 and 3,000 uS/cm, with initial values defined using the observed data (Table 21). Calibrated groundwater EC values are:

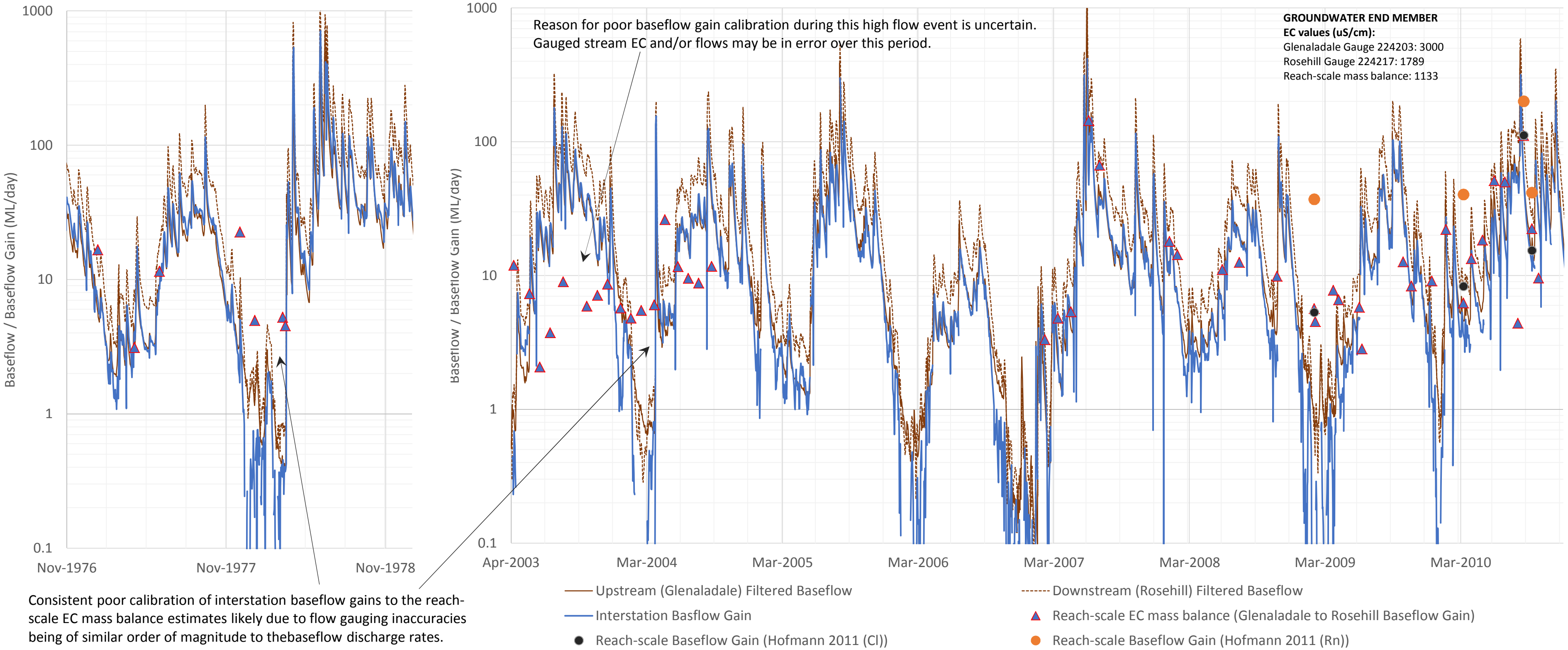
- For the upstream Glenaladale gauge (224203), the maximum value of 3,000 uS/cm was reached. Further increases were considered unwarranted because there are too few supporting data;
- For the downstream Rosehill gauge (224217), the optimal groundwater EC end member value was 1,789 uS/cm. This end member EC for the Rosehill gauge reflects the dominant contribution to lower catchment baseflows from the alluvial plains between Glenaladale and Rosehill. In this reach, groundwater EC averages 1,133 uS/cm, and varies from 485-2,649 uS/cm (Table 22).

The calibrated interstation baseflow gains for the lower Mitchell River are presented as the solid blue line in Figure 29. These are compared to the reach-scale baseflow gains derived using the reach-scale EC mass balance (Section 4.2.2; blue triangles on Figure 29), and to those derived by Hofmann (2011) using radon and chloride (Section 4.2.1 and 4.2.2; shown as circles on Figure 29). For reference, the estimated baseflow time series of the Glenaladale and Rosehill gauges are shown for comparison as solid and dashed brown lines respectively.

The calibration is of variable quality. During low flow periods, the calibration is of poorest quality, which is likely due to flow gauging errors being of a similar order to (or larger than) the baseflow gains.

Recommendation

Based upon this assessment, calibration of the baseflow estimates derived for individual flow gauges to reach-scale baseflow gains, derived via an EC mass balance, is considered of great value to improving the reliability of the interstation baseflow gains and losses derived through subtracting downstream filtered baseflow time series from those of upstream gauges. This has been applied for the Latrobe and Thomson catchments, and is documented in Section 4.4.



Reason for poor baseflow gain calibration during this high flow event is uncertain. Gauged stream EC and/or flows may be in error over this period.

GROUNDWATER END MEMBER
EC values (uS/cm):
Glenaladale Gauge 224203: 3000
Rosehill Gauge 224217: 1789
Reach-scale mass balance: 1133

Consistent poor calibration of interstation baseflow gains to the reach-scale EC mass balance estimates likely due to flow gauging inaccuracies being of similar order of magnitude to thebaseflow discharge rates.

Figure 2y Interstation Baseflow Gain Calibration: Mitchell River

4.3.2 Defining groundwater end member EC using gauged stream EC at lowest flows

In response to the significant uncertainties in the groundwater EC end member used in the mass balance, and the high sensitivity of the baseflow estimates to this parameter, Cartwright (2013) suggested that: "*an alternative and potentially easier way of constraining the groundwater end member is to use the highest EC concentrations recorded during the low flow periods when the river is most likely to be fed mainly or entirely by groundwater inflows*". This approach effectively assumes that at the time of the highest record stream EC, 100% of the water flowing down the stream comprises regional groundwater.

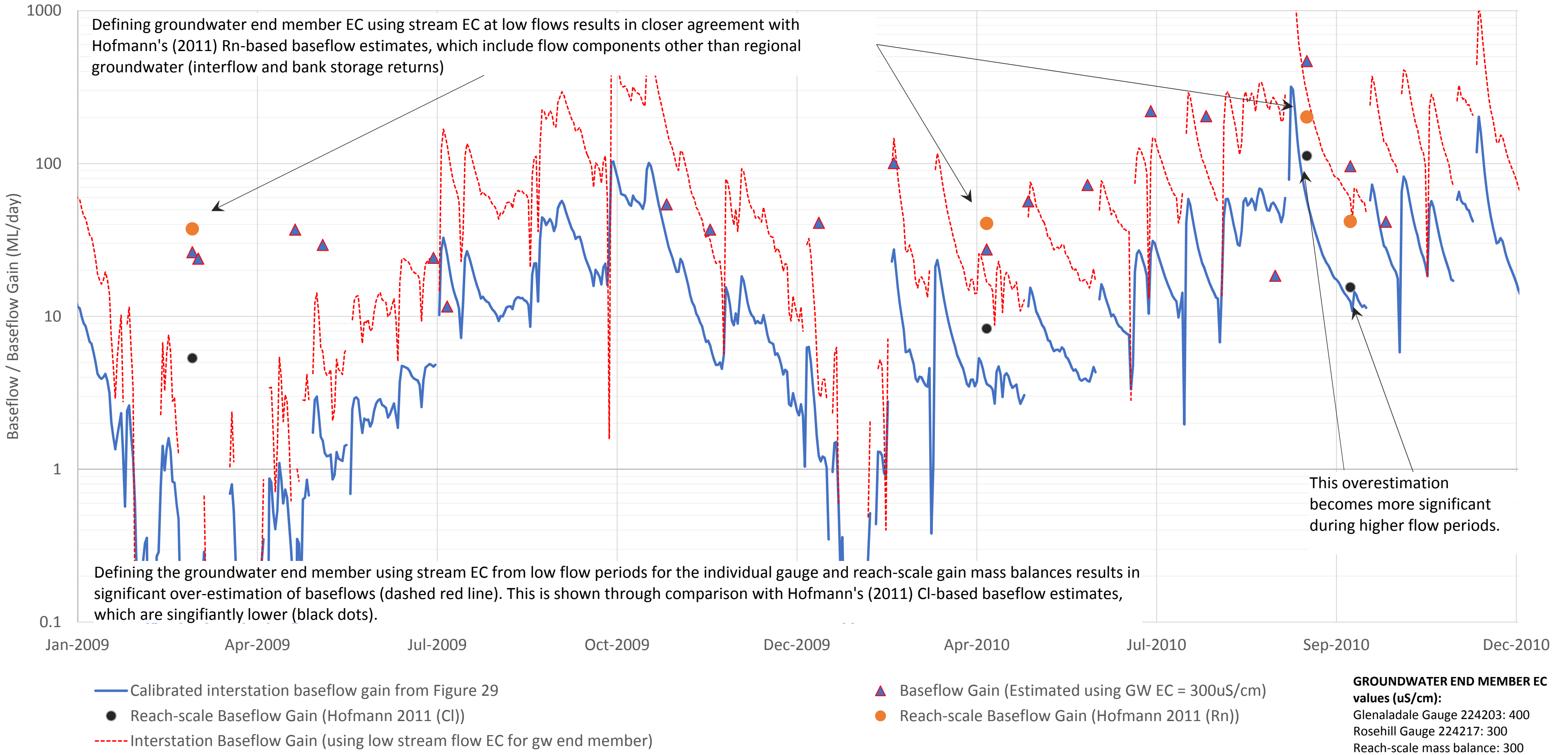
In the case of the Mitchell River, the maximum recorded stream EC at the upstream gauge (224203) at Glenaladale is 400 uS/cm. At the downstream end of the river, at Rosehill, the maximum stream EC is 300 uS/cm. This estimate excludes one reading of 1,204 uS/cm in January 2006, which is considered to be an anomaly. The anomalous reading had similar gauged flows in the preceding and subsequent weeks (100 to 170 ML/day) and gauged EC in the corresponding weeks of only 106 uS/cm and 126 uS/cm. Inspection of the groundwater EC data for the catchment (Figure 21, Table 21 and Table 22) indicate that the highest recorded stream EC at both gauges is significantly lower than the EC of groundwater, and is in fact more than one standard deviation below the mean groundwater EC.

The effect of this approach is shown in Figure 30, through comparison with Hofmann's baseflow estimates, and the calibrated baseflow gains along the lower Mitchell developed for this study and presented in Section 4.3.1. As expected, the baseflow gains derived using low stream flow EC to define the groundwater end member results in baseflow estimates more reflective of Hofmann's radon-based estimates, which include interflow and bank storage returns. They are consistently higher than Hofmann's chloride-based estimates, and those derived using EC for this study.

Clearly, gauged stream EC during low flows is reflective of significant flow contributions from components other than groundwater. This is supported by the detailed studies of Hofmann (2011), and Eckhardt (2008) makes reference to this. Using ^{222}Rn, Hofmann showed that even when considering the bank storage and interflow components of stream flow, there are significant other components (presumably delayed runoff and interflow) contributing to stream flows during low flow periods (Figure 28).

Recommendation

Based upon this analysis, it is recommended that the groundwater EC end member is ***not*** defined using the lowest recorded stream EC, unless there is no other information to support this parameter, and the stream is unregulated. In the case of streams in which flow is regulated through reservoir releases, this approach should certainly not be taken, because in these cases the lowest recorded stream EC will almost always reflect a mixture of all flow components (runoff, baseflow, interflow and bank storage) that have been mixed within the reservoir over time prior to release. Therefore, this approach has not been applied in to the Latrobe and Thomson-Macalister catchments.



Defining groundwater end member EC using stream EC at low flows results in closer agreement with Hofmann's (2011) Rn-based baseflow estimates, which include flow components other than regional groundwater (interflow and bank storage returns)

This overestimation becomes more significant during higher flow periods.

Defining the groundwater end member using stream EC from low flow periods for the individual gauge and reach-scale gain mass balances results in significant over-estimation of baseflows (dashed red line). This is shown through comparison with Hofmann's (2011) Cl-based baseflow estimates, which are singifiantly lower (black dots).

GROUNDWATER END MEMBER EC values (uS/cm):
Glenaladale Gauge 224203: 400
Rosehill Gauge 224217: 300
Reach-scale mass balance: 300

Figure Hɸ Interstation Baseflow Gain Calibration: Mitchell River (defining the groundwater end member EC using stream EC at lowest flows)

4.3.3 Eckhardt Filter parameters

Costelloe (2013) and Eckhardt (2008) both recommend restricting the Eckhardt baseflow filter parameter Alpha to observed gauged stream flow recession rates (the master recession curve), and the range in their variability. This change was recommended in order to recognise the conceptual basis of the Eckhardt filter of log-linear discharge rates from the groundwater system to streams (Eckhardt, 2008).

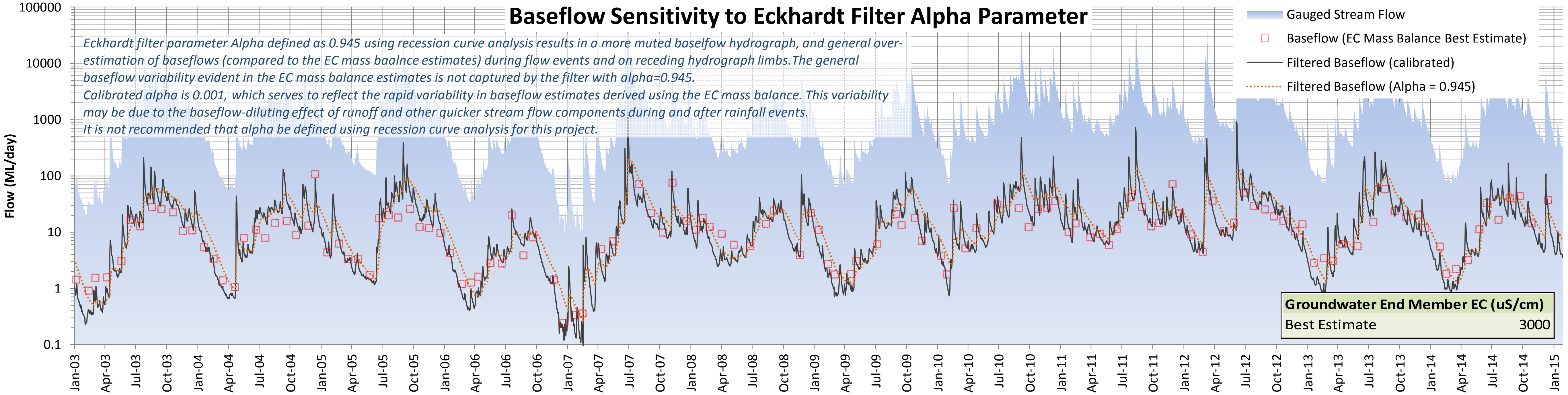
Figure 31 presents a comparison of the calibrated Eckhardt filter's baseflow time series (using Alpha = 0.001; black line in Figure 31) with that for an Alpha value of 0.945 (dashed orange line in Figure 31), which was estimated via recession curve analysis as per Eckhardt (2008). Alpha has a negligible impact on the magnitude of filtered baseflow, whilst altering the shape of the baseflow hydrograph; the higher Alpha parameter results in a more temporally muted and delayed baseflow hydrograph compared to the calibrated filter. This results in degradation of the calibration to baseflows estimated using the EC mass balance (red square in Figure 31), and a systematic overestimation of baseflow during flow events and the subsequent recession period.

The reason for the calibrated Alpha value (0.001) not reflecting the master recession curve (Alpha = 0.945) is probably that the Eckhardt filter was designed to filter out the traditional definition of baseflow from gauged records (i.e. including interflow and bank storage returns), not just the regional groundwater discharge component.

Costelloe (2013) also suggested defining the Eckhardt BFImax filter parameter as the maximum estimated baseflow index (BFI) of the baseflow estimates derived via the EC mass balance. In this case, the maximum BFI is 0.05. The lower chart in Figure 31 presents a comparison of the calibrated baseflow filter estimates (BFImax = 0.012; black line) with that using a BFImax of 0.05 (dashed orange line). It is clear that the higher BFImax value recommended for application severely and systematically degrades the calibration of the digital filter to the baseflow estimates from the EC mass balance (red squares in Figure 31); estimated baseflow are consistently higher than those of the calibrated filter and the EC mass balance. The reason for this is probably related to that described above for the Alpha parameter; i.e. the Eckhardt filter was designed to filter out the traditional definition of baseflow from stream flow hydrographs, not solely the regional groundwater discharge component which is the objective of this project.

Recommendation

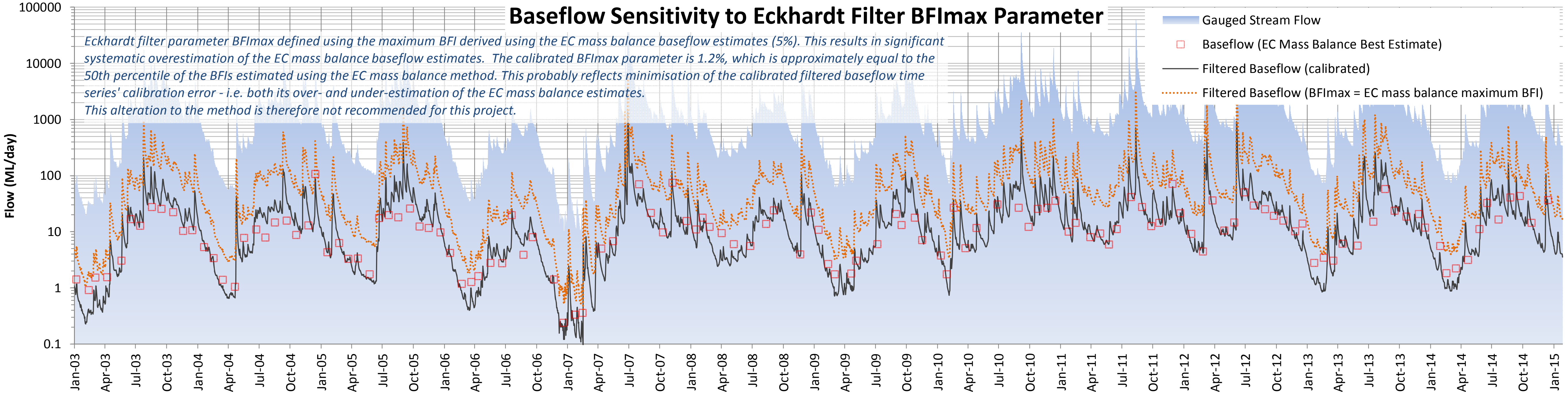
Changing the Eckhardt filter's Alpha and BFImax parameters to reflect observed stream flow recession rates and the EC-estimated maximum BFI is therefore not considered suitable for the current study, which aims to estimate the regional groundwater discharge component within stream flows, rather than flow components such as interflow and bank storage returns. As such Eckhardt filter's Alpha and BFImax parameters were calibrated to achieve a best fit to the EC derived baseflow estimates.



Baseflow Sensitivity to Eckhardt Filter Alpha Parameter

Eckhardt filter parameter Alpha defined as 0.945 using recession curve analysis results in a more muted baselfow hydrograph, and general over-estimation of baseflows (compared to the EC mass baalnce estimates) during flow events and on receding hydrograph limbs.The general baseflow variability evident in the EC mass balance estimates is not captured by the filter with alpha=0.945.
Calibrated alpha is 0.001, which serves to reflect the rapid variability in baseflow estimates derived using the EC mass balance. This variability may be due to the baseflow-diluting effect of runoff and other quicker stream flow components during and after rainfall events.
It is not recommended that alpha be defined using recession curve analysis for this project.

Groundwater End Member EC (uS/cm)	
Best Estimate	3000



Baseflow Sensitivity to Eckhardt Filter BFImax Parameter

Eckhardt filter parameter BFImax defined using the maximum BFI derived using the EC mass balance baseflow estimates (5%). This results in significant systematic overestimation of the EC mass balance baseflow estimates. The calibrated BFImax parameter is 1.2%, which is approximately equal to the 50th percentile of the BFIs estimated using the EC mass balance method. This probably reflects minimisation of the calibrated filtered baseflow time series' calibration error - i.e. both its over- and under-estimation of the EC mass balance estimates.
This alteration to the method is therefore not recommended for this project.

Figure 3л SŜnăʎúʎØʎúè !yl-fèăʎă 2Ŧ 9ǒɿKl-ǊŘú CʎfúŜǊ tl-Ǌl-ϒŜúŜǊă ó aʎúǑKŜff wʎØŜǊ l-ú DfŜyfl-Řl-fŜú

4.3.4 Removing periods of poor (non-linear) flow-EC relationships from individual gauge-based EC mass balances

The reliability of baseflow estimates derived using EC for the mass balance approach does not appear to be negatively affected by non-linear relationships between stream flow and EC. This is concluded on the basis that the baseflow fluxes estimated using Hofmann's detailed sampling and analysis for major ions along the lower Mitchell River are practically the same as those derived using EC at just the upstream and downstream gauges (Section 4.2.2 and Figure 28). This is despite there being significant variations in the relative input from interflow and bank storage over time relative to regional groundwater inputs, as indicated by Hofmann's ^{222}Rn-based 'baseflow' estimates compared to the Cl-based estimates.

Non-linearities between gauged stream flows and EC are observed in the case of the Mitchell River (as shown in Figure 32), and were raised as an issue by the previous studies of GHD (2013a and 2013b) and the technical reviewers of those studies. It was put forward that flow-EC relationship non-linearities arising from processes such as interflow, bank storage returns, and regulation of river flows and EC by reservoir releases also negatively affect the reliability of the baseflow estimates derived using the EC mass balance method, and subsequent training of the Eckhardt digital filter to those estimates.

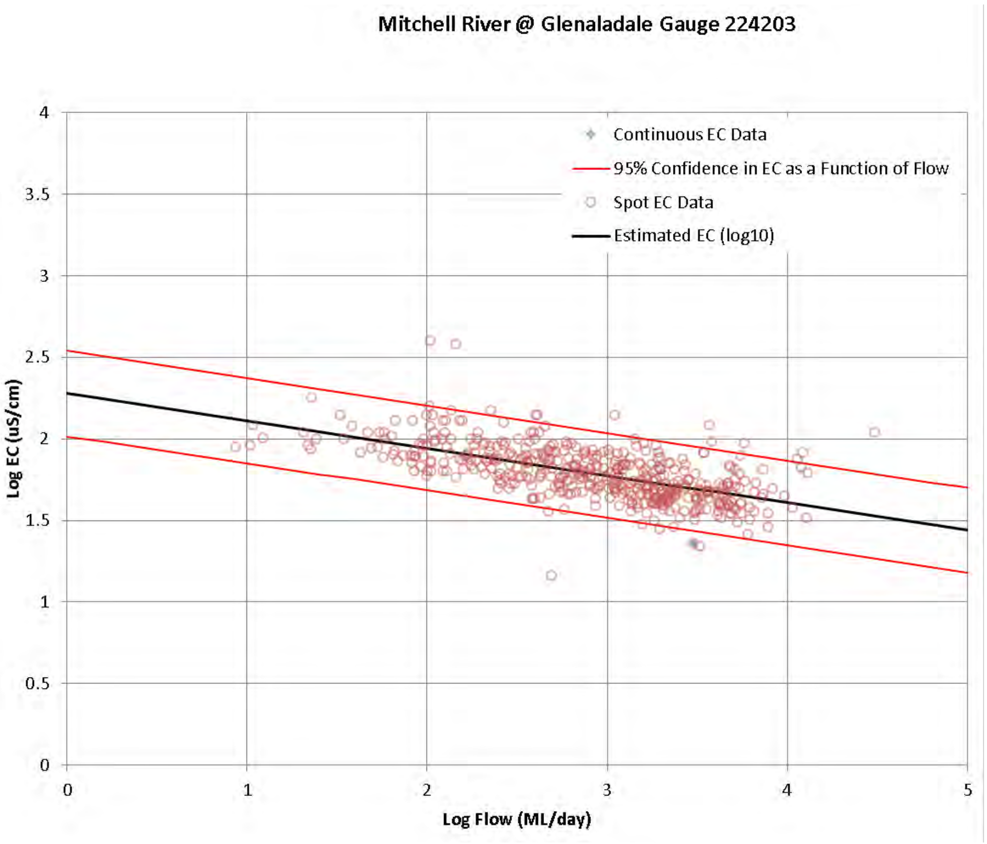


Figure 31 Non-linear gauged stream flow and EC relationship

However, these processes do not introduce EC from sources other than regional groundwater, which is being used in this study to quantify baseflow. They may however affect the timing and rate of groundwater (and EC) discharge to the stream. In the case of reservoir releases, stream flows may vary by orders of magnitude, whilst EC fluctuates around the range of the EC of water stored within the reservoir over time; the stream EC is still reflective of baseflow inputs to the stream upstream of the reservoir, but its temporal signature has been 'smudged' through mixing of waters over time within the reservoir. Feasible

In the case of bank storage, gauged stream EC at a given stream flow rate could vary over a significant range simply due to mixing of water in bank storage with regional groundwater to varying degrees. The degree of mixing between regional groundwater and water in bank storage may vary depending on (for example):

- The time over which water is held in bank storage before discharging back into the stream
- The volume of water emplaced within bank storage for a given flow event and/or sequence of events. For larger and/or more frequent flow events, a larger volume would be expected to enter bank storage than smaller events, or isolated events, or
- The antecedent regional groundwater conditions – i.e. during periods of higher groundwater level, there may be a larger rate of regional groundwater flow into the zone of bank storage.

Further to these previously identified issues, non-linearities in the flow-EC relationship may simply arise through variable rates of groundwater discharge to streams over time in response to groundwater recharge rates and corresponding changes in groundwater levels and gradients towards the stream, as discussed by Eckhardt (2008).

This discussion suggests that in order to reliably apply the EC mass balance method, there does not necessarily need to be a strong log-linear relationship between gauged stream EC and flow, as was suggested in the previous studies and technical reviews. This is supported by the comparison of the EC-derived baseflow estimates of this study with those of Hofmann (2011) in Figure 28, which includes quantification of interflow and bank storage return rates (estimated using ^{222}Rn), as distinct from regional groundwater discharge to the stream. The latter estimates of Hofmann (2011) estimated using detailed Cl surveys down the river are very similar to those derived using gauged EC at the upstream and downstream gauges. The differences are negligible in light of the objectives of this study, and are within the range of uncertainty of the estimates regardless.

Recommendation

Although stream flow-EC relationships are often non-linear, EC remains a conservative tracer of groundwater (baseflow) input to stream flow, assuming that there are no other significant sources of salts, which is the case for the Gippsland rivers analysed in this study. An exception to this applies for those Latrobe River reaches affected by saline industrial water returns (Section 3.5.1); however, addressing this issue has been recommended. It is therefore concluded that this proposed change to the method is not warranted. It has therefore not been applied in the current study, nor is it recommended for future application of the method, except in catchments in which there are significant contributions to stream EC from sources other than groundwater.

4.4 Revised baseflow estimates

Based on the outcomes of the testing discussed in Sections 4.2 and 4.3, the changes to the baseflow method that are considered suitable and valuable for improving the accuracy and/or reliability of the baseflow estimates which have been applied to the Mitchell, Thomson Macalister and Latrobe Rivers are listed below and discussed in this chapter:

- Reach-scale EC Mass Balance; and
- Constraining the interstation baseflow analysis.

4.4.1 Latrobe River

Reach-scale EC mass balance: Latrobe River

The revised method for applying the reach-scale EC mass balance (discussed in Section 4.2.2) was applied at the following gauges within the Latrobe River catchment:

- Latrobe River between Scarnes Bridge and Rosedale (Figure 33), applying a groundwater end member EC of 3151 (1133 – 8765); and
- Latrobe River between Rosedale and Kilmany South (Figure 34), applying a groundwater end member EC of 1561 (688 – 3541).

The groundwater EC end member ($c_{G\ reach}$) was defined using the average groundwater EC within the interstation catchments from the groundwater boreholes, and uncertainty analysis of the estimated baseflow gains to the reach were assessed using the standard deviation from the groundwater boreholes (outlined in Table 6 – Section 3.2.1).

As discussed in Section 3.2.1, there was evidence of an apparent 1-day time lag between Scarnes Bridge and Rosedale on the Latrobe River which was accounted for when conducting the reach-scale EC mass balance.

Constraining interstation baseflow analyses: Latrobe River

The automated calibration software PEST (Doherty, 2010) was used to calibrate the interstation baseflow gains, adopting the same approach as discussed in Section 4.3.1. Calibration was achieved through adjustment of the groundwater EC end members for the upstream and downstream gauges. Groundwater EC values were allowed to vary one standard deviation from the mean, with initial values defined using the observed data, where Table 23 summarises the PEST input parameters and calibrated end members.

The calibrated interstation baseflow gains for the mid-Latrobe River (between Scarnes Bridge and Rosedale) are presented as the solid blue line in Figure 35. Comparison to the reach-scale baseflow gains derived using the reach-scale EC mass balance (blue triangles, as discussed above and shown on Figure 33), indicate that there is consistently poor calibration of interstation baseflow gains to the reach-scale EC mass balance estimates at low flows. This is most likely due to flow gauging inaccuracies being of similar order of magnitude to the baseflow discharge rates.

The calibrated interstation baseflow gains for the lower-Latrobe River (between Rosedale and Kilmany South) are presented as the solid blue line in Figure 36. These are compared to the reach-scale baseflow gains derived using the reach-scale EC mass balance (blue triangles, as discussed above and shown on Figure 34), which indicates relatively good calibration is achieved.

Table 24 Latrobe River – Calibrated Groundwater End Member EC

Gauge ID	Gauge Name	GW EC End Member: Initial value (lower and upper bounds)	Calibrated groundwater EC end member
226227	Latrobe River at Kilmany South	1102 (377 - 3219)	2807
226033	Latrobe River at Scarnes Bridge	701 (279 - 3000)	3000
226228	Latrobe River at Rosedale (Main Stream)	967 (313 – 3000)	3000

Eckhardt Filter parameters: Latrobe River

The Eckhardt filter's Alpha and BFI-max parameters were calibrated to achieve a best fit to the EC derived baseflow estimates, where Table 24 summarises the revised Eckhardt filter parameters for the assessed gauges within the Latrobe River catchment.

Table 25 Latrobe River - Eckhardt Filter parameters

Gauge	BFI Max	Alpha	Nash-Sutcliffe Coefficient
226005	0.195	0.001	0.62
226007	0.005	0.001	0.41
226021	0.157	0.001	0.60
226033	0.091	0.062	0.94
226216	0.063	0.001	0.69
226227	0.098	0.001	0.89
226228	0.109	0.032	0.96
226408	0.270	0.001	0.77
226415	0.154	0.001	0.98

The gauged flow and EC regressions (Appendix B), EC-derived baseflow estimates (Appendix C), and baseflow estimate uncertainty analysis (Appendix D) were re-derived in this study using revised filter parameters and calibrated end member estimates. The key points of note and differences between the baseflow estimates derived in the previous study (GHD, 2013b) and the current for the Latrobe River for the assessed gauges are discussed below.

Latrobe River at Thoms Bridge (226005)

The baseflow estimates derived in the current study for the Latrobe River at Thoms Bridge (226005) are very similar to the previous study (GHD, 2013b). This is largely attributed to no additional EC data to calibrate the baseflow estimates, as EC observations were terminated in 2002.

A reach-scale mass balance between Latrobe River at Thoms Bridge and Latrobe River at Scarnes Bridge was not undertaken as there is insufficient concurrent information to include the major tributaries (Tyers River and Traralgon Creek). Furthermore, this reach includes a saline industrial water discharge from APM which is of a similar magnitude to the expected baseflow gains which would need to be accounted for in the reach-scale mass balance. Further data would need to be collected to adequately account for the industrial water returns.

A minor revision to the best estimate groundwater end member EC resulted in a small reduction in the BFI and an improvement in the Eckhardt filter calibration (Nash-Sutcliffe coefficient of 0.62). The uncertainty of the baseflow estimates at this gauge was within a similar range to the previous study (GHD, 2013b).

Tyers River at Browns (226007)

The baseflow estimates derived in the current study for the Tyers River at Browns (226007) are substantially lower than those derived in the previous study (GHD, 2013b), largely attributed to revisions in the groundwater EC end members. Previously, the groundwater end member EC was estimated as 320 uS/cm, based on a single borehole. The best estimate of groundwater end member EC was refined as part of this study based on interpolated mapped data, adopting an EC of 828 uS/cm, which is more consistent with groundwater EC for nearby upland catchments. The significantly higher groundwater end member EC results in a significantly reduced estimate of baseflow; where previously BFIs ranged from 1% to 9%, the new estimate is a constant 0.5%.

In this current study, the Eckhardt filter was left unmodified and the calibration was relatively poor (Nash-Sutcliffe coefficient of 0.41). This is most likely a result of the effects of the upstream reservoir.

The uncertainty of the baseflow estimates within this sub-catchment is high due to the limited data to estimate the groundwater end member EC. Previously, a range of 80-800 uS/cm was adopted for the groundwater end member EC; however, a refined approach using the minimum and maximum groundwater end member EC estimates for nearby similar catchments has resulted in a range of 80 – 2,237 uS/cm. While the uncertainty has increased, this is a result of a more conservative approach to the definition of the minimum and maximum groundwater end member EC estimates.

Latrobe River at Rosedale (Main Stream) (226228)

The groundwater end member EC for the Latrobe River at Rosedale (226228) was revised based on the reach-scale EC mass balance for the reach from Latrobe River at Scarnes Bridge to Latrobe River at Kilmany South. The groundwater end members were calibrated to fit the expected baseflow gain based on the reach-scale mass balances. This resulted in a best estimate groundwater end member EC of 3,000 uS/cm at this gauge. It is possible that an improved calibration could be achieved by accepting a higher EC; however, there is insufficient evidence to support a groundwater end member EC greater than 3,000 uS/cm in this study.

With the revised groundwater end member EC, a significantly improved calibration of the Eckhardt filter was achieved (Nash-Sutcliffe coefficient of 0.96). The resultant BFI was a constant 10%, significantly different to the previously estimated BFIs that oscillated between 5% and 25%.

The best estimate groundwater end member EC is the maximum of the expected range of groundwater EC for this site; therefore, it is unlikely that baseflow is over-estimated at this site.

Tanjil River at Tanjil South (226216)

Tanjil River at Tanjil South (226216) has a poor calibration of the Eckhardt filter (Nash-Sutcliffe coefficient of 0.69), primarily as a result of the regulating effect of Blue Rock Reservoir. Previously, an improved calibration was achieved using the modified Eckhardt filter; however in this study the unmodified Eckhardt filter has been applied, highlighting the poor correlation between the EC derived baseflow estimate and the Eckhardt filter.

Morwell River at Yallourn (226408)

The baseflow estimates derived in the current study for the Morwell River at Yallourn (226408) are substantially higher than those derived in the previous study (GHD, 2013b), primarily attributed to a reduction in the best estimate runoff end member. The previous runoff end member estimate of 370 uS/cm was unrealistically high and likely impacted by the saline industrial returns of the Hazelwood and Yallourn power stations. A more realistic runoff endmember of 44 uS/cm based on the streamflow gauge at Tanjil River at Tanjil South was adopted.

Latrobe River at Scarnes Bridge (226033)

The groundwater end member EC for the Latrobe River at Scarnes Bridge (226033) was revised based on the reach-scale EC mass balance for the reaches from Latrobe River at Scarnes Bridge to Latrobe River at Kilmany South. The groundwater end members were calibrated to fit the expected baseflow gain based on the reach scale mass balances. This resulted in a best estimate groundwater end member EC of 3000 uS/cm. It is possible that an improved calibration could be achieved by accepting a higher EC; however, there is insufficient evidence to support a groundwater end member EC greater than 3000 at this time.

Application of the revised groundwater end member EC resulted in a significant improvement in the calibration of the Eckhardt filter (Nash-Sutcliffe coefficient of 0.94). The resultant BFI was a constant 9%, somewhat different to the previously estimated BFIs that oscillated from 12% to 15%.

The best estimate groundwater end member EC is the maximum of the expected range of groundwater EC for this site; therefore, it is unlikely that baseflow is over-estimated at this site.

Latrobe River at Kilmany South (226227)

The groundwater end member EC for the Latrobe River at Kilmany South (226227) was revised based on the reach-scale EC mass balance for the reaches from Latrobe River at Scarnes Bridge to Latrobe River at Kilmany South. The groundwater end members were calibrated to fit the expected baseflow gain based on the reach scale mass balances. This resulted in a best estimate groundwater end member of 2807 uS/cm.

Application of the revised groundwater end member EC resulted in a significant improvement in the calibration of the Eckhardt filter (Nash-Sutcliffe coefficient of 0.89). The resultant BFI was a constant 11%, similar to the previously estimated BFIs that oscillated from 4% to 18%.

The best estimate groundwater end member is the maximum of the expected range of groundwater EC for this site; therefore it is unlikely that baseflow is over-estimated at this site.

Narracan Creek at Moe (226021)

The baseflow estimates derived in the current study for Narracan Creek at Moe (226021) are very similar to the previous study (GHD, 2013b). While the groundwater end member EC was revised upwards based on additional data (increased from 489 to 602 uS/cm), the runoff end member EC was also revised down (reduced from 135 to 44 uS/cm), which neutralises the impacts on baseflow estimates.

Traralgon Creek at Traralgon South (SEC) (226415)

The baseflow estimates derived in the current study for Traralgon Creek at Traralgon South (SEC) (226415) are substantially higher than those derived in the previous study (GHD, 2013b), primarily attributed to a reduction in the best estimate runoff end member. The previous runoff end member estimate of 180 uS/cm was unrealistically high. A more realistic runoff endmember of 44 uS/cm based on the streamflow gauge at Tanjil River at Tanjil South was adopted.

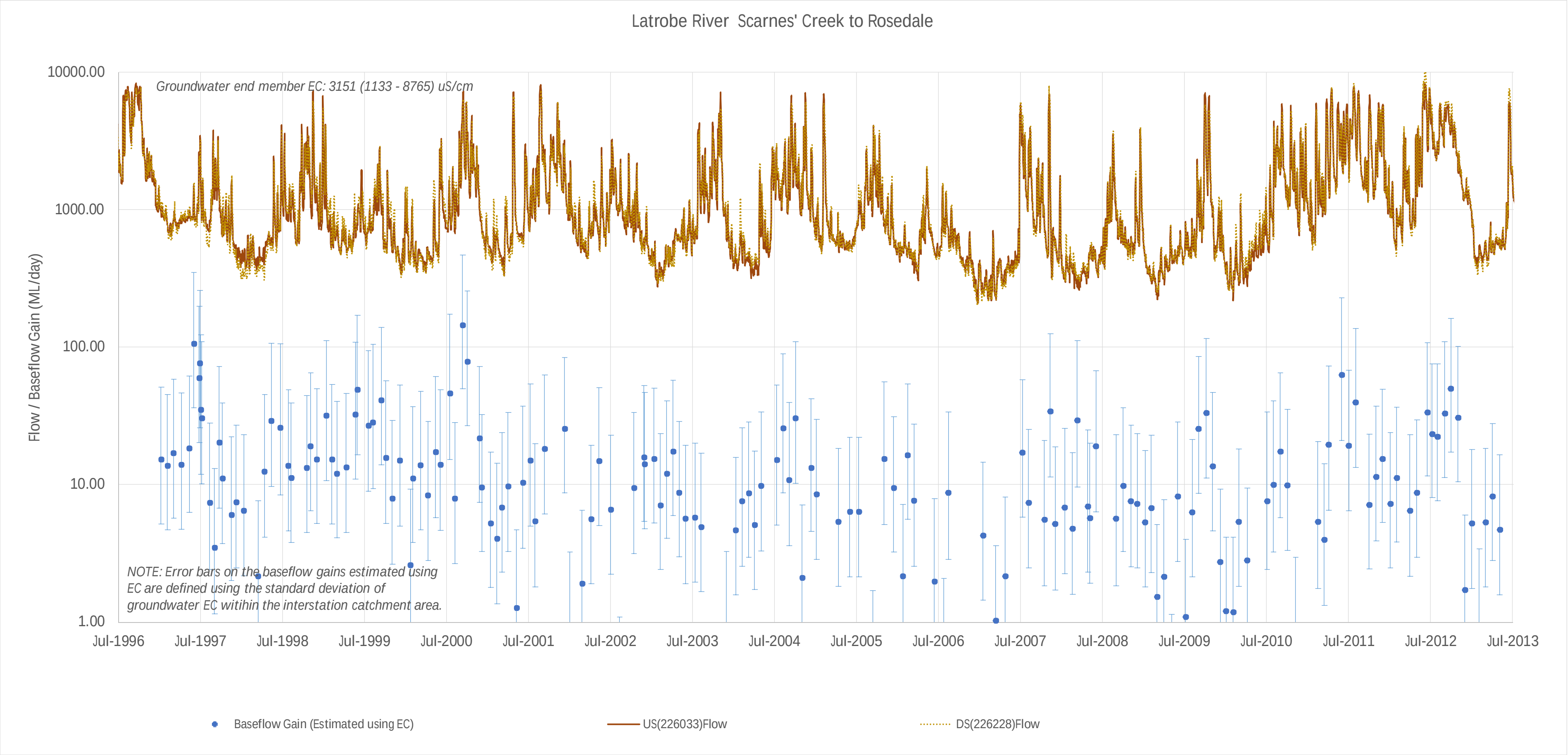
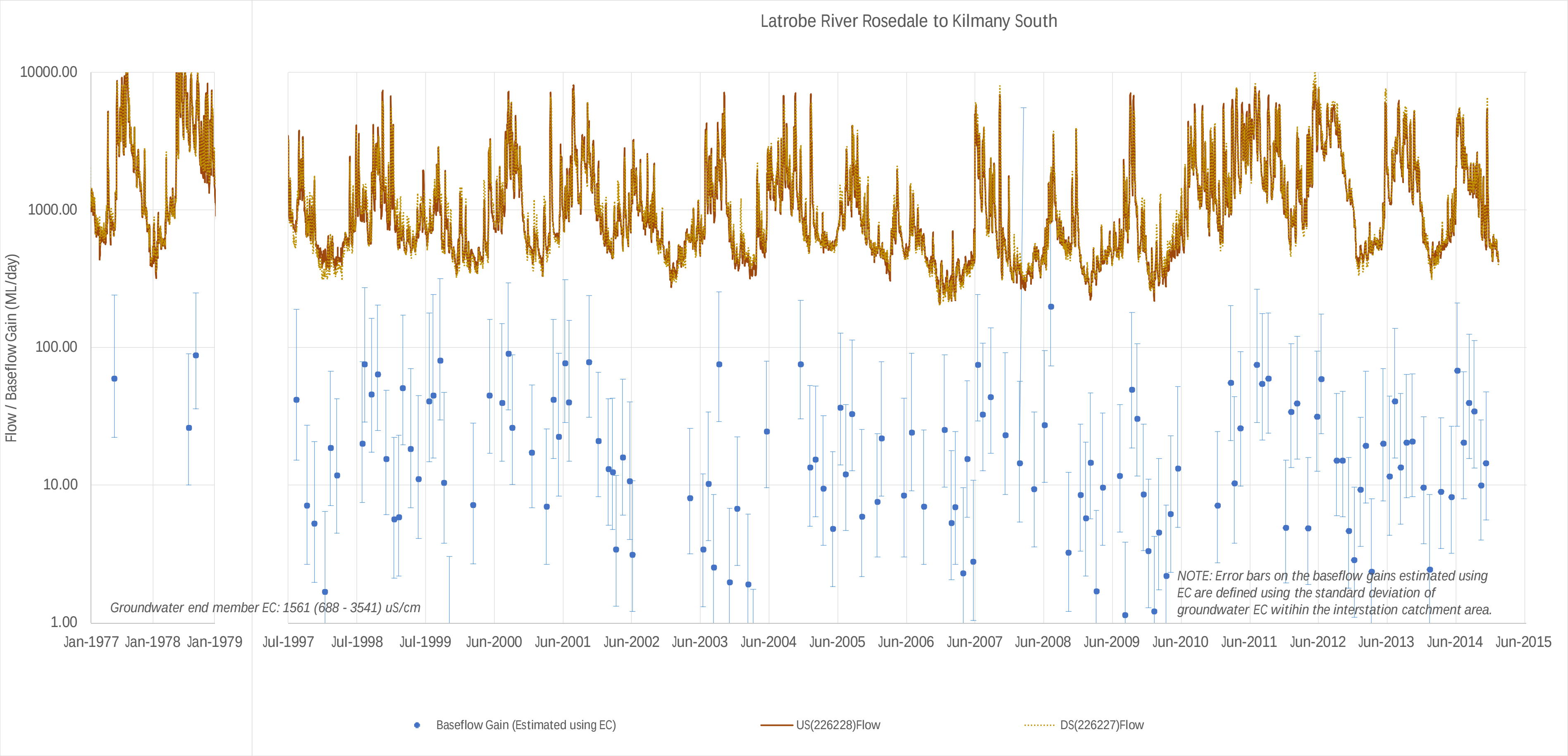


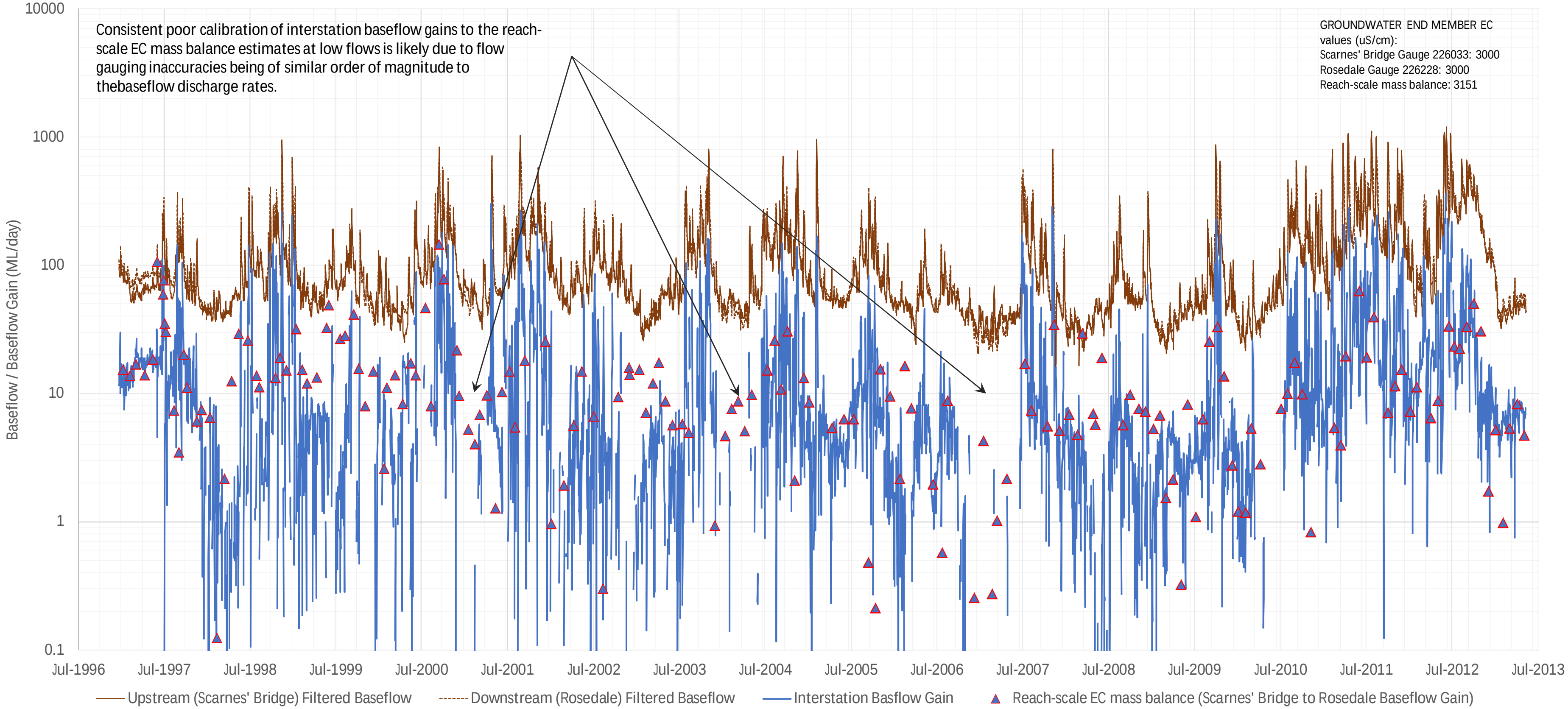
Figure 3H Reach-Scale Baseflow Gain Estimates for the Latrobe River Scarnes' Bridge to Rosedale



Groundwater end member EC: 1561 (688 - 3541) uS/cm

NOTE: Error bars on the baseflow gains estimated using EC are defined using the standard deviation of groundwater EC within the interstation catchment area.

Figure **30** Reach-Scale Baseflow Gain Estimates for the Latrobe River Rosedale to Kilmany South

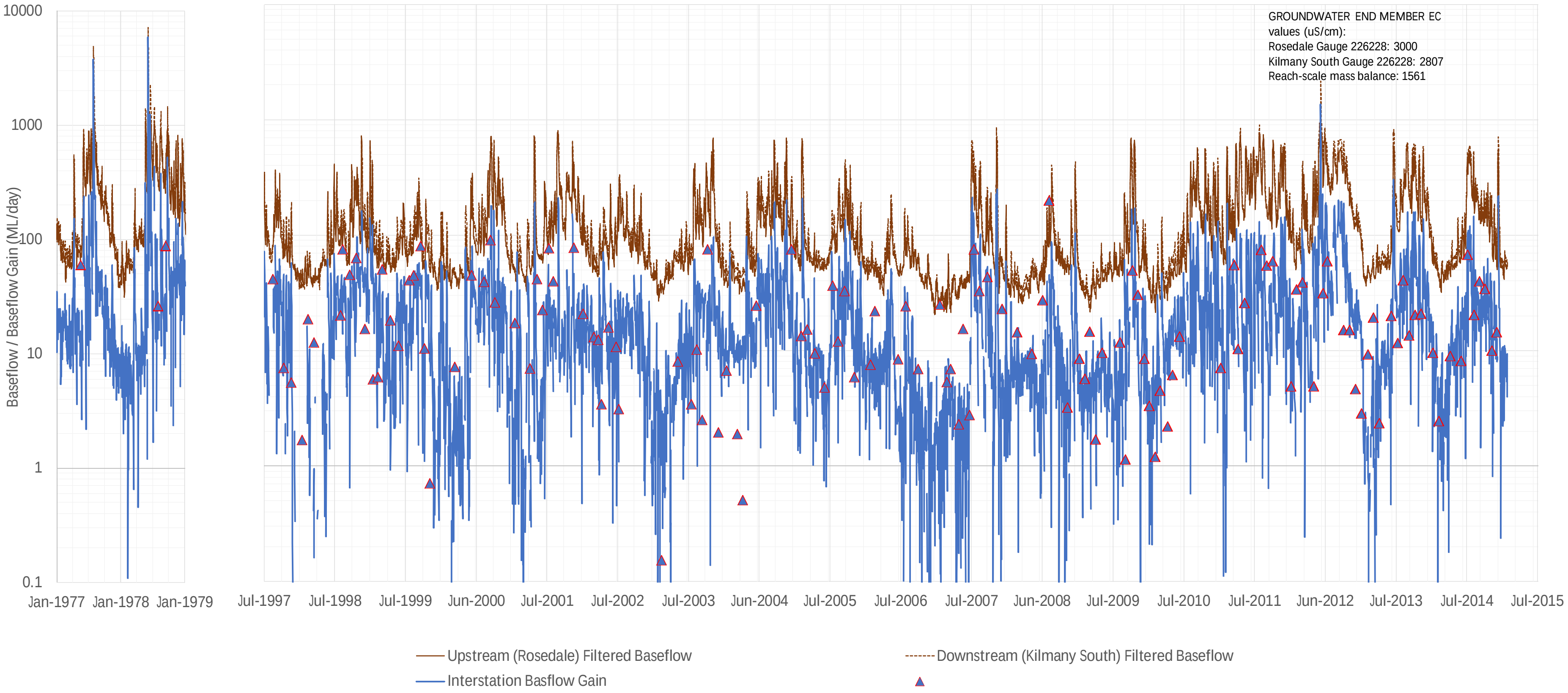


Consistent poor calibration of interstation baseflow gains to the reach-scale EC mass balance estimates at low flows is likely due to flow gauging inaccuracies being of similar order of magnitude to thebaseflow discharge rates.

GROUNDWATER END MEMBER EC values (uS/cm):
Scarnes' Bridge Gauge 226033: 3000
Rosedale Gauge 226228: 3000
Reach-scale mass balance: 3151

Figure **3n** Interstation Baseflow Gain Calibration: Latrobe River Scarnes' Bridge to Rosedale

G:\31\32709\Technical\Design\Analysis\Latrobe\Interstation\pest_Latrobemaster\d0xx_Latrobe228_Sensitivity_GWEndMember_LowFlowEC.xlsx (Figure 29)



GROUNDWATER END MEMBER EC
values (uS/cm):
Rosedale Gauge 226228: 3000
Kilmany South Gauge 226228: 2807
Reach-scale mass balance: 1561

Figure **3p** Interstation Baseflow Gain Calibration: Latrobe River Rosedale to Kilmany South

4.4.2 Thomson-Macalister River

Reach scale EC mass balance: Thomson-Macalister River

The revised method for applying the reach-scale EC mass balance (discussed in Section 4.2.2) was applied at the following gauges within the Thomson-Macalister catchment:

- Thomson River between Heyfield and Wandocka (Figure 37), applying a groundwater end member EC of 1444 (758 - 2750) uS/cm;
- Macalister River between Glenmaggie and Riverslea (Figure 38) applying a groundwater end member EC of 1129 (384 - 3319) uS/cm; and
- Lower Thomson-Macalister River from Wandocka to Bundalaguah including Macalister River (Figure 39), applying a groundwater end member EC of 965 (394 - 2366) uS/cm.

The groundwater EC end member ($c_{G\ reach}$) was defined using the average groundwater EC within the interstation catchments from the groundwater boreholes, and uncertainty analysis of the estimated baseflow gains to the reach were assessed using the standard deviation from the groundwater boreholes (outlined in Table 16 – Section 3.3.1).

Reach-scale mass balance of the Thomson River at Heyfield (including Rainbow Creek) to Wandocka indicate that the reach has baseflow gains in wetter periods, and not in drier periods, which is consistent with findings from the ecoMarkets Model as discussed in Section 3.3.3.

There is minimal data for the Macalister River between Glenmaggie and Riverslea, with only eight concurrent recordings of EC.

Constraining interstation baseflow analyses: Thomson-Macalister River

The automated calibration software PEST (Doherty, 2010) was used to calibrate the interstation baseflow gains for the three interstation sub-catchments listed in the section above, adopting the same approach as discussed in Section 4.3.1. Calibration was achieved through adjustment of the groundwater EC end members for the upstream and downstream gauges. Groundwater EC values were allowed to vary one standard deviation from the mean, with initial values defined using the observed data, where Table 25 summarises the PEST input parameters and calibrated end members.

The calibrated interstation baseflow gains for the Thomson River between Heyfield and Wandocka are presented as the solid blue line in Figure 40. Comparison to the reach-scale baseflow gains derived using the reach-scale EC mass balance (blue triangles, as discussed above and shown on Figure 38), indicate that there is consistently poor calibration of interstation baseflow gains to the reach-scale EC mass balance estimates at low flows. This is most likely due to flow gauging inaccuracies being of similar order of magnitude to the baseflow discharge rates.

The calibrated interstation baseflow gains for the Macalister River between Glenmaggie and Riverslea are presented as the solid blue line in Figure 41. Comparison to the reach-scale baseflow gains derived using the reach-scale EC mass balance (blue triangles, as discussed above and shown on Figure 39) indicate that there is consistently poor calibration of interstation baseflow gains to the reach-scale EC mass balance estimates at low flows. It should also be noted that there is very limited data to calibrate the interstation baseflow gains on the Macalister River between Glenmaggie and Riverslea, with only eight concurrent recordings of EC to derive the reach-scale mass balance estimates.

The calibrated interstation baseflow gains for the lower Thomson-Macalister River are presented as the solid blue line in Figure 42. Comparison to the reach-scale baseflow gains derived using the reach-scale EC mass balance (blue triangles, as discussed above and shown on Figure 39), indicate that there is consistently poor calibration of interstation baseflow gains to the reach-scale EC mass balance estimates at low flows. It should also be noted that a relatively poor baseflow gain calibration during high flow events is also experienced for two estimates of reach-scale EC mass balance in late 2012. While the reason for the poor calibration is uncertain, it could be attributed to a gauging error in the stream EC and / or flows over this period.

Table 26 Thomson-Macalister River – Calibrated Groundwater End Member EC

Gauge ID	Gauge Name	GW EC End Member: Initial value (lower and upper bounds)	Calibrated groundwater EC end member
225200	Thomson River at Heyfield	643 (192 - 1935)	1022
225212	Thomson River at Wandocka	1,444 (312 - 2518)	1399
225204	Macalister River at Lake Glenmaggie	839 (1810 - 4500)	4500
225247	Macalister River at Riverslea	1,129 (406 - 3462)	1150
225232	Thomson River at Bundalaguah	965 (384 - 2929)	1198

Eckhardt Filter parameters: Thomson-Macalister River

The Eckhardt filter's Alpha and BFI-max parameters were calibrated to achieve a best fit to the EC derived baseflow estimates, where Table 26 summarises the revised Eckhardt filter parameters for the assessed gauges within the Thomson-Macalister River catchment.

Table 27 Thomson-Macalister River - Eckhardt Filter Parameters

Gauge	Revised Parameters		
	BFI Max	Alpha	Nash-Sutcliffe Coefficient
225204	0.005	0.010	0.89
225231	0.066	0.320	0.92
225247	0.033	0.001	0.60
225200	0.013	0.001	0.51
225232	0.044	0.001	0.59
225212	0.019	0.31	0.78
225236	0.017	0.16	0.65

The gauged flow and EC regressions (Appendix B), EC-derived baseflow estimates (Appendix C), and baseflow estimate uncertainty analysis (Appendix D) were re-derived in this study using revised filter parameters and calibrated end member estimates. The key points of note and differences between the baseflow estimates derived in the previous study (GHD, 2013b) and the current for the Thomson-Macalister River for the assessed gauges are discussed below.

Thomson River U/S of Cowwarr Weir (225231)

The baseflow estimates derived in the current study for the Thomson River U/S of Cowwarr Weir (225231) are lower than those derived in the previous study (GHD, 2013a), largely attributed to revisions in the runoff and groundwater EC end members. Previously, the runoff end member EC was estimated as 12.5 uS/cm; where review has indicated that this very low recorded EC is likely to be an outlier. The best estimate of runoff end member EC was refined as part of this study based the 5th percentile EC of 48 uS/cm, which is more consistent with the EC observed at high flow on the gauge at Heyfield and Wandocka.

Previously the groundwater end member EC was estimated as 320 uS/cm (based on a single bore). This best estimate of groundwater end member EC was refined adopting an EC of 794 uS/cm based on interpolated mapped data, which is more consistent with groundwater EC for nearby upland catchments. The higher groundwater end member EC combined with the higher runoff end member EC results in a significantly reduced estimate of baseflow, where the new estimate is a relatively constant BFI of 1.5% compared to a previous estimate of approximately 20%.

In this study the Eckhardt filter was left unmodified and the calibration was relatively good (Nash-Sutcliffe coefficient of 0.92).

The uncertainty for this site is relatively high as a result of the limited data to estimate the groundwater end member EC. Previously a range of 160-480 uS/cm (mean±50%) was adopted for the groundwater end member EC; however, a refined approach using the minimum and maximum groundwater end member EC estimates for nearby similar catchments results in a range of 80-4230 uS/cm. While the uncertainty has increased, this is a result of a more conservative approach to definition of the minimum and maximum groundwater end member EC estimates.

Thomson River at Heyfield (225200)

The baseflow estimates derived in the current study for the Thomson River at Heyfield (225200) are lower than those derived in the previous study (GHD, 2013a), largely attributed to revisions in the groundwater EC end member.

The groundwater end member EC for this gauge was revised based on the reach-scale EC mass balance for the reaches from Thomson River at Heyfield to Thomson River at Bundalaguah including the Macalister River from Glenmaggie. The groundwater end members were calibrated to fit the expected baseflow gain based on the reach scale mass balances. This resulted in a best estimate groundwater end member of 1022 uS/cm. The revised groundwater end member EC is significantly higher than the previously estimated groundwater end member, resulting in BFI estimates of 1% compared to the previous estimates of 10%.

A review of the flow EC data that the 1st percentile observed EC of 56 uS/cm is representative of high flow conditions at this site, therefore this value was adopted.

Rainbow Creek at Heyfield (225236)

A review of the flow EC data indicated that the very low recorded ECs at Rainbow Creek at Heyfield (225236) are likely to be outliers; therefore the 1st percentile observed EC at the Thomson River at Heyfield gauge was adopted.

The groundwater end member EC for this gauge was revised based on the reach scale EC mass balance for the reaches from Thomson River at Heyfield to Thomson River at Bundalaguah including the Macalister River from Glenmaggie. The groundwater end members were calibrated to fit the expected baseflow gain based on the reach scale mass balances. This resulted in a best estimate groundwater end member of 2000. It is possible that an improved calibration could be achieved by accepting a higher EC; however, there is insufficient evidence to support a groundwater EC end member greater than 2000 at this time.

This higher groundwater end member EC resulted in a reduced estimate of baseflow compared the previous study.

Thomson River at Wandocka (225212)

The baseflow estimates derived in the current study for the Thomson River at Wandocka (225212) are lower than those derived in the previous study (GHD, 2013a), largely attributed to revisions in the groundwater EC end member.

The groundwater end member EC for this gauge was revised based on the reach scale EC mass balance for the reaches from Thomson River at Heyfield to Thomson River at Bundalaguah including the Macalister River from Glenmaggie. The groundwater end members were calibrated to fit the expected baseflow gain based on the reach scale mass balances. This resulted in a best estimate groundwater end member of 1399.

Thomson River at Bundalaguah (225232)

The baseflow estimates derived in the current study for the Thomson River at Bundalaguah (225232) are lower than those derived in the previous study (GHD, 2013a), largely attributed to revisions in the groundwater EC end member.

The groundwater end member EC for this gauge was revised based on the reach scale EC mass balance for the reaches from Thomson River at Heyfield to Thomson River at Bundalaguah including the Macalister River from Glenmaggie. The groundwater end members were calibrated to fit the expected baseflow gain based on the reach scale mass balances. This resulted in a best estimate groundwater end member of 1198.

This higher groundwater end member EC results in a reduced estimate of baseflow compared the previous study.

Macalister River at Lake Glenmaggie (Tail Gauge) (225204)

The baseflow estimates derived in the current study for the Macalister River at Lake Glenmaggie (Tail Gauge) (225204) are lower than those derived in the previous study (GHD, 2013a), largely attributed to revisions in the groundwater EC end member.

The groundwater end member EC for this gauge was revised based on the reach scale EC mass balance for the reaches from Thomson River at Heyfield to Thomson River at Bundalaguah including the Macalister River from Glenmaggie. The groundwater end members were calibrated to fit the expected baseflow gain based on the reach scale mass balances. This resulted in a best estimate groundwater end member of 4500, it is possible that an improved calibration could be achieved by accepting a higher EC however there is insufficient evidence to support an groundwater EC end member greater than 4500 at this time.

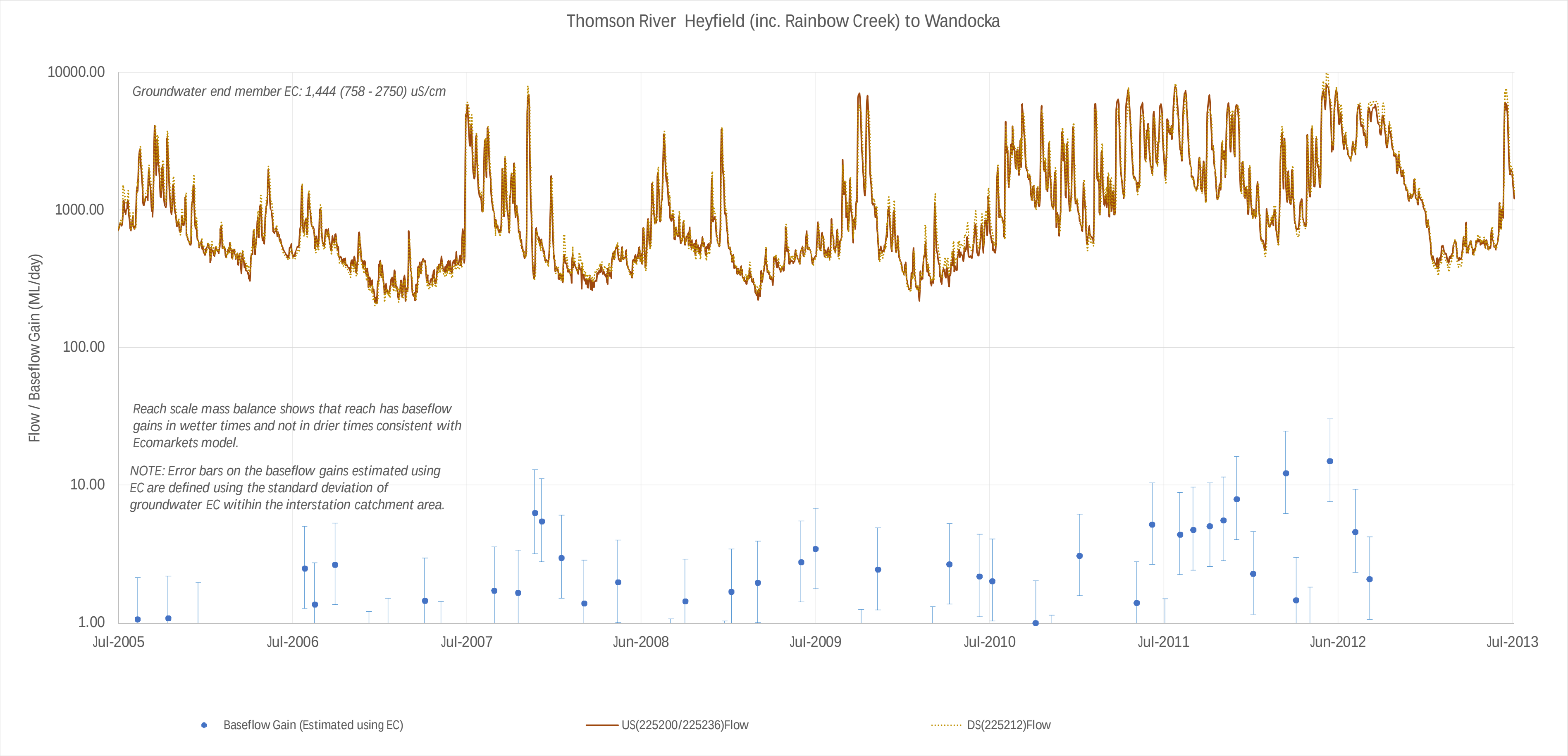
This significantly higher groundwater end member EC results in a significantly reduced estimate of baseflow compared the previous study.

Macalister River at Riverslea (225247)

The baseflow estimates derived in the current study for the Macalister River at Riverslea (225247) are lower than those derived in the previous study (GHD, 2013a), largely attributed to revisions in the groundwater EC end member.

The groundwater end member EC for this gauge was revised based on the reach scale EC mass balance for the reaches from Thomson River at Heyfield to Thomson River at Bundalaguah including the Macalister River from Glenmaggie. The groundwater end members were calibrated to fit the expected baseflow gain based on the reach scale mass balances. This resulted in a best estimate groundwater end member of 1150.

This higher groundwater end member EC results in a significantly reduced estimate of baseflow compared the previous study.



Thomson River Heyfield (inc. Rainbow Creek) to Wandocka

Groundwater end member EC: 1,444 (758 - 2750) uS/cm

Reach scale mass balance shows that reach has baseflow gains in wetter times and not in drier times consistent with Ecomarkets model.

NOTE: Error bars on the baseflow gains estimated using EC are defined using the standard deviation of groundwater EC witihin the interstation catchment area.

Figure 3**c** Reach-Scale Baseflow Gain Estimates for the Thomson River (Heyfield to Wandocka)

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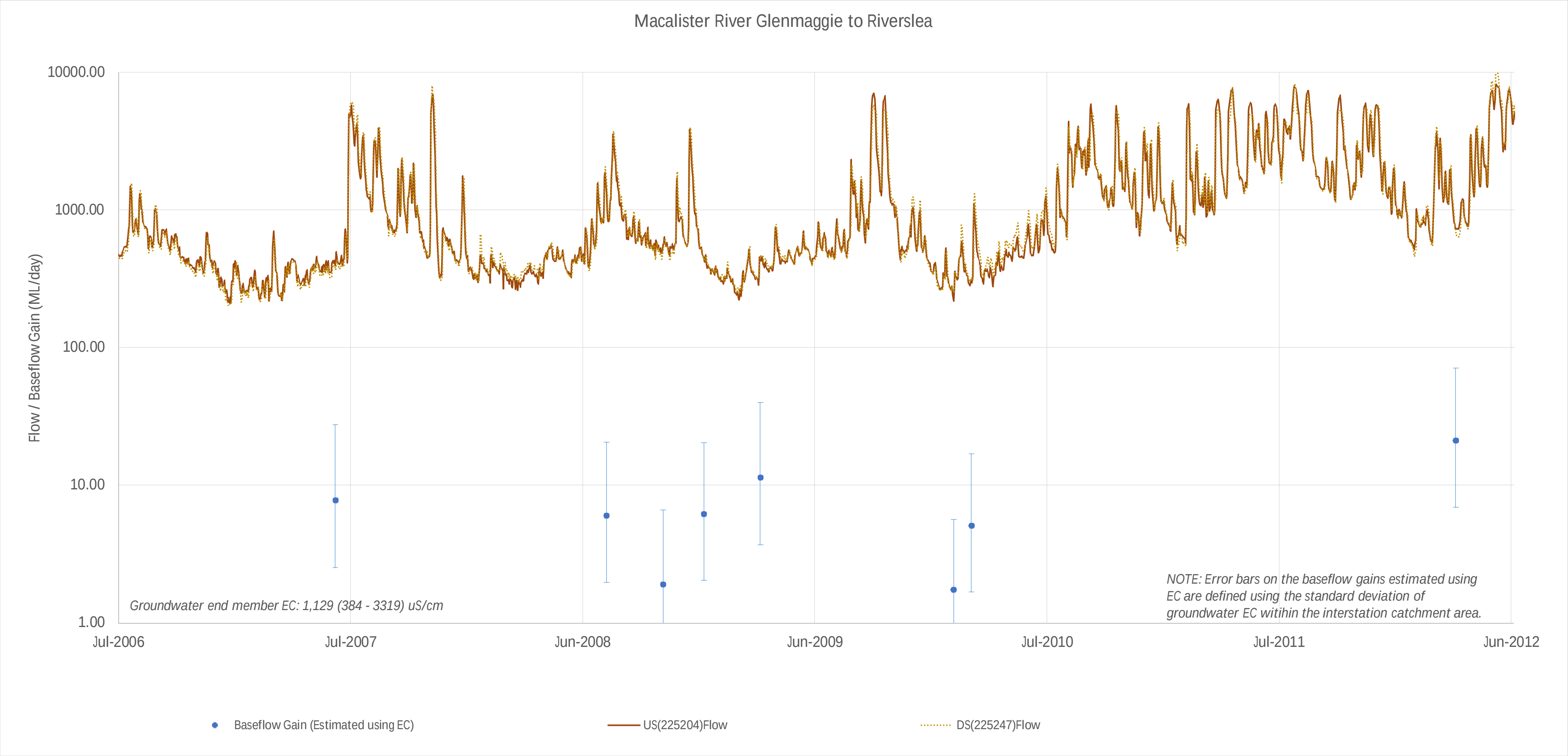


Figure 3т Reach-Scale Baseflow Gain Estimates for the Macalister River

G:\31\32709\Technical\Design\Analysis\Thomson Macalister\interstation\d0xx_Thomson225247_Reach_EC_Balance.xlsx (Figure 28)

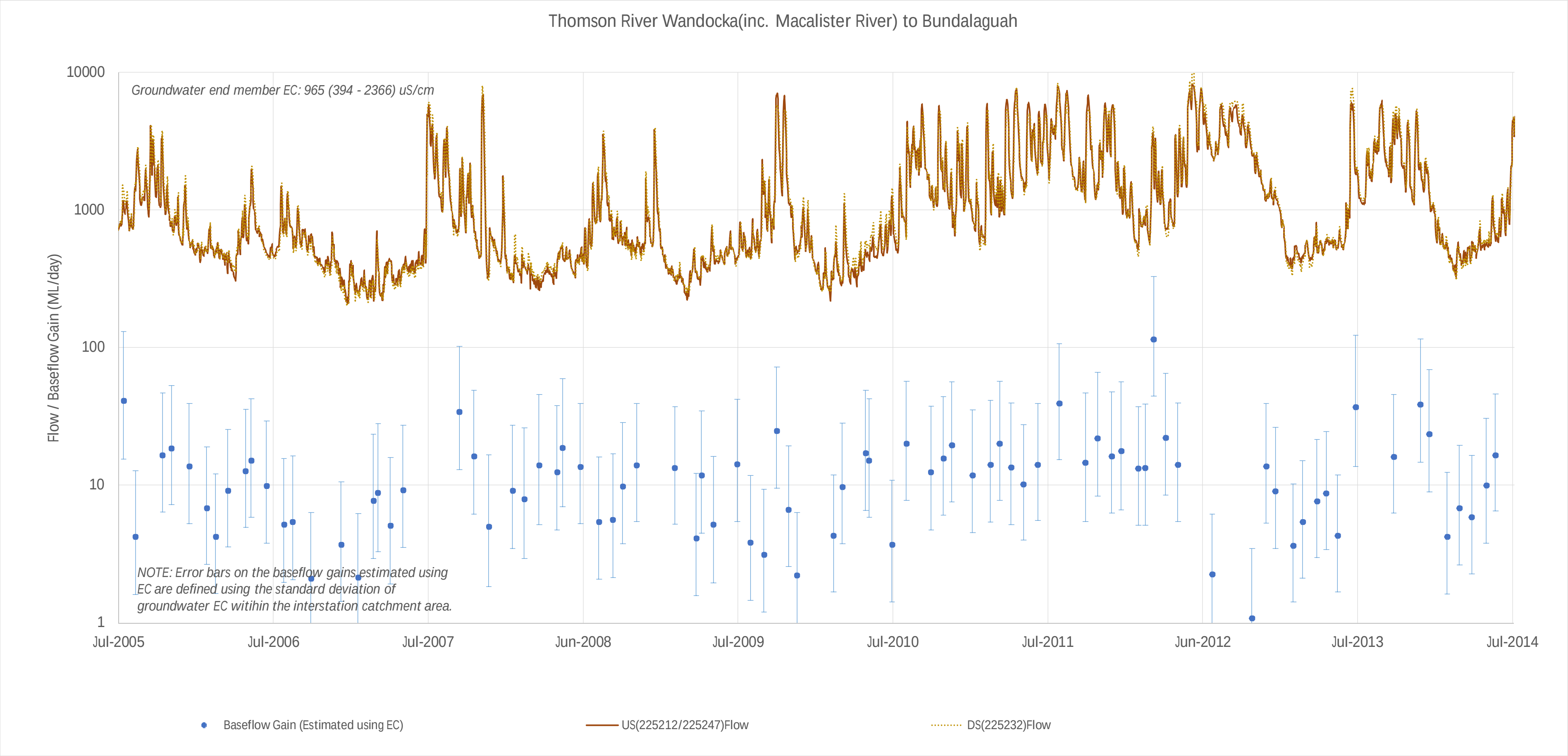
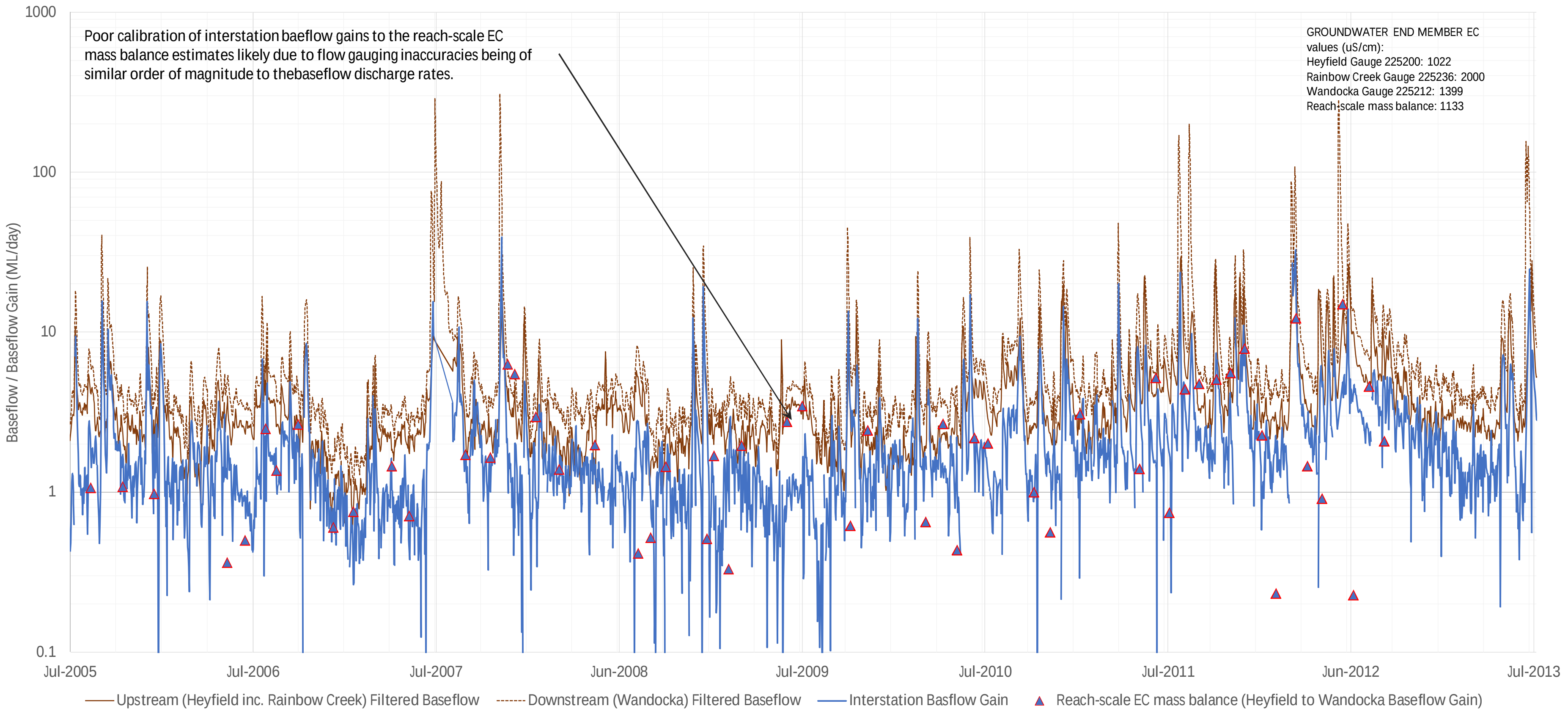


Figure 3**y** Reach-Scale Baseflow Gain Estimates for the Thomson River (Wandocka to Bundalaguah)

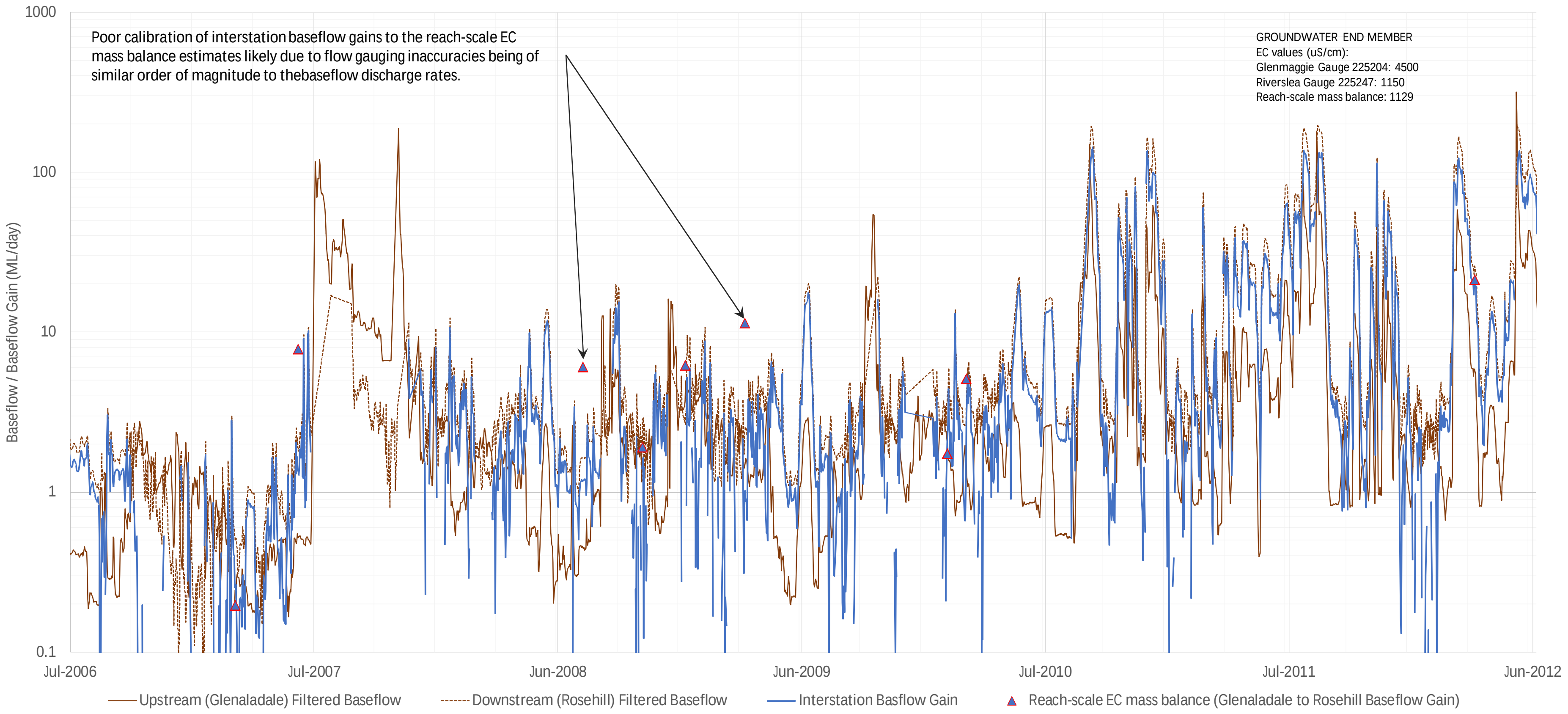


Poor calibration of interstation baeflow gains to the reach-scale EC mass balance estimates likely due to flow gauging inaccuracies being of similar order of magnitude to thebaseflow discharge rates.

GROUNDWATER END MEMBER EC values (uS/cm):
Heyfield Gauge 225200: 1022
Rainbow Creek Gauge 225236: 2000
Wandocka Gauge 225212: 1399
Reach-scale mass balance: 1133

Figure **oф** Interstation Baseflow Gain Calibration: Thomson River Heyfield to Wandocka

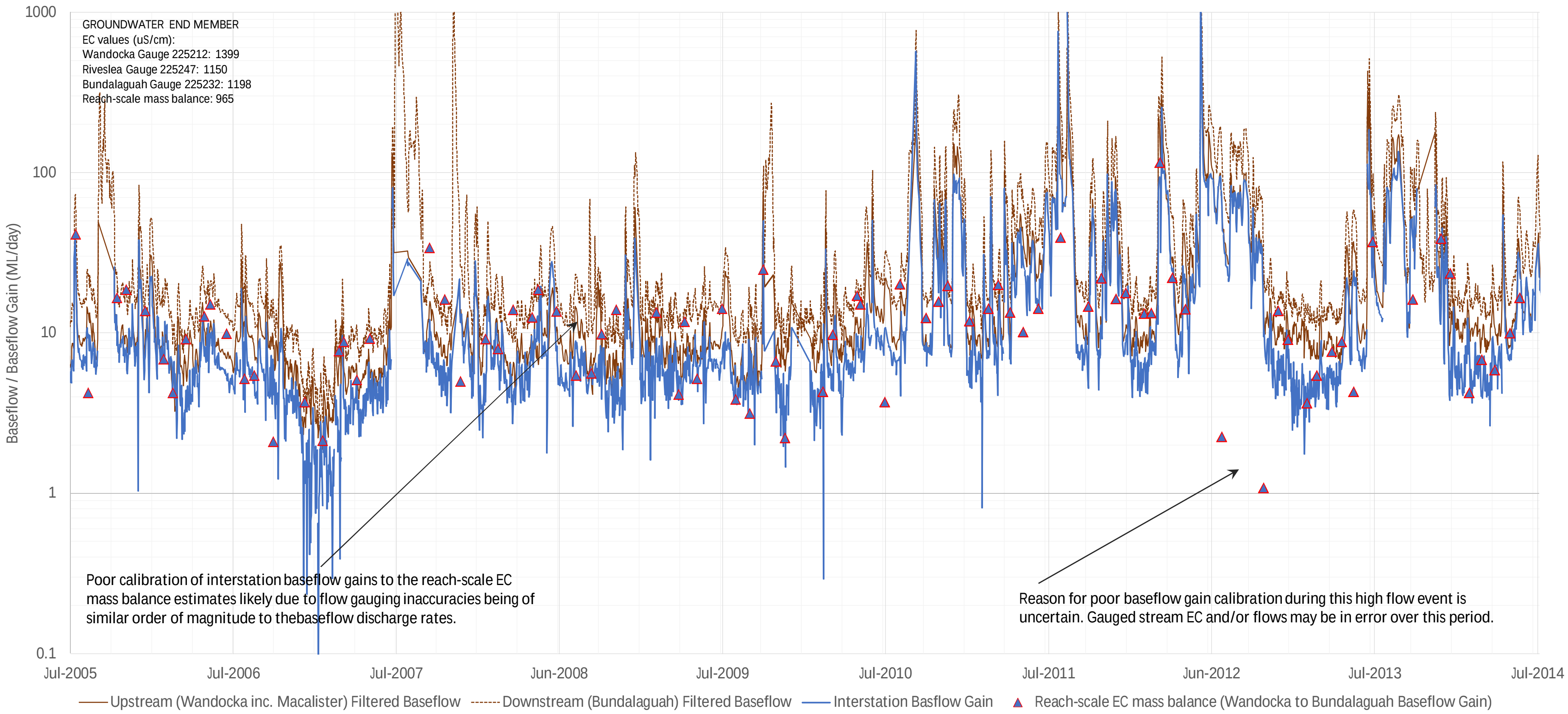
G:\31\32709\Technical\Design\Analysis\Thomson Macalister\interstation\pest_Thomsonmaster\d0xx_Thomson212_Sensitivity_GWEndMember_LowFlowEC.xlsx (Figure 29)



Poor calibration of interstation baseflow gains to the reach-scale EC mass balance estimates likely due to flow gauging inaccuracies being of similar order of magnitude to thebaseflow discharge rates.

GROUNDWATER END MEMBER
EC values (uS/cm):
Glenmaggie Gauge 225204: 4500
Riverslea Gauge 225247: 1150
Reach-scale mass balance: 1129

Figure **4л** Interstation Baseflow Gain Calibration: Macalister River Glenmaggie to Riverslea



GROUNDWATER END MEMBER
EC values (uS/cm):
Wandocka Gauge 225212: 1399
Riveslea Gauge 225247: 1150
Bundalaguah Gauge 225232: 1198
Reach-scale mass balance: 965

Poor calibration of interstation baseflow gains to the reach-scale EC mass balance estimates likely due to flow gauging inaccuracies being of similar order of magnitude to thebaseflow discharge rates.

Reason for poor baseflow gain calibration during this high flow event is uncertain. Gauged stream EC and/or flows may be in error over this period.

Figure **4M** Interstation Baseflow Gain Calibration: Thomson River Wandocka to Bundalaguah

4.4.3 Mitchell River

Baseflow analysis of the Mitchell River is discussed in detail in Sections 4.2 and 4.3, where Figure 28 (Section 4.2.2) presents the baseflow estimates derived using the reach-scale EC mass balance method for the lower Mitchell River, and Figure 29 presents the interstation baseflow analysis for the lower Mitchell River, and is discussed in Section 4.3.1.

The Eckhardt filter’s Alpha and BFI-max parameters were calibrated to achieve a best fit to the EC derived baseflow estimates, where Table 26 summarises the revised Eckhardt filter parameters for the assessed gauges within the Mitchell River catchment.

The gauged flow and EC regressions (Appendix B), EC-derived baseflow estimates (Appendix C), and baseflow estimate uncertainty analysis (Appendix D) were re-derived in this study using revised filter parameters and calibrated end member estimates.

Table 28 Mitchell River - Eckhardt Filter Parameters

Gauge	Revised Parameters		
	BFI Max	Alpha	N-S Coefficient
224203	0.012	0.001	0.87
224217	0.023	0.302	0.73

4.5 Improvements to the baseflow assessment method

Based on the outcomes of testing the recommended refinements to the baseflow method to the on the Mitchell River catchment, the changes to the baseflow method that are considered suitable and valuable for improving the accuracy and/or reliability of the baseflow estimates have been applied to the Mitchell, Thomson-Macalister and Latrobe Rivers.

The most significant improvement to the method is the use of reach scale EC mass balance to estimate interstation baseflow gains, used in conjunction to constrain the estimate of groundwater end member EC at the upstream and downstream gauges. Application of these two refinements to the method results in an estimate of baseflow at each gauge that is in agreement with the interstation baseflow gains.

The refined method applied in this study utilises groundwater tracer data in two different ways to constrain digitally filtered baseflow time series estimates. The two different ways EC data are used are:

1. An EC mass balance on individual gauged flow and EC data, which produces baseflow time series estimates for the entire area upstream of the gauge; and
2. A reach-scale EC mass balance utilising flow and EC data at upstream/downstream gauge pairs to estimate baseflow gains within specific river reaches. The reach-scale baseflow gains can then be used to further constrain the individual gauged baseflow time series estimates at the upstream and downstream gauges.

The two EC mass balance data sets are used to calibrate a digital baseflow filter for individual flow gauges, which produces a calibration-constrained continuous daily time series of baseflow estimates for the entire period of available stream flow gauging. This allows for assessment of both seasonal and inter-annual baseflow behaviour. It also allows for temporal expansion of reach-scale baseflow gains estimated using the reach-scale EC mass balance, by subtracting two (upstream and downstream) filtered (calibrated) baseflow time series' from one another.

The two EC mass balance methods can estimate baseflows to both regulated and unregulated rivers, which traditional digital baseflow filter methods cannot. In rivers regulated by reservoirs, baseflow estimates for gauges located below the reservoir will be limited in their estimation of seasonal baseflow variability, due to the flow- and EC-homogenising effect of reservoir storage and subsequent release. However, the long term average estimated baseflow gains to the reservoir catchment are unaffected by reservoir regulation because EC is a conservative groundwater (baseflow) tracer. Similarly, for reaches downstream of reservoirs that are gauged by upstream/downstream pairs, baseflow gains to those reaches estimated using a reach-scale EC mass balance are entirely unaffected by river regulation from upstream reservoirs.

In addition to these refinements to the baseflow estimation method, the Eckhardt filter's Alpha and BFImax parameters were calibrated to achieve a best fit to the EC derived baseflow estimates. The other changes to the methodology which were tested on the Mitchell River catchment were not to significantly improve the estimation of baseflow from regional groundwater, and therefore have not been applied to the Mitchell, Thomson-Macalister and Latrobe Rivers. The bulk baseflow time-series were regenerated for all assessed gauges in the Mitchell, Thomson-Macalister and Latrobe Rivers, applying the changes to the method noted above, and also extending the surface water flow and EC data from the 2013 studies (GHD 2013a, GHD, 2013b).

It is noted that that while the application of additional assessment methods was reviewed using the Mitchell River as a case study, the key recommendations are also applicable to the Latrobe and Thomson-Macalister catchments despite being very different systems, and are discussed below.

Sellinger (1996) rating curve baseflow estimation method

The "rating curve" method of Sellinger (1996) for estimating baseflow contributions to stream flow was considered for application in this project. However, given that the primary objective of this project is the estimation of regional groundwater discharge to streams, rather than intermediate flow components such as bank storage returns and interflow, the Sellinger (1996) rating curve method is not regarded as applicable to the current study.

Defining groundwater end member EC using gauged stream EC at lowest flows

Based on analysis in the Mitchell River, it is recommended that the groundwater EC end member is *not* defined using the lowest recorded stream EC, unless there is no other information to support this parameter, and the stream is unregulated. In the case of streams in which flow is regulated through reservoir releases – as is the case across the Latrobe River and Thomson-Macalister River catchments, this approach should certainly not be taken, because in these cases the lowest recorded stream EC will almost always reflect a mixture of all flow components (runoff, baseflow, interflow and bank storage) that have been mixed within the reservoir over time prior to release. Therefore, this approach has not been applied in to the Latrobe and Thomson-Macalister catchments.

Eckhardt Filter parameters

Changing the Eckhardt filter's Alpha and BFImax parameters to reflect observed stream flow recession rates and the EC-estimated maximum BFI is not considered suitable for the current study, which aims to estimate the regional groundwater discharge component within stream flows, rather than flow components such as interflow and bank storage returns. As such Eckhardt filter's Alpha and BFImax parameters were calibrated to achieve a best fit to the EC derived baseflow estimates.

Removing periods of poor (non-linear) flow-EC relationships from individual gauge-based EC mass balances

Although stream flow-EC relationships are often non-linear, EC remains a conservative tracer of groundwater (baseflow) input to stream flow, assuming that there are no other significant sources of salts, which is the case for the Gippsland rivers analysed in this study. An exception to this applies for those Latrobe River reaches affected by saline industrial water returns; however, addressing this issue has been recommended (Section 5.1.1). It is therefore concluded that this proposed change to the method is not warranted. It has therefore not been applied in the current study, nor is it recommended for future application of the method, except in catchments in which there are significant contributions to stream EC from sources other than groundwater.

5. Data gaps

5.1 Introduction

Findings from the catchment characterisation (Section 3) and the application of the recommended changes and additions to the baseflow assessment method (Section 4) have highlighted a number of data gaps which increase the uncertainty of baseflow estimates. The key data include:

- Surface water streamflow and EC – gaps in concurrent flow and EC gauging data between upstream and downstream sites which reduce the ability to implement interstation analyses
- Groundwater EC - limited groundwater monitoring bores in upland catchments to derive groundwater EC end members
- Surface Water Management – gaps in the surface water management data, in particular river diversions and returns, and
- Independent baseflow studies – limited relevant independent baseflow studies to assess the effects of the recommended changes and additions to the baseflow assessment method on the reliability of the baseflow estimates.

Data gaps for each of the three catchments assessed are outlined below.

5.1.1 Latrobe River

Data gaps

Table 28 summarises the data availability for the individual assessed gauges within the Latrobe River catchment. Table 28 highlights that all gauges have sufficient surface water flow gauging data, with more than 15 years of gauging record. However, there is limited surface water EC data available for many of the smaller tributaries, which limits the ability to conduct interstation analysis for the upper Latrobe River. Table 28 also highlights that there is very limited groundwater EC borehole data available for the upper reaches of the Latrobe River catchment, which increases the uncertainty around the groundwater EC end member estimates.

Table 29 Latrobe River Data availability – total upstream catchment

Gauge	Flow Period	Count of flow readings	SW EC Period	Count of SW EC readings	Count of GW EC Boreholes
226216	2/04/1955 - 18/02/2015	21,873	11/01/1990 - 4/09/2012	85	5
226021	27/06/1996 - 3/02/2015	6,793	12/10/2005 - 7/02/2012	73	2
226408	31/08/2001 - 3/02/2015	4,553	17/01/1991 - 2/12/2014	141	1
226005	17/01/1962 - 3/02/2015	19,333	11/01/1990 - 18/10/2004	151	182
226007	18/08/1961 - 16/02/2015	16,538	29/07/2003 - 16/12/2014	127	0
226415	2/07/1997 - 23/02/2015	6,415	2/12/2002 - 26/06/2007	230	0
226033	21/12/1996 - 12/05/2013	5,977	16/12/1996 - 12/05/2013	5,740	195
226228	2/12/1936 - 8/02/2015	28,515	2/01/1990 - 3/12/2014	293	248
226227	17/12/1976 - 8/02/2015	7,549	20/12/1996 - 10/03/2015	6,385	341

Table 29 summarises the data availability for the interstation gauge pairs within the Latrobe River catchment. This highlights that there is no concurrent EC and flow data to conduct interstation analyses for the upper Latrobe River (upstream of Scarnes Bridge). A gauging, sampling and analysis program for (at a minimum) stream flow and EC is recommended to address this data gap. This would need to be conducted at the bottom end of the tributaries (Tyers River, Wades Creek and Traralgon Creek) to enable assessment of baseflow gains along the Latrobe River.

Additionally, the application of the baseflow estimation method complicated by significant saline industrial water returns, which artificially increase gauged stream EC and flow in the upper reaches of the Latrobe River catchment (upstream of Scarnes Bridge). Table 9 and Table 10 (Section 3.2.2) summarise the data availability for the industrial returns in the Latrobe River catchment, which highlights that there is insufficient surface water EC gauging to account for the effect of the industrial returns in the reach scale mass balances. To mitigate this issue, one approach could be to isolate the effects of the industrial discharges by considering interstation reaches upstream and downstream of reservoir or discharge point. This is discussed in further detail in Section 5.2.

Table 30 Latrobe River data availability – interstation reaches

Interstation Section	Interstation Gauge Pairs	Period of con-current flow and SW EC readings	Count of con-current flow and SW EC readings	Count of GW EC Boreholes
Latrobe River upstream of Thoms Bridge	226216, 226021, 226408, 226005	NA	0	174
Latrobe River between Thoms Bridge and Scarnes Bridge	226005, 226007, 226415, 226033	NA	0	13
Latrobe River between Scarnes Bridge and Rosedale	226033, 226228	7/01/1997 - 5/05/2013	194	53
Latrobe River between Rosedale and Kilmany South	226228, 226227	18/05/1977 - 3/12/2014	222	93

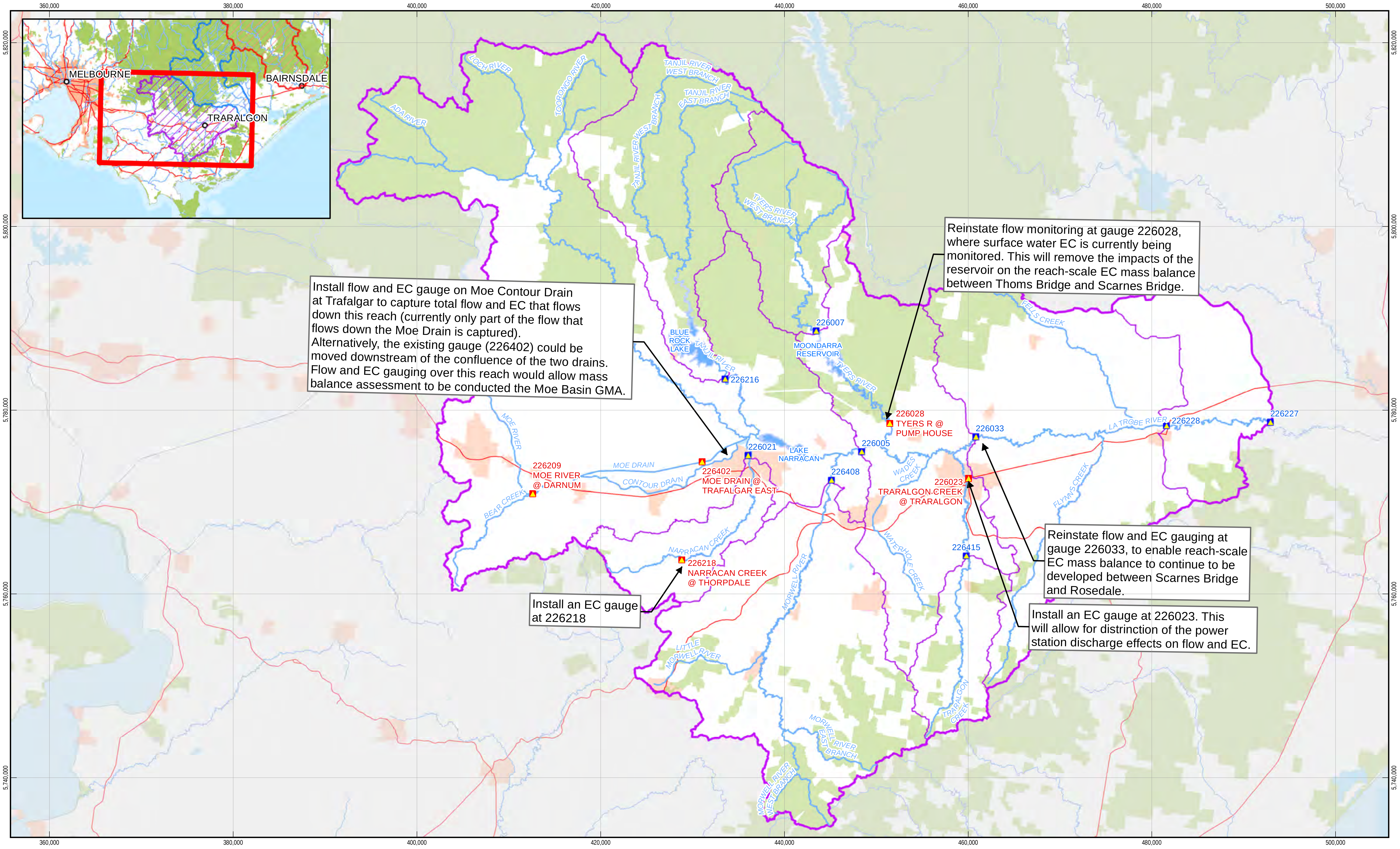
Long term recommendations

Table 30 and Figure 43 summarise a number of long-term recommendations for data collection at priority reaches within the Latrobe River catchment. The main objective of these recommendations is to generate con-current flow and surface water EC data for a large proportion of the river, which will allow for interstation analysis to identify baseflow gains. The Latrobe River has data gaps in all reaches except Rosedale-Kilmany.

The primary long term recommendation for the Latrobe River catchment is to update the surface water monitoring to include the Moe Drain. Surface water flow and EC are currently monitored in The Moe River at Darnum (gauge 226209) and on the Moe Drain at Trafalgar East (226402); however, a key data gap is the absence of flow and EC monitoring on the Moe Contour drain. Therefore, the limited data does not enable baseflow interstation analyses to be conducted for the Moe reach covering the Moe GMA where significant groundwater usage occurs. It is recommended that in the long-term a flow and EC gauge is installed on the Moe Contour Drain at Trafalgar to capture the total flow and EC that flows down this reach. Alternatively, the existing gauge on the Moe Drain at Trafalgar East could be moved downstream of the confluence with the Moe Contour Drain to capture all flows.

Table 31 Long term data collection recommendations – Latrobe River

Reach	Long-term Recommendations	Justification	Priority
Moe River - Darnum to Trafalgar East (226209 – 226402)	Install a flow and EC gauge on Moe Contour Drain at Trafalgar to capture total flow and EC along this reach (currently only part of the flow that flows down the Moe Drain is captured).	This reach covers the Moe GMA and includes significant groundwater usage. Currently this data gap limits the applicability of the baseflow separation method.	High
Latrobe River between Rosedale to Kilmany South (226228 – 226227)	Continue current gauging, install EC loggers or coordinate spot EC readings to be taken on the same day.	Initial estimates indicate that this reach is strongly gaining.	Low
Latrobe - Scarnes Bridge to Rosedale (226033 – 226228)	Reinstate flow and EC gauging at 226033.	Initial estimates indicate that this reach is moderately gaining.	Moderate
Narracan Creek - Thorpdale to Moe (226218 – 226021)	Commence EC gauging at 226218	This reach has limited groundwater use; however, study of this reach will allow for a better breakdown of the baseflow contribution to the Latrobe River.	Moderate
Latrobe - US Thoms Bridge (226005)	This reach has many tributaries and includes Narracan Reservoir. It is highly recommended that the reach be disaggregated upstream of Thoms Bridge into smaller reaches. A possible solution is to install a flow and EC gauge immediately downstream of Lake Narracan (possibly at Yallourn Weir).	The reach between Lake Narracan and Thoms Bridge has very low shallow groundwater usage, and as such, has a limited potential for impacts on baseflow, however the reach includes significant groundwater extraction related to coal mining which may have an impact on baseflow	Moderate
Latrobe - Thoms Bridge to Scarnes Bridge (226005 – 226033)	It is recommended to reinstate flow and EC gauging at gauges 226033 and 226028, as well as installing an EC gauge at 226023.	This reach has limited shallow groundwater usage, and as such, has a limited potential for impacts on baseflow. However the reach includes significant groundwater extraction related to coal mining which may have an impact on baseflow. Additionally, installing an EC gauge at Traralgon Creek at Traralgon (226023) would allow for distinction of power station discharge effects on flow and EC.	Moderate



Install flow and EC gauge on Moe Contour Drain at Trafalgar to capture total flow and EC that flows down this reach (currently only part of the flow that flows down the Moe Drain is captured). Alternatively, the existing gauge (226402) could be moved downstream of the confluence of the two drains. Flow and EC gauging over this reach would allow mass balance assessment to be conducted the Moe Basin GMA.

Reinstate flow monitoring at gauge 226028, where surface water EC is currently being monitored. This will remove the impacts of the reservoir on the reach-scale EC mass balance between Thoms Bridge and Scarnes Bridge.

Reinstate flow and EC gauging at gauge 226033, to enable reach-scale EC mass balance to continue to be developed between Scarnes Bridge and Rosedale.

Install an EC gauge at 226023. This will allow for distrinction of the power station discharge effects on flow and EC.

Install an EC gauge at 226218

Paper Size A3

0 2 4 8 12 16
Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

▲ Additional Gauges to Assess

▲ Surface Water Gauges (Assessed)

🟦 Major Water Area

— Major Watercourse

▭ Latrobe River Catchment

▭ Assessed sub-catchments

Department of Environment, Land, Water & Planning
Gippsland River Baseflow Assessment

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Latrobe River
Long-term Data Recommendations

Figure 42

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Data source: DEWLP, VICMaps, 2015; GHD, Baseflow Catchments, 2015; DELWP, WMIS Surface and Groundwater Data, 2015. Created by: adrummond

5.1.2 Thomson-Macalister River

Data gaps

Table 31 summarises the data availability for the individual assessed gauges within the Thomson-Macalister River catchment. Similar to the Latrobe River catchment, the Thomson-Macalister River has sufficient surface water flow gauging records at all sites. However, there is limited surface water EC data available for the Thomson River upstream of Heyfield and the Macalister River at Riverslea, which limits the ability to conduct interstation analysis for the Thomson-Macalister River. Table 31 also highlights that there is very limited groundwater EC borehole data available for the upper reaches of Thomson River (upstream of Cowwarr Weir) and Macalister River (upstream of Glenmaggie), which increases the uncertainty around the groundwater EC end member estimates in these catchments.

Table 31 summarises the data availability for the interstation gauge pairs within the Thomson-Macalister River catchment. This highlights that there is very limited concurrent EC data to conduct interstation analyses for the upper Thomson River catchment (between Cowwarr Weir and Heyfield), with three data points not sufficient to make a reliable estimate of interstation baseflow gains. Hydrographic analysis (Section 3.3.1) indicated that Rainbow Creek near Heyfield appears to result in persistent locally losing conditions, where artificial maintenance of elevated surface water levels relative to the regional watertable. On the nearby main stem of the Thomson River in this area however, variable gaining/losing conditions appear to prevail, because of its greater depth of incision compared to Rainbow Creek. Local anecdotal experience from the West Gippsland CMA also suggests that the Thomson River is predominantly losing from Cowwarr Weir to some distance downstream of Heyfield (Anthony Goode, Personal Communication, 2015). However, the scarcity of con-current flow and surface water EC recordings limited the ability to conduct addition interstation assessment of this reach in Stage 1 of this study. Further monitoring of surface water flow and EC along this reach could be conducted as part of the Stage 2 investigation, to provide additional evidence to confirm or deny whether or not this reach is in fact 'losing' as local anecdotal experience suggests.

There are large surface water diversions within the Thomson-Macalister River catchment, which impact the results of the interstation assessments. While the average diversion volumes have been summarised as part of this study, further investigation is required to collate time-series diversion data (available in REALM model) to account for these impacts, particularly at Cowwarr Weir and Maffra Weir.

Table 32 Thomson Macalister River Data availability – total upstream catchment

Gauge	Flow Period	Count of flow readings	SW EC Period	Count of SW EC readings	Count of GW EC Boreholes
225200	1/05/1992 - 1/03/2015	8,266	25/01/2005 - 5/09/2012	83	13
225204	29/03/1960 - 11/02/2015	20,004	11/01/1990 - 4/12/2014	379	4
225212	30/03/1963 - 28/01/2015	17,957	9/01/1991 - 30/07/2014	3,226	23
225231	2/04/1976 - 8/02/2015	14,367	5/12/2002 - 29/12/2014	140	1
225232	4/11/1976 - 8/02/2015	11,449	20/12/1996 - 22/03/2015	6,346	139
225236	10/04/1992 - 3/02/2015	8,121	13/07/2005 - 5/09/2012	80	
225247	12/01/2001 - 12/02/2015	4,700	16/12/1996 - 23/12/2014	96	73

Table 33 Thomson Macalister River data availability – interstation reaches

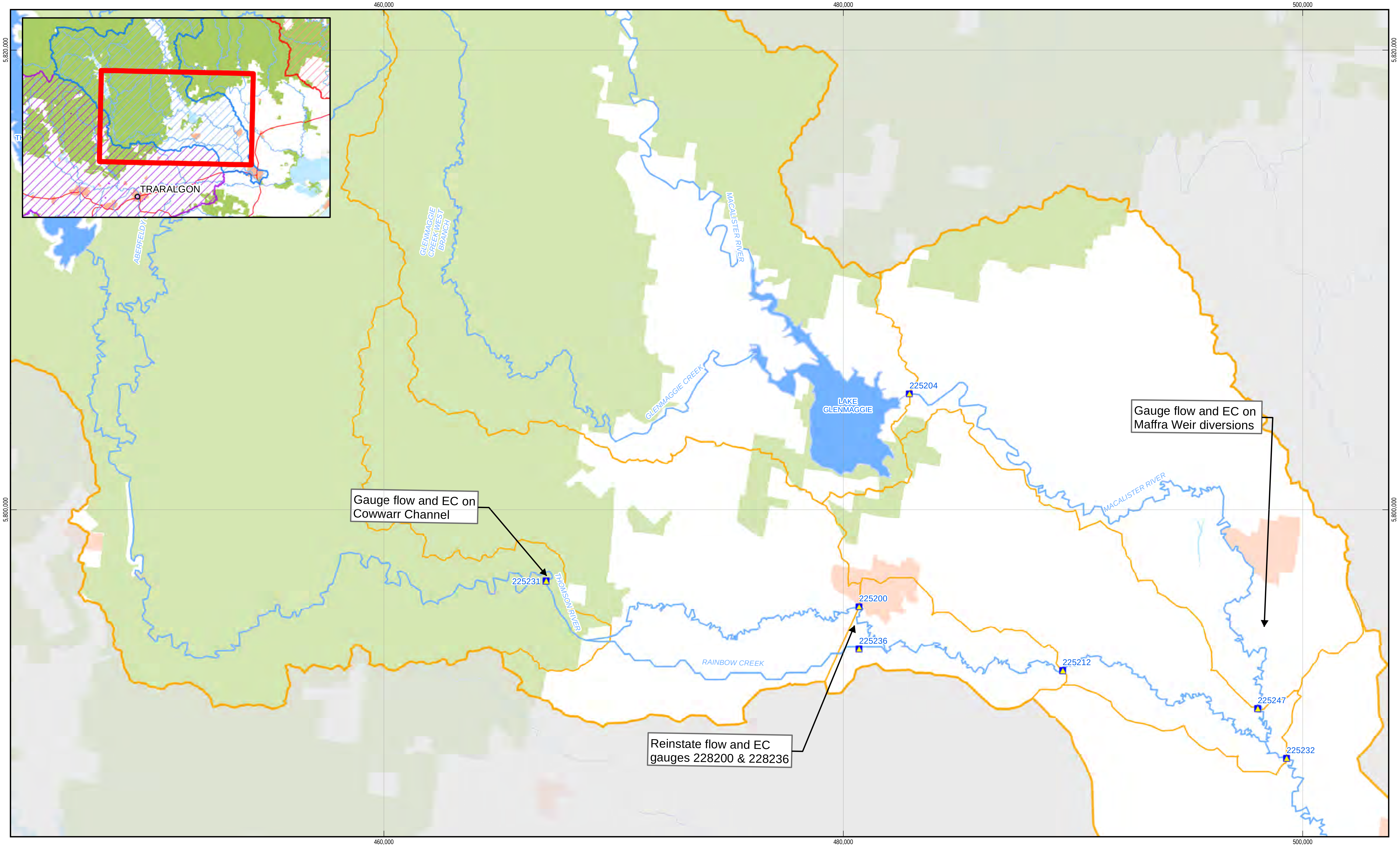
Interstation Section	Interstation Gauge Pairs	Period of con-current flow and SW EC readings	Count of con-current flow and SW EC readings	Count of GW EC Boreholes
Thomson River between Cowwarr Weir and Heyfield	225231, 225200, 225236	17/10/2007 8/04/2010	3	12
Thomson River between Heyfield and Wandocka	225200, 225236, 225212	10/08/2005 5/09/2012	73	10
Lower Thomson-Macalister River from Wandocka to Bundalaguah including Macalister River	225212, 225232, 225247	13/07/2005 22/05/2014	93	43
Macalister River between Glenmaggie and Riverslea	225204, 225247	5/03/2007 4/04/2012	9	69

Long term recommendations

Table 33 and Figure 44 summarise a number of long-term recommendations for data collection at priority reaches within the Thomson-Macalister catchment. The main objective of these recommendations is to generate con-current flow EC data for the reach between Cowwarr and Heyfield and the reach between Heyfield and Wandocka.

Table 34 Long term data collection recommendations – Thomson-Macalister River

Reach	Long-term Recommendations	Justification	Priority
Thomson - Cowwarr to Heyfield (225231 – 225200) & Thomson - Heyfield to Wandocka (225200 – 225212)	Reinstate EC gauging at 225200	This reach is of interest to WGCMA. Surface water EC gauging will provide additional evidence to confirm or deny whether or not this reach is in fact 'losing' as local anecdotal opinion suggests.	High
Macalister - Glenmaggie to Riverslea (225204 – 225247)	Continue current flow gauging, install EC loggers or coordinate spot EC readings to be taken on the same day.	This reach is relatively well monitored.	Low
Thomson - Wandocka to Bundalaguah (225212 – 225232)	Continue current flow gauging, install EC loggers or coordinate spot EC readings to be taken on the same day.	This reach is relatively well monitored.	Low



Gauge flow and EC on Cowwarr Channel

Gauge flow and EC on Maffra Weir diversions

Reinstate flow and EC gauges 228200 & 228236

Paper Size A3

0 0.5 1 2 3 4

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

- ▲ Surface Water Gauges (Assessed)
- 🟦 Major Water Area
- — Major Watercourse
- ▭ Thomson Macalister River Catchment
- ▭ Assessed sub-catchments

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Gippsland River Baseflow Assessment

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Thomson-Macalister River
Long-term Data Recommendations

Figure 43

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Data source: DEWLP, VICMaps, 2015; GHD, Baseflow Catchments, 2015; DELWP, WMIS Surface and Groundwater Data, 2015; Created by: adrummond

5.1.3 Mitchell River

Data gaps

Table 34 summarises the data availability for the individual assessed gauges within the Mitchell River catchment. The Mitchell River has sufficient surface water flow gauging records and surface water EC records at both the sites to enable interstation analyses. Table 34 highlights while there is very limited groundwater EC borehole data available for the Mitchell River upstream of Glenaladale, there is sufficient groundwater EC data in the interstation catchment to estimate a groundwater EC end member.

The Mitchell River is relatively unimpacted by water management activities, with no major on-stream storages, and diversions are small relative to streamflow. While the average diversion volumes have been summarised as part of this study, further investigation is required to collate time-series diversion data (if available) to account for these impacts.

Table 35 Mitchell River Data availability – total upstream catchment

Gauge	Flow Period	Count of flow readings	SW EC Period	Count of SW EC readings	Count of GW EC Boreholes
224203	8/08/1937 - 26/01/2015	28,296	9/01/1990 - 15/12/2014	290	3
224217	30/10/1976 - 22/02/2015	5,140	8/04/2003 - 29/12/2014	527	57

Table 36 Mitchell River data availability – interstation reaches

Interstation Section	Interstation Gauge Pairs	Period of con-current flow and SW EC readings	Count of con-current flow and SW EC readings	Count of GW EC Boreholes
Mitchell River between Glenaladale and Rosehill	224203, 224217	11/01/1977 15/12/2014	82	54

Long-term recommendations

This reach is relatively well monitored for the purpose of applying the baseflow separation method and undertaking interstation analysis.

Table 37 Long term data collection recommendations – Mitchell River

Reach	Long-term Recommendations	Pros/Cons	Priority
Mitchell - Glenaladale to Rosehill (224203 – 224217)	Continue current flow gauging, install EC loggers or coordinate spot EC readings to be taken on the same day.	This reach is relatively well monitored.	Low

5.2 Recommendations for Stage 2

It is recognised that the while long-term data collection (as recommended in Section 5.1) is the optimal approach for refining baseflow estimates, is not possible to apply in this project given the short time-frame. Improved baseflow estimates are important for long-term groundwater-surface water management and provide valuable context in a range of water management issues, such as assessing the impact of groundwater extraction on environment flows in priority reaches and groundwater dependant ecosystems.

To address the data gaps identified requires a concerted monitoring campaign (as recommended in Section 5.1) with a relatively high capital and operating cost over a number of years (5-10 years). With this in mind, the recommendations for Stage 2 are focussed on activities that can be undertaken within the time and budget available in the order of $50,000, and can achieve an improvement in the baseflow separation accuracy or uncertainty. While highly localised studies and field data do not broadly inform the regional-scale conceptualisation and analysis of groundwater-surface water interactions, they do provide a valuable basis for constraining the estimates and thereby improving the confidence of more broad-scale approaches. Based on the key findings from this study, and the data gaps highlighted in Section 5.1, the following section discusses a number of localised studies of priority reaches to be undertaken in Stage 2 of this project.

It is recommended that the targeted sites for field assessment be discussed between the relevant authorities (CMA’s, SRW and DELWP) in a workshop, to prioritise the field assessments on reaches which will deliver most value to the project, while meeting the requirements of the Gippsland CMAs and the Bioregional Assessment Program. Additionally, the Gippsland Regional Water Monitoring Partnership should be consulted prior to development of new monitoring programs. The role of the Partnership is to coordinate water monitoring in the region because historically there was a lot of duplication and gaps.

The baseflow separation method is most uncertain when applied to upland catchments that have very limited groundwater EC data available. These catchments are relatively undeveloped and new data would be difficult to generate; however given that the lack of development, it is perhaps less important to reduce the uncertainty of these estimates. While the upland EC end members and baseflow estimates are likely to remain uncertain, it is also likely that they remain relatively unchanged, and it is unlikely that groundwater management actions can have a significant effect (except for forestry and fire management which can have a significant impact on baseflow).

In contrast, the lower reaches of the rivers have a larger amount of useful water information and the majority of water use. Applying reach scale mass balances to improve the estimate of interstation baseflow allows for a more reliable estimate of baseflow in the reaches where groundwater management actions can have a significant impact.

It is recommended that reach scale mass balance be applied to as much of the catchment as possible, with particularly focus on areas with high water use (the Groundwater Management Areas and Water Supply Protection Areas). The data required to achieve this is concurrent flow and EC data at the upstream and downstream gauges of the interstation reach, and groundwater EC data for bores within the interstation catchment, preferably with a good spatial distribution (including bores close to the stream).

Three types of field activities are proposed; the project budget does not allow for all of these to be applied to all reaches, therefore a decision will need to be taken as to the best use of resources and/or the preferred location of these activities. The three main activities include: flow and EC accretion profiling, EC and flow logging, and groundwater sampling. These options are discussed in more detail below.

EC is suggested as a tracer for future field monitoring programs, as the key objective is the estimation of the manageable component of baseflow to streams. The manageable component of baseflow is defined in this study as the regional groundwater discharge to rivers, as opposed to other flow components such as interflow and bank storage returns which can be measured by tracers such as Radon (Hoffman, 2011). EC is a conservative tracer of regional groundwater that has been shown to provide similar baseflow estimates to more detailed analyses using major ions and other tracers. The key advantage of using EC as a tracer is that it is and has historically been widely gauged throughout Victoria, and has been used in this study and previous studies (GHD 2013a, GHD 2013b) to provide long-term historical and ongoing estimates of baseflow behaviour to many Victorian streams. Therefore, acquiring additional EC flow data will be able to be used directly to ground-truth the baseflow estimates derived in the current and previous studies.

The specific recommendations for each reach are detailed in Table 37. It is important to note that while this represents a range of options that can be explored; budgetary constraints will only allow for the implementation of a limited number of these activities. As a point of reference, preliminary inquiries indicate that flow and EC accretion profiling could be undertaken for two to three reaches whereas EC sensors and loggers could likely only be implemented on one reach depending on complexity. The costs of these activities will need to be balanced against the benefits of each action and the interests and needs of stakeholders.

Flow and EC accretion profiling

This activity involves undertaking instantaneous streamflow gauging and EC sampling at a series of sites along a river reach. This allows a mass balance to be undertaken on each section and for the specific sections were groundwater enters the stream to be identified, and that baseflow to be quantified.

It is expected that 4-5 sites would be sampled within a River reach in two sampling expeditions to capture spring and summer baseflow contributions. Typically baseflow is easier to measure during low flow periods, and sampling events during spring and summer align with the project time-frame for Stage 2 investigations. However, it is noted that this period also corresponds with the irrigation season when streamflow is highly modified by weir regulation, river diversions, and irrigation drainage.

This data and analysis allows for a more detailed verification of the baseflow estimates derived from the baseflow separation method. This data may also be analysed to refine the baseflow separation method for the reach where such data is collected.

The main benefit of this activity is ground-truthing of the baseflow separation method and allow for refinement of the method in reaches where we already have sufficient data to apply the baseflow separation method. The main limitation is that it is only a snapshot in time of the baseflow processes and these results may not be representative of average/typical conditions.

Installation of EC sensors, flow gauges and data loggers

This activity involves the installation of EC sensors, pressure sensors, and data loggers to allow for collection of these data at sites where no data is currently collected. This allows a single gauge baseflow separation to be undertaken for a site that currently has no estimate of baseflow. If the installation of sensors is done such that new interstation pairs can be analysed, this would permit a reach scale mass balance to be undertaken for a reach that currently has no estimate. Preliminary inquiries indicate that the cost of this option is greater than the flow and EC accretion profiling, and it is therefore likely this option would be applied at comparatively fewer locations.

The main benefit of this activity is the collection of data that permits baseflow estimates to be made at sites that currently have no estimate of baseflow. A limitation of this method is that the relatively short period of data collection (up to 6 months) may not be representative of the full range of streamflow/baseflow conditions. However, as discussed in Section 4, the independent assessment on the lower Mitchell River while only comprising of four sampling events, was extremely valuable in ground-truthing the baseflow estimates derived in this study. Therefore, while this approach has its limitations, it should provide a relatively solid improvement in the baseflow estimates.

Sampling of groundwater EC in private bores

To improve the best estimate of groundwater end member EC one potential option is to sample private groundwater bores in targeted locations to improve the distribution of EC data points that contribute to the groundwater end member EC. A sampling campaign would target bores in reaches and areas that have no or very limited groundwater EC data and private bores exist that could be sampled.

While it is expected that this approach could deliver a more robust best estimate of groundwater EC and as a consequence, a more refined estimate of the interstation baseflow gains; it is anticipated that the large variance in groundwater EC will not be reduced, and as such, the uncertainty of the groundwater end member EC will remain high. Therefore, this activity could be of limited value. It is recommended that more effort be undertaken in Stage 2 of the study to ensure that all available groundwater data in these areas has been used in the analysis.

Additionally, the outcome of this activity is dependent on access to private bores, with the cost of acquiring this data dependent on the cooperation of landholders. Advice from the West Gippsland CMA indicates that there is still a high degree of anxiety in parts of the community regarding Coal Seam Gas and coal development; therefore, cooperation could be limited.

Given these limitations, the success of groundwater investigations in improving groundwater estimates is uncertain, and likely to be costly. While it is recommended that this option is discussed at the initiation of Stage 2, it is anticipated that surface water flow and EC sampling would provide more valuable information to ground-truth baseflow estimates.

Table 38 Stage 2 Recommendations

Reach	US Gauge	DS Gauge	Stage 2 Recommendations	Justification	Priority
Latrobe - Rosedale to Kilmany South	226228	226227	Flow and EC accretion profiling.	Initial estimates indicate that this reach is strongly gaining. The proposed action would allow for ground-truthing and refinement	Moderate
Latrobe - US Thoms Bridge	226021, 226216, 226408	226005	None	This reach has limited data, and is best split into smaller reaches some of which do have data. The reach between Lake Narracan and Thoms Bridge has very low shallow groundwater usage and as such has a limited potential for impacts on baseflow.	Low
Latrobe - Thoms Bridge to Scarnes Bridge	226005	226033	EC sensors and loggers are required at 4 sites, a pressure sensor is required at 2 sites, and a rating table must be developed at one site.	This reach has a large number of data gaps and implementation of these recommendations may exceed the entire stage 2 budget.	Low
Latrobe - Scarnes Bridge to Rosedale	226033	226228	Flow and EC accretion profiling.	Initial estimates indicate that this reach is strongly gaining. The proposed action would allow for ground-truthing and refinement.	Moderate
Narracan Creek - Thorpdale to Moe	226218	226021	EC sensor and logger at 2 sites	This reach has limited groundwater extraction and as such is a lower priority for investigation.	Low
Moe River - Darnum to Trafalgar East	226209	226402	EC sensor, pressure sensor and logger on Moe Contour Drain, with rating table to be developed for site.	This site may require a large proportion of the stage 2 budget to implement.	Low
Thomson - Heyfield to Wandocka	225200	225212	Flow and EC accretion profiling.	This reach is of interest to WGCMA. Surface water flow and EC accretion profiling will provide additional evidence to confirm or deny whether or not this reach is in fact 'losing' as local anecdotal opinion suggests. EC sampling of private bores could be undertaken to provide a more robust estimate of the groundwater end member.	Moderate
Thomson - Cowwarr to Heyfield	225231	225200	EC sensor and logger at 226231, 226236 and 226200. Flow and EC accretion profiling	This reach is of interest to WGCMA. Surface water flow and EC accretion profiling will provide additional evidence to confirm or deny whether or not this reach is in fact 'losing' as local anecdotal opinion suggests. Additional sampling will provide valuable information to the limited existing data. EC sampling of private bores could be undertaken to provide a more robust estimate of the groundwater end member.	Moderate
Macalister - Glenmaggie to Riverslea	225204	225247	Flow and EC accretion profiling.	Initial estimates indicate that this reach is strongly gaining. The proposed action would allow for ground-truthing and refinement.	Moderate
Thomson - Wandocka to Bundalaguah	225212	225232	Flow and EC accretion profiling.	Initial estimates indicate that this reach is strongly gaining. The proposed action would allow for ground-truthing and refinement.	Moderate

6. Conclusions

This study conducted an assessment into improving the accuracy of baseflow estimates for the Latrobe, Thomson-Macalister and Mitchell River catchments, building on work undertaken in prior studies (GHD 2013a; GHD, 2013b). One key outcome from this study was the broad characterisation of the physical and water management characteristics of the three Gippsland catchments which highlights the suitability and limitations of estimating baseflow in different areas of the catchments. In addition, other lines of evidence were compiled to provide an independent characterisation of baseflow within the catchments. These included developing reach scale scatter plots of stream flow and EC readings, hydrographic comparison of surface water levels along the reach and groundwater levels at nearby bores, and a thorough a literature review of external independent baseflow studies in the area.

The recommended adjustments to the baseflow assessment method suggested from the independent technical reviewers comments of the previous studies (GHD 2013a, GHD 2013b) were tested using the Mitchell River as a case study. The most significant improvement to the method is the use of a reach scale EC mass balance to estimate interstation baseflow gains, used in conjunction with the existing method to constrain the estimate of groundwater end member EC at the upstream and downstream gauges.

The refined method applied in this study utilises groundwater tracer data in two different ways to constrain digitally filtered baseflow time series estimates:

1. An EC mass balance on individual gauged flow and EC data, which produces baseflow time series estimates for the entire area upstream of the gauge, and
2. A reach-scale EC mass balance utilising flow and EC data at upstream/downstream gauge pairs to estimate baseflow gains within specific river reaches. The reach-scale baseflow gains can then be used to further constrain the individual gauged baseflow time series estimates at the upstream and downstream gauges.

The two EC mass balance data sets are used to calibrate a digital baseflow filter for individual flow gauges, which produces a calibration-constrained continuous daily time series of baseflow estimates for the entire period of available stream flow gauging. This allows for assessment of both seasonal and inter-annual baseflow behaviour. It also allows for temporal expansion of reach-scale baseflow gains estimated using the reach-scale EC mass balance, by subtracting two (upstream and downstream) filtered (calibrated) baseflow time series from one another.

The two EC mass balance methods can estimate baseflows to both regulated and unregulated rivers, which traditional digital baseflow filter methods cannot. In rivers regulated by reservoirs, baseflow estimates for gauges located below the reservoir will be limited in their estimation of seasonal baseflow variability, due to the flow- and EC-homogenising effect of reservoir storage and subsequent release. However, the long term average estimated baseflow gains to the reservoir catchment are unaffected by reservoir regulation because EC is a conservative groundwater (baseflow) tracer. Similarly, for reaches downstream of reservoirs that are gauged by upstream/downstream pairs, baseflow gains to those reaches estimated using a reach-scale EC mass balance are entirely unaffected by river regulation from upstream reservoirs.

Reach-scale baseflow gains estimated using a reach-scale EC mass balance are however affected by diversions from streams. This is partially accounted for in the method applied in this study, by assuming that the flow through a given reach is the average of the flow at the upstream and downstream ends. This means that diversions, and other losses (e.g. to groundwater and/or bank storage), are assumed to be spread evenly across the entire reach; this may not always be the case, and could result in either over- or under-estimated baseflow gains. Hence the upstream/downstream flow-averaging method applied in this study is considered appropriate for reach-scale EC mass balances.

It is noted that alternative methods could be used to account for this effect, such as adjusting the gauged flow and EC at the downstream end of a reach based on gauged flow losses across the reach. This approach could however be adjusting flow and EC data to remove the effects of gauging error, rather than true flow losses to diversions or other avenues. Unravelling the effects of gauging error from those of diversions and other flow losses is probably impossible in practice.

The potential implications of the flow-averaging approach adopted in this study are:

- The groundwater end member EC for upstream gauges may be over-estimated, and therefore the baseflow estimates for these gauges may be underestimated. This is not considered a significant issue because the estimated reach-scale baseflow gains for the lower reaches, which are unaffected by the issue, are considered the most valuable output of the study; these reaches are in the areas of most intensive land and groundwater use, whereas upland areas comprise relatively poor aquifers with very little groundwater use and land development, and
- Estimated reach-scale baseflow gains represent partially "naturalised" baseflows; i.e. estimated baseflows include at least a portion of baseflow that may have been diverted from the river.

Surface water diversions also affect individual gauge-based baseflow time series estimates, but only for gauges that are ***not*** located on reaches where reach-scale EC mass balances are possible. For these gauges, the estimated baseflow time series represent the baseflow to the stream ***after*** surface water diversions have removed some of that baseflow (i.e. these are "impacted" baseflow estimates).

The baseflow separation method is most uncertain when applied to upland catchments that have very limited groundwater EC data available. These catchments are relatively undeveloped and new data would be difficult to generate; however given that the lack of development, it is perhaps less important to reduce the uncertainty of these estimates. While the upland EC end members and baseflow estimates are likely to remain uncertain, it is also likely that they remain relatively unchanged. It is also unlikely that groundwater management actions can have a significant effect (except for forestry and fire management which can have a significant impact on baseflow).

In contrast, the lower reaches of the rivers have a larger amount of useful water information and the majority of water use. Applying reach scale mass balances to improve the estimate of interstation baseflow allows for a more reliable estimate of baseflow in the reaches where groundwater management actions can have a significant impact.

The monitoring to be undertaken as part of Stage 2 is focussed on activities that can be undertaken within the time and available budget (around $50,000), and can achieve an improvement in the baseflow estimation accuracy or uncertainty. While highly localised studies and field data do not broadly inform the regional-scale conceptualisation and analysis of groundwater-surface water interactions, they do provide a valuable basis for constraining the estimates and thereby improving the confidence of more broad-scale approaches. Potential monitoring programs for Stage 2 include flow and EC accretion profiling, installation of EC sensors, flow gauges and data loggers and sampling of groundwater EC in private bores.

The targeted sites for field assessment will be discussed between the relevant authorities (CMA's, SRW and DELWP) in a workshop at commencement of Stage 2, to prioritise the field assessments on reaches which will deliver most value to the project, while meeting the requirements of the Gippsland CMA and the Bioregional Assessment Program.

One of the objectives of this project is the quantification of the potential risk of coal seam gas and coal mining development to groundwater-surface water interactions and groundwater-dependent environmental values of the Gippsland's rivers. Initial findings from this study and others indicate that the potential effect of depressurisation of aquifers by the Latrobe Valley coal mines on shallow groundwater levels (and therefore groundwater-surface water interactions), is relatively insignificant in the (shallow) Yallourn Formation. Findings indicate that groundwater levels in the (shallow) Yallourn Formation around the three Latrobe Valley mines have not been significantly depressurised, whereas depressurisation increases significantly in the deeper formations. A review of potential methods, such as simple analytical tools that can be used to inform the timing and magnitude of coal seam gas extraction impacts on baseflow, will be conducted in Stage 2 of this project, which could be applied to provide additional evidence to confirm these conclusions.

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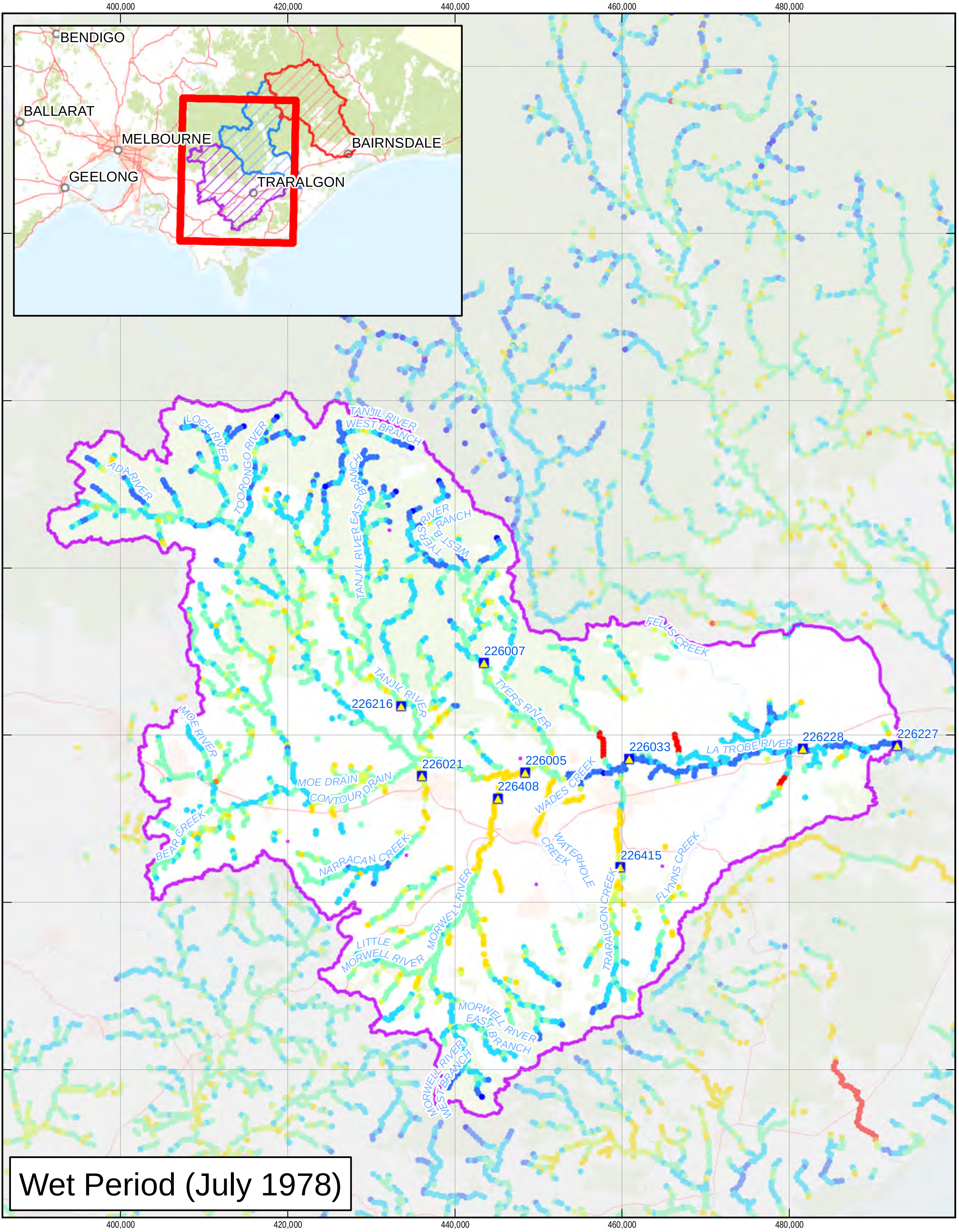
Appendices

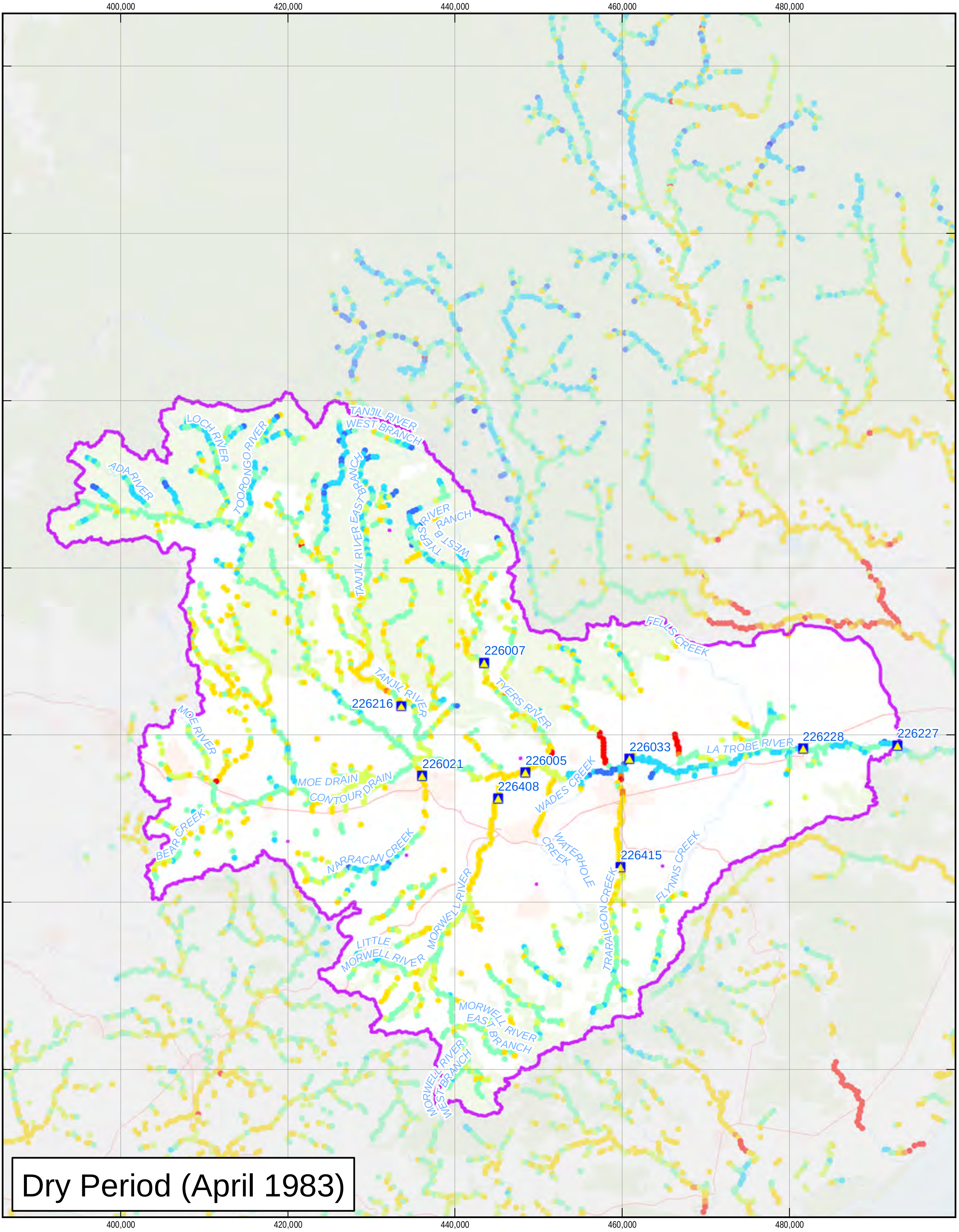
Appendix A – ecoMarkets Modelled Spatial Baseflow Gains and Losses

Appendix A1 – West Gippsland ecoMarkets Model: Latrobe River – Modelled Spatial Baseflow Gains and Losses

Appendix A2 – West Gippsland ecoMarkets Model: Thomson Macalister River – Modelled Spatial Baseflow Gains and Losses

Appendix A3 – East Gippsland ecoMarkets Model: Mitchell River – Modelled Spatial Baseflow Gains and Losses





Paper Size A3

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Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

Stream Leakage

ML/day

- ● -2.35 - -0.97 (Strongly Gaining)
- ● -0.96 - -0.50
- ● -0.49 - -0.25
- ● -0.24 - -0.10
- ● -0.09 - -0.05 (Weakly Gaining)
- ● -0.04 - 0.05 (Neutral)
- ● 0.06 - 0.10 (Weakly Losing)
- ● 0.11 - 0.25 (Strongly Losing)
- ▲ Surface Water Gauges (Assessed)
- ▭ Latrobe River Catchment

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West Gippsland ecoMarkets Model
Latrobe River - Modelled Spatial Baseflow Gains and Losses

Job Number	31-32709
Revision	0
Date	27 May 2015

Appendix A1

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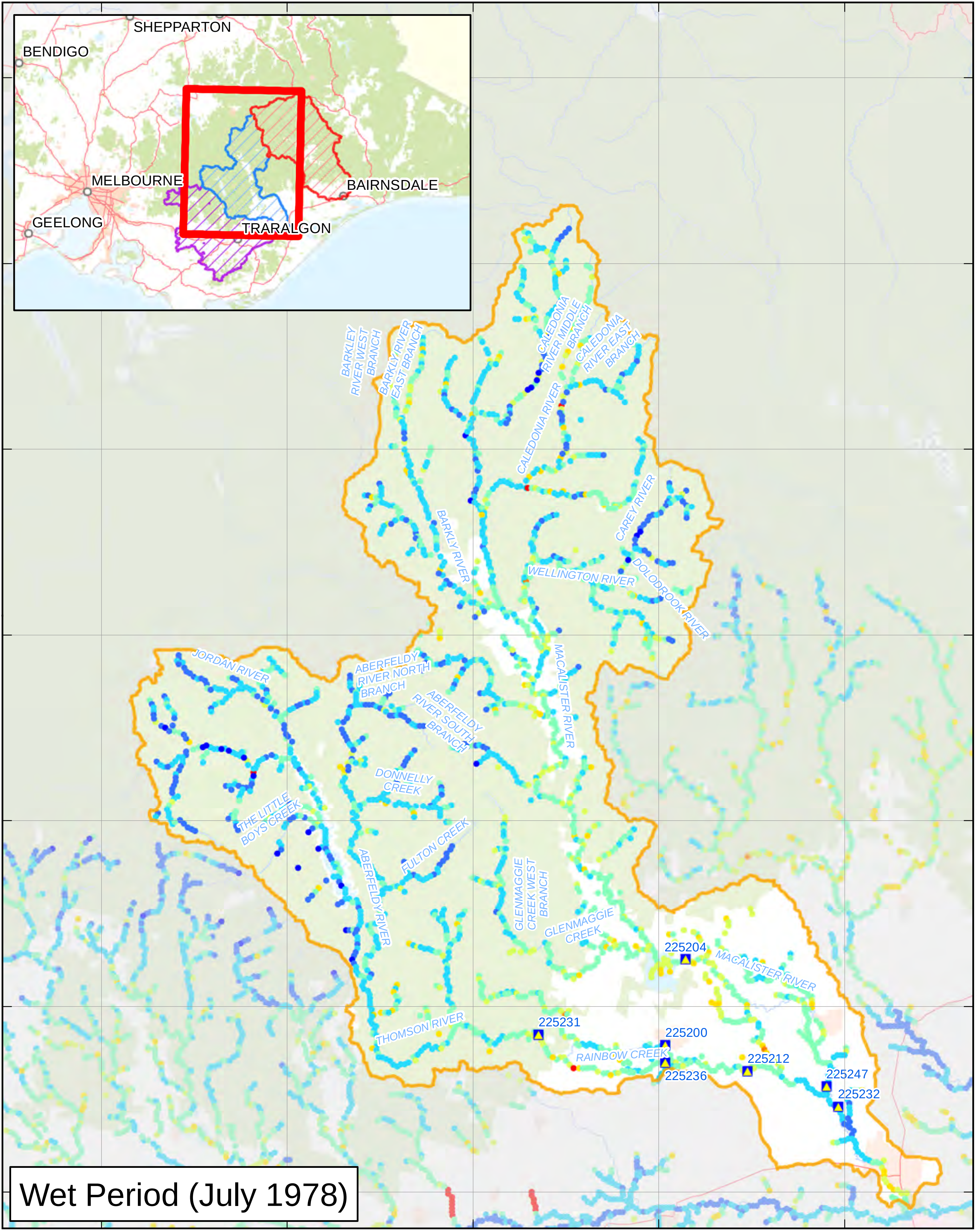
Data source: DEWLP, VICMaps, 2015; GHD, Baseflow Catchments, 2015; GHD, ecoMarkets Model Results, 2010. Created by:adrummond



Wet Period (July 1978)

Dry Period (April 1983)

Paper Size A3

0 3 6 12 18 24

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

Stream Leakage

ML/day

● -2.35 - -0.97 (Strongly Gaining)

● -0.96 - -0.50

● -0.49 - -0.25

● -0.24 - -0.10

● -0.09 - -0.05 (Weakly Gaining)

● -0.04 - 0.05 (Neutral)

● 0.06 - 0.10 (Weakly Losing)

● 0.11 - 0.25 (Strongly Losing)

▲ Surface Water Gauges (Assessed)

▭ Thomson Macalister River Catchment

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Gippsland Rivers Baseflow Assessment

West Gippsland ecoMarkets Model Thomson Macalister River - Modelled Spatial Baseflow Gains and Losses

Job Number	31-32709
Revision	0
Date	27 May 2015

Appendix A2

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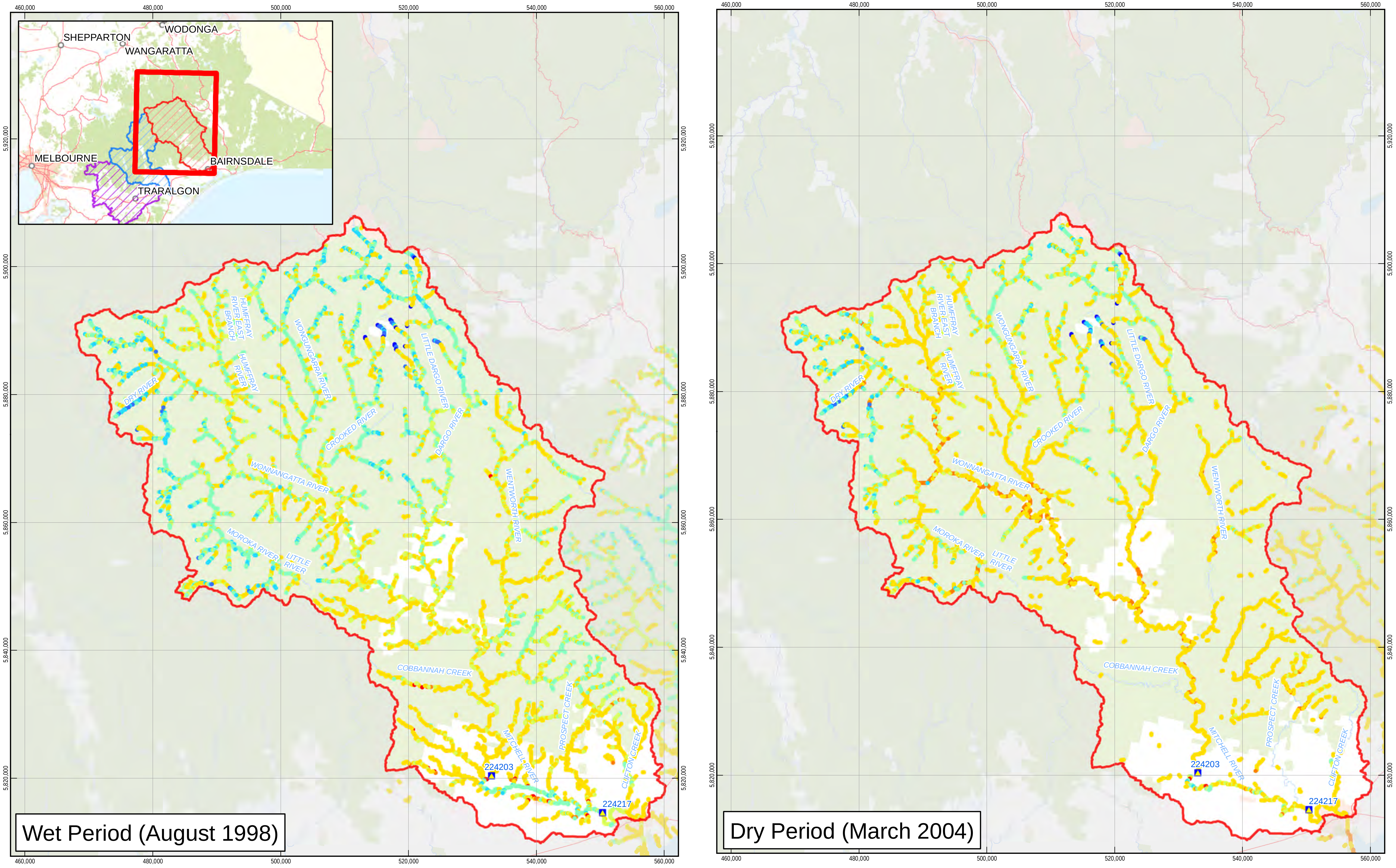

Paper Size A3

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Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

Stream Leakage

MD/day

- ● -2.35 - -0.97 (Strongly Gaining)
- ● -0.96 - -0.50
- ● -0.49 - -0.25
- ● -0.24 - -0.10
- ● -0.09 - -0.05 (Weakly Gaining)
- ● -0.04 - 0.05 (Neutral)
- ● 0.06 - 0.10 (Weakly Losing)
- ● 0.11 - 0.25 (Strongly Losing)
- ▲ Surface Water Gauges (Assessed)
- ▭ Mitchell River Catchment

Department of Environment, Land, Water & Planning
Gippsland Rivers Baseflow Assessment

East Gippsland ecoMarkets Model
Mitchell River - Modelled Spatial Baseflow Gains and Losses

Job Number	31-32709
Revision	0
Date	27 May 2015

Appendix A3

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Data source: DEWLP, VICMaps, 2015; GHD, Baseflow Catchments, 2015; GHD, East Gippsland ecoMarkets Model, 2010. Created by:adrummond

Appendix B – Revised Gauged Flow and EC Regressions

B1 – Latrobe River at Thoms Bridge (226005)

B2 – Tyers River at Browns (226007)

B3 – Narracan Creek at Moe (226021)

B4 – Latrobe River at Scarnes Bridge (226033)

B5 – Tanjil River at Tanjil South (226216)

B6 – Latrobe River at Kilmany South (226227)

B7 – Latrobe River at Rosedale (Main Stream) (226228)

B8 – Morwell River at Yallourn (226408)

B9 – Traralgon Creek at Traralgon South (SEC) (226415)

B10 – Thomson River at Heyfield (225200)

B11 – Macalister River at Lake Glenmaggie (Tail Gauge) (225204)

B12 – Thomson River at Wandocka (225212)

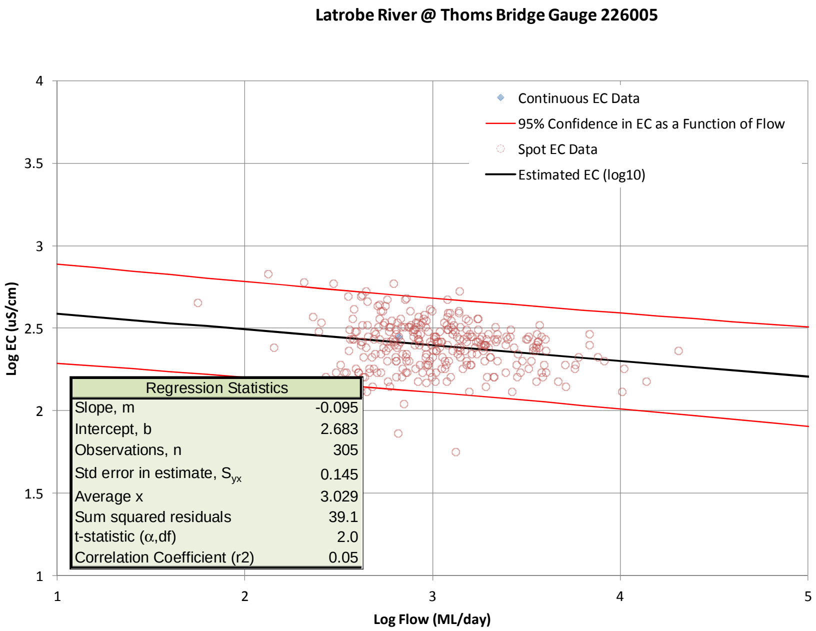
B13 – Thomson River U/S of Cowwarr Weir (225231)

B14 – Thomson River at Bundalaguah (225232)

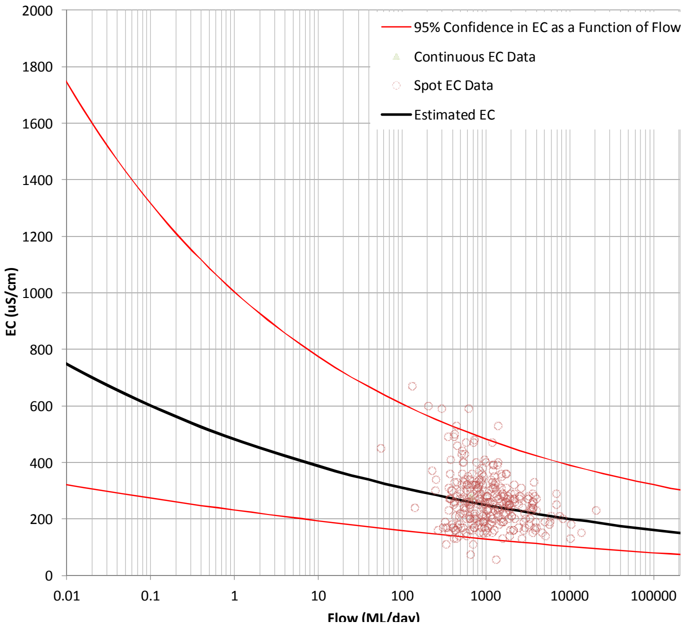
B15 – Macalister River at Riverslea (225247)

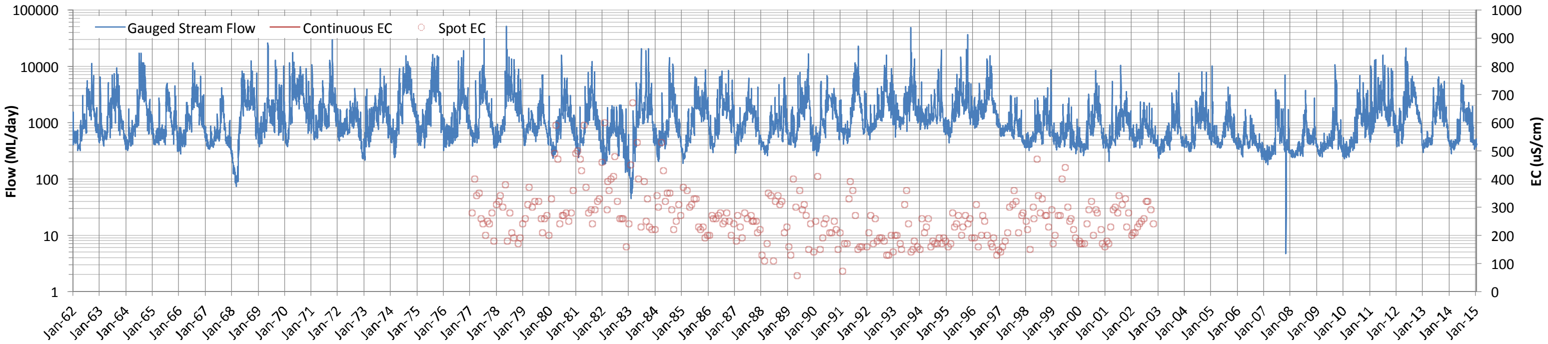
B16 – Mitchell River at Glenaladale (224203)

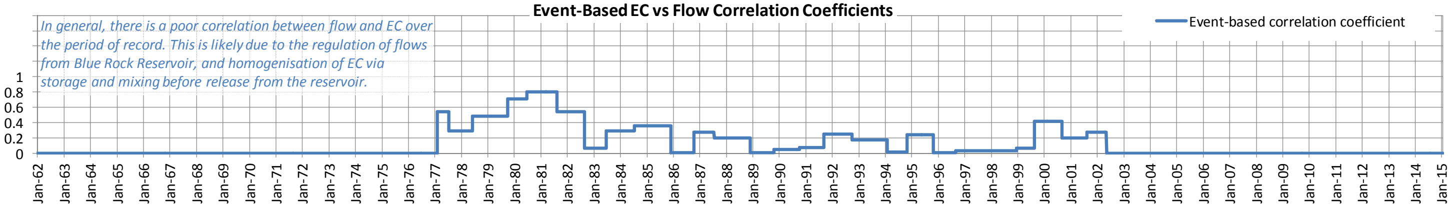
B17 – Mitchell River at Rosehill (224217)



Regression Statistics	
Slope, m	-0.095
Intercept, b	2.683
Observations, n	305
Std error in estimate, S_{yx}	0.145
Average x	3.029
Sum squared residuals	39.1
t-statistic (α,df)	2.0
Correlation Coefficient (r2)	0.05

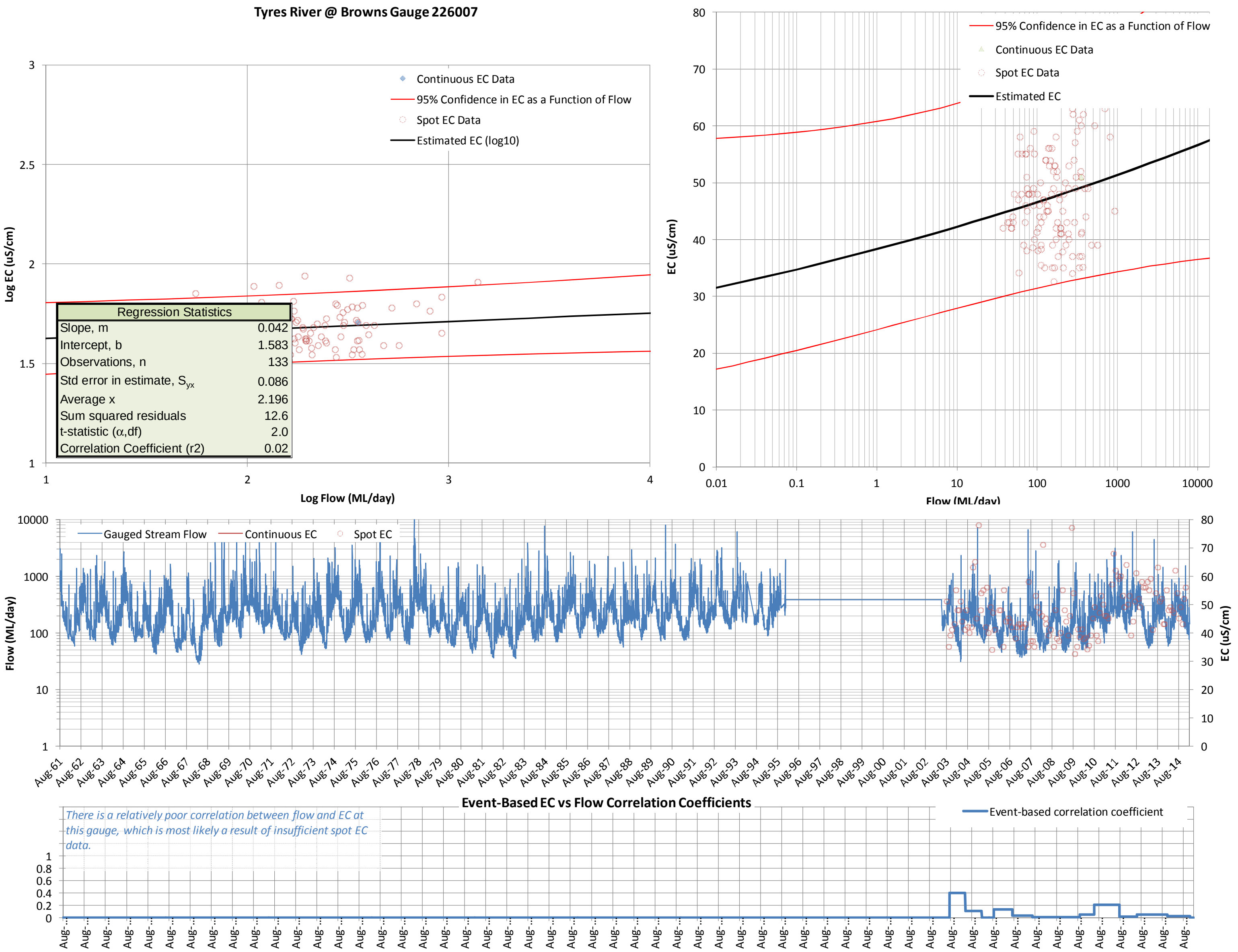






In general, there is a poor correlation between flow and EC over the period of record. This is likely due to the regulation of flows from Blue Rock Reservoir, and homogenisation of EC via storage and mixing before release from the reservoir.

Figure B1between Stream Flow and EC on the Latrobe River at Thoms Bridge



Regression Statistics	
Slope, m	0.042
Intercept, b	1.583
Observations, n	133
Std error in estimate, S_{yx}	0.086
Average x	2.196
Sum squared residuals	12.6
t-statistic (α,df)	2.0
Correlation Coefficient (r2)	0.02

There is a relatively poor correlation between flow and EC at this gauge, which is most likely a result of insufficient spot EC data.

Figure B2between Stream Flow and EC on the Tyres River at Browns

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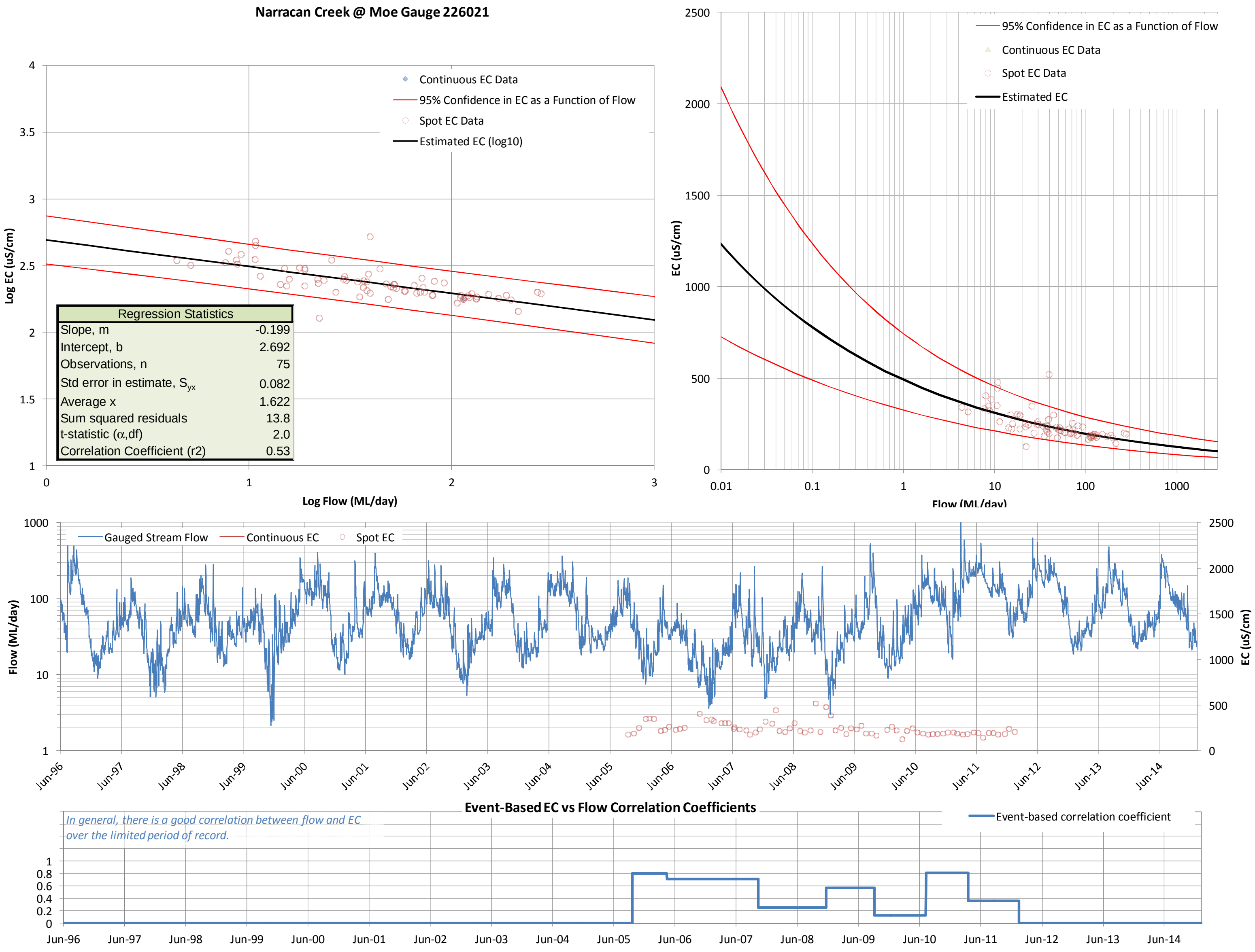

Regression Statistics	
Slope, m	-0.199
Intercept, b	2.692
Observations, n	75
Std error in estimate, S_{yx}	0.082
Average x	1.622
Sum squared residuals	13.8
t-statistic (α,df)	2.0
Correlation Coefficient (r2)	0.53

In general, there is a good correlation between flow and EC over the limited period of record.

Figure B3between Stream Flow and EC on the Narracan Creek at Moe

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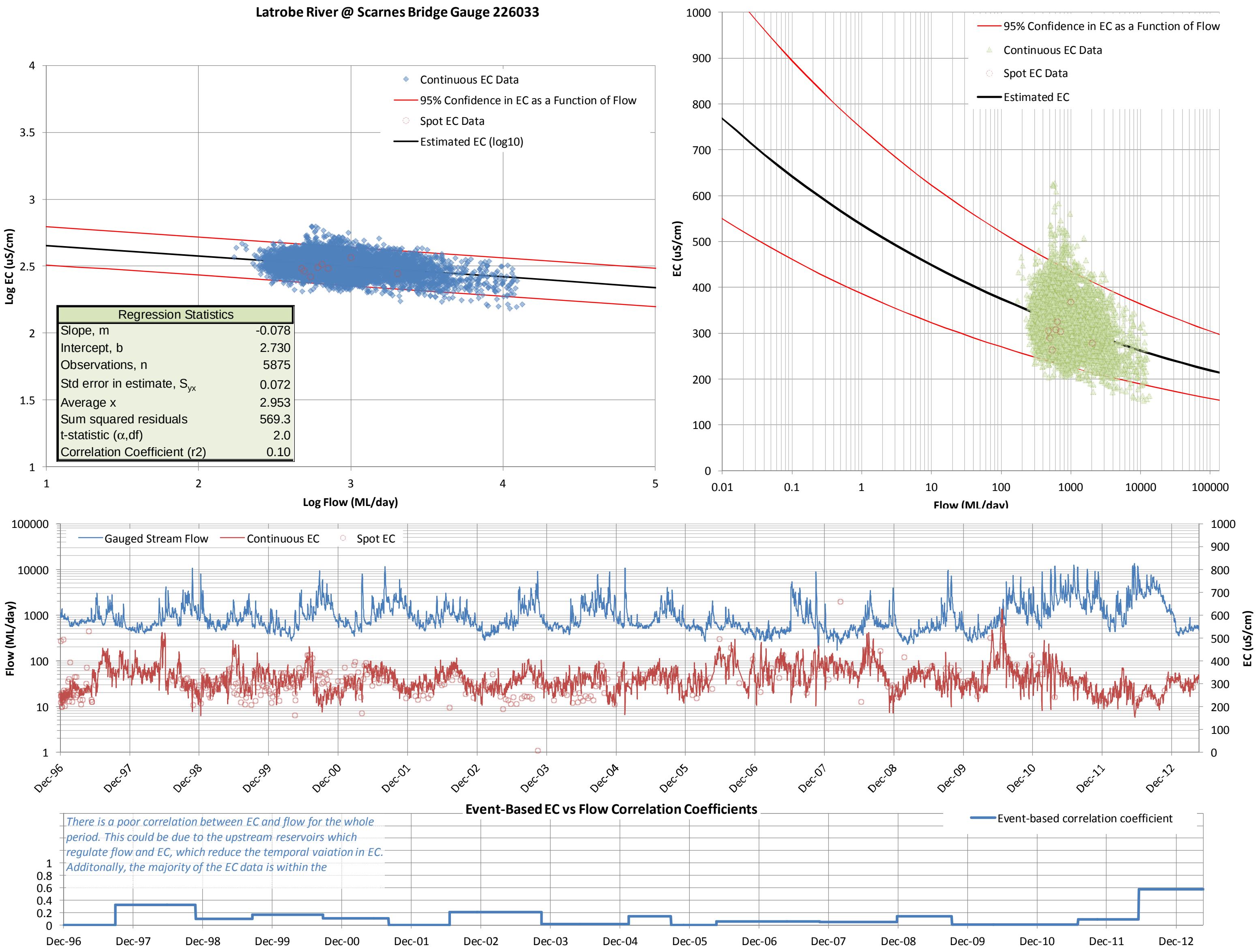

Regression Statistics	
Slope, m	-0.078
Intercept, b	2.730
Observations, n	5875
Std error in estimate, S_{yx}	0.072
Average x	2.953
Sum squared residuals	569.3
t-statistic (α,df)	2.0
Correlation Coefficient (r2)	0.10

There is a poor correlation between EC and flow for the whole period. This could be due to the upstream reservoirs which regulate flow and EC, which reduce the temporal vaiation in EC. Additonally, the majority of the EC data is within the

Figure B4between Stream Flow and EC on the Latrobe River at Scarns Bridge

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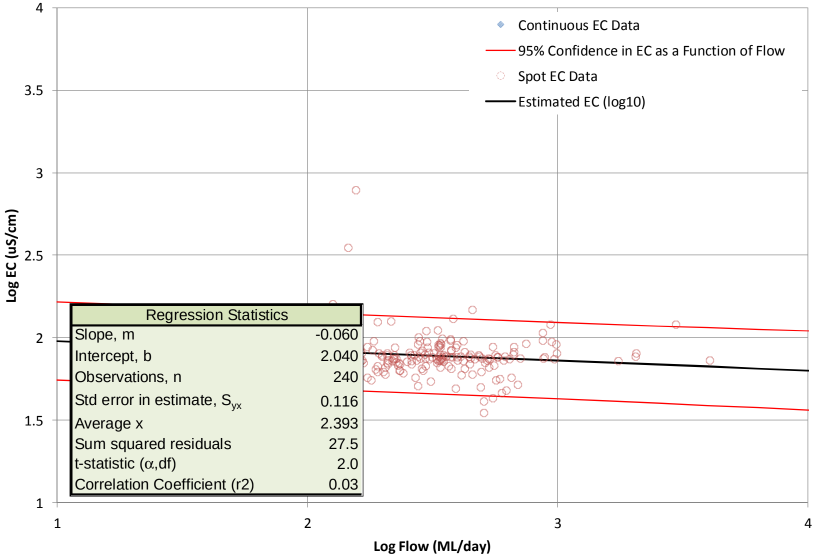
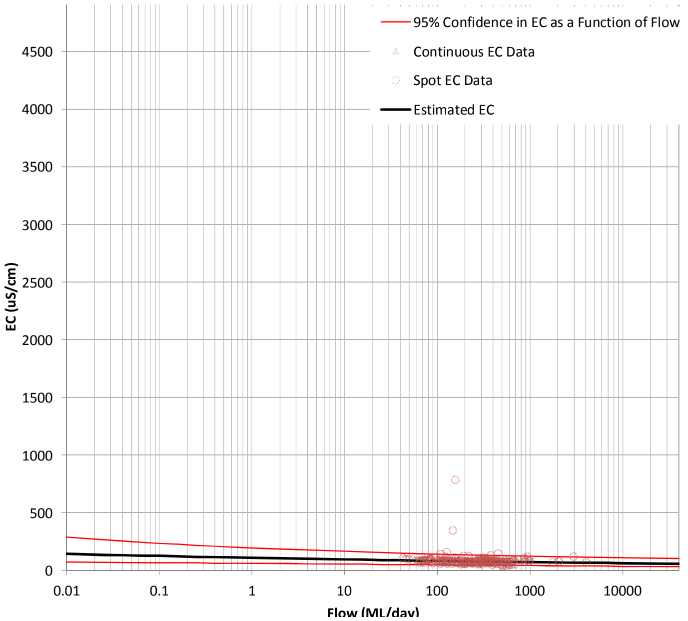
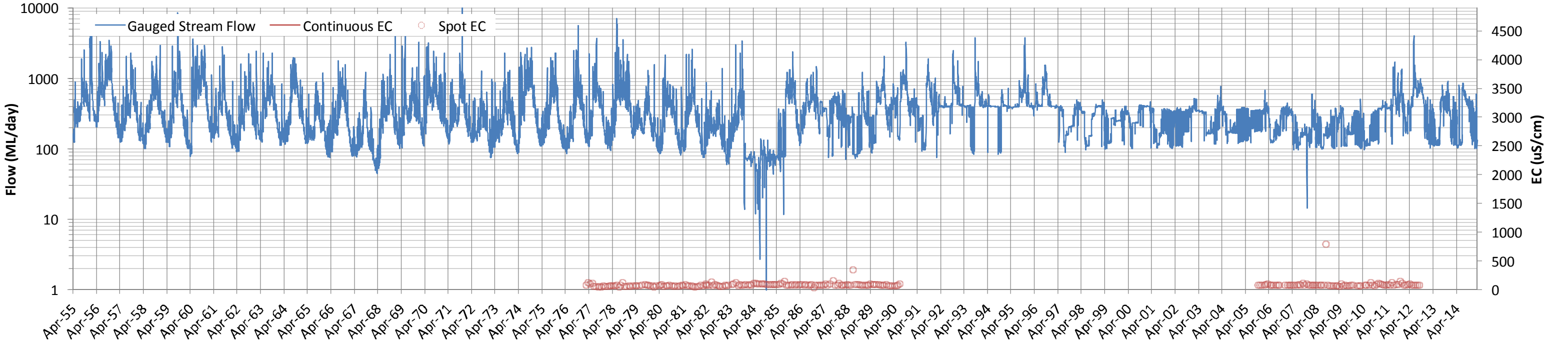
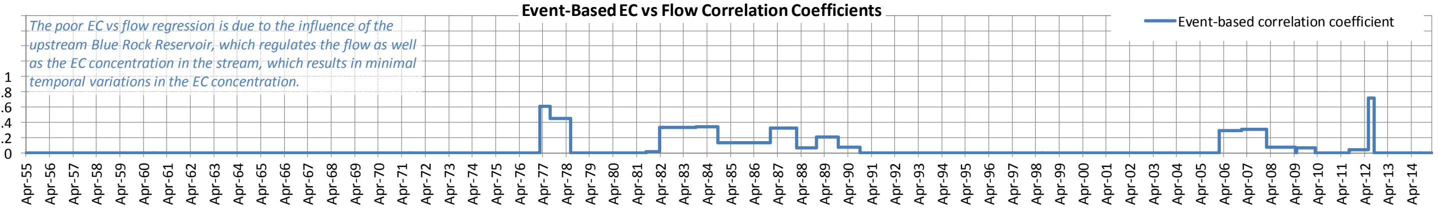
Tanjil River @ Tanjil South Gauge 226216



Regression Statistics	
Slope, m	-0.060
Intercept, b	2.040
Observations, n	240
Std error in estimate, S_{yx}	0.116
Average x	2.393
Sum squared residuals	27.5
t-statistic (α,df)	2.0
Correlation Coefficient (r2)	0.03

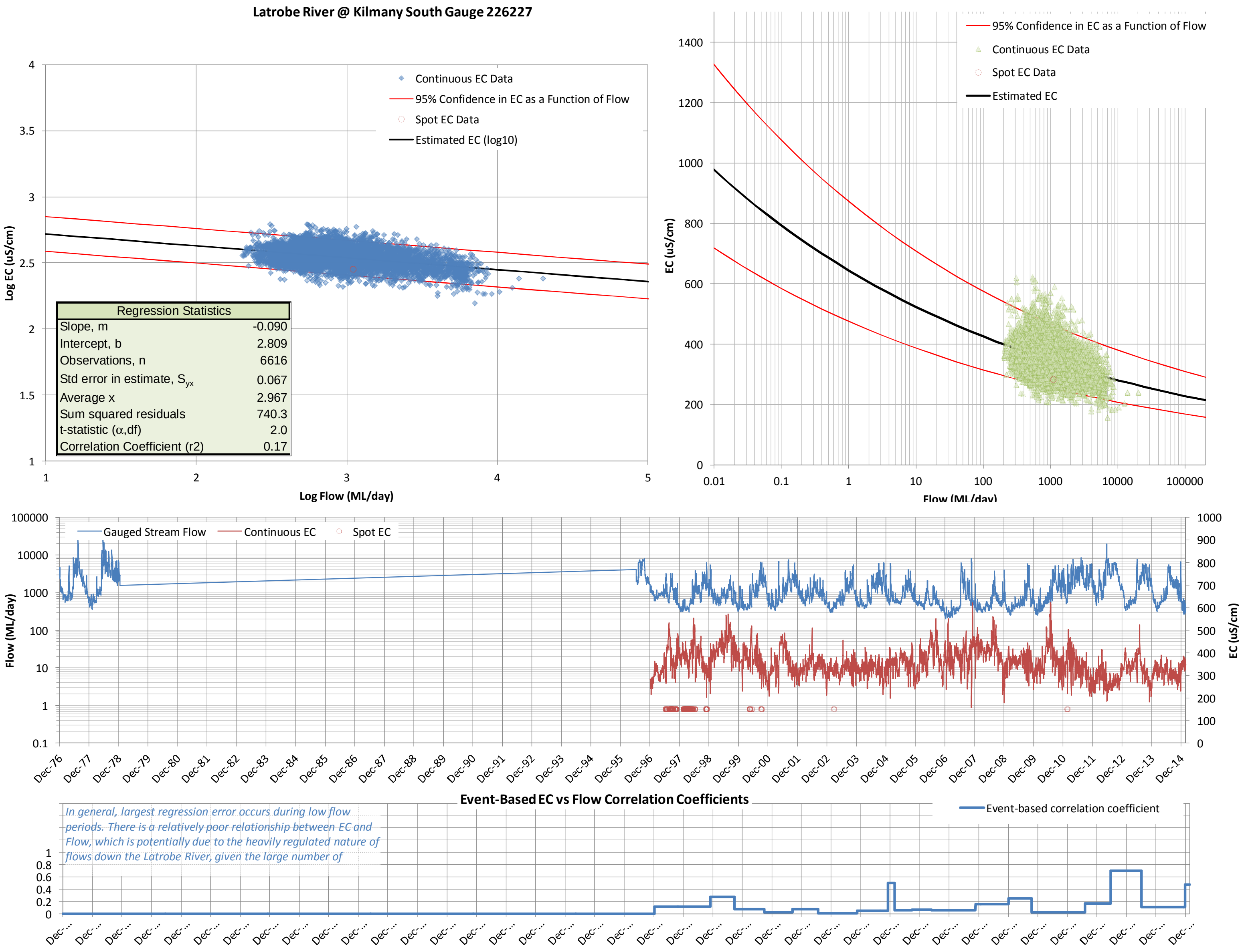






The poor EC vs flow regression is due to the influence of the upstream Blue Rock Reservoir, which regulates the flow as well as the EC concentration in the stream, which results in minimal temporal variations in the EC concentration.

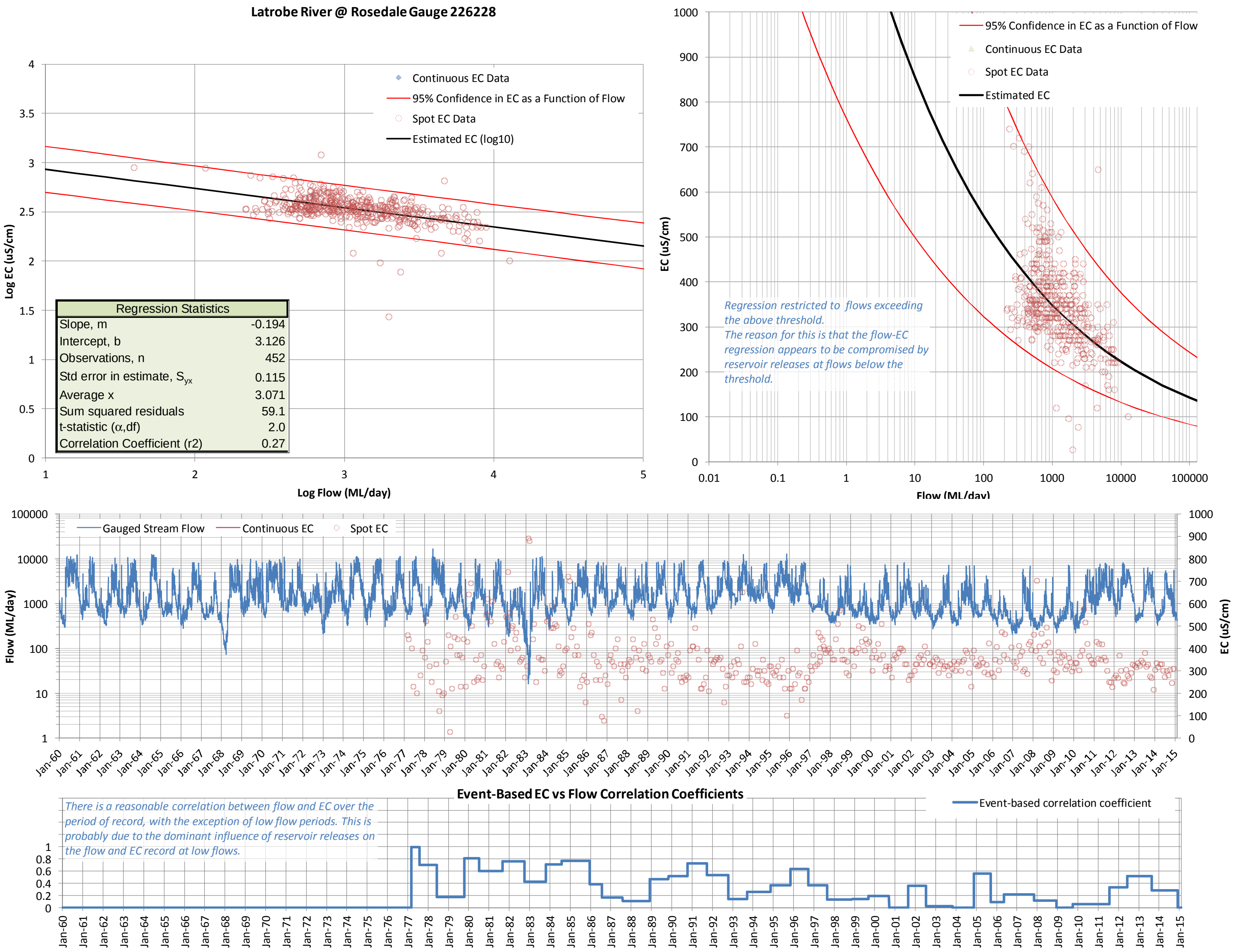
Figure B5between Stream Flow and EC on the Tanjil River at Tanjil South



Regression Statistics	
Slope, m	-0.090
Intercept, b	2.809
Observations, n	6616
Std error in estimate, S_{yx}	0.067
Average x	2.967
Sum squared residuals	740.3
t-statistic (α,df)	2.0
Correlation Coefficient (r2)	0.17

In general, largest regression error occurs during low flow periods. There is a relatively poor relationship between EC and Flow, which is potentially due to the heavily regulated nature of flows down the Latrobe River, given the large number of

Figure B6between Stream Flow and EC on the Latrobe River at Kilmany South

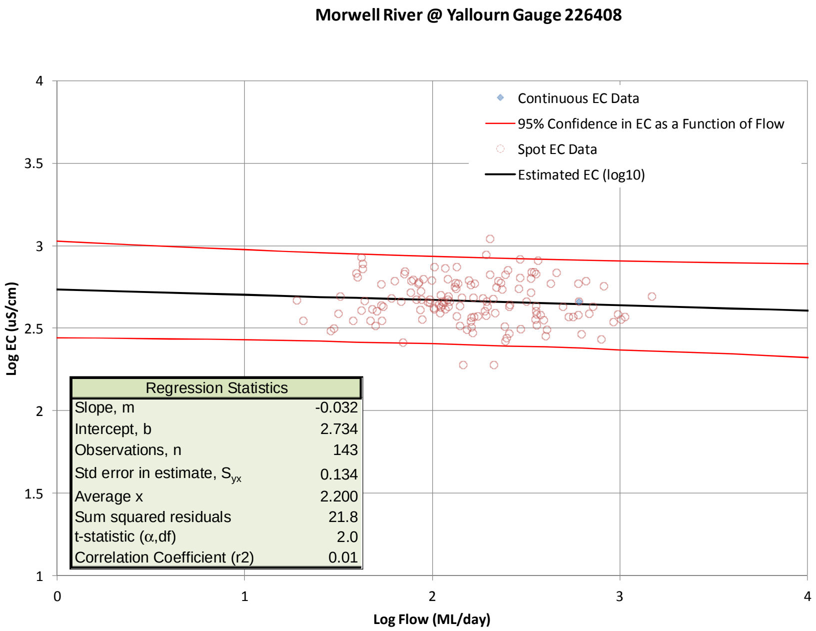


Regression Statistics	
Slope, m	-0.194
Intercept, b	3.126
Observations, n	452
Std error in estimate, S_{yx}	0.115
Average x	3.071
Sum squared residuals	59.1
t-statistic (α,df)	2.0
Correlation Coefficient (r2)	0.27

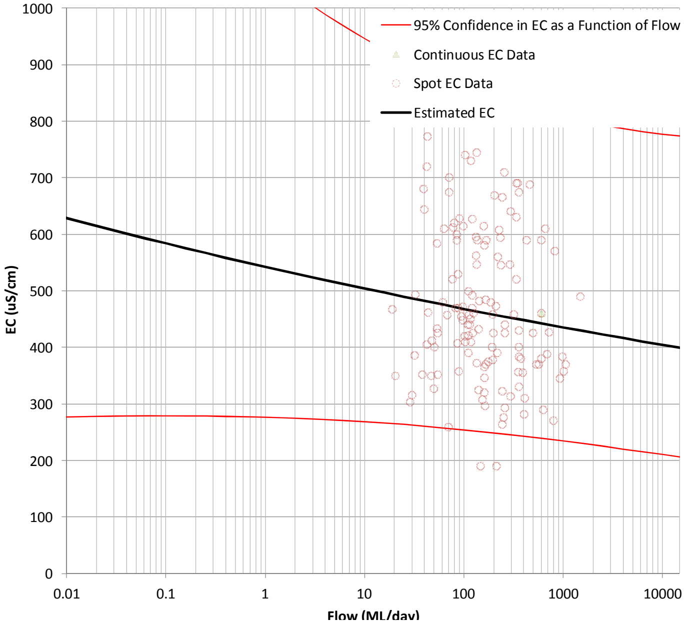
Regression restricted to flows exceeding the above threshold. The reason for this is that the flow-EC regression appears to be compromised by reservoir releases at flows below the threshold.

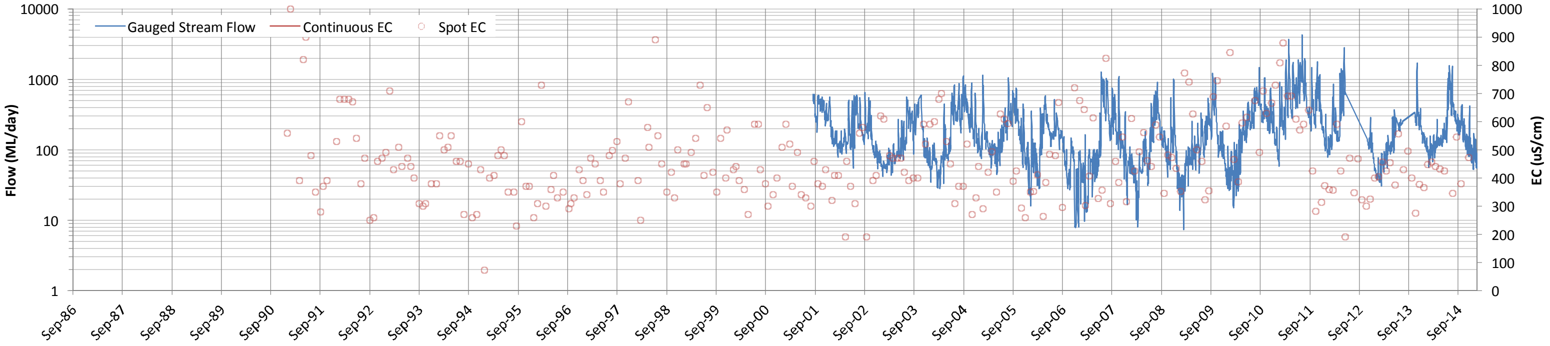
There is a reasonable correlation between flow and EC over the period of record, with the exception of low flow periods. This is probably due to the dominant influence of reservoir releases on the flow and EC record at low flows.

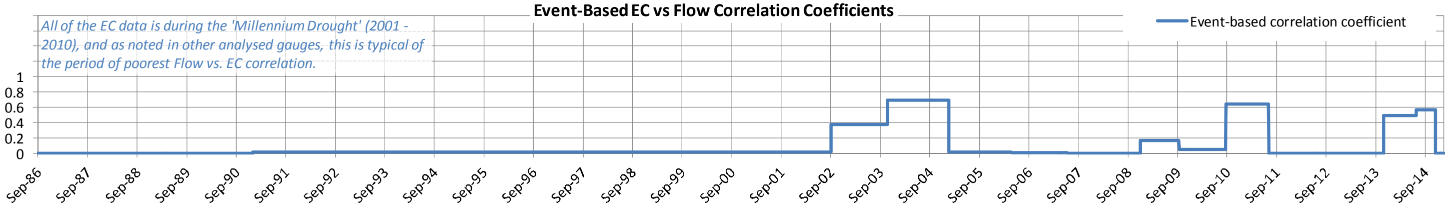
Figure B7between Stream Flow and EC on the Latrobe River at Rosedale



Regression Statistics	
Slope, m	-0.032
Intercept, b	2.734
Observations, n	143
Std error in estimate, S_{yx}	0.134
Average x	2.200
Sum squared residuals	21.8
t-statistic (α,df)	2.0
Correlation Coefficient (r2)	0.01

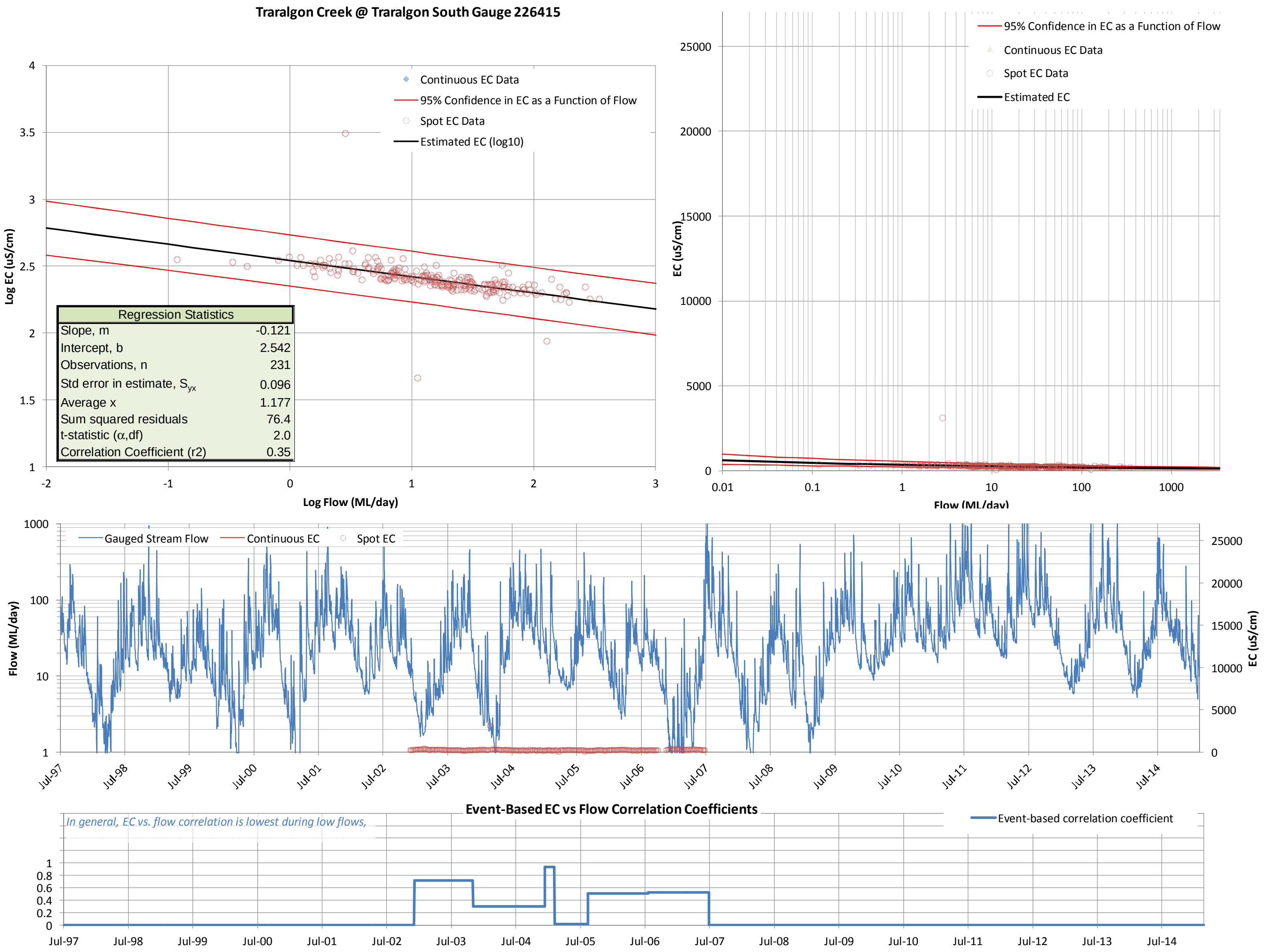






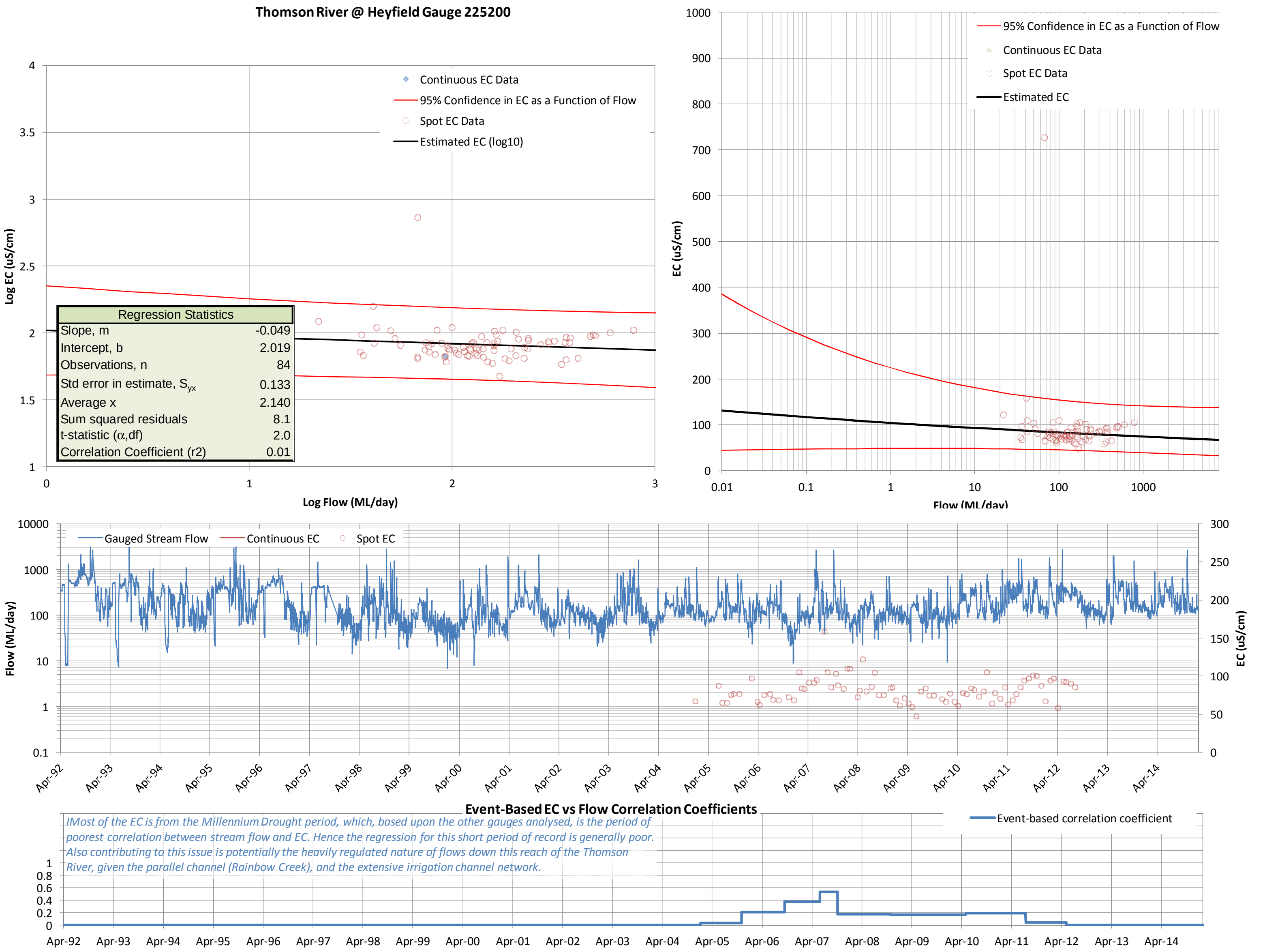
All of the EC data is during the 'Millennium Drought' (2001 - 2010), and as noted in other analysed gauges, this is typical of the period of poorest Flow vs. EC correlation.

Figure B8between Stream Flow and EC on the Morwell River at Yallourn



Regression Statistics	
Slope, m	-0.121
Intercept, b	2.542
Observations, n	231
Std error in estimate, S_{yx}	0.096
Average x	1.177
Sum squared residuals	76.4
t-statistic (α,df)	2.0
Correlation Coefficient (r2)	0.35

Figure B9between Stream Flow and EC on the Traralgon Creek at Traralgon South

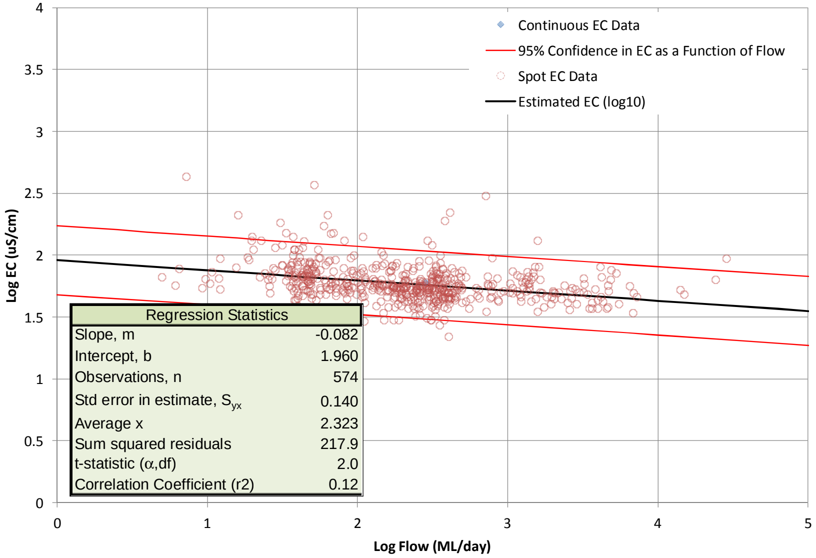


Regression Statistics	
Slope, m	-0.049
Intercept, b	2.019
Observations, n	84
Std error in estimate, S_{yx}	0.133
Average x	2.140
Sum squared residuals	8.1
t-statistic (α,df)	2.0
Correlation Coefficient (r2)	0.01

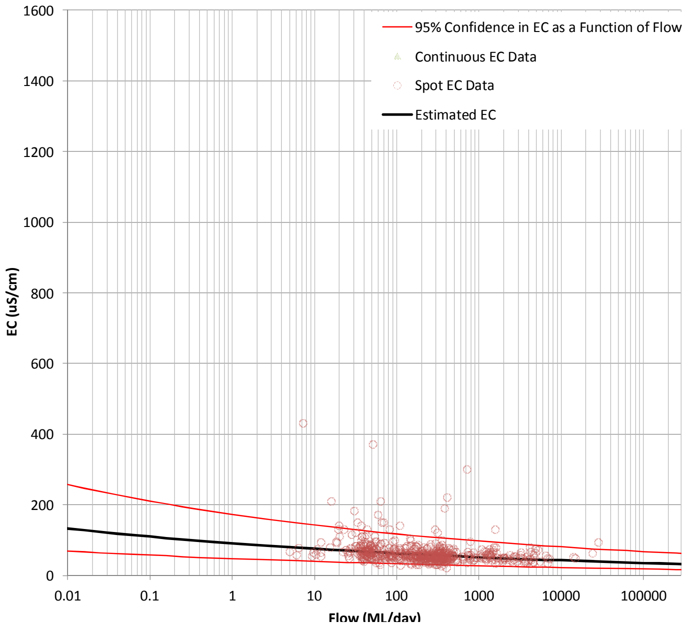
IMost of the EC is from the Millennium Drought period, which, based upon the other gauges analysed, is the period of poorest correlation between stream flow and EC. Hence the regression for this short period of record is generally poor. Also contributing to this issue is potentially the heavily regulated nature of flows down this reach of the Thomson River, given the parallel channel (Rainbow Creek), and the extensive irrigation channel network.

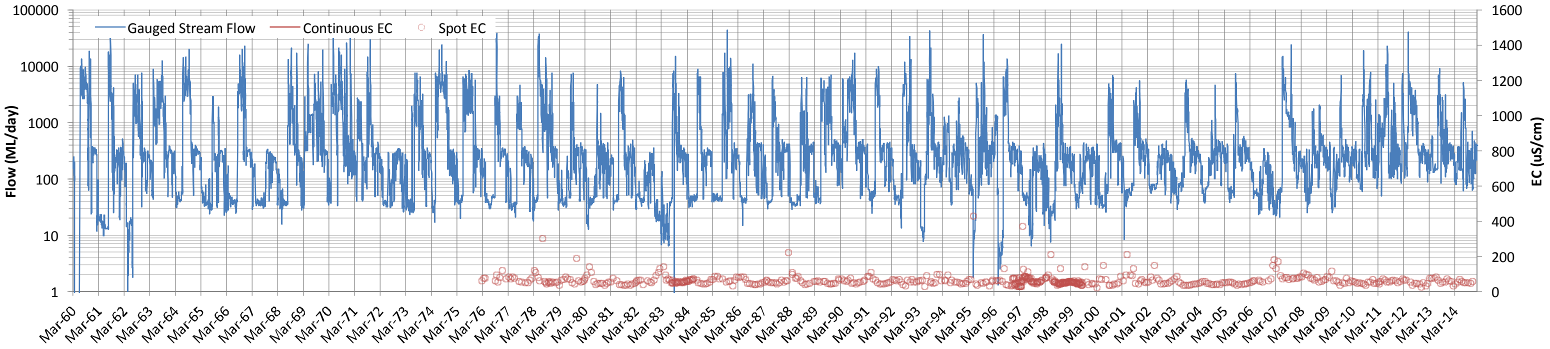
Figure B10between Stream Flow and EC on the Thomson River @ Heyfield

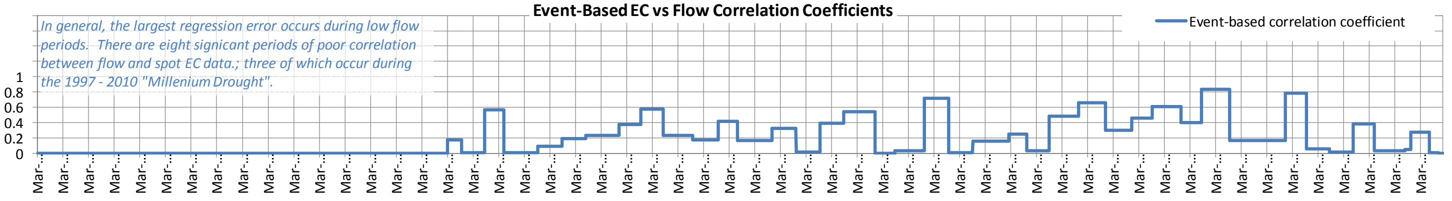
Macalister River @ Glenmaggie Tailgauge 225204



Regression Statistics	
Slope, m	-0.082
Intercept, b	1.960
Observations, n	574
Std error in estimate, S_{yx}	0.140
Average x	2.323
Sum squared residuals	217.9
t-statistic (α,df)	2.0
Correlation Coefficient (r2)	0.12

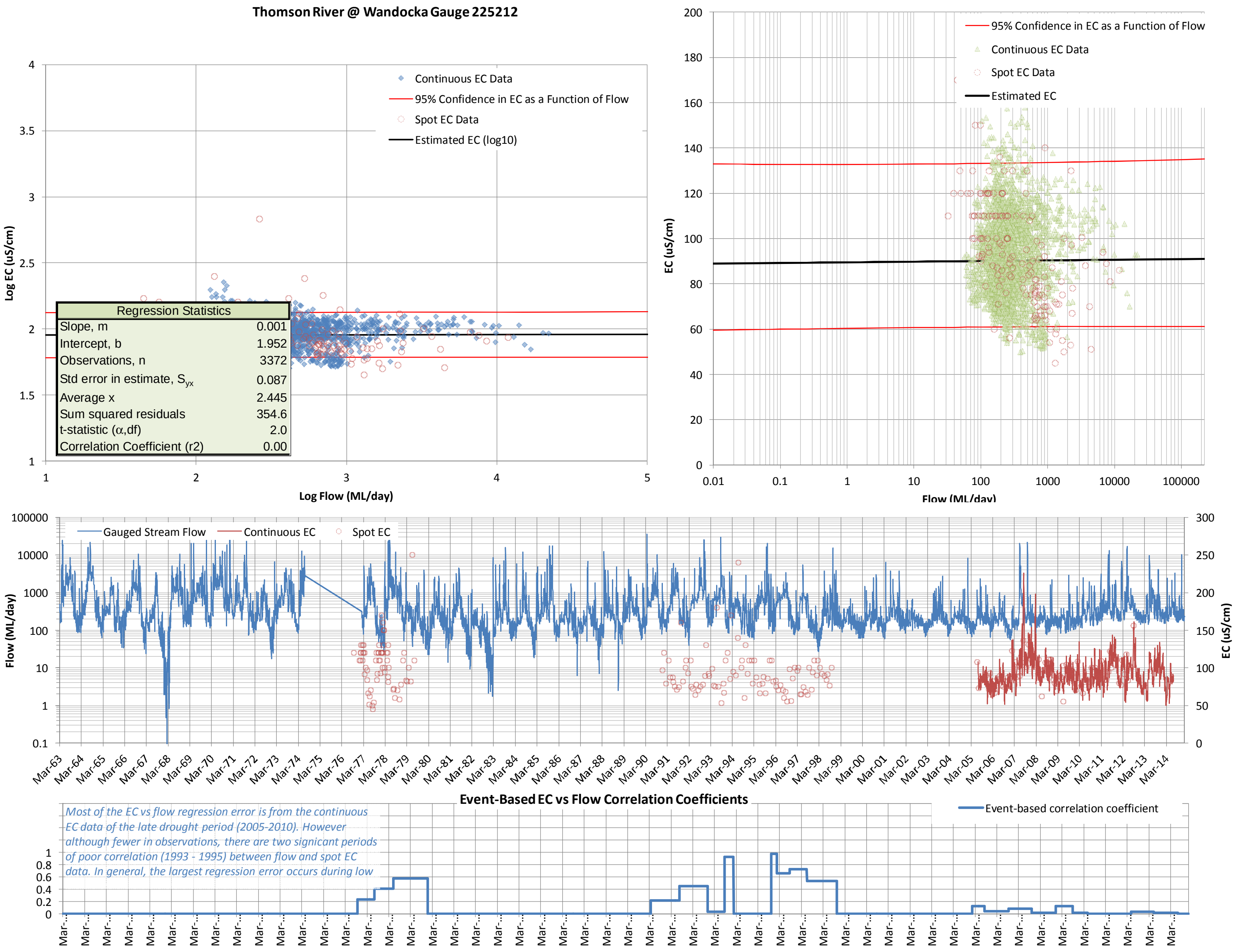






In general, the largest regression error occurs during low flow periods. There are eight signicant periods of poor correlation between flow and spot EC data.; three of which occur during the 1997 - 2010 "Millenium Drought".

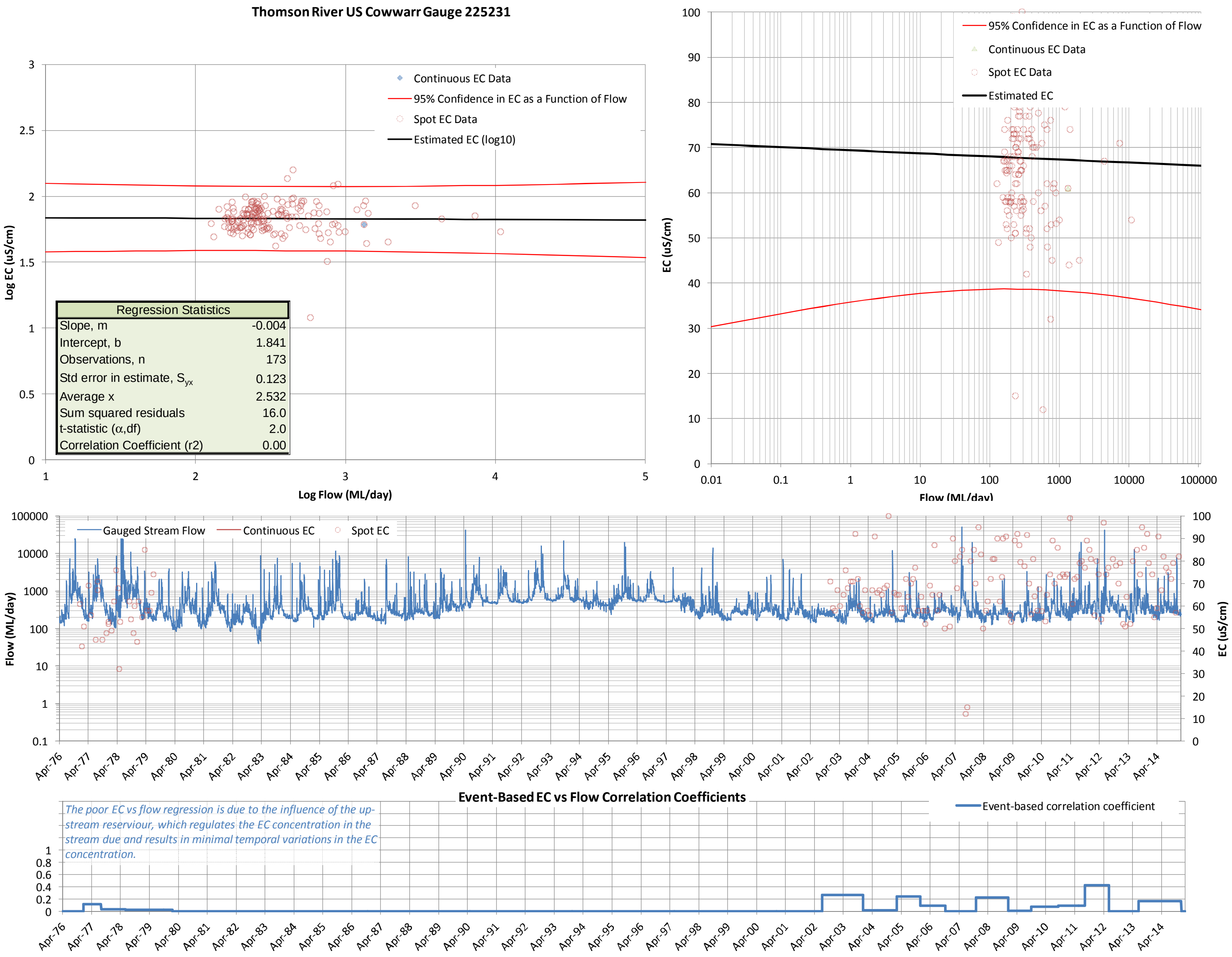
Figure B11between Stream Flow and EC on the Macalister River at Glenmaggie



Regression Statistics	
Slope, m	0.001
Intercept, b	1.952
Observations, n	3372
Std error in estimate, S_{yx}	0.087
Average x	2.445
Sum squared residuals	354.6
t-statistic (α,df)	2.0
Correlation Coefficient (r2)	0.00

Most of the EC vs flow regression error is from the continuous EC data of the late drought period (2005-2010). However although fewer in observations, there are two signicant periods of poor correlation (1993 - 1995) between flow and spot EC data. In general, the largest regression error occurs during low

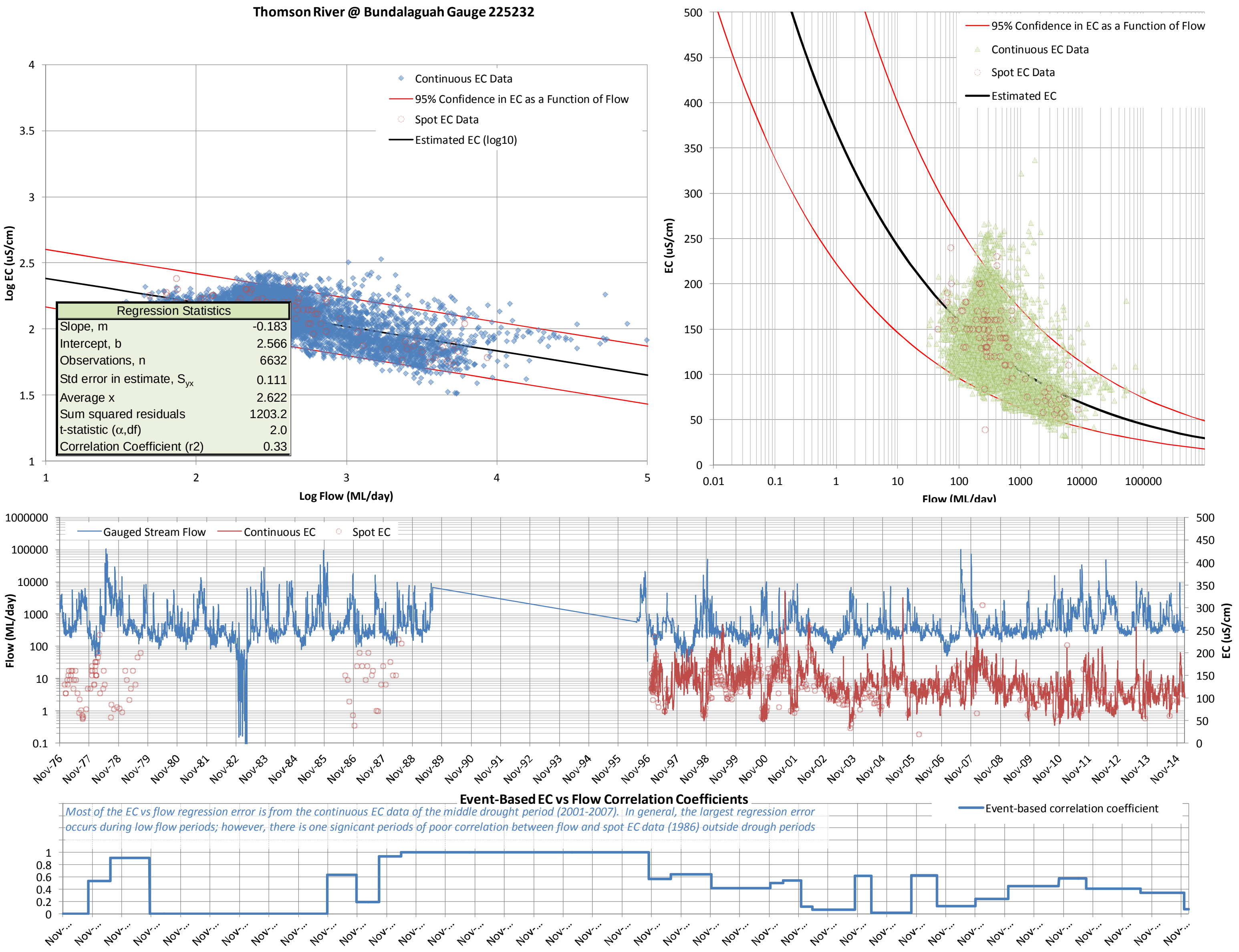
Figure B12between Stream Flow and EC on the Thomson River @ Wandocka



Regression Statistics	
Slope, m	-0.004
Intercept, b	1.841
Observations, n	173
Std error in estimate, S_{yx}	0.123
Average x	2.532
Sum squared residuals	16.0
t-statistic (α,df)	2.0
Correlation Coefficient (r2)	0.00

The poor EC vs flow regression is due to the influence of the up-stream reserviour, which regulates the EC concentration in the stream due and results in minimal temporal variations in the EC concentration.

Figure B13between Stream Flow and EC on the Thomson River U/S Cowwarr Weir



Regression Statistics	
Slope, m	-0.183
Intercept, b	2.566
Observations, n	6632
Std error in estimate, S_{yx}	0.111
Average x	2.622
Sum squared residuals	1203.2
t-statistic (α,df)	2.0
Correlation Coefficient (r2)	0.33

Most of the EC vs flow regression error is from the continuous EC data of the middle drought period (2001-2007). In general, the largest regression error occurs during low flow periods; however, there is one signicant periods of poor correlation between flow and spot EC data (1986) outside drough periods

Figure B14between Stream Flow and EC on the Thomson River at Bundalaguah

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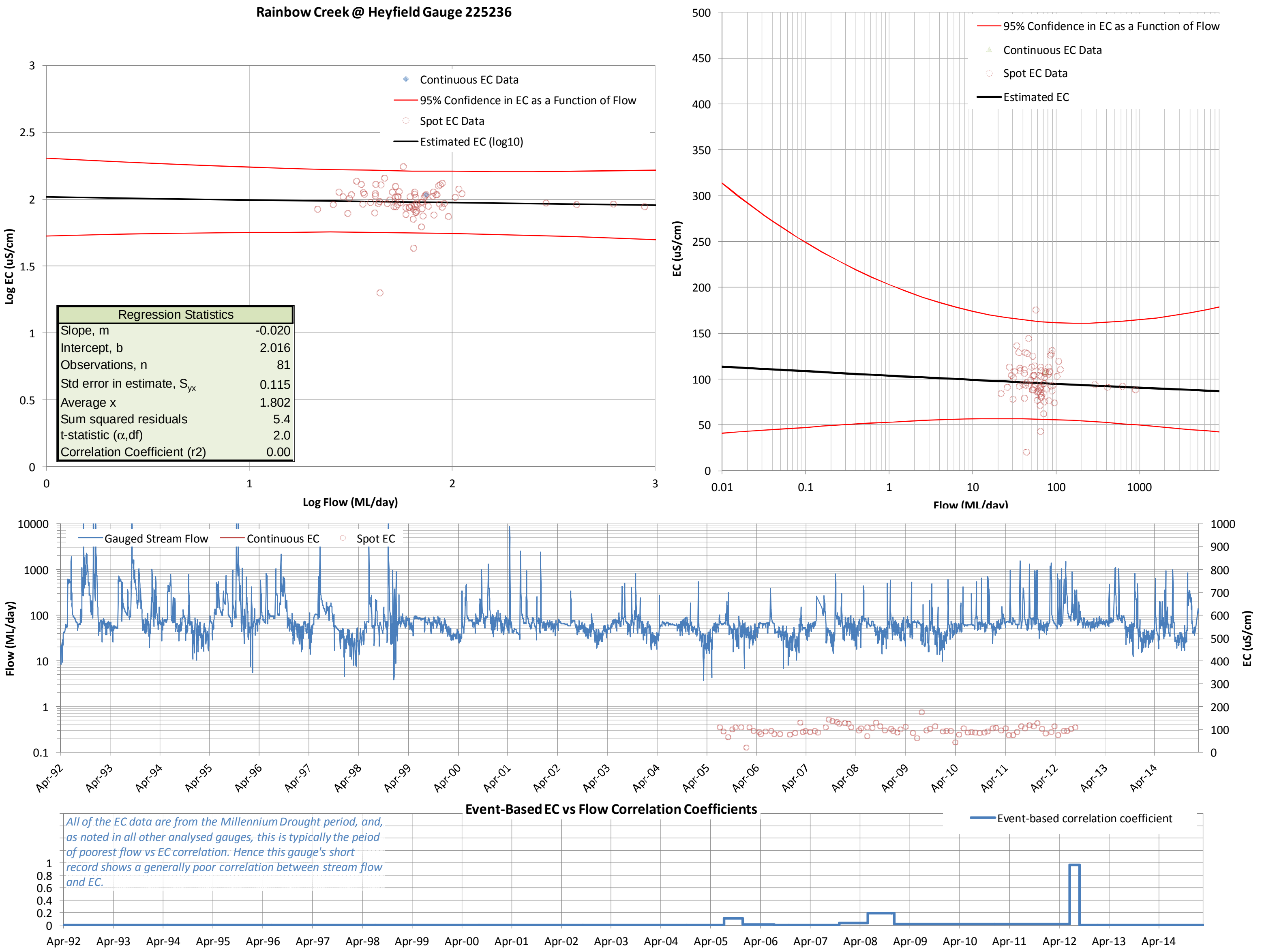
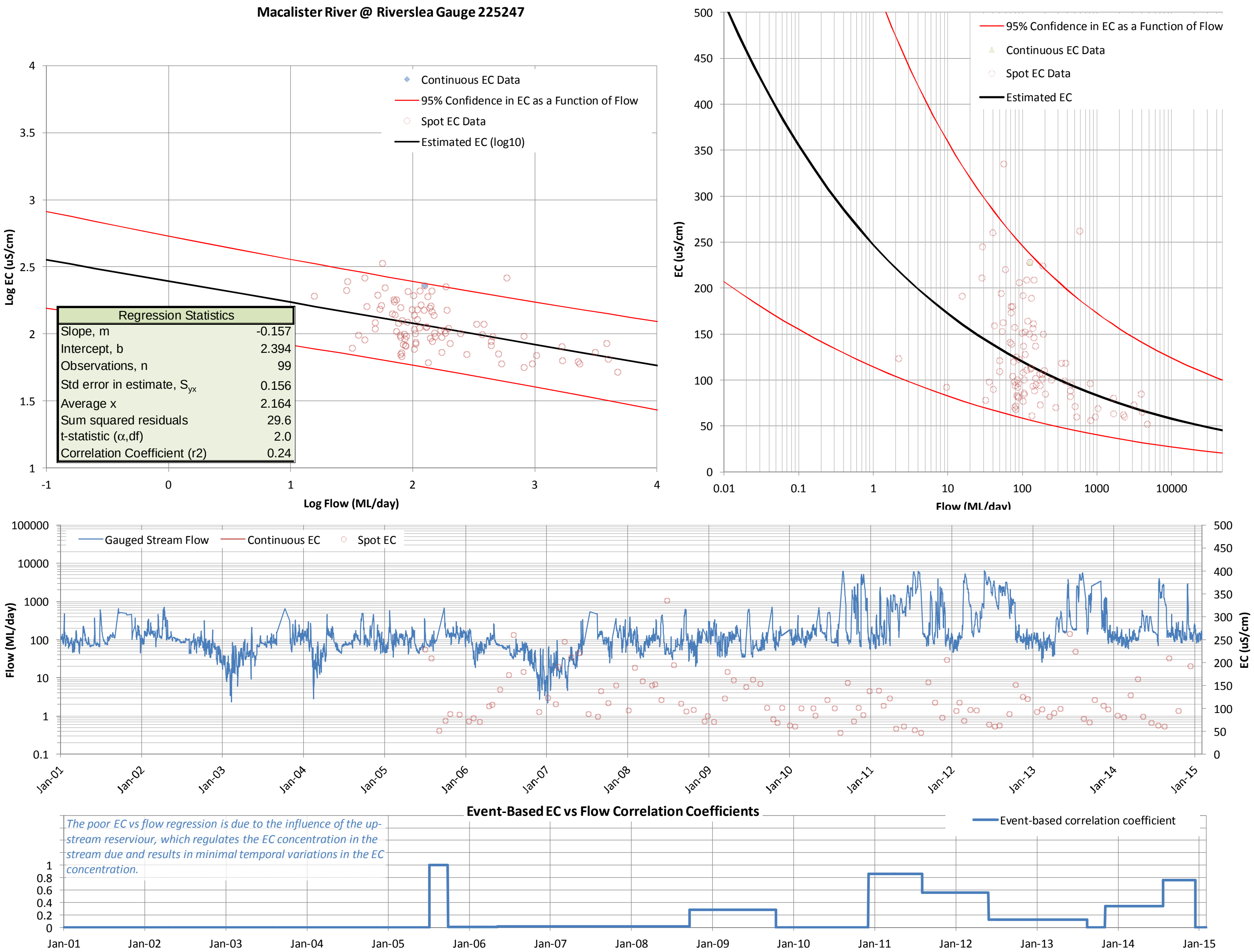


Regression Statistics	
Slope, m	-0.020
Intercept, b	2.016
Observations, n	81
Std error in estimate, S_{yx}	0.115
Average x	1.802
Sum squared residuals	5.4
t-statistic (α,df)	2.0
Correlation Coefficient (r2)	0.00

All of the EC data are from the Millennium Drought period, and, as noted in all other analysed gauges, this is typically the peiod of poorest flow vs EC correlation. Hence this gauge's short record shows a generally poor correlation between stream flow and EC.

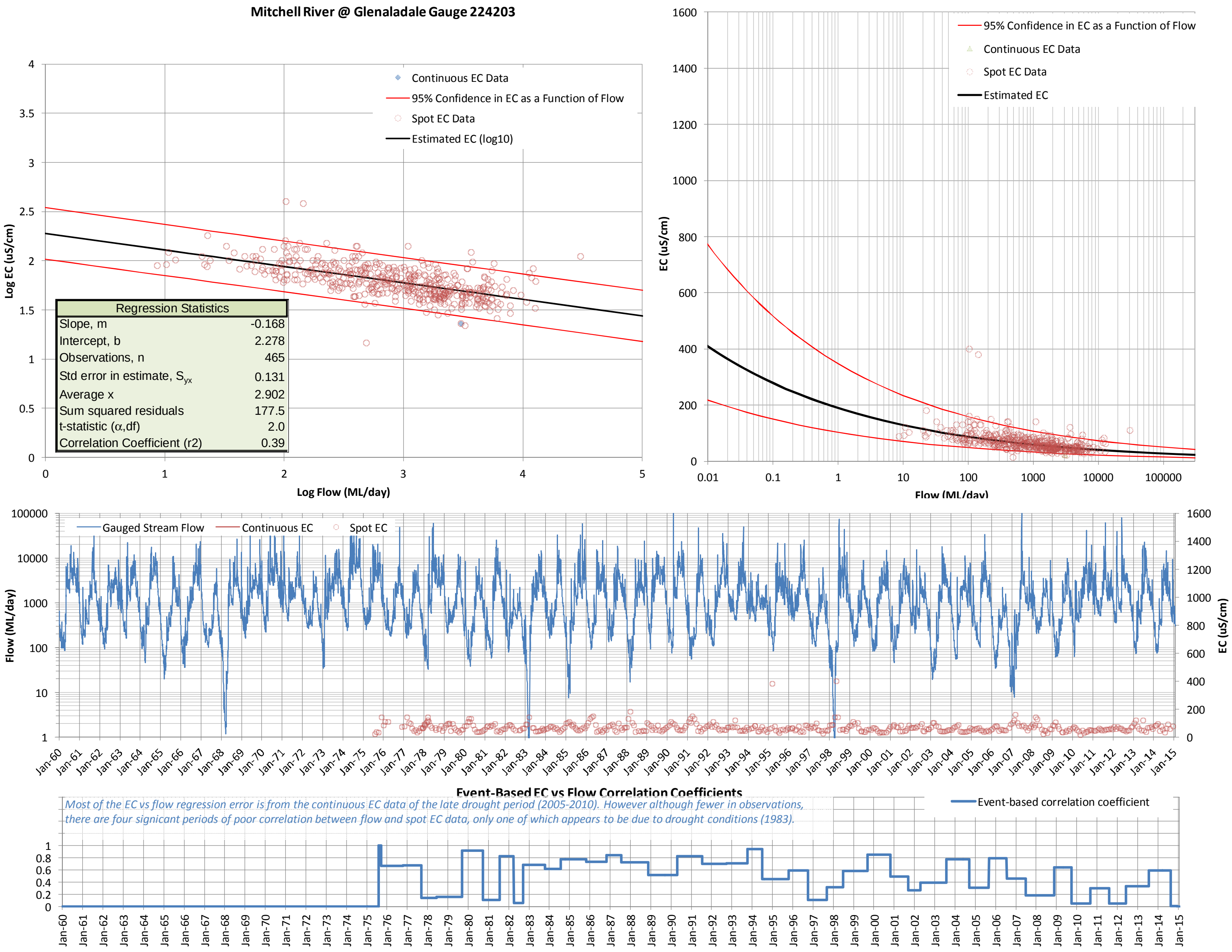
Figure B15between Stream Flow and EC on the Rainbow Creek @ Heyfield



Regression Statistics	
Slope, m	-0.157
Intercept, b	2.394
Observations, n	99
Std error in estimate, S_{yx}	0.156
Average x	2.164
Sum squared residuals	29.6
t-statistic (α,df)	2.0
Correlation Coefficient (r2)	0.24

The poor EC vs flow regression is due to the influence of the up-stream reserviour, which regulates the EC concentration in the stream due and results in minimal temporal variations in the EC concentration.

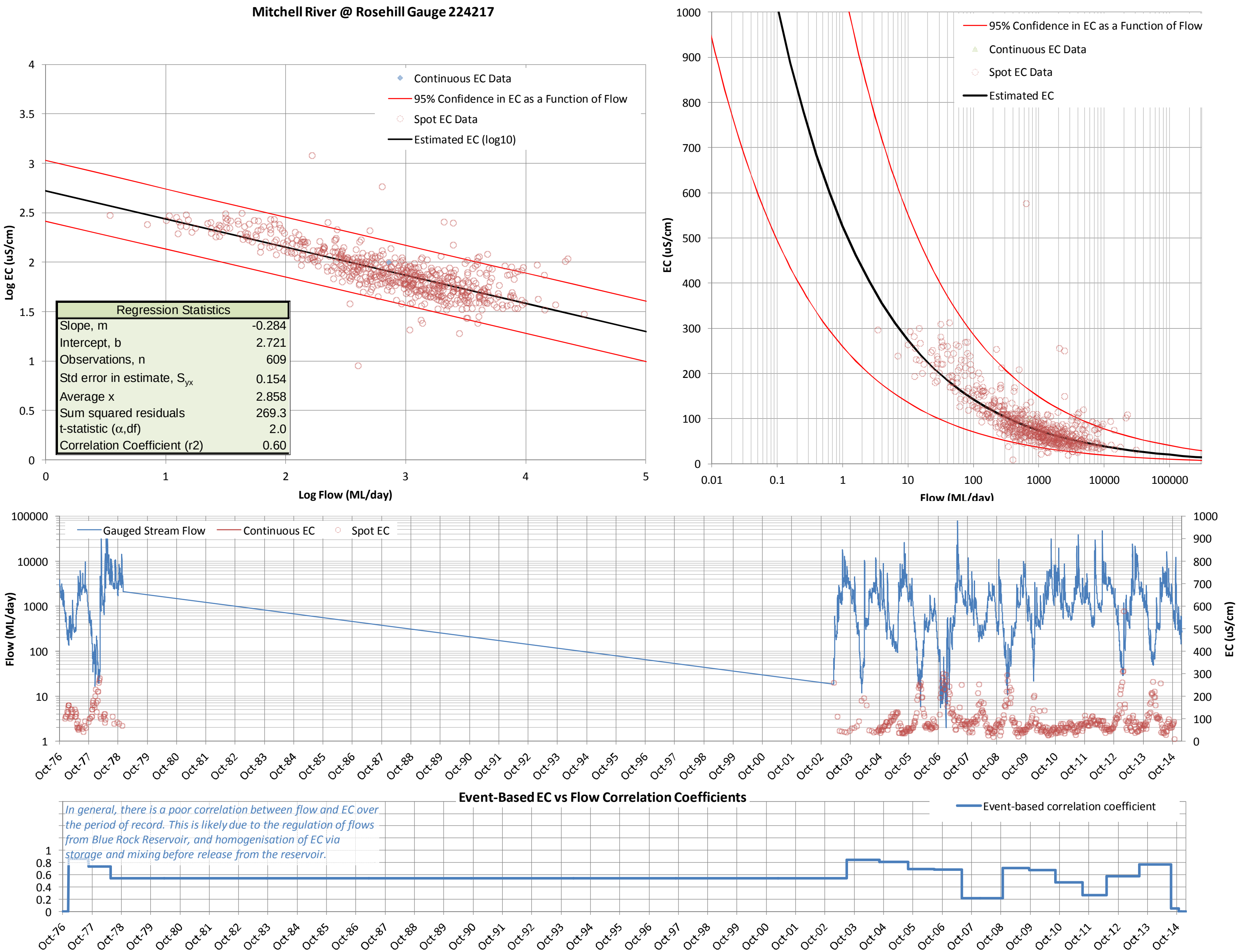
Figure B16between Stream Flow and EC on the Macalister River at Riversleigh



Regression Statistics	
Slope, m	-0.168
Intercept, b	2.278
Observations, n	465
Std error in estimate, S_{yx}	0.131
Average x	2.902
Sum squared residuals	177.5
t-statistic (α,df)	2.0
Correlation Coefficient (r2)	0.39

Most of the EC vs flow regression error is from the continuous EC data of the late drought period (2005-2010). However although fewer in observations, there are four signicant periods of poor correlation between flow and spot EC data, only one of which appears to be due to drought conditions (1983).

Figure B17Relationships between Stream Flow and EC on the Mitchell River @ Glenaladale

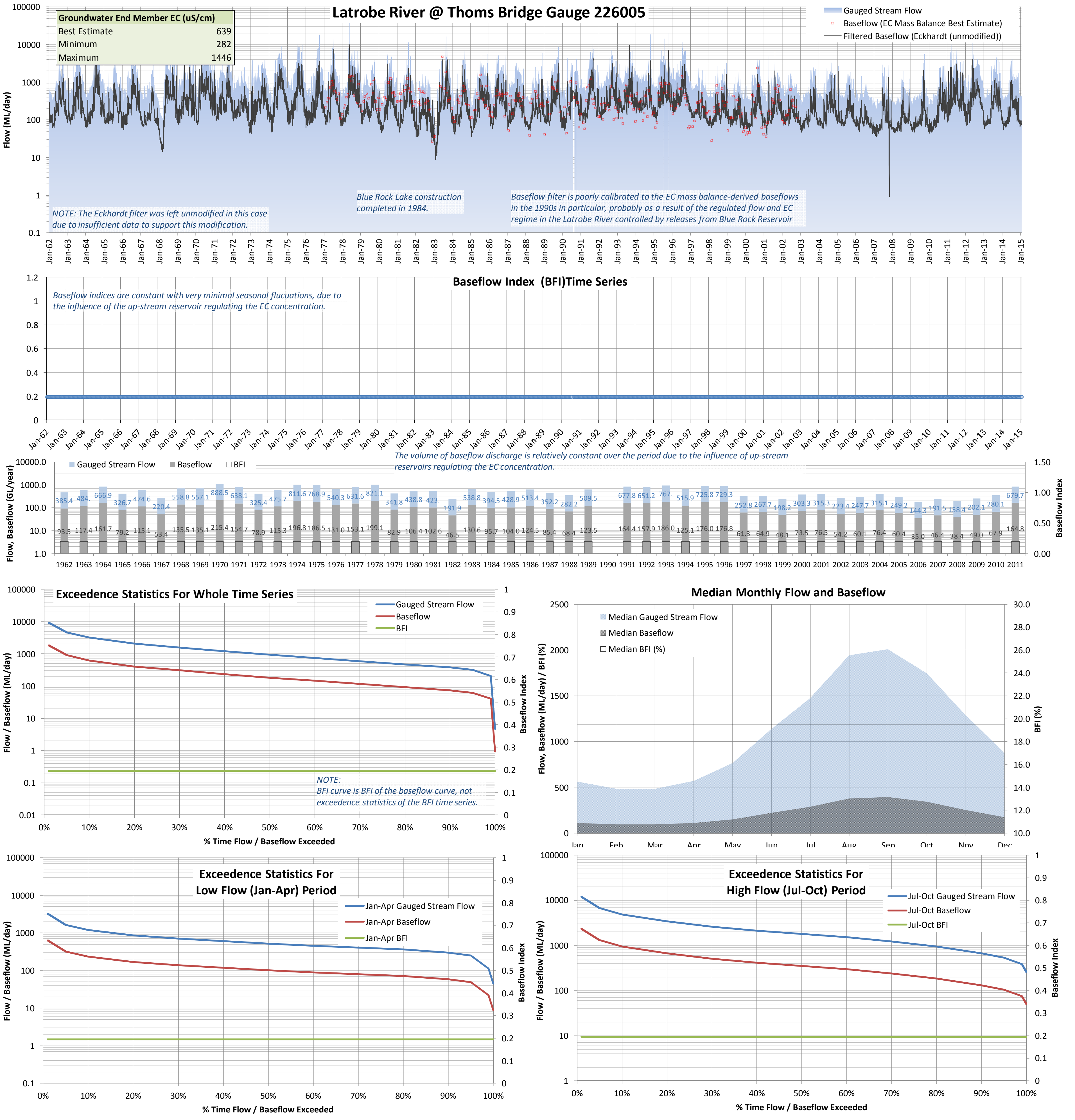


Regression Statistics	
Slope, m	-0.284
Intercept, b	2.721
Observations, n	609
Std error in estimate, S_{yx}	0.154
Average x	2.858
Sum squared residuals	269.3
t-statistic (α,df)	2.0
Correlation Coefficient (r2)	0.60

In general, there is a poor correlation between flow and EC over the period of record. This is likely due to the regulation of flows from Blue Rock Reservoir, and homogenisation of EC via storage and mixing before release from the reservoir.

Figure B18Relationships between Stream Flow and EC on the Mitchell

Appendix C – EC-Derived Baseflow Estimates



Latrobe River @ Thoms Bridge Gauge 226005

Groundwater End Member EC (uS/cm)	
Best Estimate	639
Minimum	282
Maximum	1446

NOTE: The Eckhardt filter was left unmodified in this case due to insufficient data to support this modification.

Blue Rock Lake construction completed in 1984.

Baseflow filter is poorly calibrated to the EC mass balance-derived baseflows in the 1990s in particular, probably as a result of the regulated flow and EC regime in the Latrobe River controlled by releases from Blue Rock Reservoir

Baseflow Index (BFI)Time Series

Baseflow indices are constant with very minimal seasonal flucuations, due to the influence of the up-stream reservoir regulating the EC concentration.

The volume of baseflow discharge is relatively constant over the period due to the influence of up-stream reservoirs regulating the EC concentration.

Exceedence Statistics For Whole Time Series

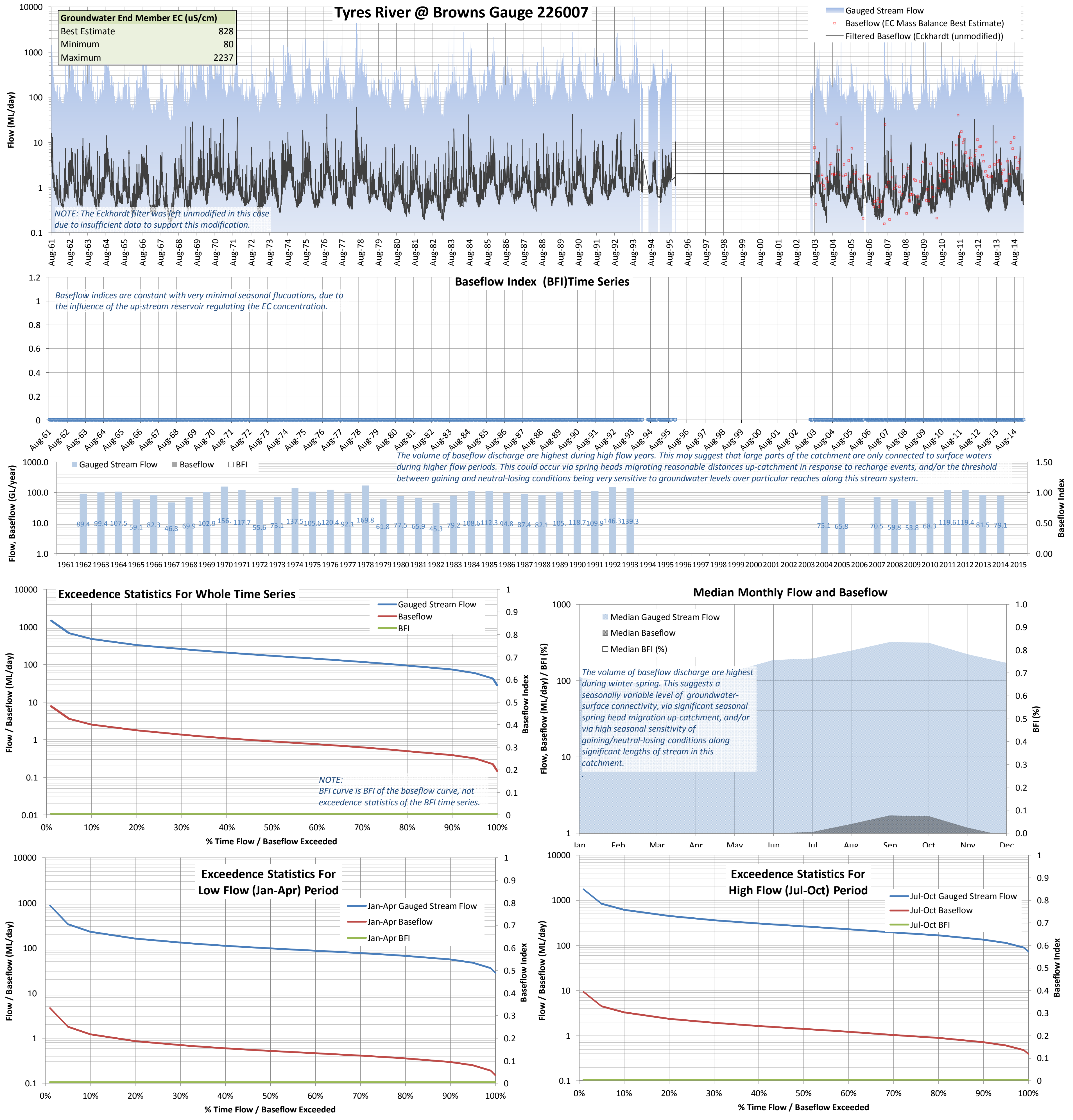
NOTE:
BFI curve is BFI of the baseflow curve, not exceedence statistics of the BFI time series.

Median Monthly Flow and Baseflow

Exceedence Statistics For Low Flow (Jan-Apr) Period

Exceedence Statistics For High Flow (Jul-Oct) Period

Figure C1 Summary Baseflow Estimation for the Latrobe River at Thoms Bridge



Groundwater End Member EC (uS/cm)	
Best Estimate	828
Minimum	80
Maximum	2237

NOTE: The Eckhardt filter was left unmodified in this case due to insufficient data to support this modification.

Baseflow indices are constant with very minimal seasonal flucuations, due to the influence of the up-stream reservoir regulating the EC concentration.

The volume of baseflow discharge are highest during high flow years. This may suggest that large parts of the catchment are only connected to surface waters during higher flow periods. This could occur via spring heads migrating reasonable distances up-catchment in response to recharge events, and/or the threshold between gaining and neutral-losing conditions being very sensitive to groundwater levels over particular reaches along this stream system.

NOTE: BFI curve is BFI of the baseflow curve, not exceedence statistics of the BFI time series.

The volume of baseflow discharge are highest during winter-spring. This suggests a seasonally variable level of groundwater-surface connectivity, via significant seasonal spring head migration up-catchment, and/or via high seasonal sensitivity of gaining/neutral-losing conditions along significant lengths of stream in this catchment.

Figure C2Summary Baseflow Estimation for the Tyres River at Browns

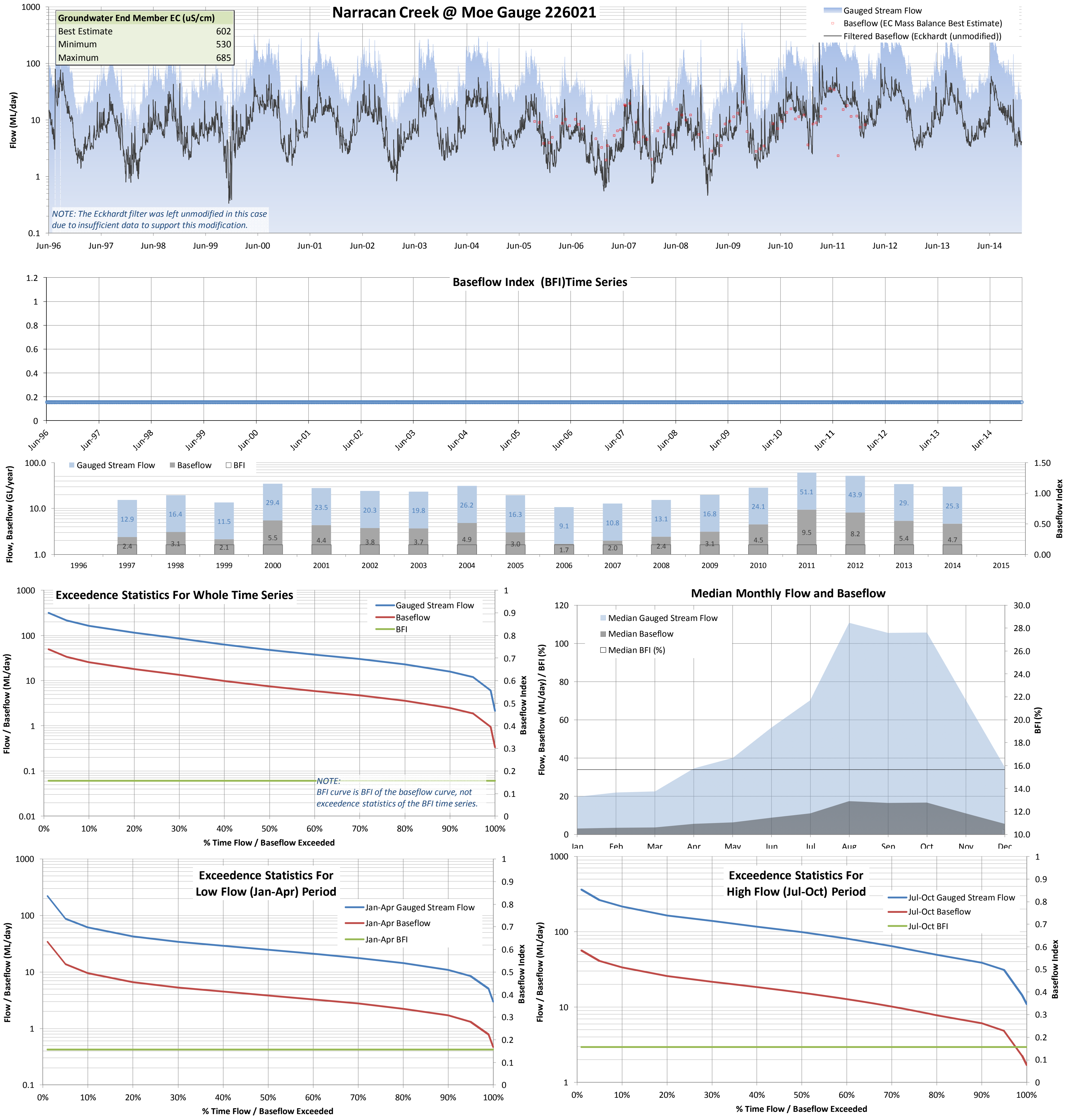
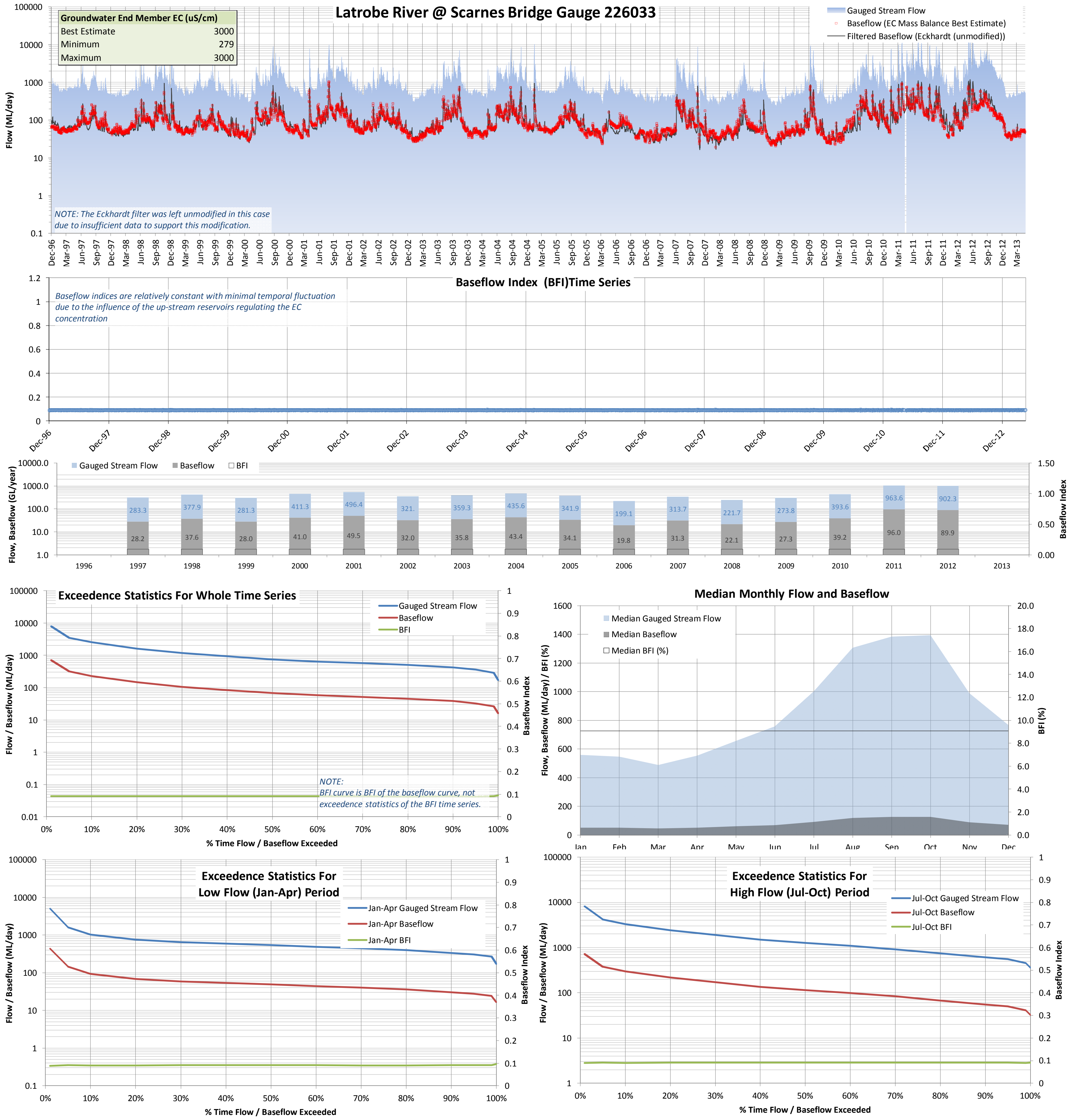


Figure C3Summary Baseflow Estimation for the Narracan Creek at Moe

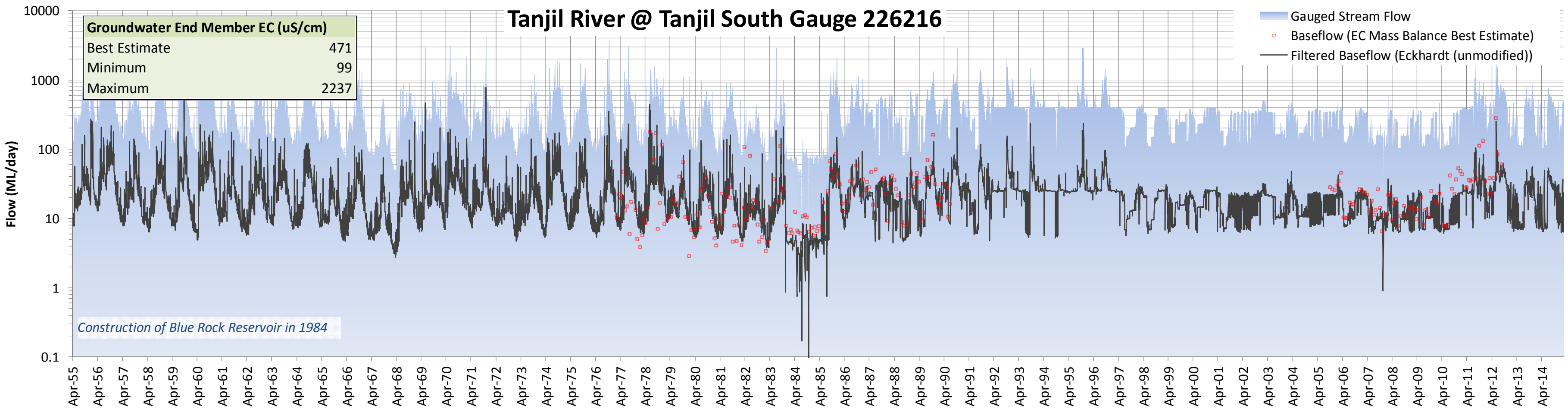


NOTE: The Eckhardt filter was left unmodified in this case due to insufficient data to support this modification.

Baseflow indices are relatively constant with minimal temporal fluctuation due to the influence of the up-stream reservoirs regulating the EC concentration

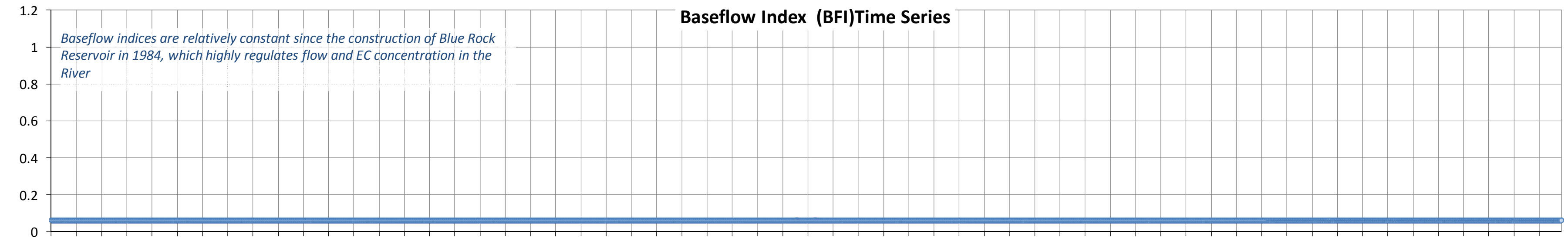
NOTE:
BFI curve is BFI of the baseflow curve, not exceedence statistics of the BFI time series.

Figure C4Summary Baseflow Estimation for the Latrobe River at Scarns Bridge

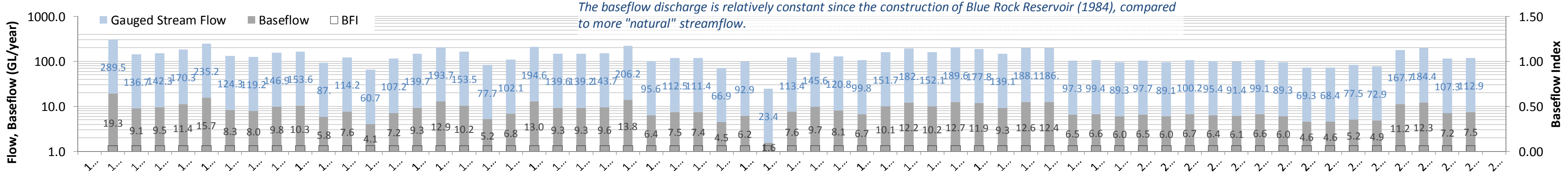


Groundwater End Member EC (uS/cm)	
Best Estimate	471
Minimum	99
Maximum	2237

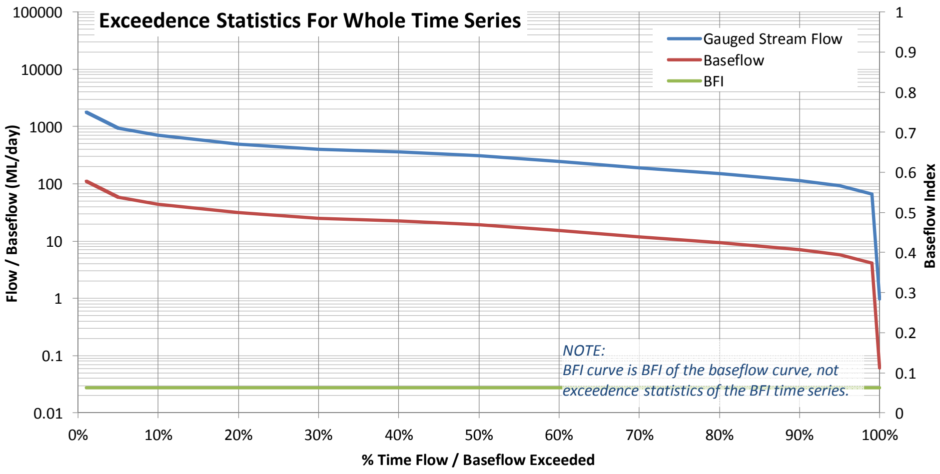
Construction of Blue Rock Reservoir in 1984



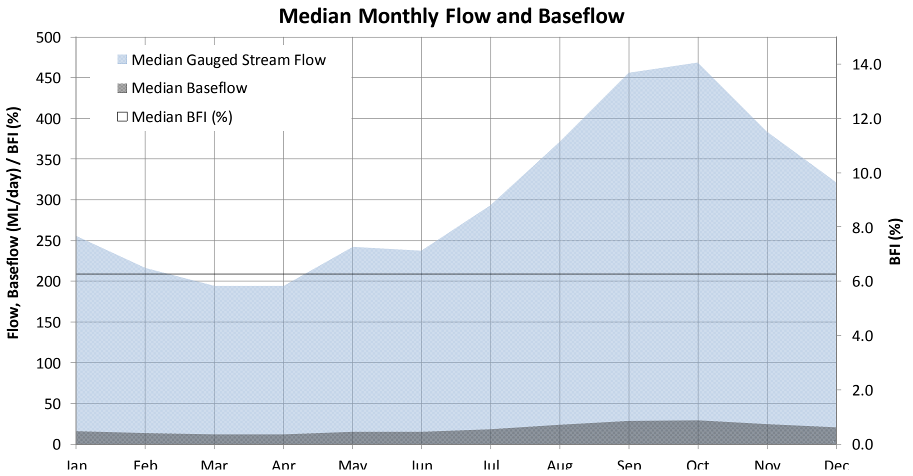
Baseflow indices are relatively constant since the construction of Blue Rock Reservoir in 1984, which highly regulates flow and EC concentration in the River

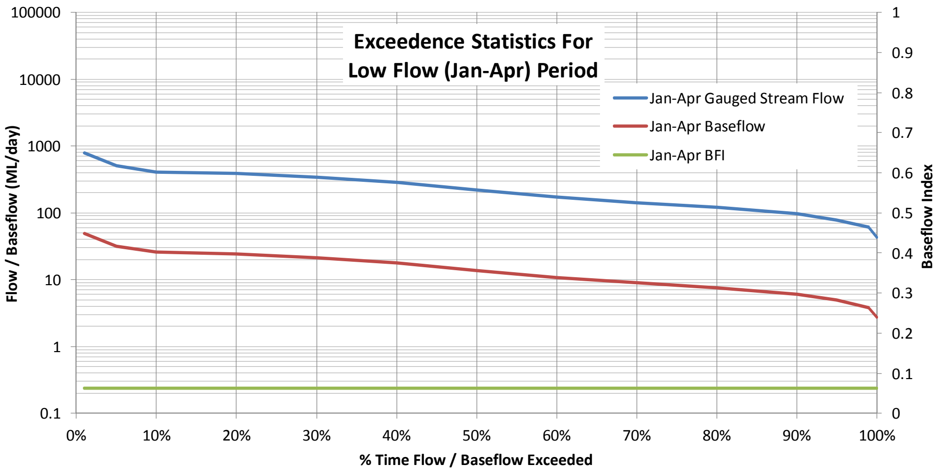


The baseflow discharge is relatively constant since the construction of Blue Rock Reservoir (1984), compared to more "natural" streamflow.



NOTE: BFI curve is BFI of the baseflow curve, not exceedence statistics of the BFI time series.





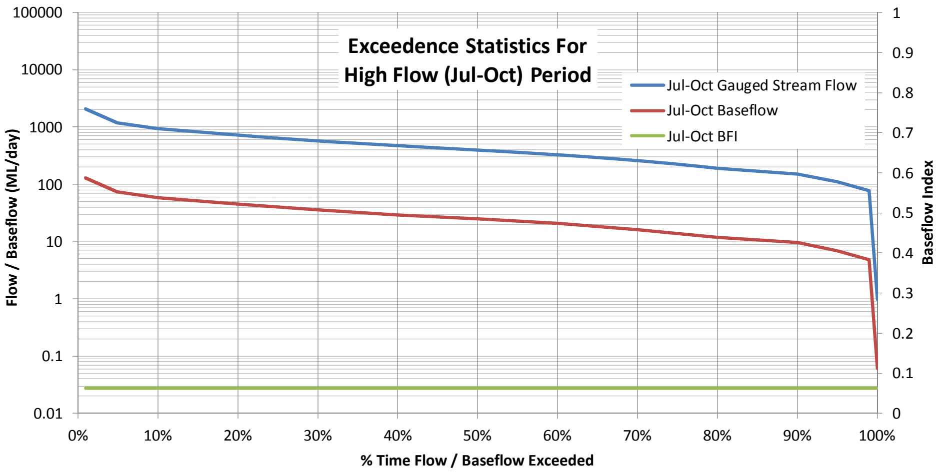
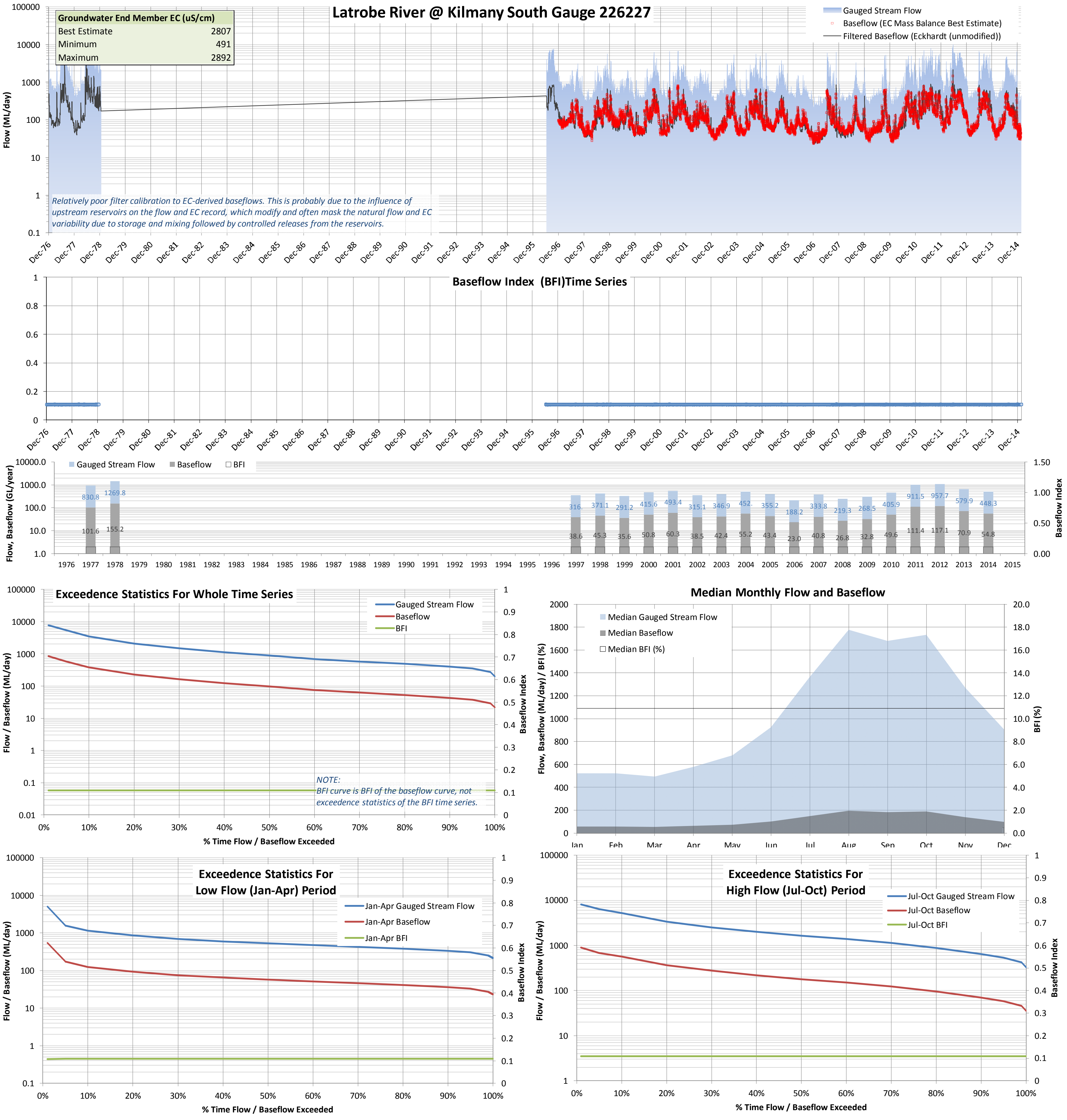


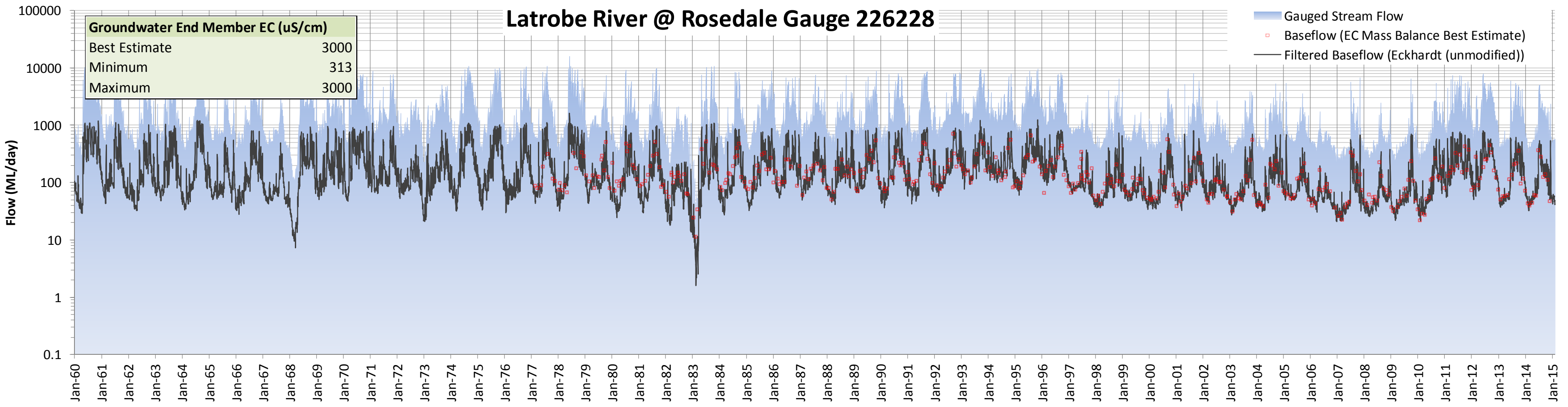
Figure C5Summary Baseflow Estimation for the Tanjil River at Tanjil South



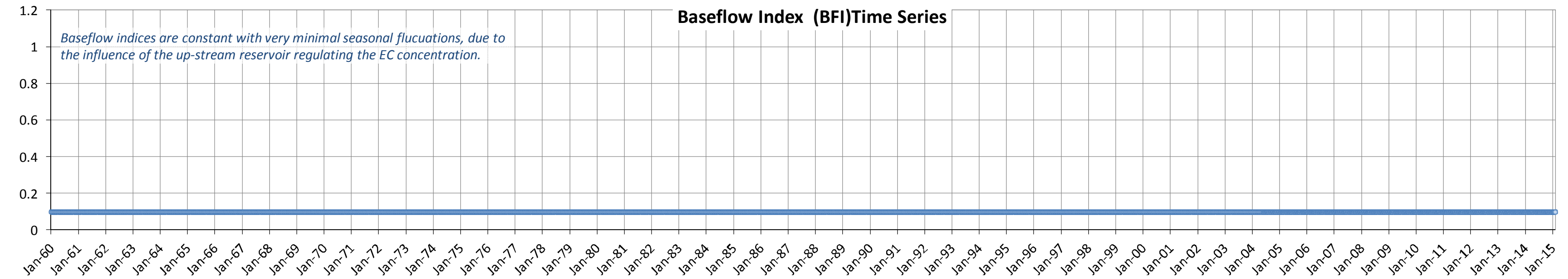
Relatively poor filter calibration to EC-derived baseflows. This is probably due to the influence of upstream reservoirs on the flow and EC record, which modify and often mask the natural flow and EC variability due to storage and mixing followed by controlled releases from the reservoirs.

NOTE: BFI curve is BFI of the baseflow curve, not exceedence statistics of the BFI time series.

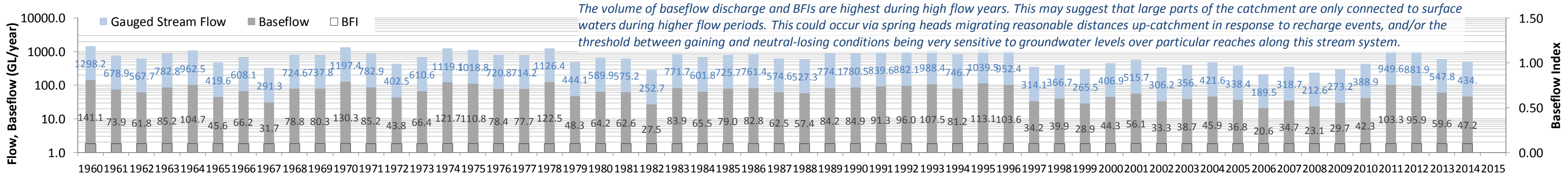
Figure C6Summary Baseflow Estimation for the Latrobe River at Kilmany South



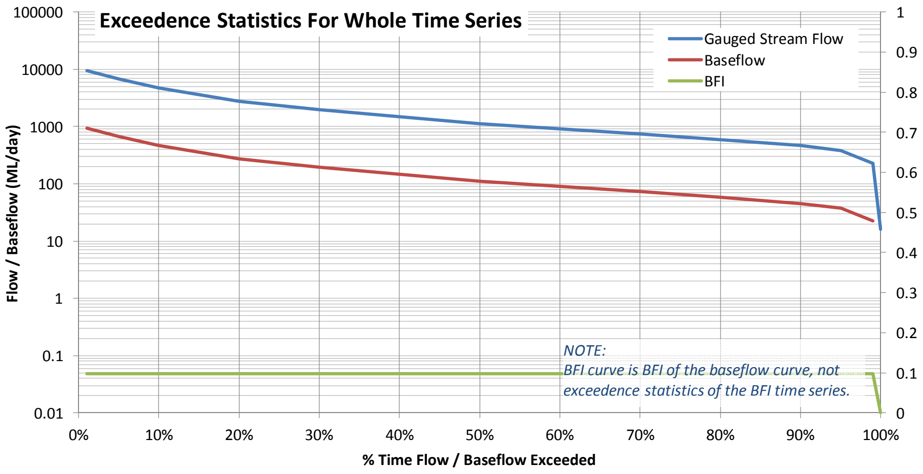
Groundwater End Member EC (uS/cm)	
Best Estimate	3000
Minimum	313
Maximum	3000



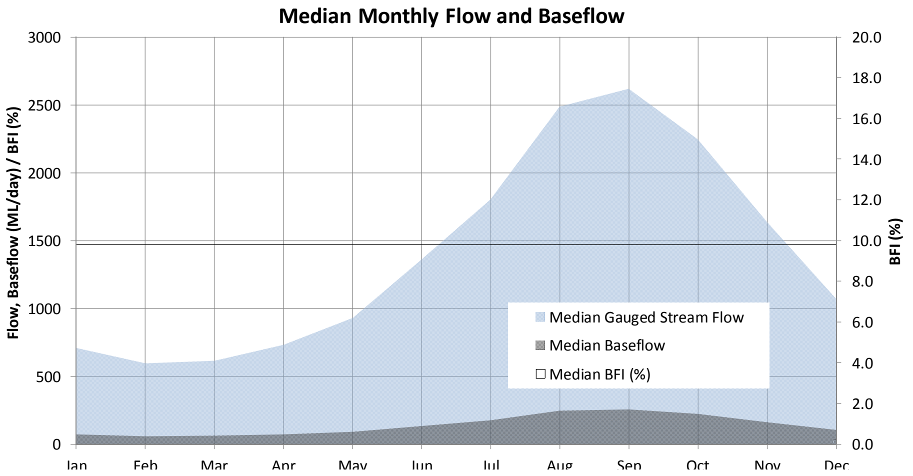
Baseflow indices are constant with very minimal seasonal flucuations, due to the influence of the up-stream reservoir regulating the EC concentration.

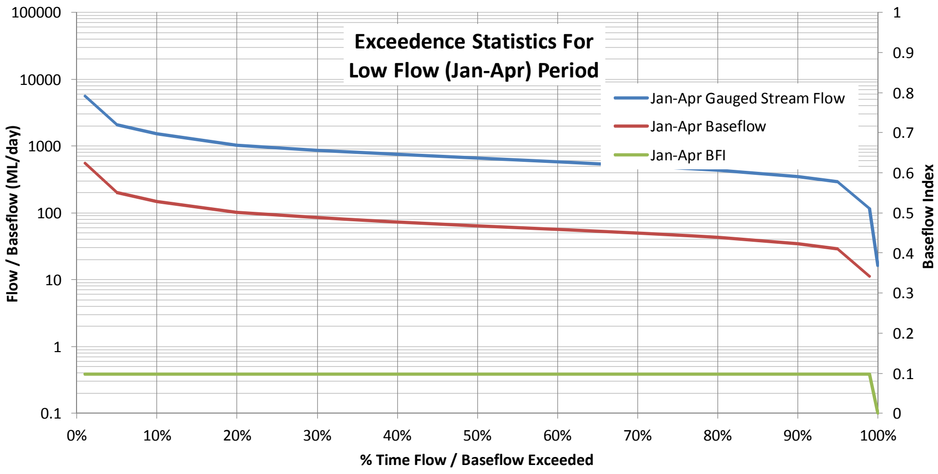


The volume of baseflow discharge and BFIs are highest during high flow years. This may suggest that large parts of the catchment are only connected to surface waters during higher flow periods. This could occur via spring heads migrating reasonable distances up-catchment in response to recharge events, and/or the threshold between gaining and neutral-losing conditions being very sensitive to groundwater levels over particular reaches along this stream system.



NOTE:
BFI curve is BFI of the baseflow curve, not exceedence statistics of the BFI time series.





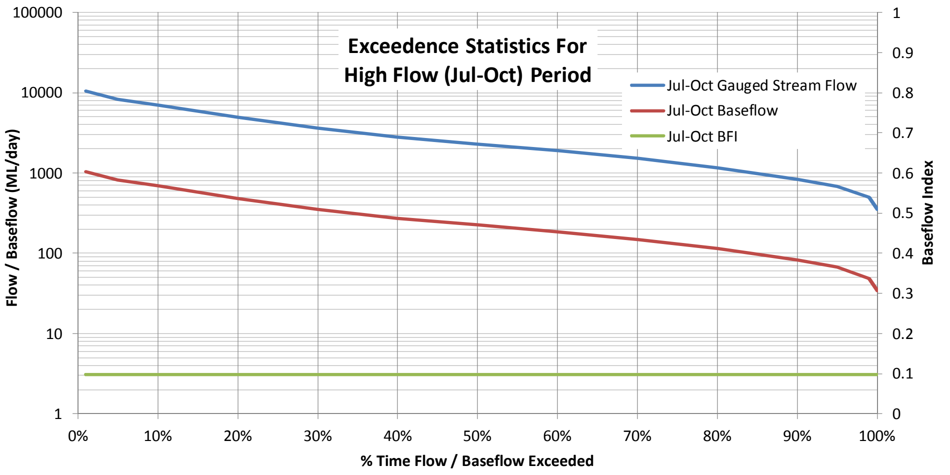


Figure C7Summary Baseflow Estimation for the Latrobe River at Rosedale

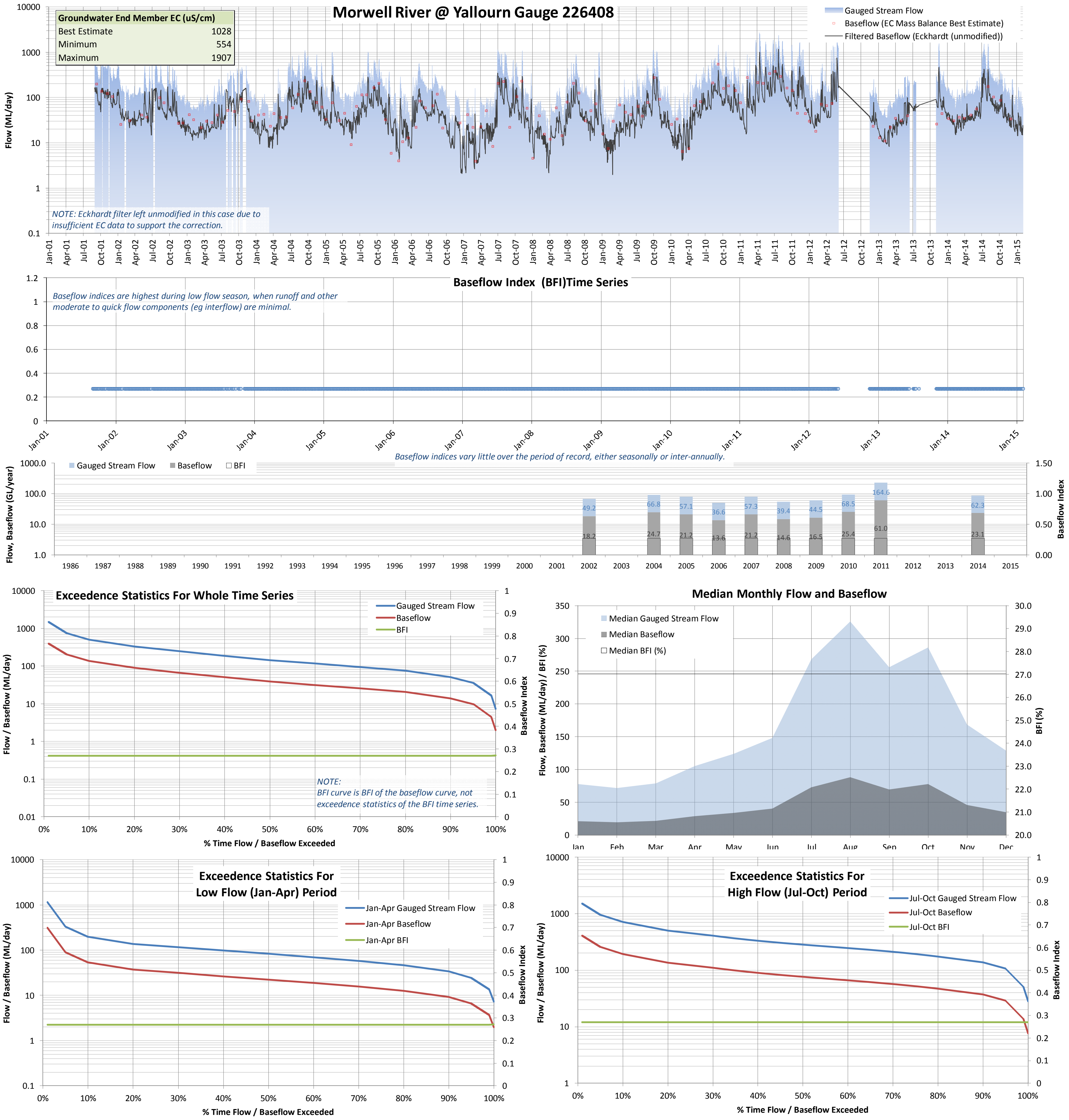
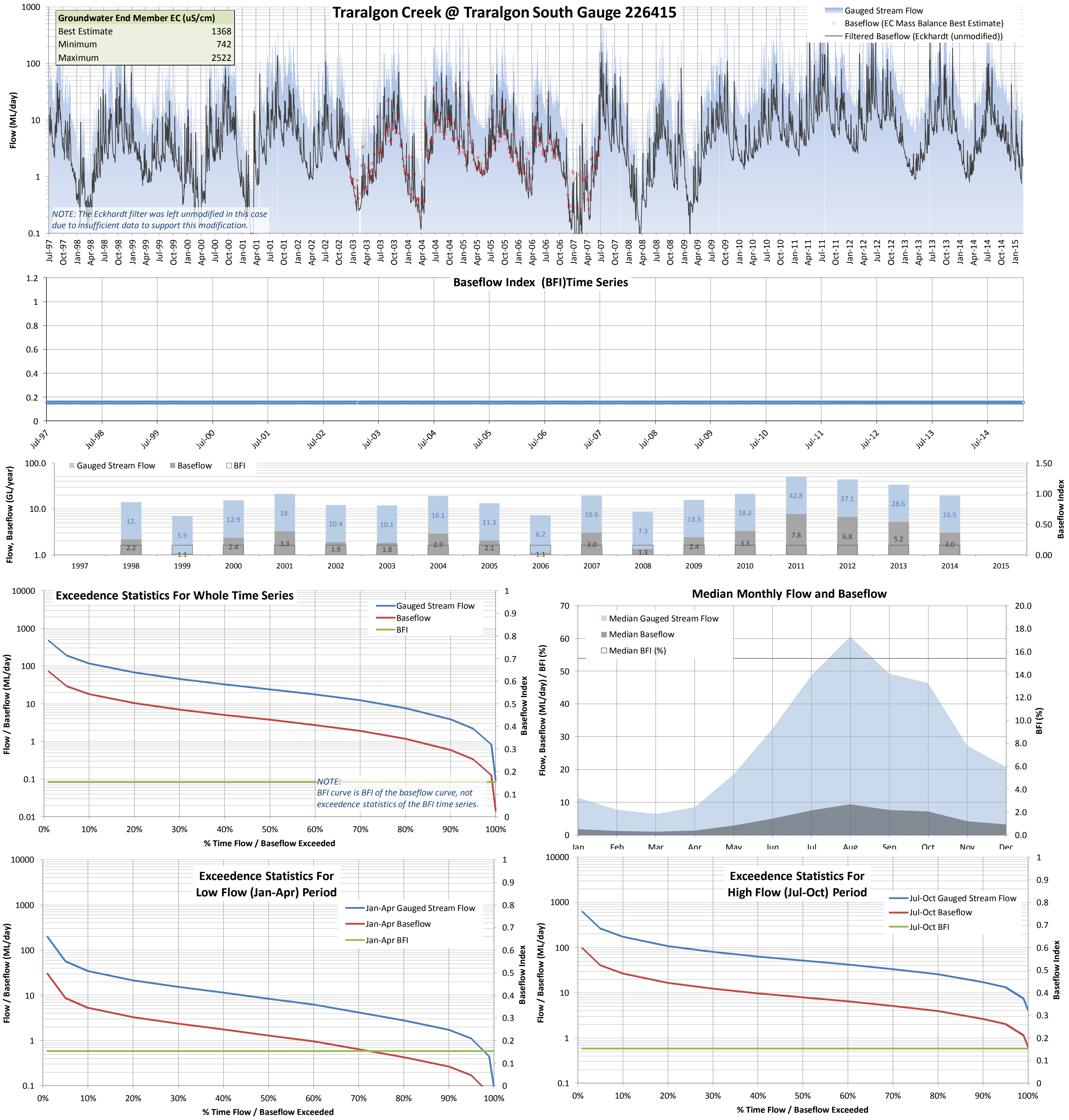


Figure C8Summary Baseflow Estimation for the Morwell River at Yallourn

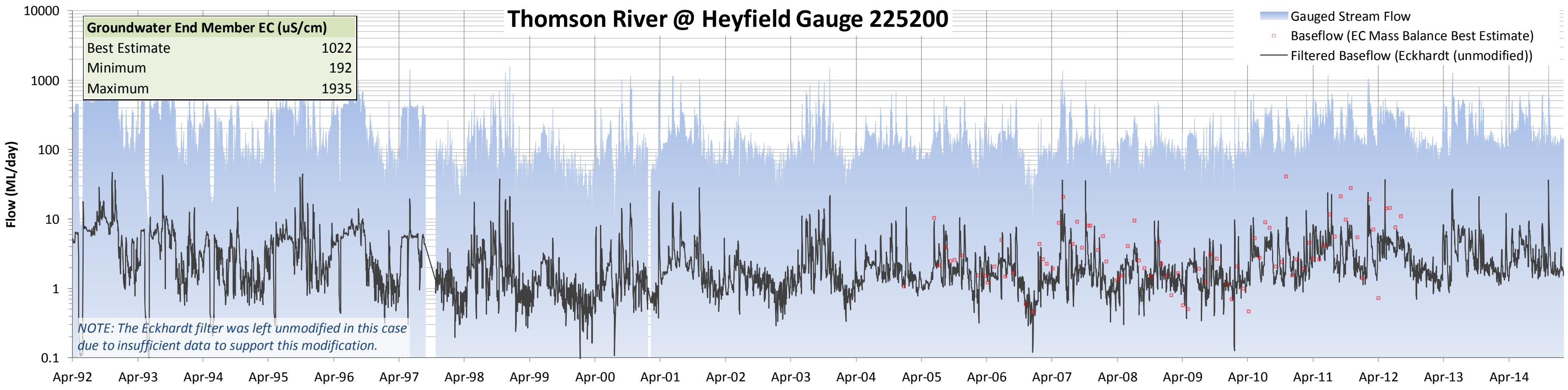


Groundwater End Member EC (uS/cm)	
Best Estimate	1368
Minimum	742
Maximum	2522

NOTE: The Eckhardt filter was left unmodified in this case due to insufficient data to support this modification.

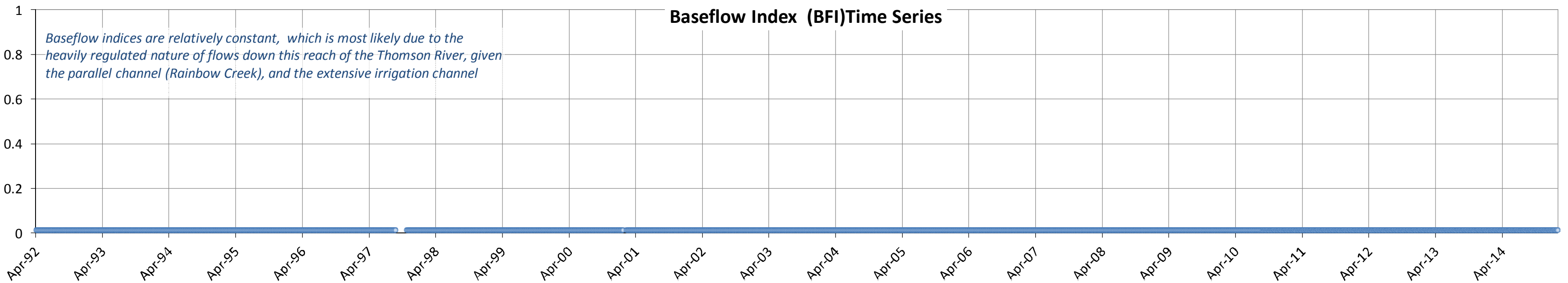
NOTE: BFI curve is BFI of the baseflow curve, not exceedence statistics of the BFI time series.

Figure C9Summary Baseflow Estimation for the Traralgon Creek at Traralgon South

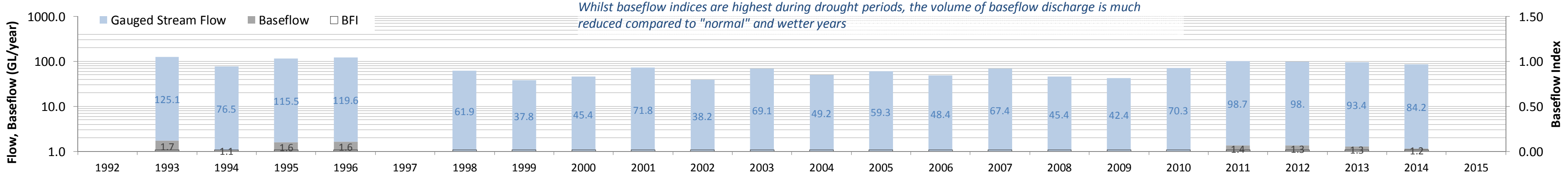


Groundwater End Member EC (uS/cm)	
Best Estimate	1022
Minimum	192
Maximum	1935

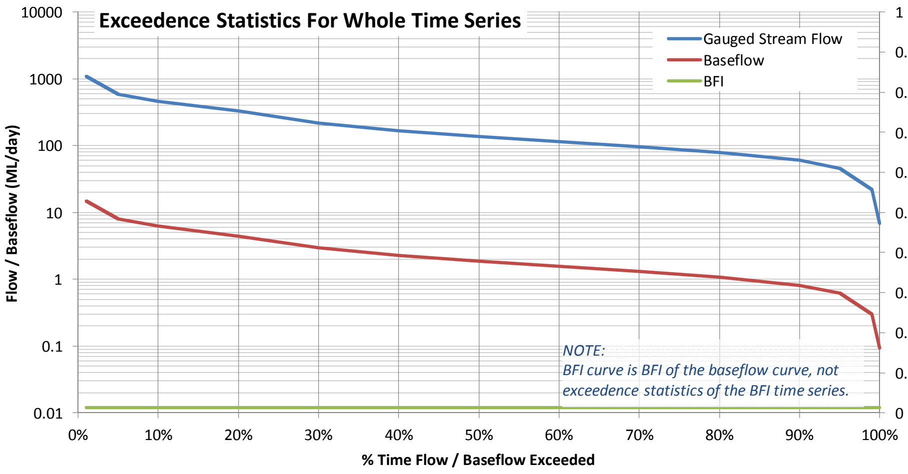
NOTE: The Eckhardt filter was left unmodified in this case due to insufficient data to support this modification.



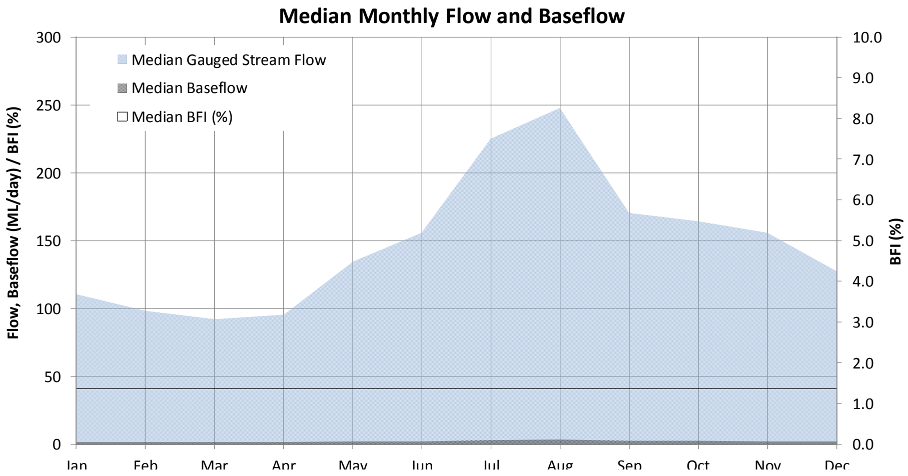
Baseflow indices are relatively constant, which is most likely due to the heavily regulated nature of flows down this reach of the Thomson River, given the parallel channel (Rainbow Creek), and the extensive irrigation channel

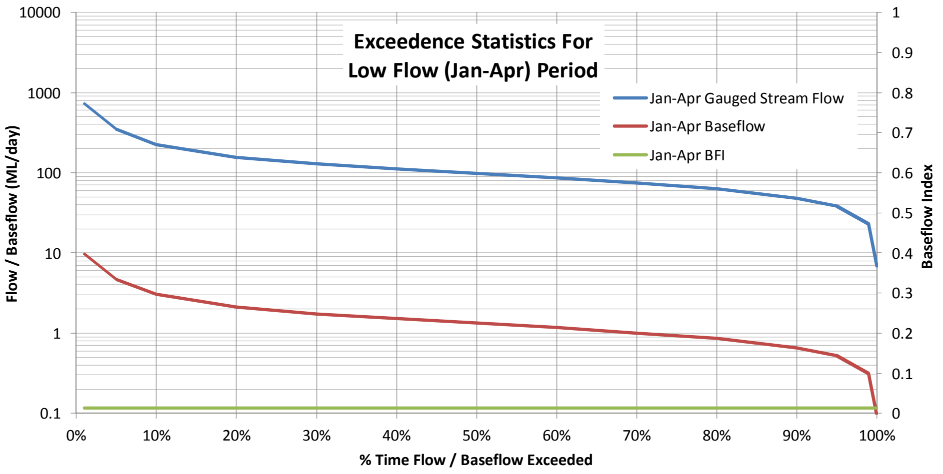


Whilst baseflow indices are highest during drought periods, the volume of baseflow discharge is much reduced compared to "normal" and wetter years



NOTE: BFI curve is BFI of the baseflow curve, not exceedence statistics of the BFI time series.





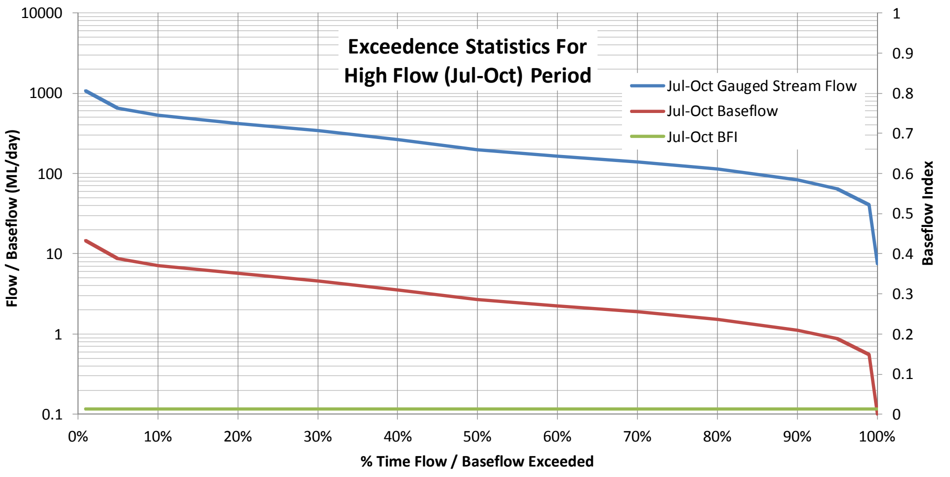
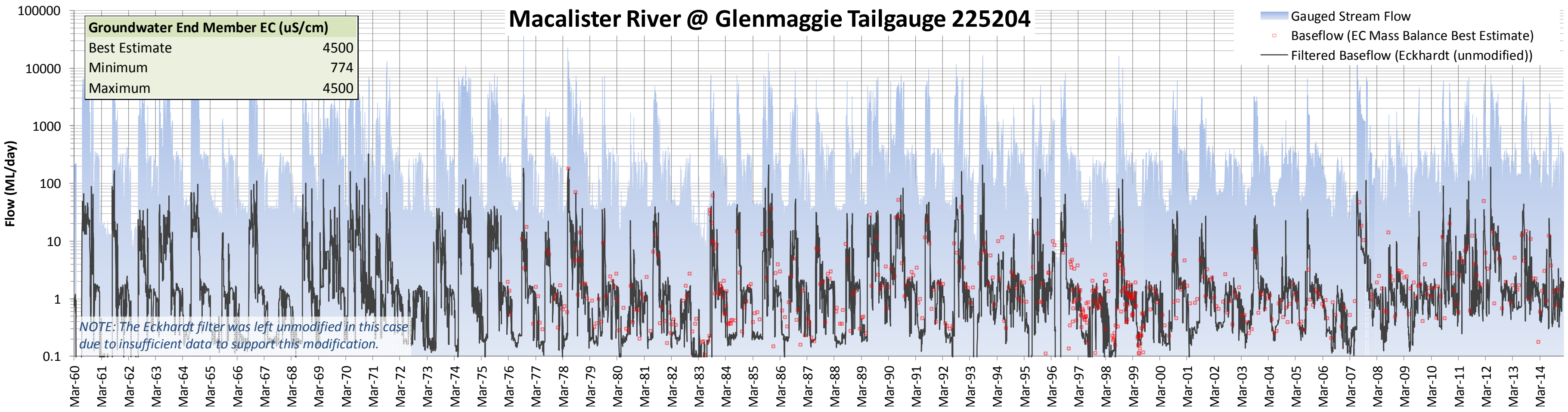
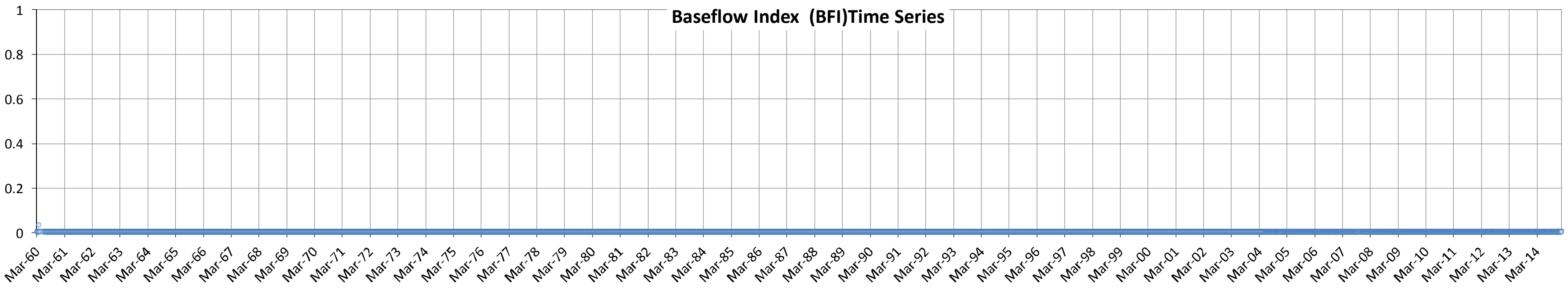
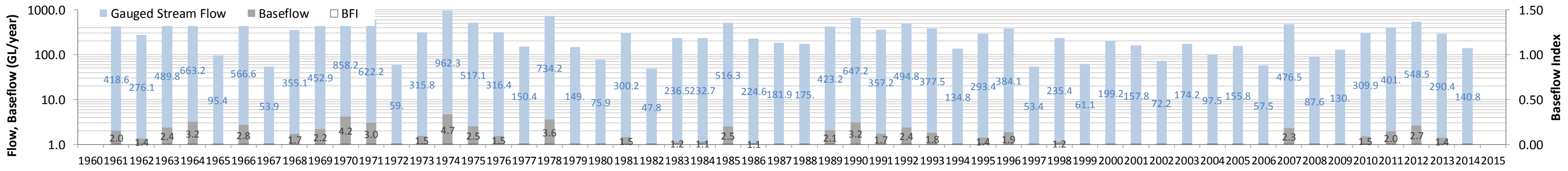
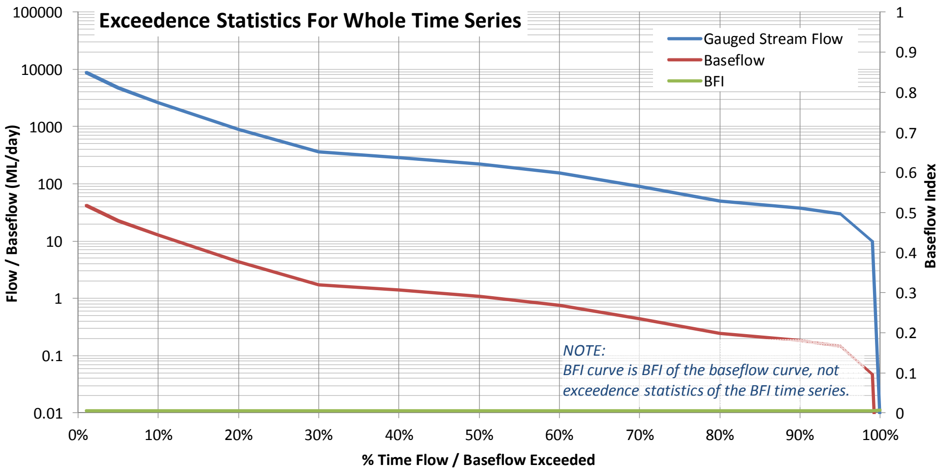


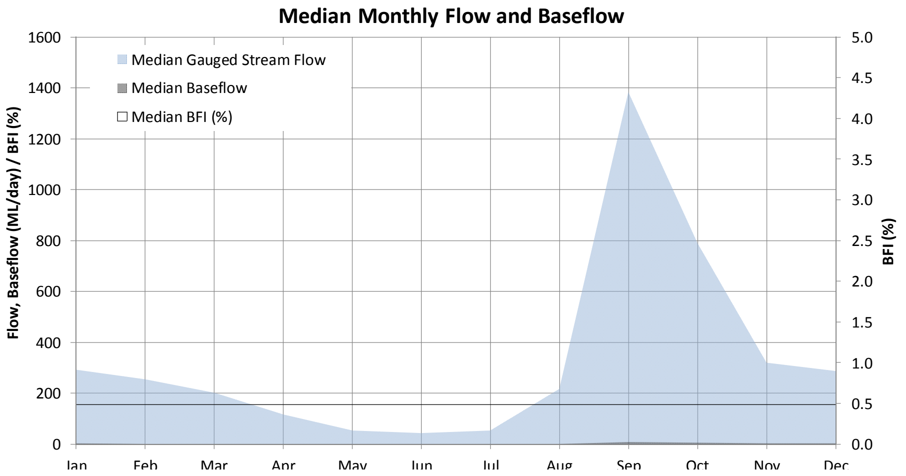
Figure C10Summary Baseflow Estimation for the Thomson River @ Heyfield

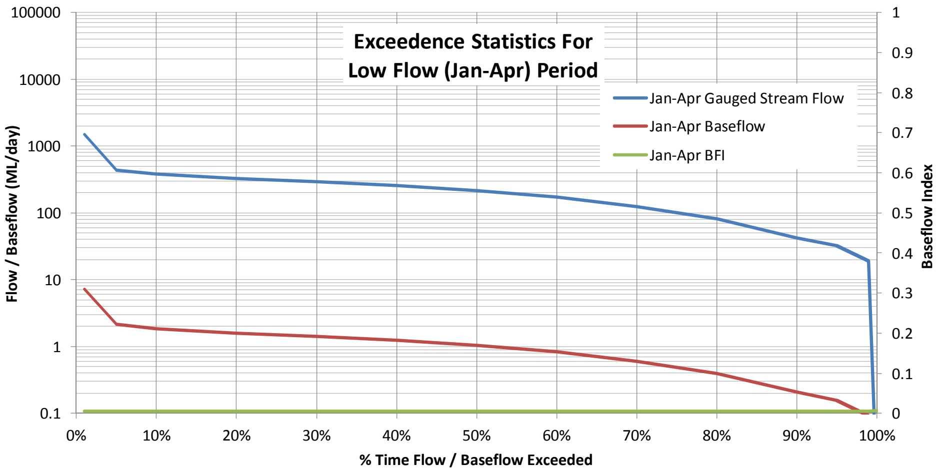












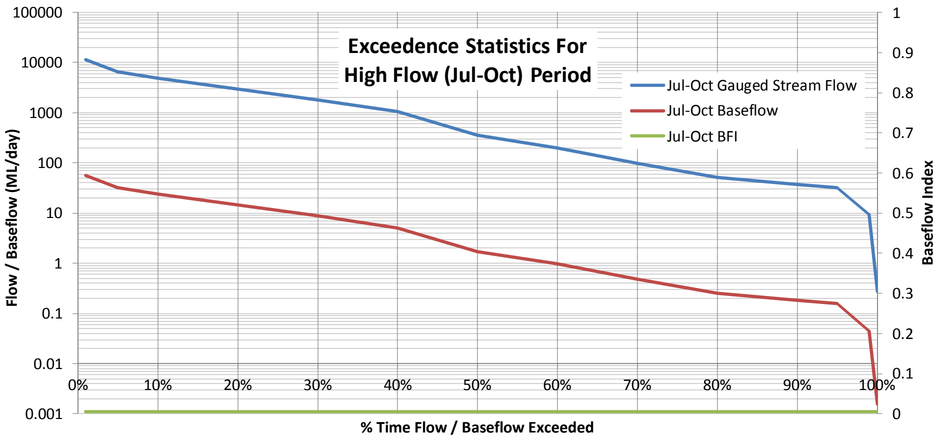
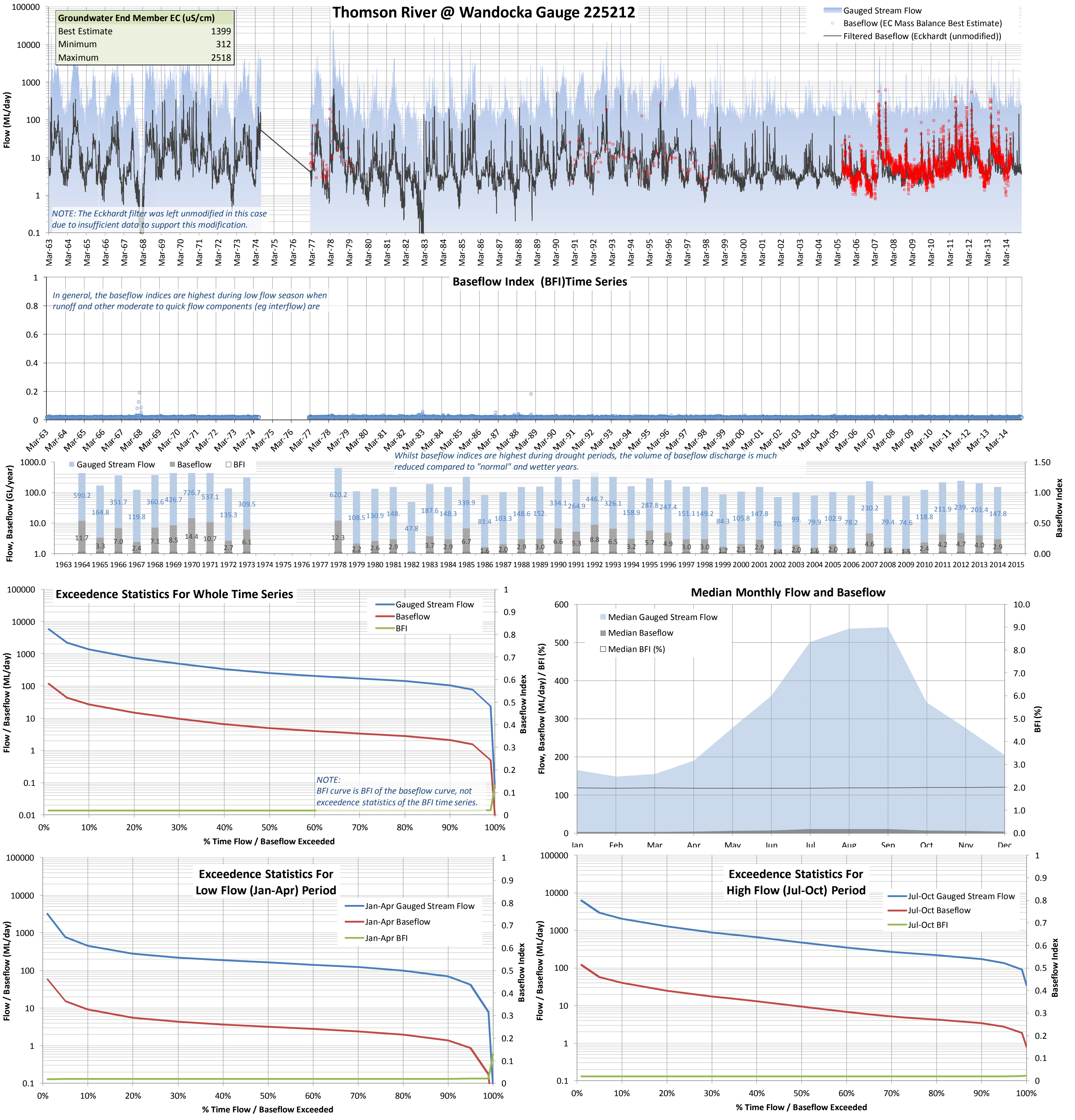


Figure C11Summary Baseflow Estimation for the Macalister River at Glenmaggie



Groundwater End Member EC (uS/cm)	
Best Estimate	1399
Minimum	312
Maximum	2518

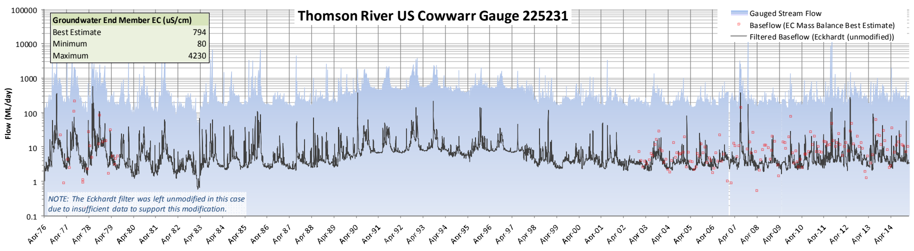
NOTE: The Eckhardt filter was left unmodified in this case due to insufficient data to support this modification.

In general, the baseflow indices are highest during low flow season when runoff and other moderate to quick flow components (eg interflow) are

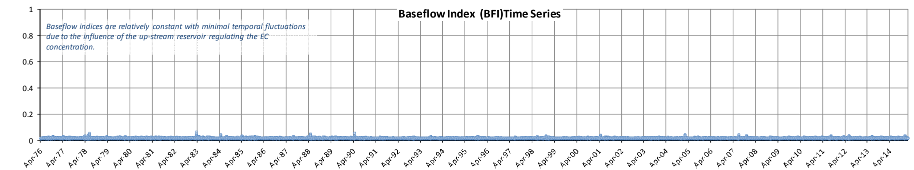
Whilst baseflow indices are highest during drought periods, the volume of baseflow discharge is much reduced compared to "normal" and wetter years.

NOTE:
BFI curve is BFI of the baseflow curve, not exceedence statistics of the BFI time series.

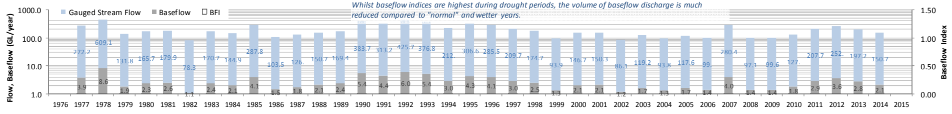
Figure C12Summary Baseflow Estimation for the Thomson River @ Wandocka



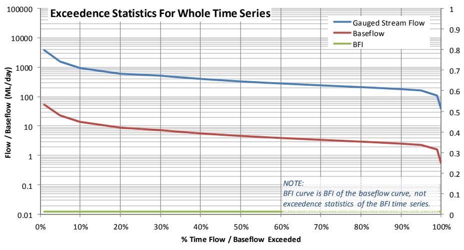
NOTE: The Eckhardt filter was left unmodified in this case due to insufficient data to support this modification.



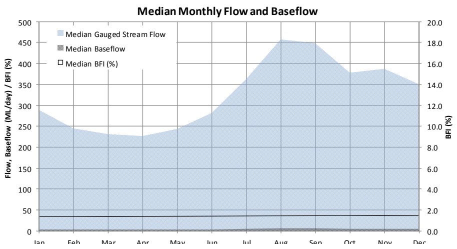
Baseflow indices are relatively constant with minimal temporal fluctuations due to the influence of the up-stream reservoir regulating the EC concentration.

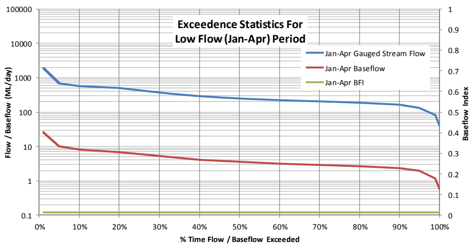


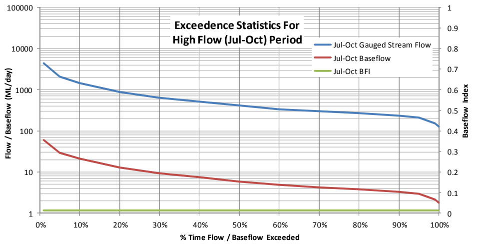
Whilst baseflow indices are highest during drought periods, the volume of baseflow discharge is much reduced compared to "normal" and wetter years.



NOTE:
BFI curve is BFI of the baseflow curve, not exceedence statistics of the BFI time series.







Blue Rock Lake construction completed in 1984.

Baseflow filter is poorly calibrated to the EC mass balance-derived baseflows in the 1990s in particular, probably as a result of the regulated flow and EC regime in the Latrobe River controlled by releases from Blue Rock Reservoir.

Baseflow indices are constant with very minimal seasonal flucuations, due to the influence of the up-stream reservoir regulating the EC concentration.

Percentile	Gauged St	Baseflow	BFI	Jan-Apr G	Jul-Oct Ga	Jan-Apr Ba	Jul-Oct Ba	Jan-Apr BI	Jul-Oct BF	BFI2	Jan-Apr BI	Jul-Oct BFI2
0.01	3848.619	54.51098	0.023763	1914.009	4399.884	25.6494	59.91019	0.023885	0.022925	0.014164	0.013401	0.013616
0.05	1566.787	22.70943	0.018005	688.1524	2081.674	9.954917	29.76733	0.017076	0.018255	0.014494	0.014466	0.0143
0.1	945.4165	13.98673	0.016472	573.1748	1450.636	8.145319	21.2708	0.015864	0.016666	0.014794	0.014211	0.014663
0.2	600.4276	8.651015	0.015331	490.5402	865.5012	6.903516	12.82502	0.015031	0.015476	0.014408	0.014073	0.014818
0.3	503.7502	7.194661	0.014807	374.909	638.304	5.325455	9.322995	0.014603	0.014956	0.014282	0.014205	0.014606
0.4	397.0196	5.732015	0.014466	291.9274	515.048	4.154521	7.523013	0.014316	0.014611	0.014438	0.014231	0.014606
0.5	319.4815	4.598598	0.014217	248.438	414.702	3.545977	5.948365	0.014132	0.014341	0.014394	0.014273	0.014344
0.6	274.637	3.931744	0.014048	222.7864	339.2288	3.178365	4.900476	0.014016	0.014105	0.014316	0.014266	0.014446
0.7	242.7439	3.445167	0.013878	201.3146	296.5904	2.873716	4.272488	0.013872	0.013867	0.014193	0.014275	0.014405
0.8	210.1416	3.002995	0.013518	185.1548	266.6326	2.648474	3.807667	0.013585	0.013415	0.01429	0.014304	0.014281
0.9	176.5876	2.52825	0.012648	162.1462	236.2802	2.340518	3.333473	0.012906	0.012423	0.014317	0.014435	0.014108
0.95	158.6601	2.271281	0.0116	134.1978	206.7448	1.941358	2.916845	0.012061	0.011325	0.014315	0.014466	0.014108
0.99	110.2832	1.589937	0.008607	83.75864	152.56	1.185866	2.172525	0.00927	0.008577	0.014417	0.014158	0.01424
1	39.071	0.572858	0.006348	39.071	127.697	0.572858	1.819056	0.006348	0.006598	0.014662	0.014662	0.014245

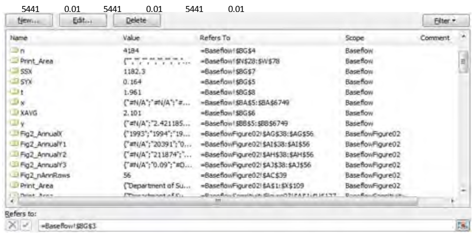
1	4
7	10
5	6
11	12

mmm	Month	Median G	Median B	Median BFI (%)
Jan	1	288.7	4.1	1.42
Feb	2	244.7	3.4	1.41
Mar	3	230.9	3.3	1.41
Apr	4	226.2	3.2	1.41
May	5	244.1	3.4	1.41
Jun	6	281.5	4.0	1.41
Jul	7	362.7	5.4	1.43
Aug	8	458.1	6.5	1.42
Sep	9	448.3	6.5	1.44
Oct	10	378.5	5.5	1.44
Nov	11	387.6	5.6	1.43
Dec	12	351.0	5.1	1.44

MaxYear
2015
Fig2_nAnnRows
77
MaxFlow
609050.5
MaxLyneHollickErrScale

MinLyneHollickErrScale

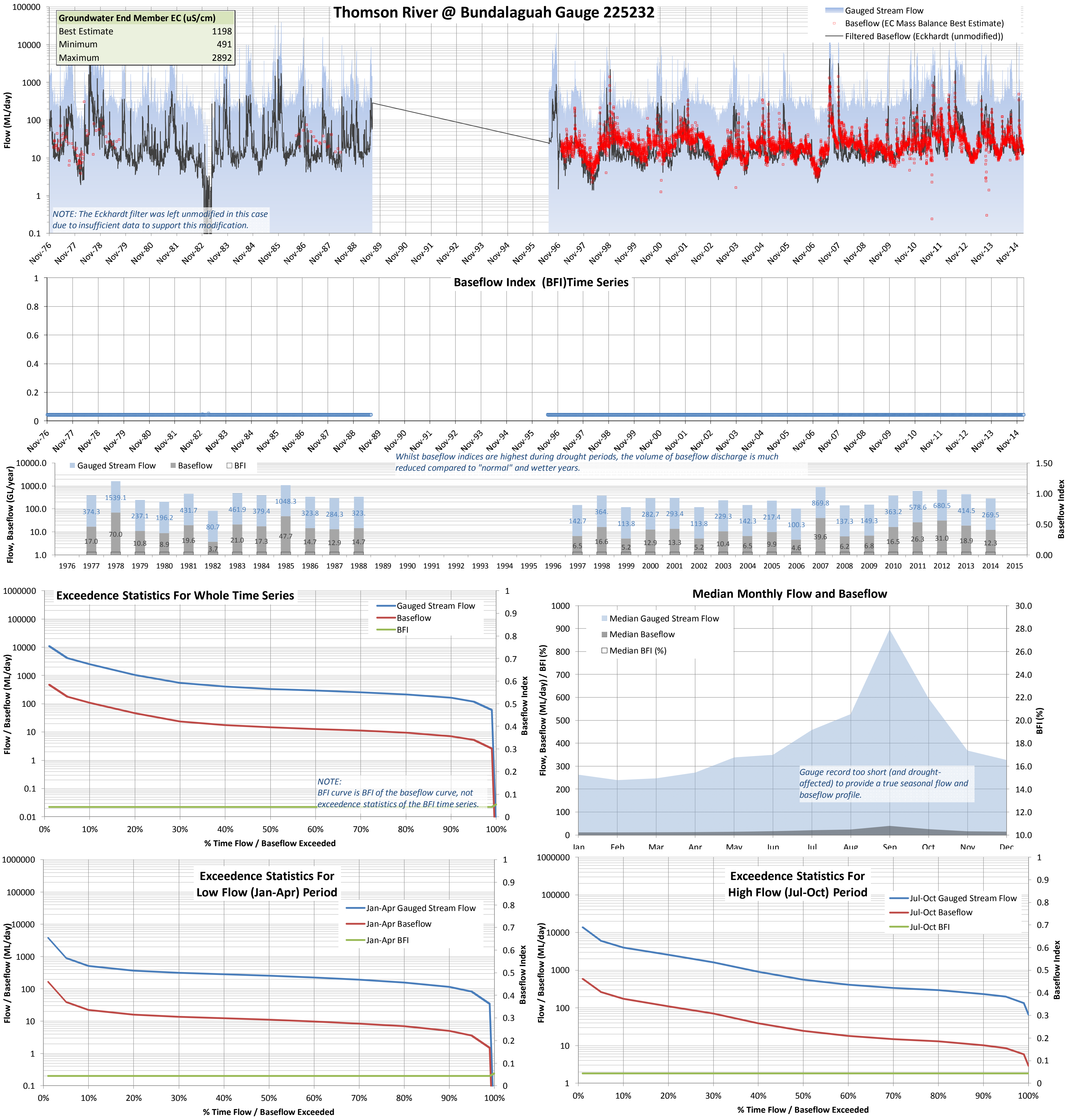
	YEAR	Gauged St	Baseflow	BFI	Baseflow	BFI (Min)	Baseflow	BFI (Max)
274	1976	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
365	1977	272223	3866	0.01	3866	0.01	3866	0.01
365	1978	609051	8635	0.01	8635	0.01	8635	0.01
365	1979	131848	1880	0.01	1880	0.01	1880	0.01
366	1980	165683	2342	0.01	2342	0.01	2342	0.01
365	1981	179925	2561	0.01	2561	0.01	2561	0.01
365	1982	78293	1113	0.01	1113	0.01	1113	0.01
365	1983	170690	2419	0.01	2419	0.01	2419	0.01
366	1984	144950	2057	0.01	2057	0.01	2057	0.01
365	1985	287772	4082	0.01	4082	0.01	4082	0.01
365	1986	103514	1472	0.01	1472	0.01	1472	0.01
365	1987	125957	1787	0.01	1787	0.01	1787	0.01
366	1988	150668	2137	0.01	2137	0.01	2137	0.01
365	1989	169411	2404	0.01	2404	0.01	2404	0.01
365	1990	383717	5441	0.01	5441	0.01	5441	0.01
365	1991	313245						
366	1992	425742						
365	1993	376819						
365	1994	211968						
365	1995	306581						
366	1996	285461						
365	1997	209737						
365	1998	174739						
365	1999	93892						
366	2000	146707						
365	2001	150310						
365	2002	86062						
365	2003	119155						
366	2004	93761						
365	2005	117600						
347	2006	99045						
357	2007	280375						
366	2008	97149						
358	2009	99624	1411	0.01	1411	0.01	1411	0.01
365	2010	126957	1801	0.01	1801	0.01	1801	0.01
365	2011	207709	2947	0.01	2947	0.01	2947	0.01
366	2012	251951	3574	0.01	3574	0.01	3574	0.01
365	2013	197199	2798	0.01	2798	0.01	2798	0.01
365	2014	150685	2139	0.01	2139	0.01	2139	0.01
28	2015	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A



Name	Value	Refers To	Scope	Comment
n	4184	=Baseflow!$BG$4	Baseflow	
Print_Area	{"","","","","","","",...	=Baseflow!$N$28:$W$78	Baseflow	
SSX	1182.3	=Baseflow!$BG$7	Baseflow	
SYX	0.164	=Baseflow!$BG$5	Baseflow	
t	1.961	=Baseflow!$BG$8	Baseflow	
x	{"#N/A";"#N/A";"#...	=Baseflow!$BA$5:$BA$6749	Baseflow	
XAVG	2.101	=Baseflow!$BG$6	Baseflow	
y	{"#N/A";"2.421185...	=Baseflow!$BB$5:$BB$6749	Baseflow	
Fig2_AnnualX	{"1993";"1994";"19...	=BaseflowFigure02!$AG$38:$AG$56	BaseflowFigure02	
Fig2_AnnualY1	{"#N/A";"20391";"0...	=BaseflowFigure02!$AI$38:$AI$56	BaseflowFigure02	
Fig2_AnnualY2	{"#N/A";"211874";"...	=BaseflowFigure02!$AH$38:$AH$56	BaseflowFigure02	
Fig2_AnnualY3	{"#N/A";"0.09";"#D...	=BaseflowFigure02!$AJ$38:$AJ$56	BaseflowFigure02	
Fig2_nAnnRows	56	=BaseflowFigure02!$AC$39	BaseflowFigure02	
Print_Area	{"Department of Su...	=BaseflowFigure02!$A$1:$X$109	BaseflowFigure02	

Refers to:
=Baseflow!$BG$3

Figure C13Summary Baseflow Estimation for the Thomson River U/S Cowwarr Weir



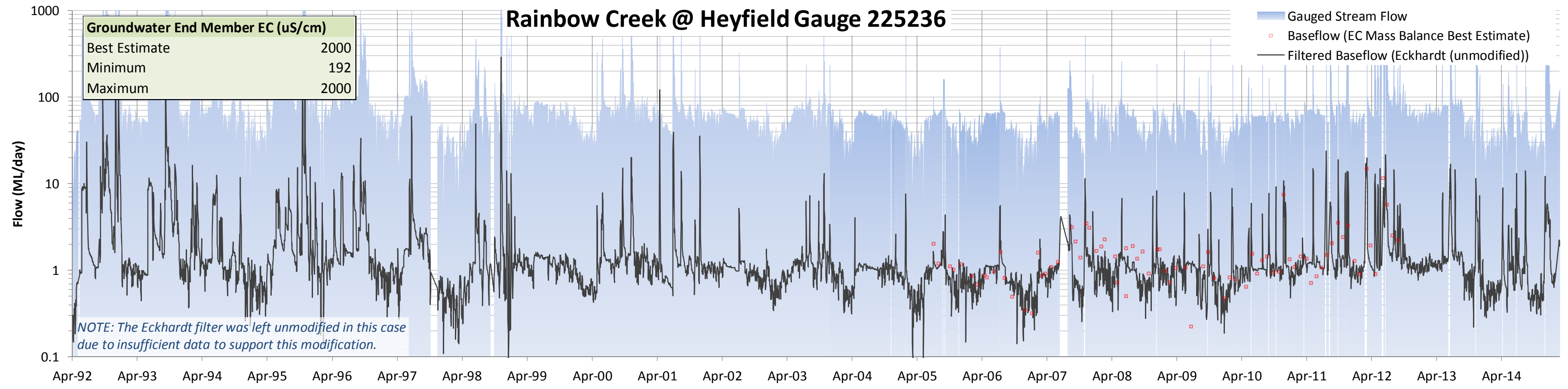
NOTE: The Eckhardt filter was left unmodified in this case due to insufficient data to support this modification.

Whilst baseflow indices are highest during drought periods, the volume of baseflow discharge is much reduced compared to "normal" and wetter years.

NOTE: BFI curve is BFI of the baseflow curve, not exceedence statistics of the BFI time series.

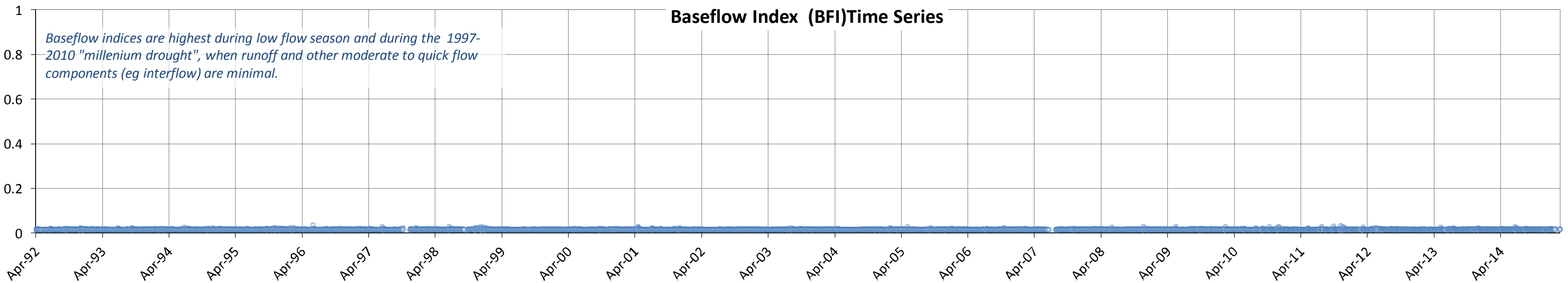
Gauge record too short (and drought-affected) to provide a true seasonal flow and baseflow profile.

Figure C14Summary Baseflow Estimation for the Thomson River at Bundalaguah

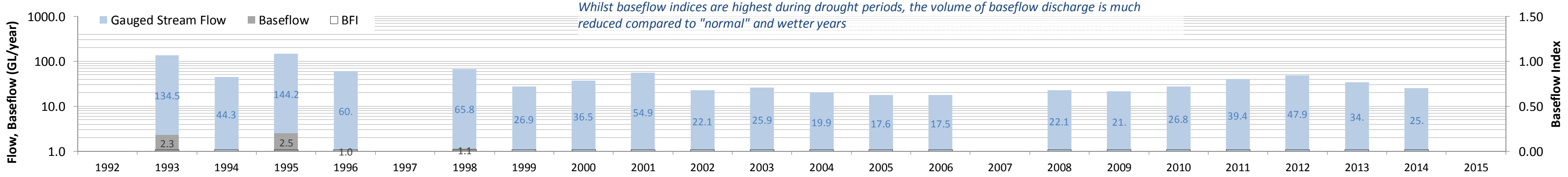


Groundwater End Member EC (uS/cm)	
Best Estimate	2000
Minimum	192
Maximum	2000

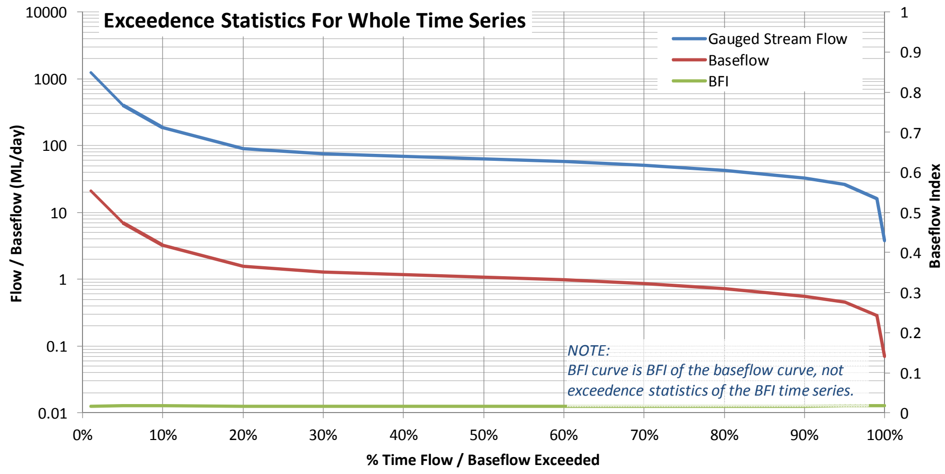
NOTE: The Eckhardt filter was left unmodified in this case due to insufficient data to support this modification.



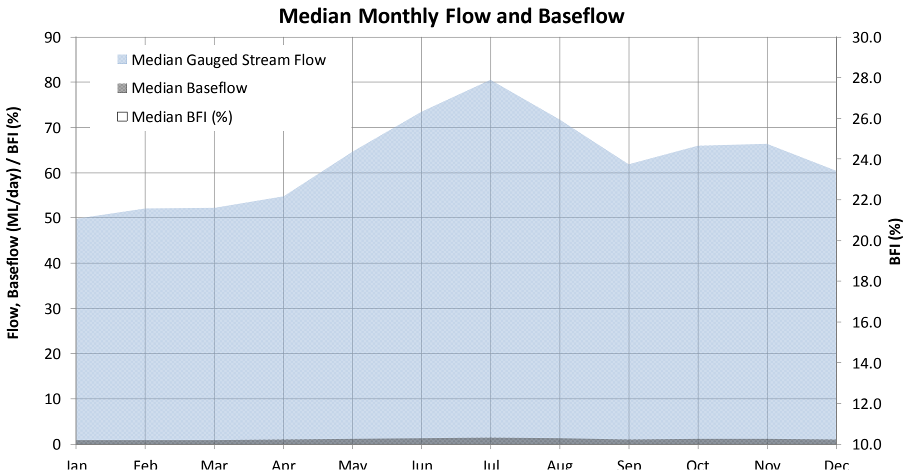
Baseflow indices are highest during low flow season and during the 1997-2010 "millenium drought", when runoff and other moderate to quick flow components (eg interflow) are minimal.

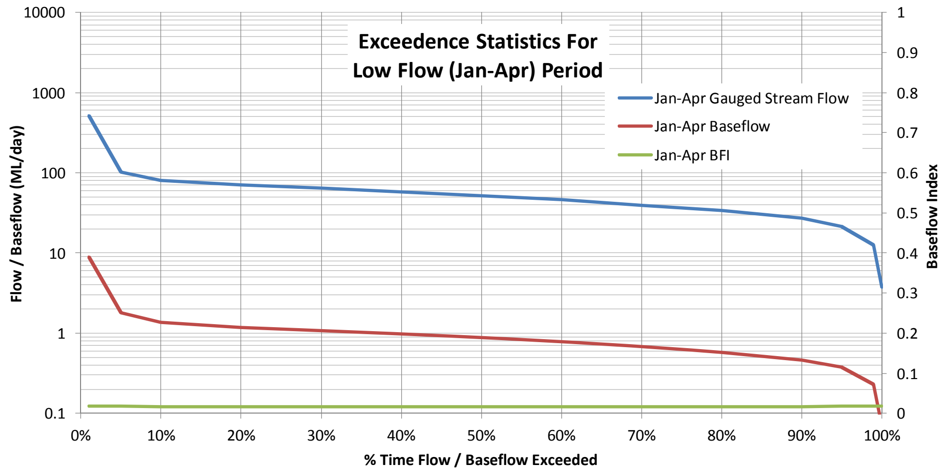


Whilst baseflow indices are highest during drought periods, the volume of baseflow discharge is much reduced compared to "normal" and wetter years



NOTE:
BFI curve is BFI of the baseflow curve, not exceedence statistics of the BFI time series.





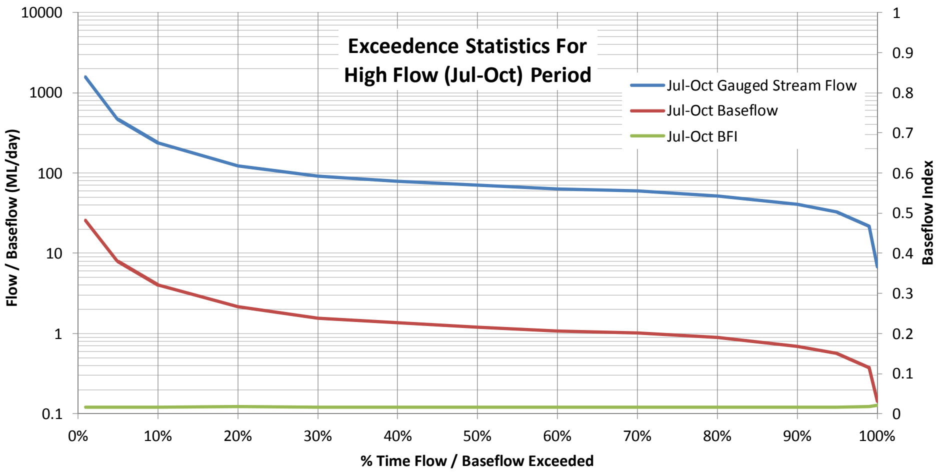
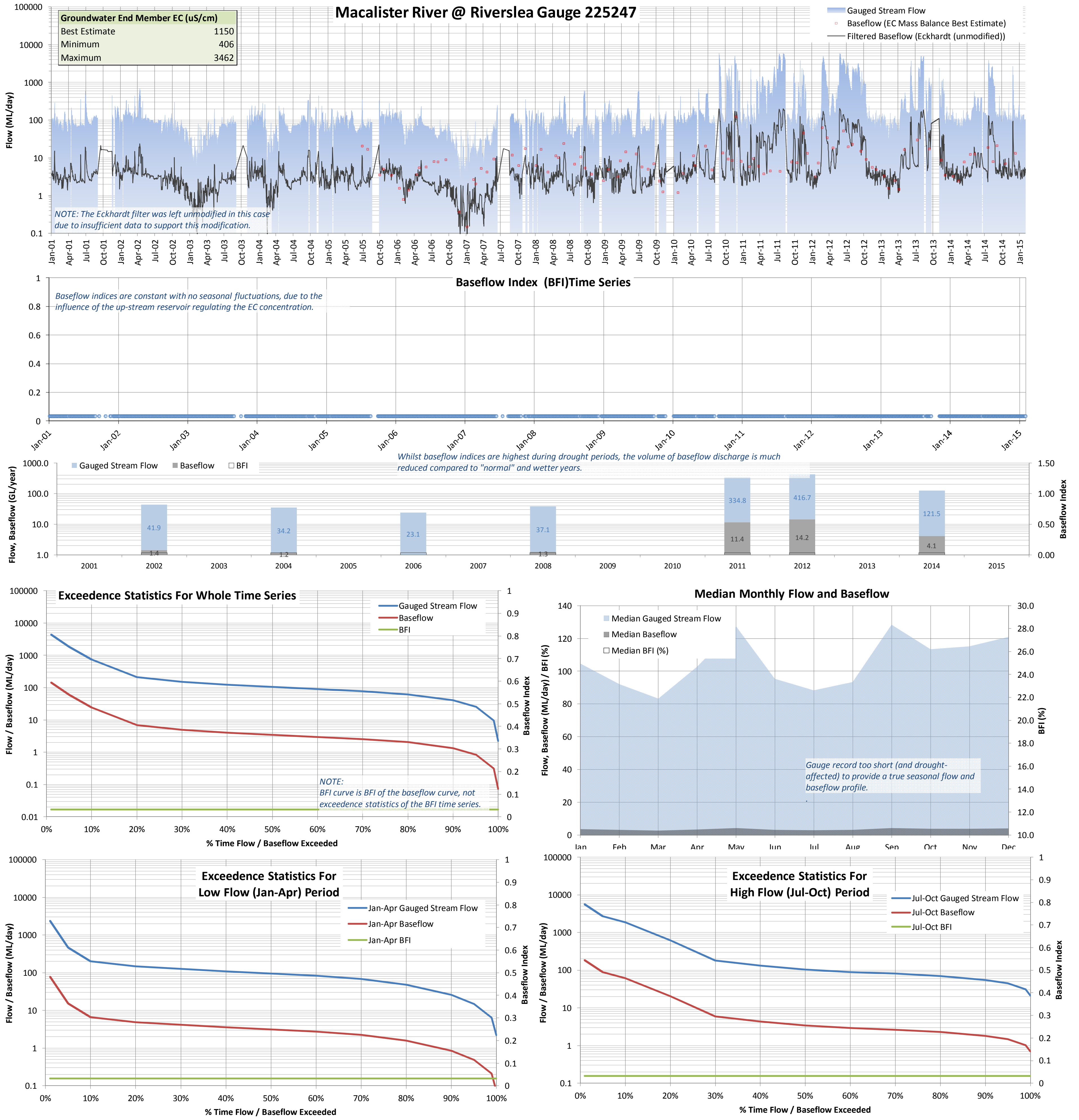


Figure C15Summary Baseflow Estimation for the Rainbow Creek @ Heyfield



Groundwater End Member EC (uS/cm)	
Best Estimate	1150
Minimum	406
Maximum	3462

NOTE: The Eckhardt filter was left unmodified in this case due to insufficient data to support this modification.

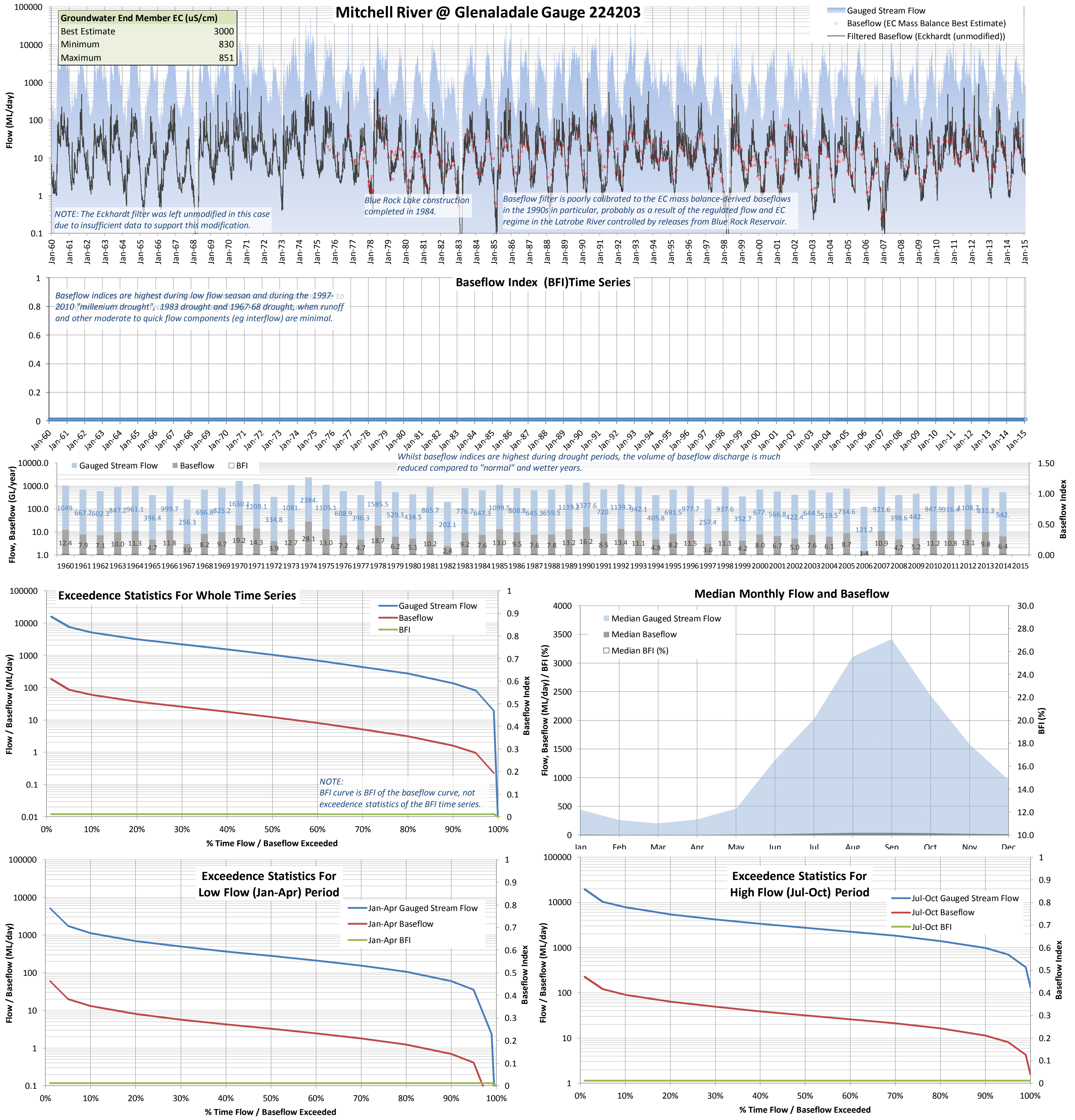
Baseflow indices are constant with no seasonal fluctuations, due to the influence of the up-stream reservoir regulating the EC concentration.

Whilst baseflow indices are highest during drought periods, the volume of baseflow discharge is much reduced compared to "normal" and wetter years.

NOTE: BFI curve is BFI of the baseflow curve, not exceedence statistics of the BFI time series.

Gauge record too short (and drought-affected) to provide a true seasonal flow and baseflow profile.

Figure C16Summary Baseflow Estimation for the Macalister River at Riversleigh



NOTE: The Eckhardt filter was left unmodified in this case due to insufficient data to support this modification.

Blue Rock Lake construction completed in 1984.

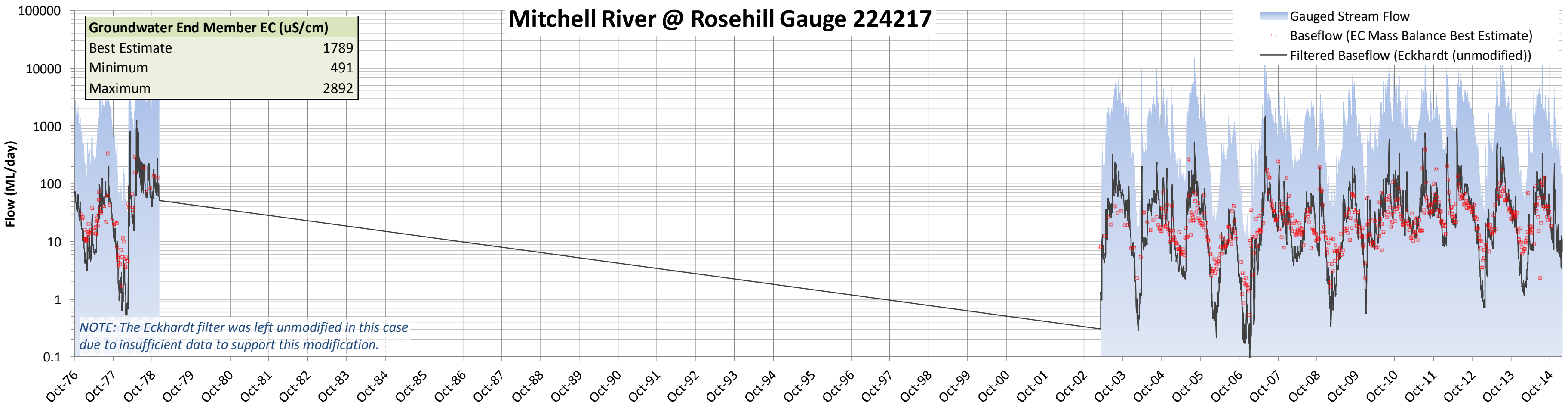
Baseflow filter is poorly calibrated to the EC mass balance-derived baseflows in the 1990s in particular, probably as a result of the regulated flow and EC regime in the Latrobe River controlled by releases from Blue Rock Reservoir.

Baseflow indices are highest during low flow season and during the 1997-2010 "millenium drought", 1983 drought and 1967-68 drought, when runoff and other moderate to quick flow components (eg interflow) are minimal.

Whilst baseflow indices are highest during drought periods, the volume of baseflow discharge is much reduced compared to "normal" and wetter years.

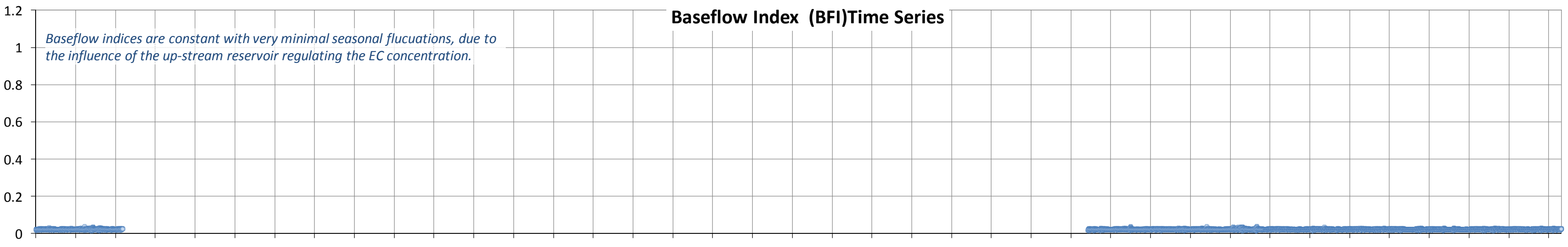
NOTE:
BFI curve is BFI of the baseflow curve, not exceedence statistics of the BFI time series.

Figure C17 Summary Baseflow Estimation for the Mitchell River @ Glenaladale

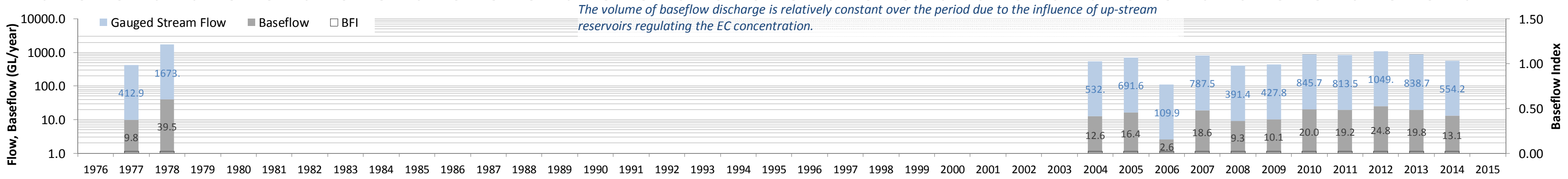


Groundwater End Member EC (uS/cm)	
Best Estimate	1789
Minimum	491
Maximum	2892

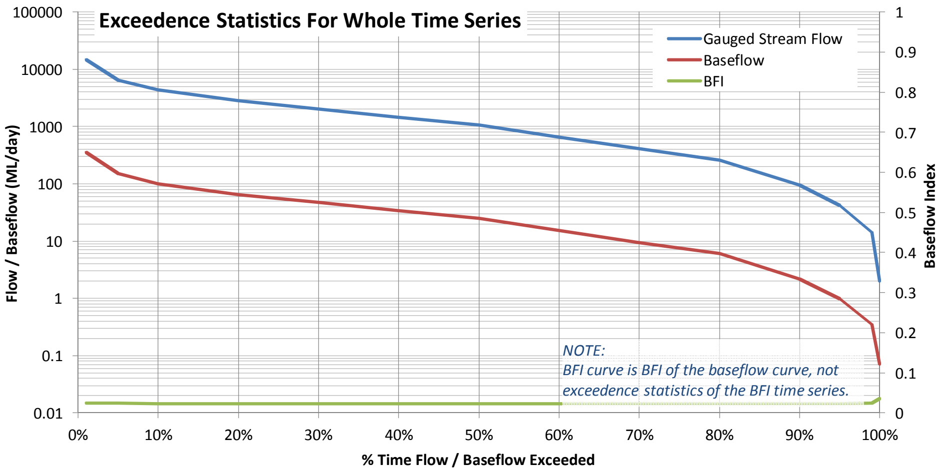
NOTE: The Eckhardt filter was left unmodified in this case due to insufficient data to support this modification.



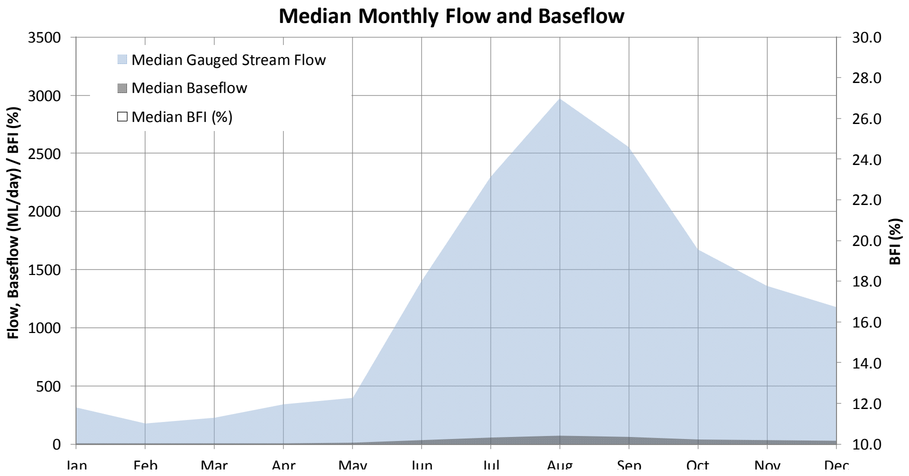
Baseflow indices are constant with very minimal seasonal flucuations, due to the influence of the up-stream reservoir regulating the EC concentration.

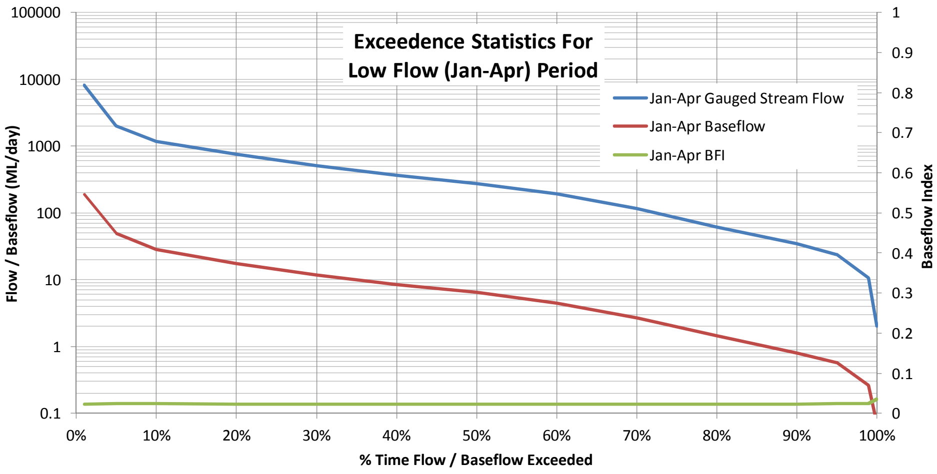


The volume of baseflow discharge is relatively constant over the period due to the influence of up-stream reservoirs regulating the EC concentration.



NOTE: BFI curve is BFI of the baseflow curve, not exceedence statistics of the BFI time series.





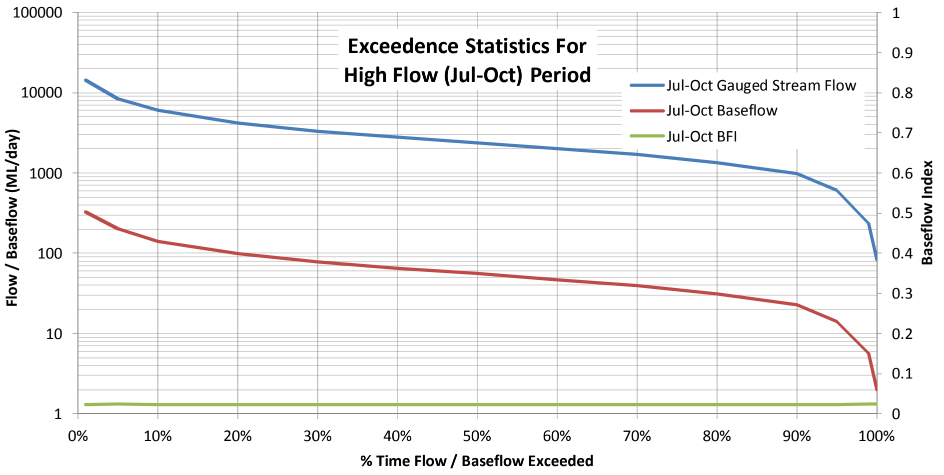


Figure C18 Summary Baseflow Estimation for the Mitchell

Appendix D – Baseflow Estimate Uncertainty Analysis

D1 – Latrobe River at Thoms Bridge (226005)

D2 – Tyers River at Browns (226007)

D3 – Narracan Creek at Moe (226021)

D4 – Latrobe River at Scarnes Bridge (226033)

D5 – Tanjil River at Tanjil South (226216)

D6 – Latrobe River at Kilmany South (226227)

D7 – Latrobe River at Rosedale (Main Stream) (226228)

D8 – Morwell River at Yallourn (226408)

D9 – Traralgon Creek at Traralgon South (SEC) (226415)

D10 – Thomson River at Heyfield (225200)

D11 – Macalister River at Lake Glenmaggie (Tail Gauge) (225204)

D12 – Thomson River at Wandocka (225212)

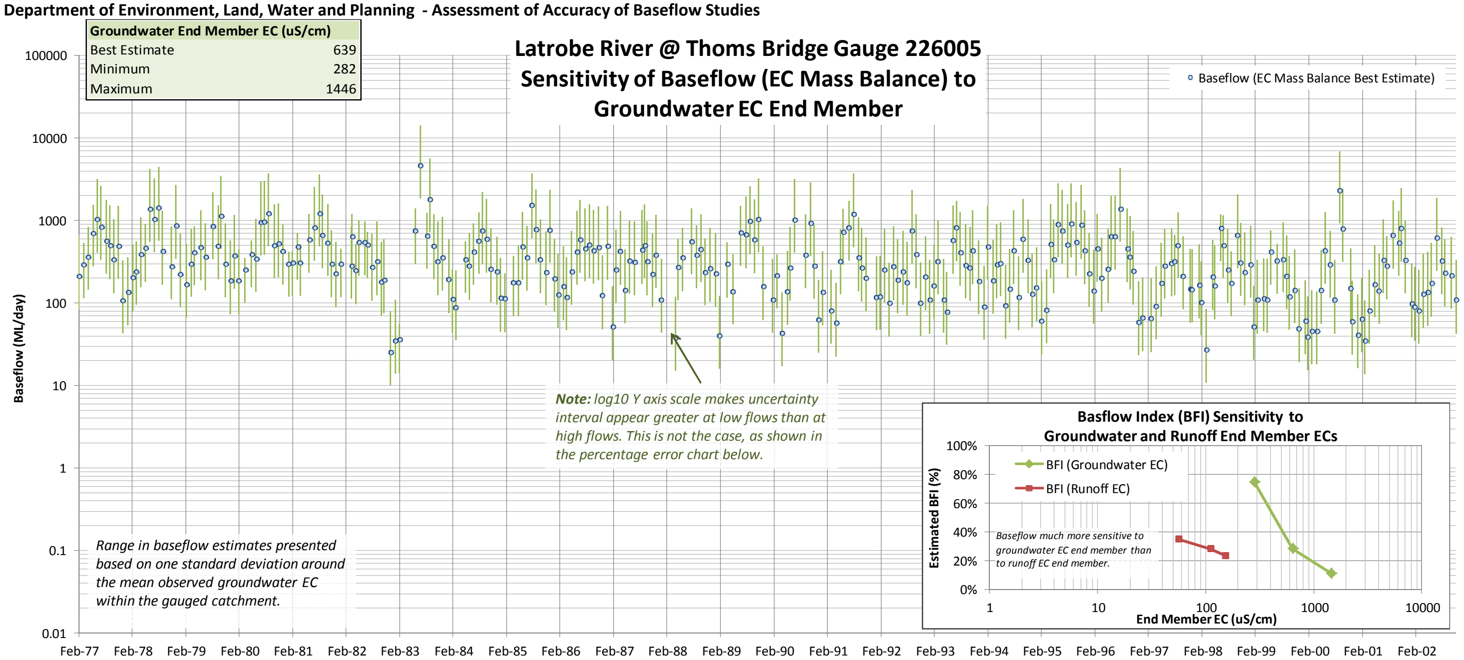
D13 – Thomson River U/S of Cowwarr Weir (225231)

D14 – Thomson River at Bundalaguah (225232)

D15 – Macalister River at Riverslea (225247)

D16 – Mitchell River at Glenaladale (224203)

D17 – Mitchell River at Rosehill (224217)



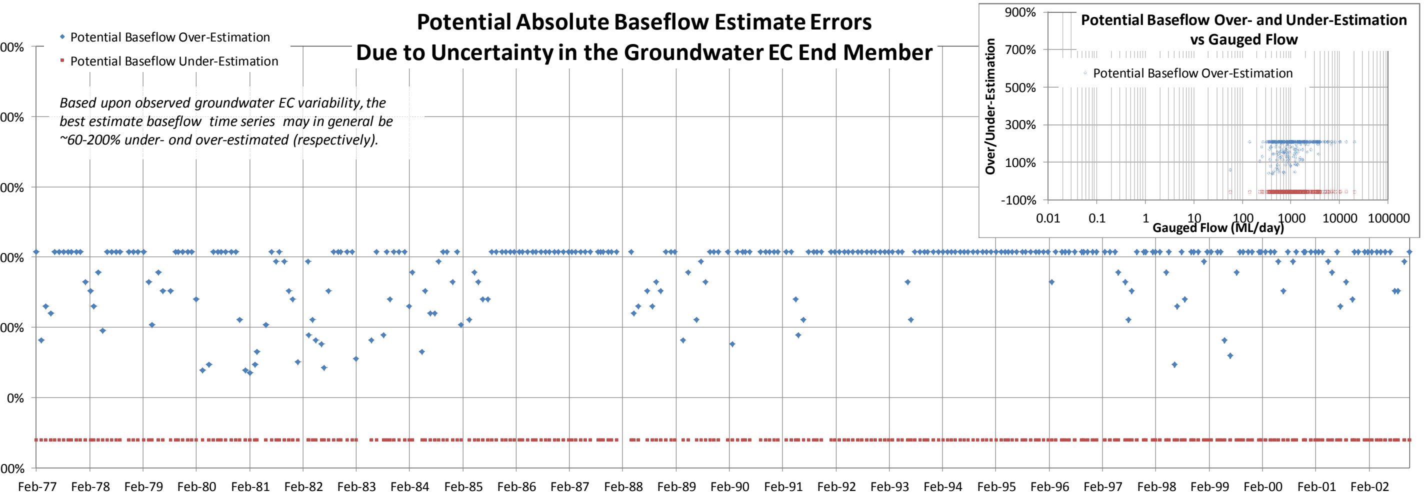
Groundwater End Member EC (uS/cm)	
Best Estimate	639
Minimum	282
Maximum	1446

Latrobe River @ Thoms Bridge Gauge 226005 Sensitivity of Baseflow (EC Mass Balance) to Groundwater EC End Member

***Note:** log10 Y axis scale makes uncertainty interval appear greater at low flows than at high flows. This is not the case, as shown in the percentage error chart below.*

Range in baseflow estimates presented based on one standard deviation around the mean observed groundwater EC within the gauged catchment.

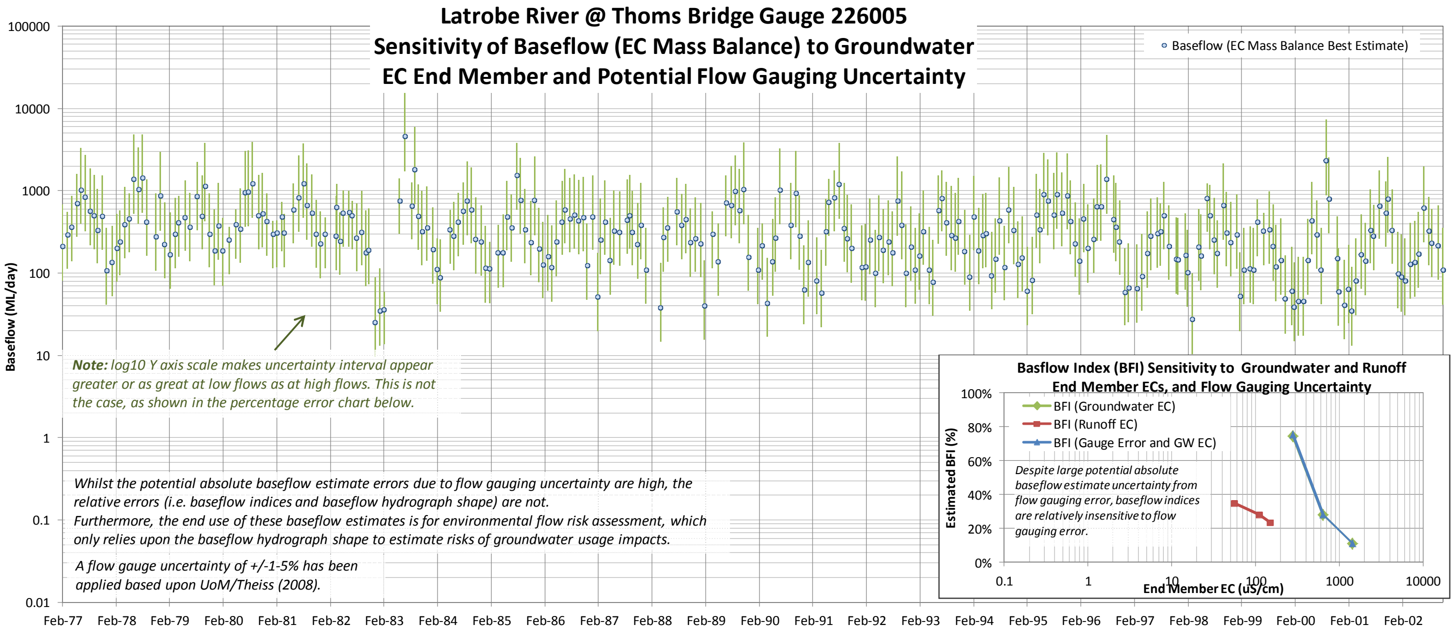
Baseflow much more sensitive to groundwater EC end member than to runoff EC end member.



Potential Absolute Baseflow Estimate Errors Due to Uncertainty in the Groundwater EC End Member

Based upon observed groundwater EC variability, the best estimate baseflow time series may in general be ~60-200% under- ond over-estimated (respectively).

Figure D1-1Baseflow Estimation Sensitivity to EC End Members for the Latrobe River at Thoms Bridge



Latrobe River @ Thoms Bridge Gauge 226005
Sensitivity of Baseflow (EC Mass Balance) to Groundwater
EC End Member and Potential Flow Gauging Uncertainty

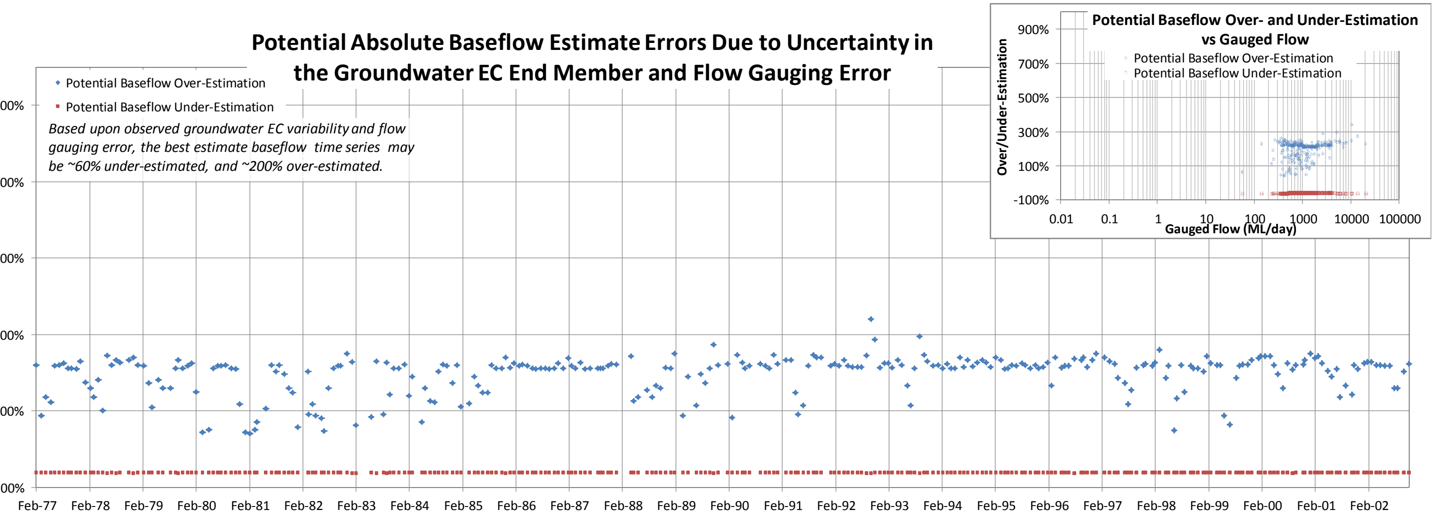
Note: *log10 Y axis scale makes uncertainty interval appear greater or as great at low flows as at high flows. This is not the case, as shown in the percentage error chart below.*

Whilst the potential absolute baseflow estimate errors due to flow gauging uncertainty are high, the relative errors (i.e. baseflow indices and baseflow hydrograph shape) are not.
Furthermore, the end use of these baseflow estimates is for environmental flow risk assessment, which only relies upon the baseflow hydrograph shape to estimate risks of groundwater usage impacts.

A flow gauge uncertainty of +/-1-5% has been applied based upon UoM/Theiss (2008).

Basflow Index (BFI) Sensitivity to Groundwater and Runoff End Member ECs, and Flow Gauging Uncertainty

Despite large potential absolute baseflow estimate uncertainty from flow gauging error, baseflow indices are relatively insensitive to flow gauging error.

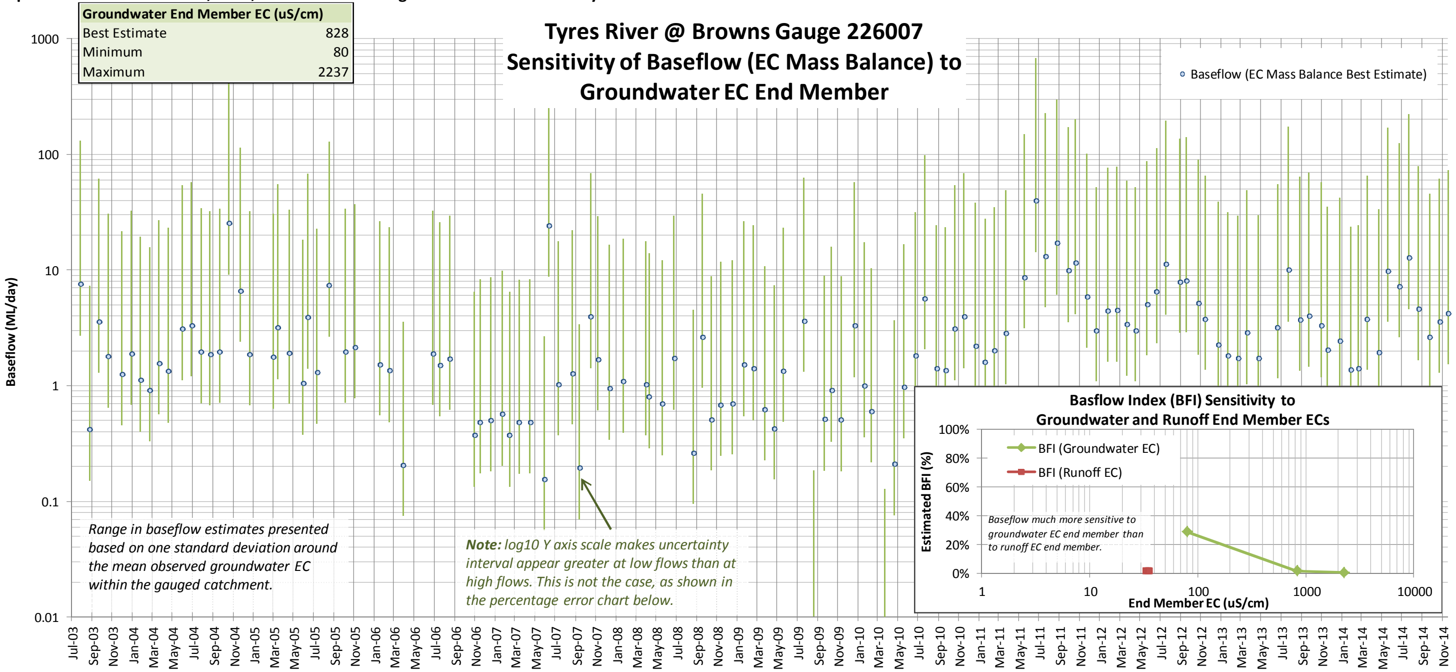


Potential Absolute Baseflow Estimate Errors Due to Uncertainty in the Groundwater EC End Member and Flow Gauging Error

Based upon observed groundwater EC variability and flow gauging error, the best estimate baseflow time series may be ~60% under-estimated, and ~200% over-estimated.

Potential Baseflow Over- and Under-Estimation vs Gauged Flow

Figure D1-2Baseflow Estimation Sensitivity to Flow Gauge Uncertainty and EC End Members for the Latrobe River at Thoms Bridge



Groundwater End Member EC (uS/cm)	
Best Estimate	828
Minimum	80
Maximum	2237

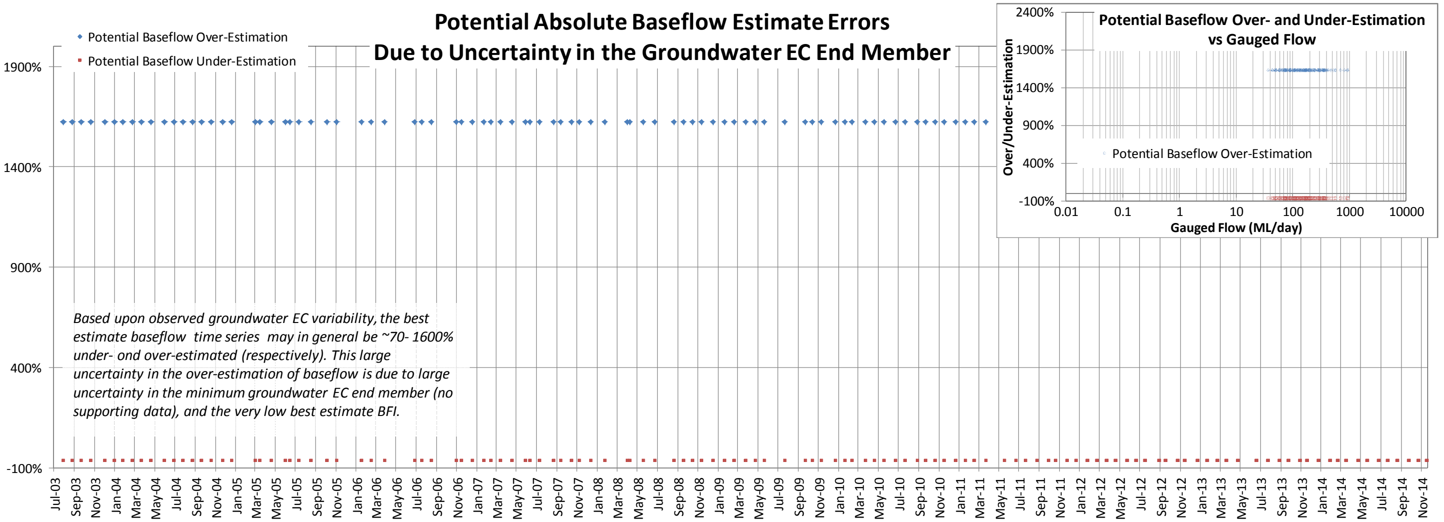
Tyres River @ Browns Gauge 226007
Sensitivity of Baseflow (EC Mass Balance) to
Groundwater EC End Member

Range in baseflow estimates presented based on one standard deviation around the mean observed groundwater EC within the gauged catchment.

***Note:** log10 Y axis scale makes uncertainty interval appear greater at low flows than at high flows. This is not the case, as shown in the percentage error chart below.*

Basflow Index (BFI) Sensitivity to
Groundwater and Runoff End Member ECs

Baseflow much more sensitive to groundwater EC end member than to runoff EC end member.

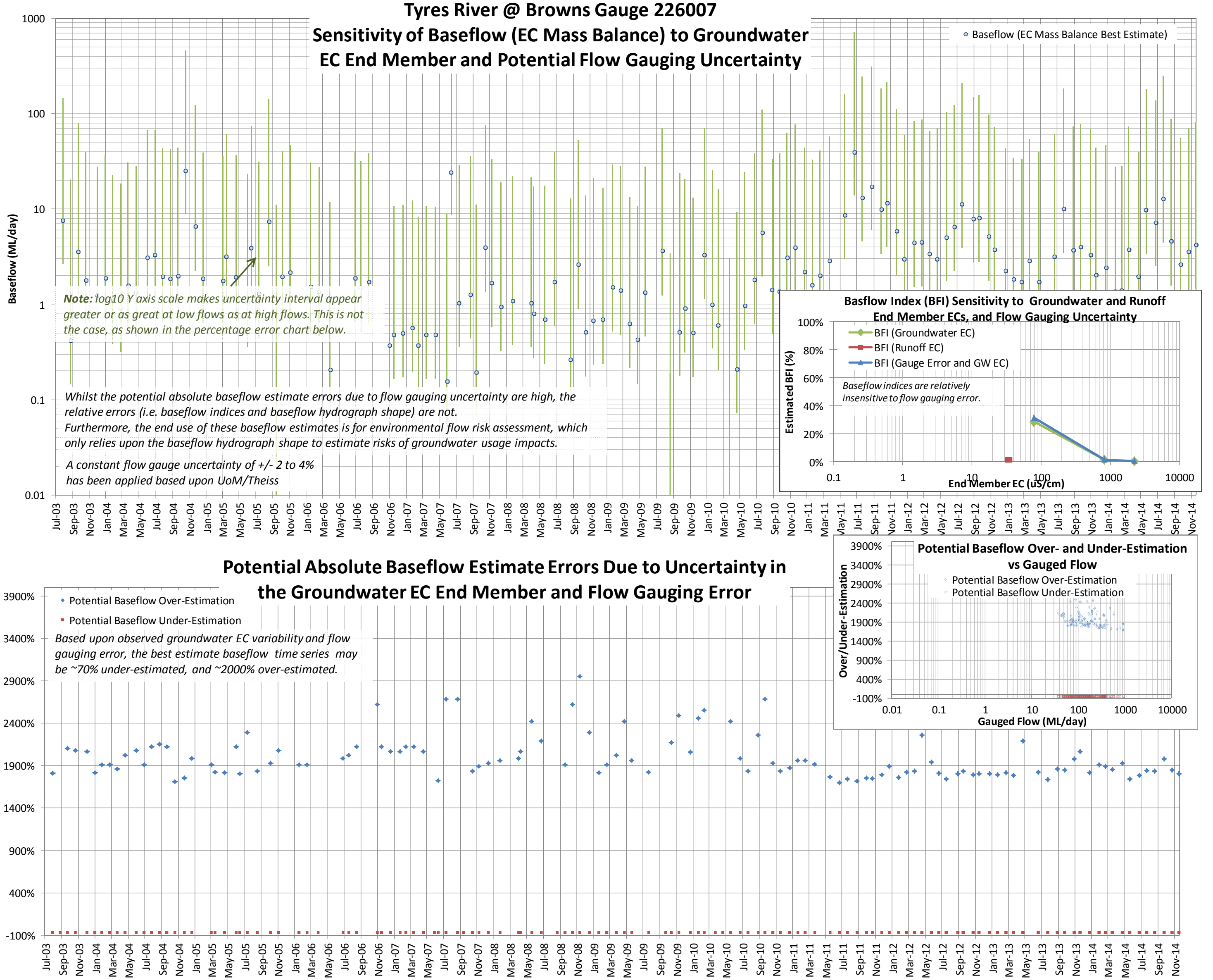


Potential Absolute Baseflow Estimate Errors
Due to Uncertainty in the Groundwater EC End Member

Based upon observed groundwater EC variability, the best estimate baseflow time series may in general be ~70- 1600% under- ond over-estimated (respectively). This large uncertainty in the over-estimation of baseflow is due to large uncertainty in the minimum groundwater EC end member (no supporting data), and the very low best estimate BFI.

Potential Baseflow Over- and Under-Estimation
vs Gauged Flow

Figure D2-1Baseflow Estimation Sensitivity to EC End Members for the Tyres River at Browns



Tyres River @ Browns Gauge 226007
Sensitivity of Baseflow (EC Mass Balance) to Groundwater
EC End Member and Potential Flow Gauging Uncertainty

Note: *log10 Y axis scale makes uncertainty interval appear greater or as great at low flows as at high flows. This is not the case, as shown in the percentage error chart below.*

Whilst the potential absolute baseflow estimate errors due to flow gauging uncertainty are high, the relative errors (i.e. baseflow indices and baseflow hydrograph shape) are not.
Furthermore, the end use of these baseflow estimates is for environmental flow risk assessment, which only relies upon the baseflow hydrograph shape to estimate risks of groundwater usage impacts.

A constant flow gauge uncertainty of +/- 2 to 4% has been applied based upon UoM/Theiss

Basflow Index (BFI) Sensitivity to Groundwater and Runoff End Member ECs, and Flow Gauging Uncertainty

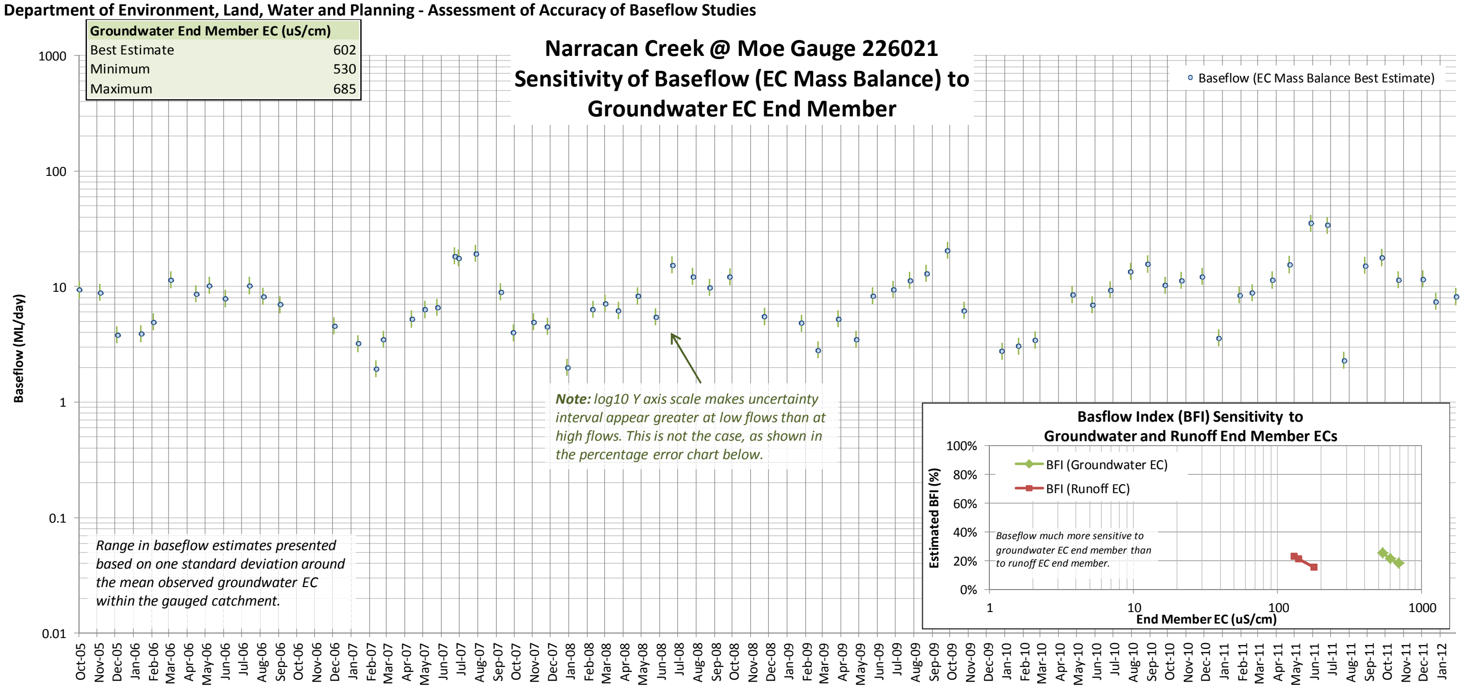
Baseflow indices are relatively insensitive to flow gauging error.

Potential Absolute Baseflow Estimate Errors Due to Uncertainty in the Groundwater EC End Member and Flow Gauging Error

Based upon observed groundwater EC variability and flow gauging error, the best estimate baseflow time series may be ~70% under-estimated, and ~2000% over-estimated.

Potential Baseflow Over- and Under-Estimation vs Gauged Flow

Figure D2-2Baseflow Estimation Sensitivity to Flow Gauge Uncertainty and EC End Members for the Tyres River at Browns



Groundwater End Member EC (uS/cm)	
Best Estimate	602
Minimum	530
Maximum	685

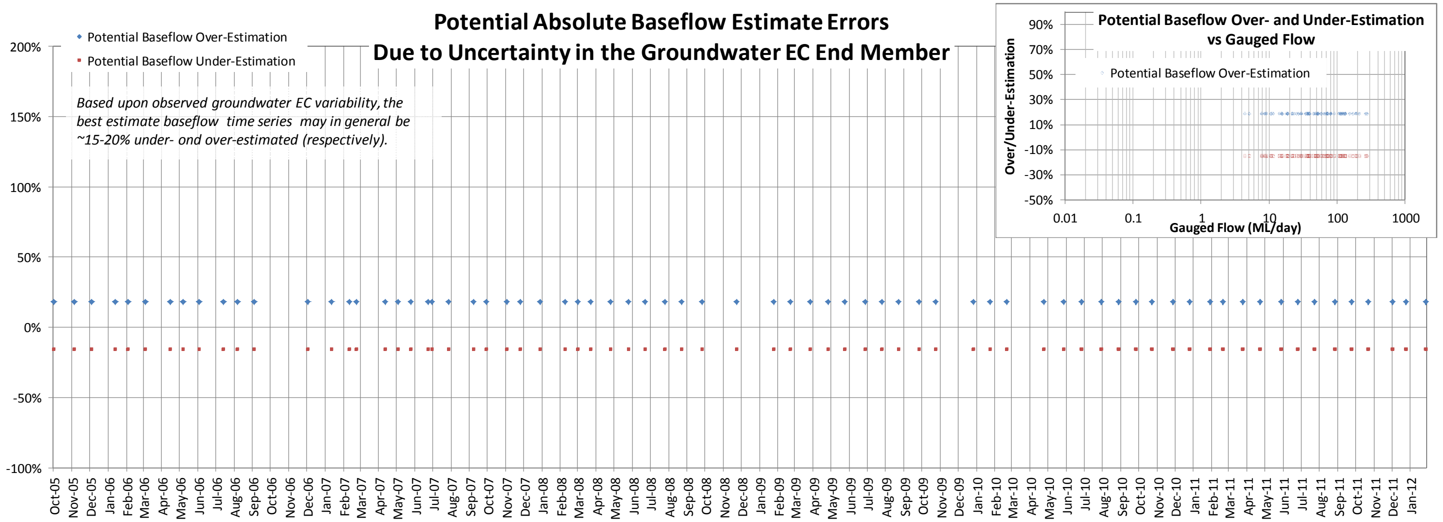
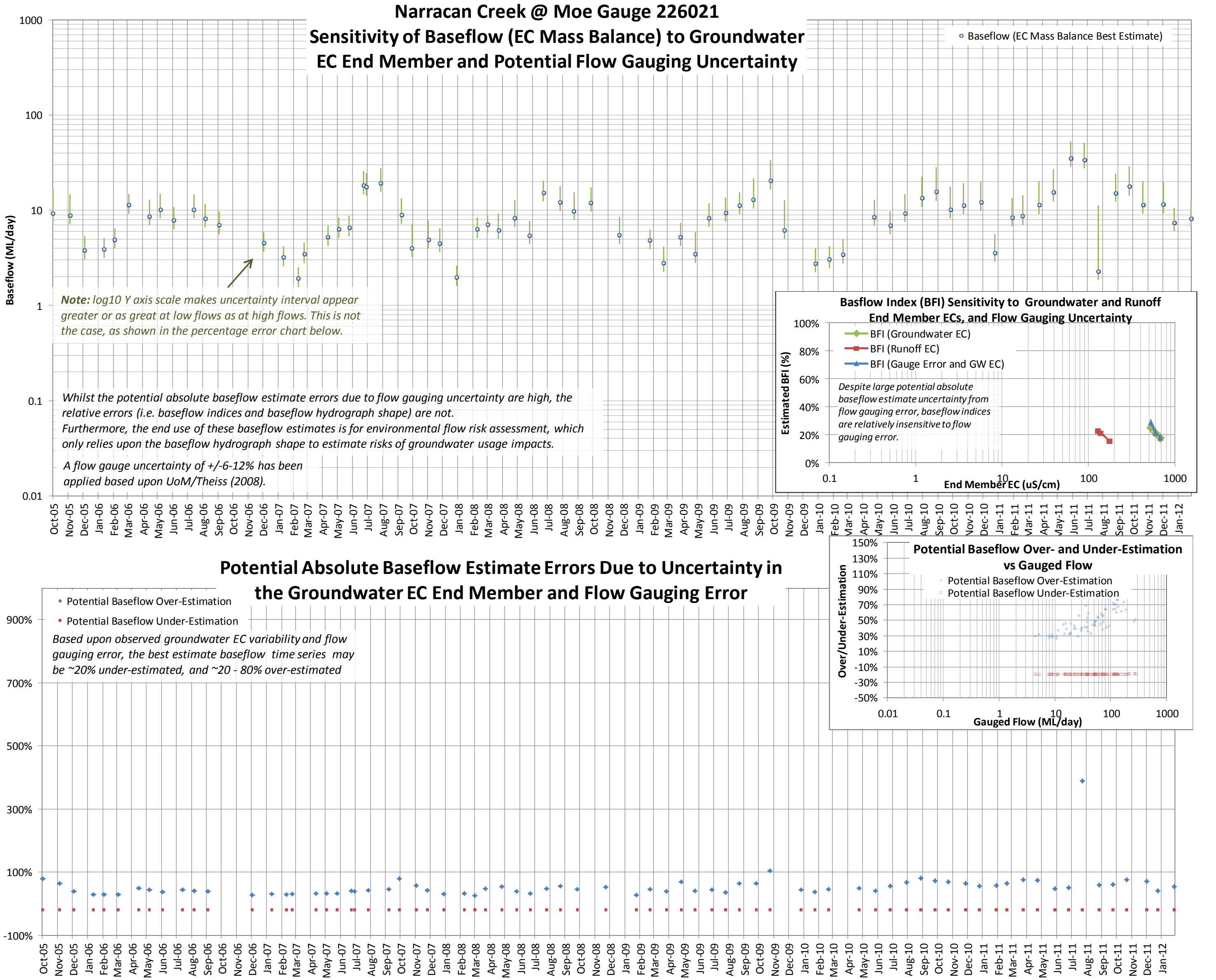


Figure D3-1Baseflow Estimation Sensitivity to EC End Members for the Narracan Creek at Moe



Note: *log10 Y axis scale makes uncertainty interval appear greater or as great at low flows as at high flows. This is not the case, as shown in the percentage error chart below.*

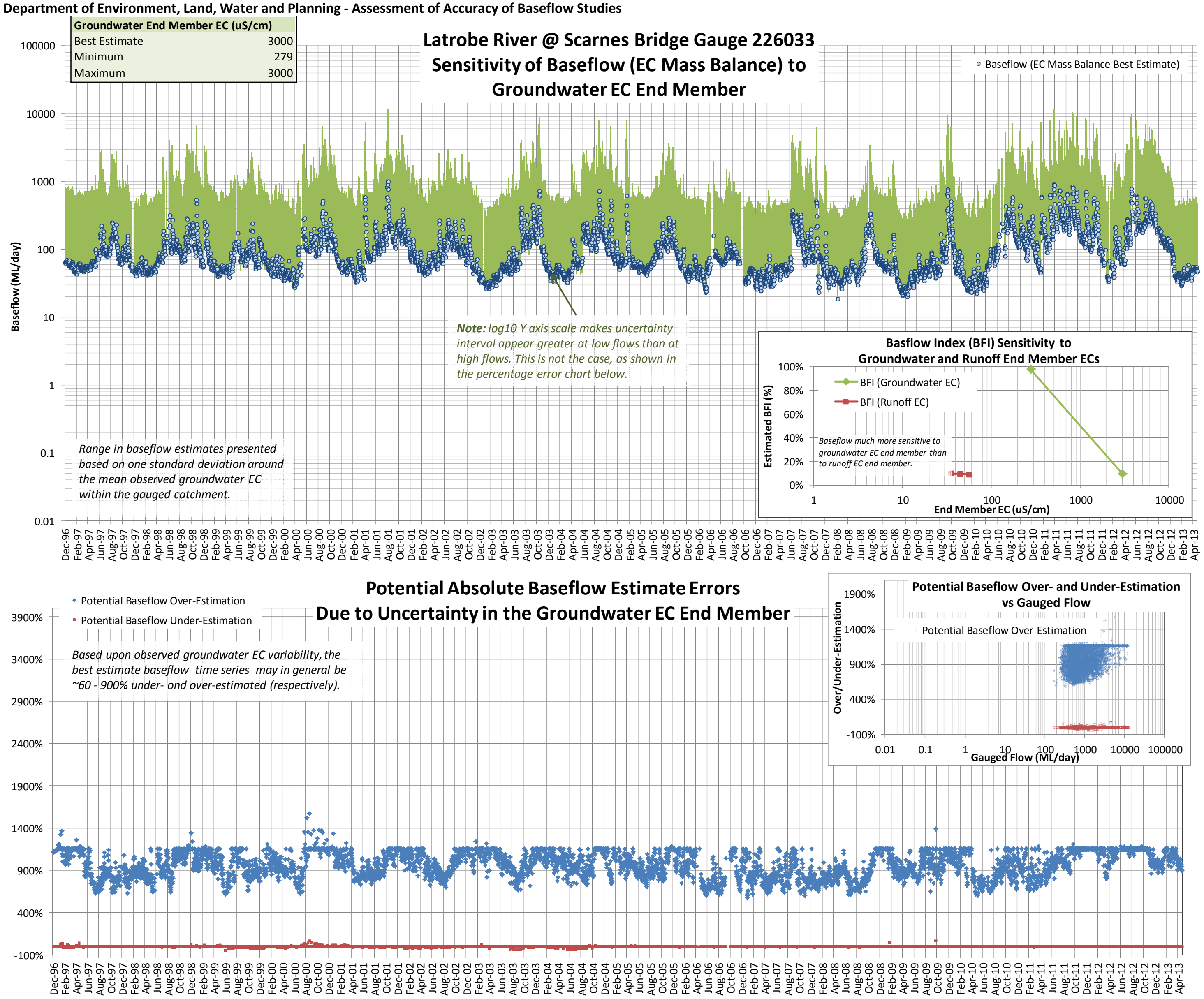
Whilst the potential absolute baseflow estimate errors due to flow gauging uncertainty are high, the relative errors (i.e. baseflow indices and baseflow hydrograph shape) are not.
Furthermore, the end use of these baseflow estimates is for environmental flow risk assessment, which only relies upon the baseflow hydrograph shape to estimate risks of groundwater usage impacts.

A flow gauge uncertainty of +/-6-12% has been applied based upon UoM/Theiss (2008).

Despite large potential absolute baseflow estimate uncertainty from flow gauging error, baseflow indices are relatively insensitive to flow gauging error.

Based upon observed groundwater EC variability and flow gauging error, the best estimate baseflow time series may be ~20% under-estimated, and ~20 - 80% over-estimated

Figure D3-2Baseflow Estimation Sensitivity to Flow Gauge Uncertainty and EC End Members for the Narracan Creek at Moe



Groundwater End Member EC (uS/cm)	
Best Estimate	3000
Minimum	279
Maximum	3000

Latrobe River @ Scarnes Bridge Gauge 226033 Sensitivity of Baseflow (EC Mass Balance) to Groundwater EC End Member

Range in baseflow estimates presented based on one standard deviation around the mean observed groundwater EC within the gauged catchment.

***Note:** log10 Y axis scale makes uncertainty interval appear greater at low flows than at high flows. This is not the case, as shown in the percentage error chart below.*

Basflow Index (BFI) Sensitivity to Groundwater and Runoff End Member ECs

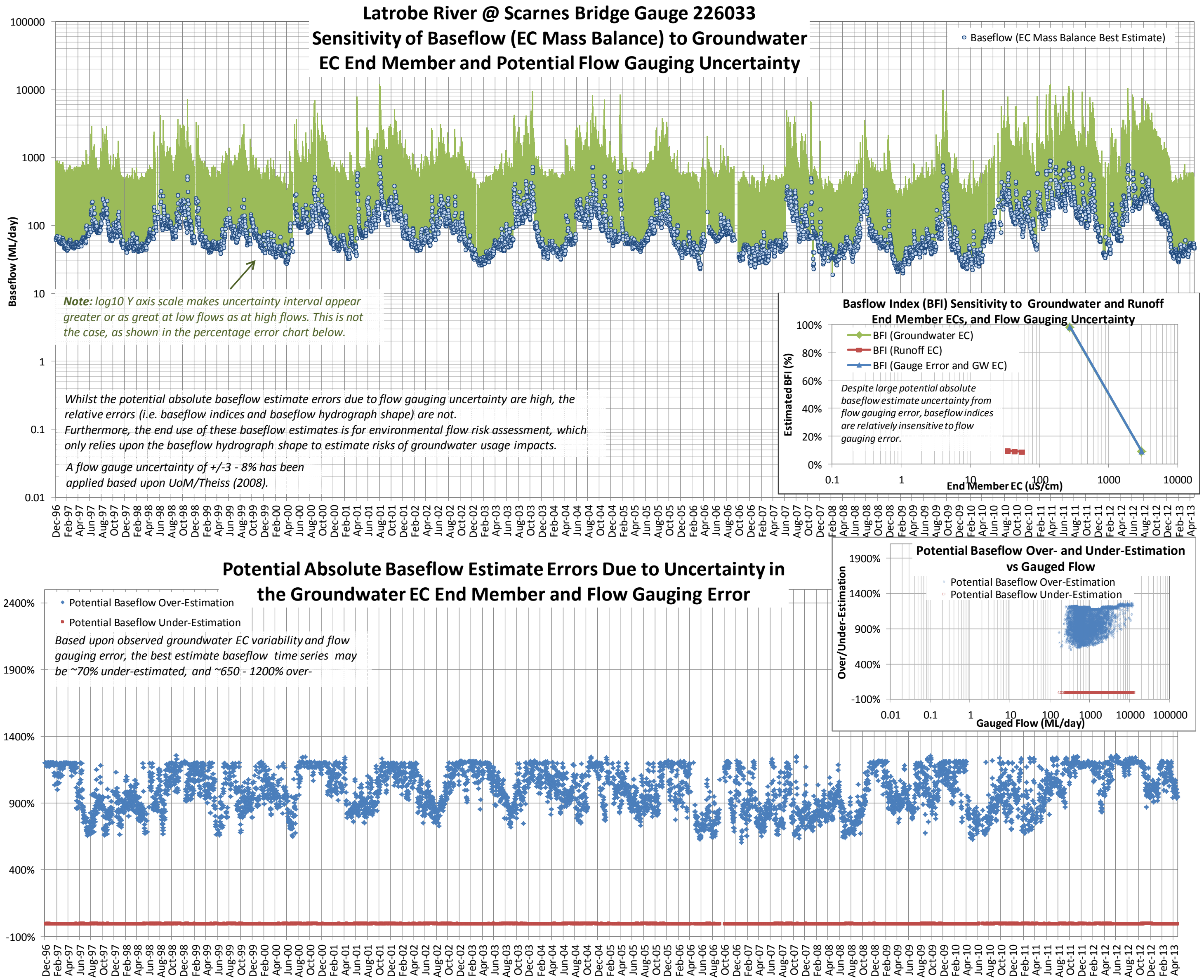
Baseflow much more sensitive to groundwater EC end member than to runoff EC end member.

Potential Absolute Baseflow Estimate Errors Due to Uncertainty in the Groundwater EC End Member

Based upon observed groundwater EC variability, the best estimate baseflow time series may in general be ~60 - 900% under- ond over-estimated (respectively).

Potential Baseflow Over- and Under-Estimation vs Gauged Flow

Figure D4-1Baseflow Estimation Sensitivity to EC End Members for the Latrobe River at Scarns Bridge



Latrobe River @ Scarnes Bridge Gauge 226033
Sensitivity of Baseflow (EC Mass Balance) to Groundwater
EC End Member and Potential Flow Gauging Uncertainty

Note: *log10 Y axis scale makes uncertainty interval appear greater or as great at low flows as at high flows. This is not the case, as shown in the percentage error chart below.*

Whilst the potential absolute baseflow estimate errors due to flow gauging uncertainty are high, the relative errors (i.e. baseflow indices and baseflow hydrograph shape) are not.
Furthermore, the end use of these baseflow estimates is for environmental flow risk assessment, which only relies upon the baseflow hydrograph shape to estimate risks of groundwater usage impacts.

A flow gauge uncertainty of +/-3 - 8% has been applied based upon UoM/Theiss (2008).

Basflow Index (BFI) Sensitivity to Groundwater and Runoff End Member ECs, and Flow Gauging Uncertainty

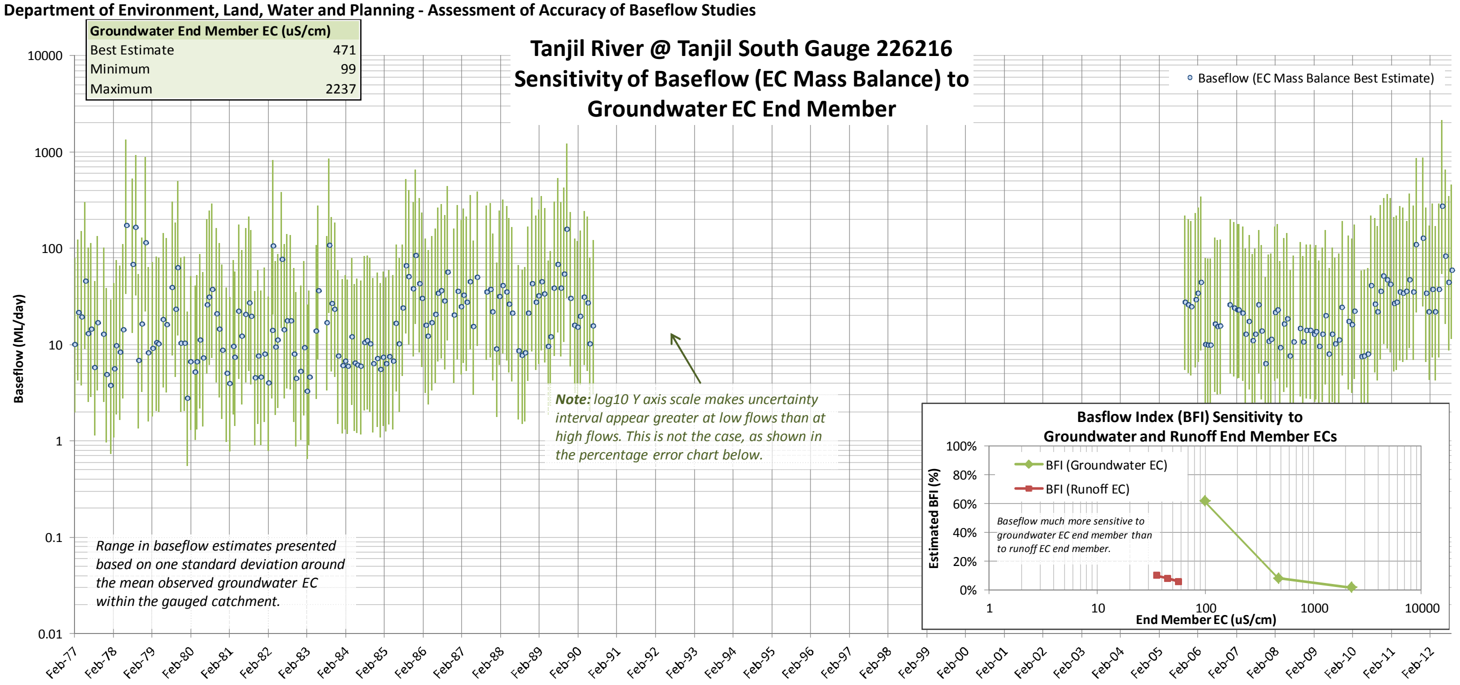
Despite large potential absolute baseflow estimate uncertainty from flow gauging error, baseflow indices are relatively insensitive to flow gauging error.

Potential Absolute Baseflow Estimate Errors Due to Uncertainty in the Groundwater EC End Member and Flow Gauging Error

Based upon observed groundwater EC variability and flow gauging error, the best estimate baseflow time series may be ~70% under-estimated, and ~650 - 1200% over-

Potential Baseflow Over- and Under-Estimation vs Gauged Flow

Figure D4-2Baseflow Estimation Sensitivity to Flow Gauge Uncertainty and EC End Members for the Latrobe River at Scarns Bridge



Groundwater End Member EC (uS/cm)	
Best Estimate	471
Minimum	99
Maximum	2237

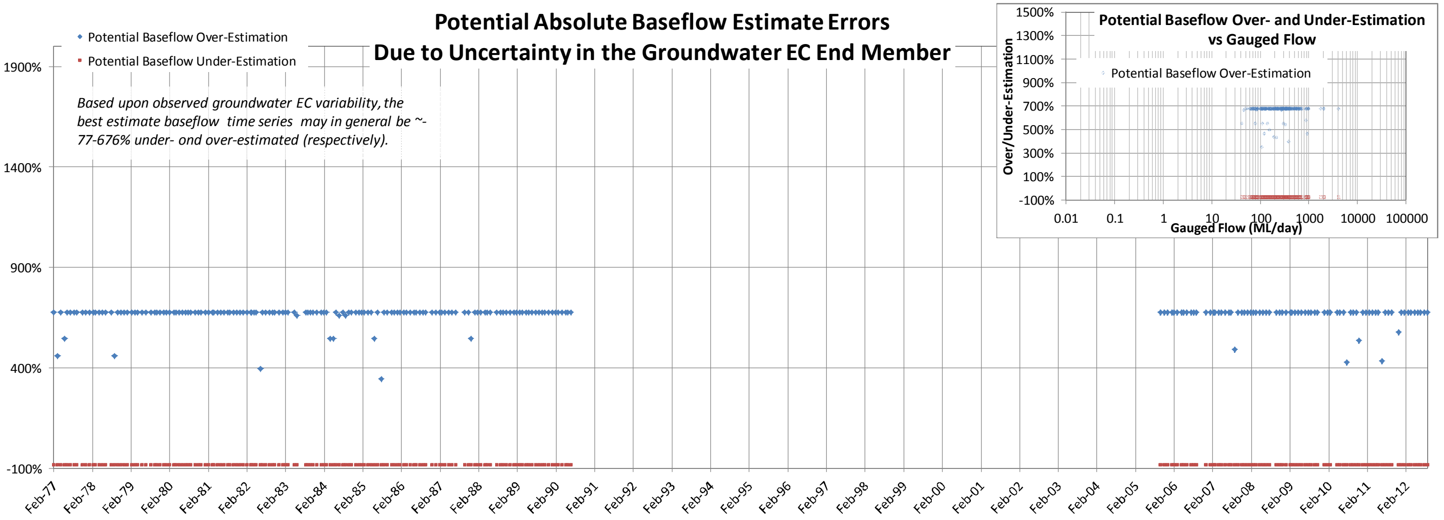
Tanjil River @ Tanjil South Gauge 226216
Sensitivity of Baseflow (EC Mass Balance) to Groundwater EC End Member

Range in baseflow estimates presented based on one standard deviation around the mean observed groundwater EC within the gauged catchment.

Note: *log10 Y axis scale makes uncertainty interval appear greater at low flows than at high flows. This is not the case, as shown in the percentage error chart below.*

Basflow Index (BFI) Sensitivity to Groundwater and Runoff End Member ECs

Baseflow much more sensitive to groundwater EC end member than to runoff EC end member.

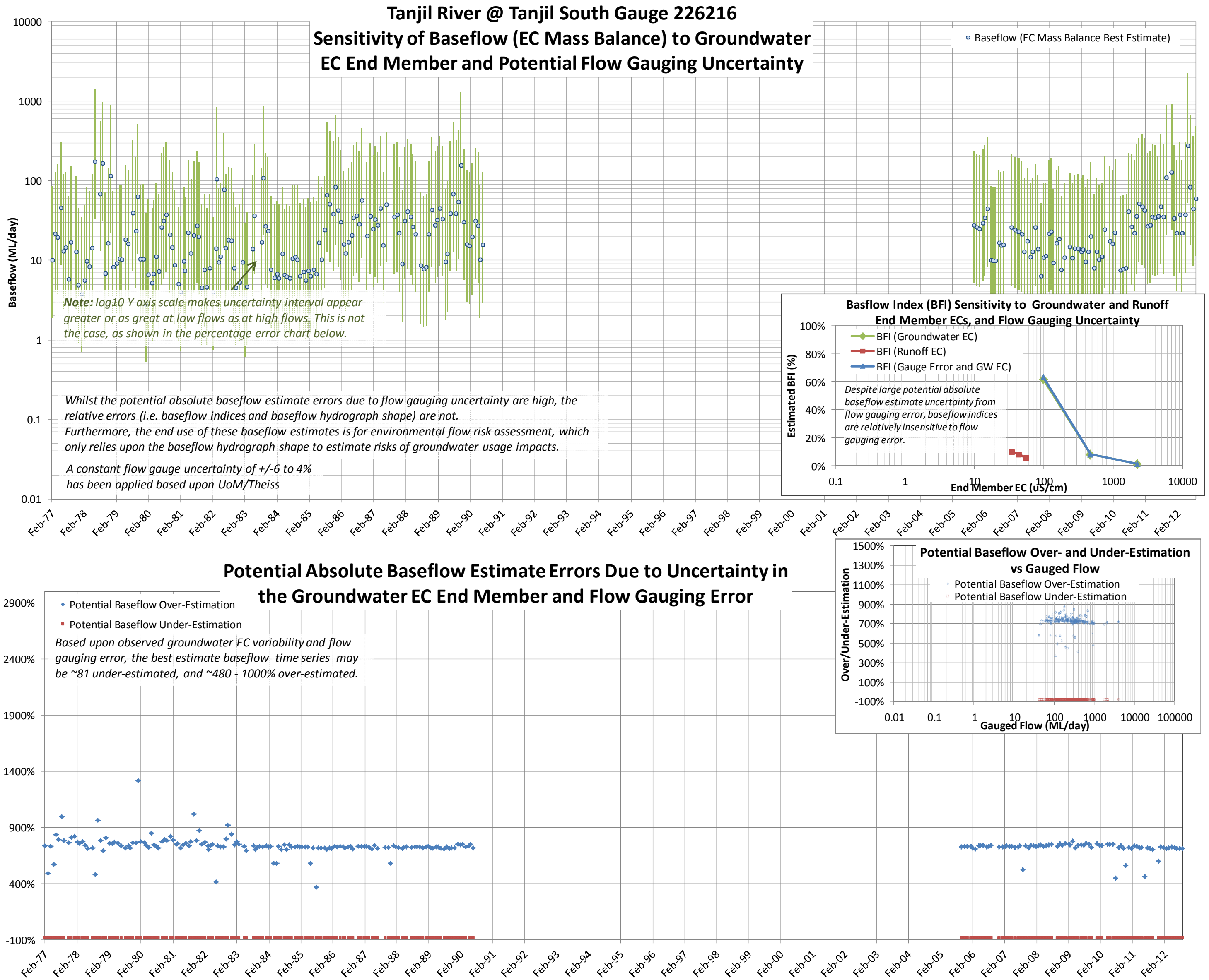


Potential Absolute Baseflow Estimate Errors
Due to Uncertainty in the Groundwater EC End Member

Based upon observed groundwater EC variability, the best estimate baseflow time series may in general be ~-77-676% under- ond over-estimated (respectively).

Potential Baseflow Over- and Under-Estimation vs Gauged Flow

Figure D5-1Baseflow Estimation Sensitivity to EC End Members for the Tanjil River at Tanjil South



Tanjil River @ Tanjil South Gauge 226216
Sensitivity of Baseflow (EC Mass Balance) to Groundwater EC End Member and Potential Flow Gauging Uncertainty

Note: *log10 Y axis scale makes uncertainty interval appear greater or as great at low flows as at high flows. This is not the case, as shown in the percentage error chart below.*

Whilst the potential absolute baseflow estimate errors due to flow gauging uncertainty are high, the relative errors (i.e. baseflow indices and baseflow hydrograph shape) are not.
Furthermore, the end use of these baseflow estimates is for environmental flow risk assessment, which only relies upon the baseflow hydrograph shape to estimate risks of groundwater usage impacts.

A constant flow gauge uncertainty of +/-6 to 4% has been applied based upon UoM/Theiss

Basflow Index (BFI) Sensitivity to Groundwater and Runoff End Member ECs, and Flow Gauging Uncertainty

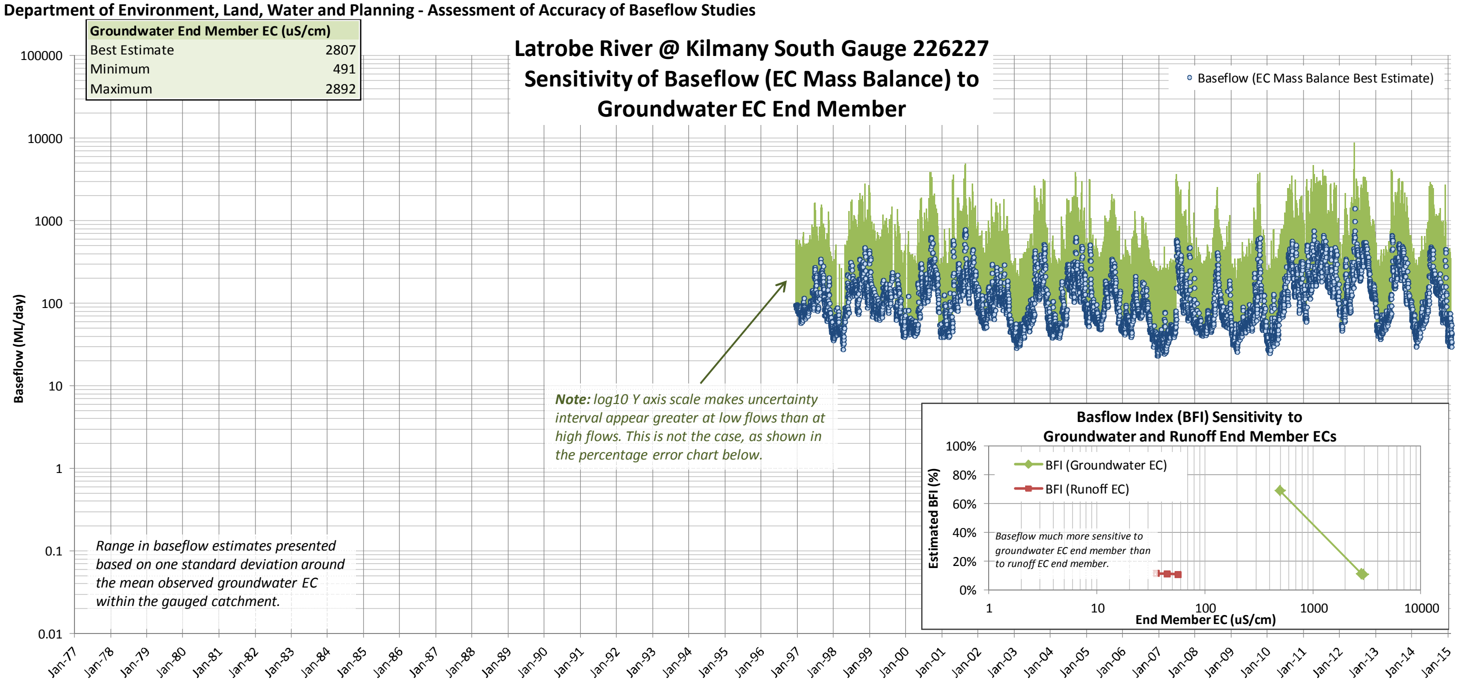
Despite large potential absolute baseflow estimate uncertainty from flow gauging error, baseflow indices are relatively insensitive to flow gauging error.

Potential Absolute Baseflow Estimate Errors Due to Uncertainty in the Groundwater EC End Member and Flow Gauging Error

Based upon observed groundwater EC variability and flow gauging error, the best estimate baseflow time series may be ~81 under-estimated, and ~480 - 1000% over-estimated.

Potential Baseflow Over- and Under-Estimation vs Gauged Flow

Figure D5-2Baseflow Estimation Sensitivity to Flow Gauge Uncertainty and EC End Members for the Tanjil River at Tanjil South



Groundwater End Member EC (uS/cm)	
Best Estimate	2807
Minimum	491
Maximum	2892

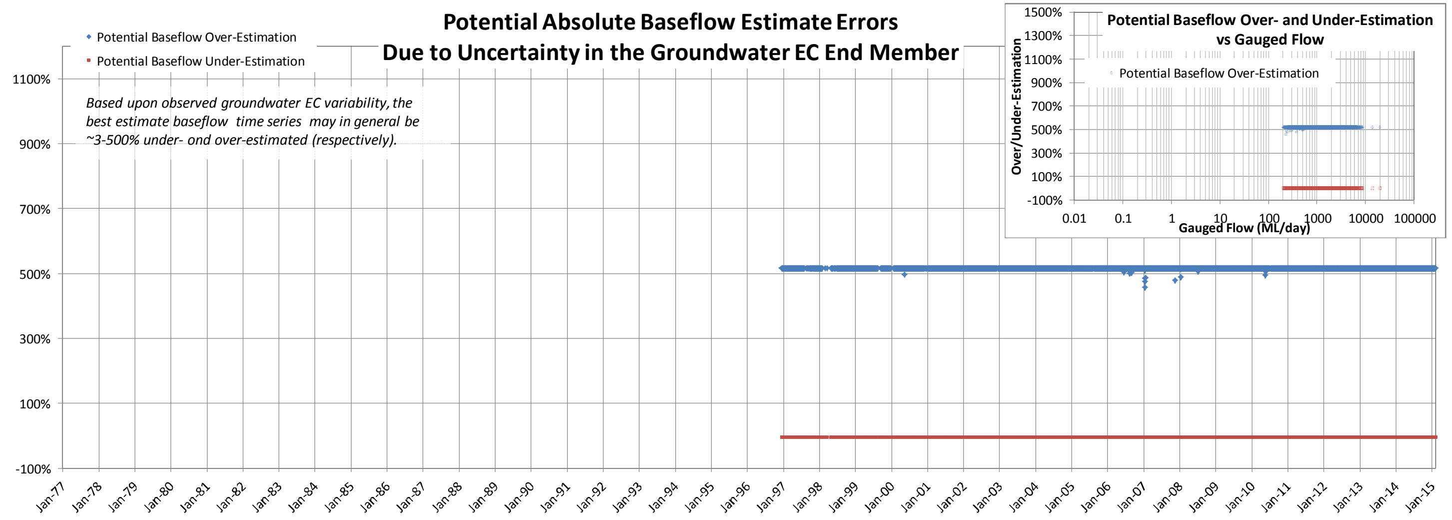
Latrobe River @ Kilmany South Gauge 226227
Sensitivity of Baseflow (EC Mass Balance) to
Groundwater EC End Member

Note: *log10 Y axis scale makes uncertainty interval appear greater at low flows than at high flows. This is not the case, as shown in the percentage error chart below.*

Range in baseflow estimates presented based on one standard deviation around the mean observed groundwater EC within the gauged catchment.

Basflow Index (BFI) Sensitivity to
Groundwater and Runoff End Member ECs

Baseflow much more sensitive to groundwater EC end member than to runoff EC end member.

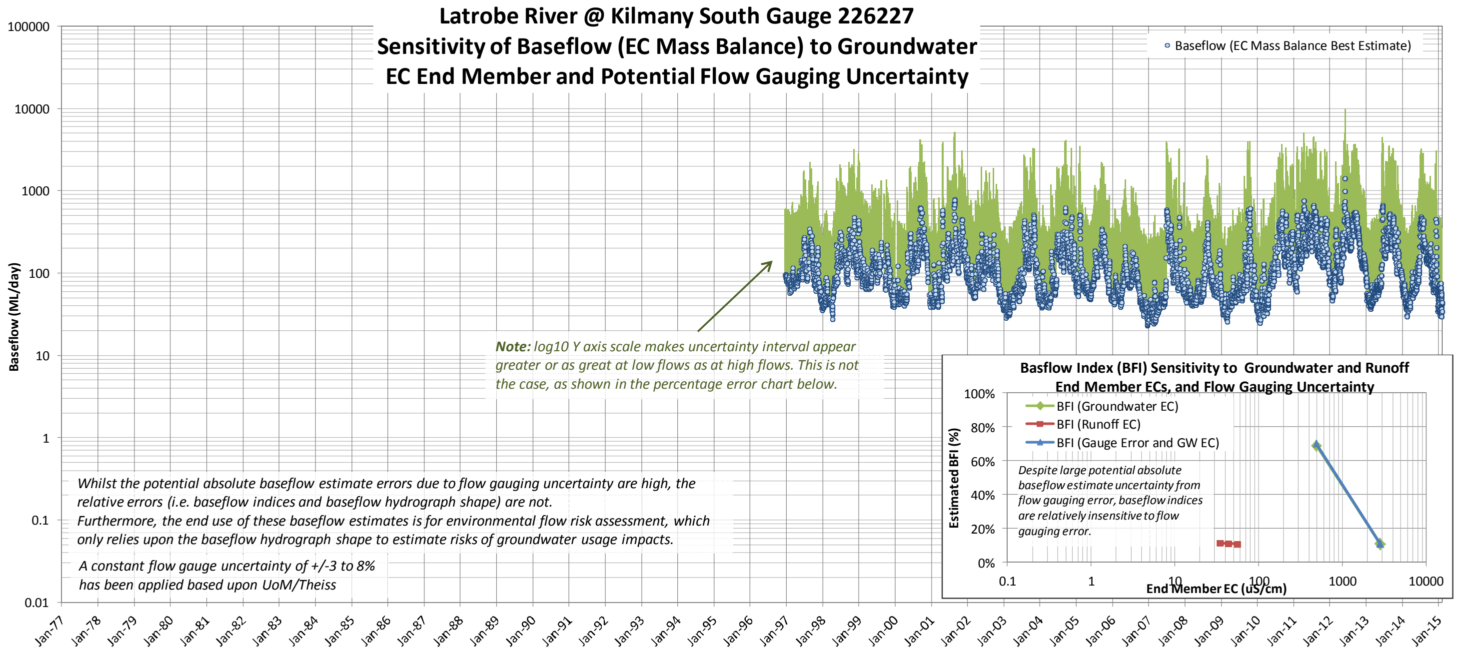


Potential Absolute Baseflow Estimate Errors
Due to Uncertainty in the Groundwater EC End Member

Based upon observed groundwater EC variability, the best estimate baseflow time series may in general be ~3-500% under- ond over-estimated (respectively).

Potential Baseflow Over- and Under-Estimation
vs Gauged Flow

Figure D6-1Baseflow Estimation Sensitivity to EC End Members for the Latrobe River at Kilmany South



Latrobe River @ Kilmany South Gauge 226227
Sensitivity of Baseflow (EC Mass Balance) to Groundwater EC End Member and Potential Flow Gauging Uncertainty

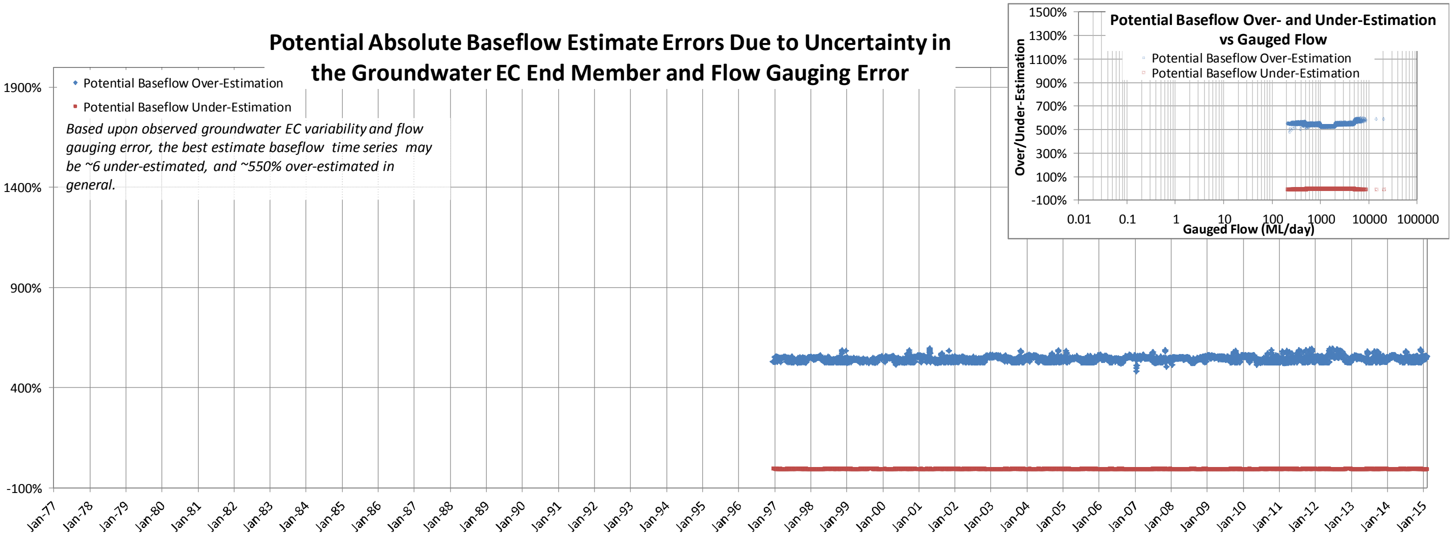
Note: log10 Y axis scale makes uncertainty interval appear greater or as great at low flows as at high flows. This is not the case, as shown in the percentage error chart below.

Whilst the potential absolute baseflow estimate errors due to flow gauging uncertainty are high, the relative errors (i.e. baseflow indices and baseflow hydrograph shape) are not.
Furthermore, the end use of these baseflow estimates is for environmental flow risk assessment, which only relies upon the baseflow hydrograph shape to estimate risks of groundwater usage impacts.

A constant flow gauge uncertainty of +/-3 to 8% has been applied based upon UoM/Theiss

Basflow Index (BFI) Sensitivity to Groundwater and Runoff End Member ECs, and Flow Gauging Uncertainty

Despite large potential absolute baseflow estimate uncertainty from flow gauging error, baseflow indices are relatively insensitive to flow gauging error.

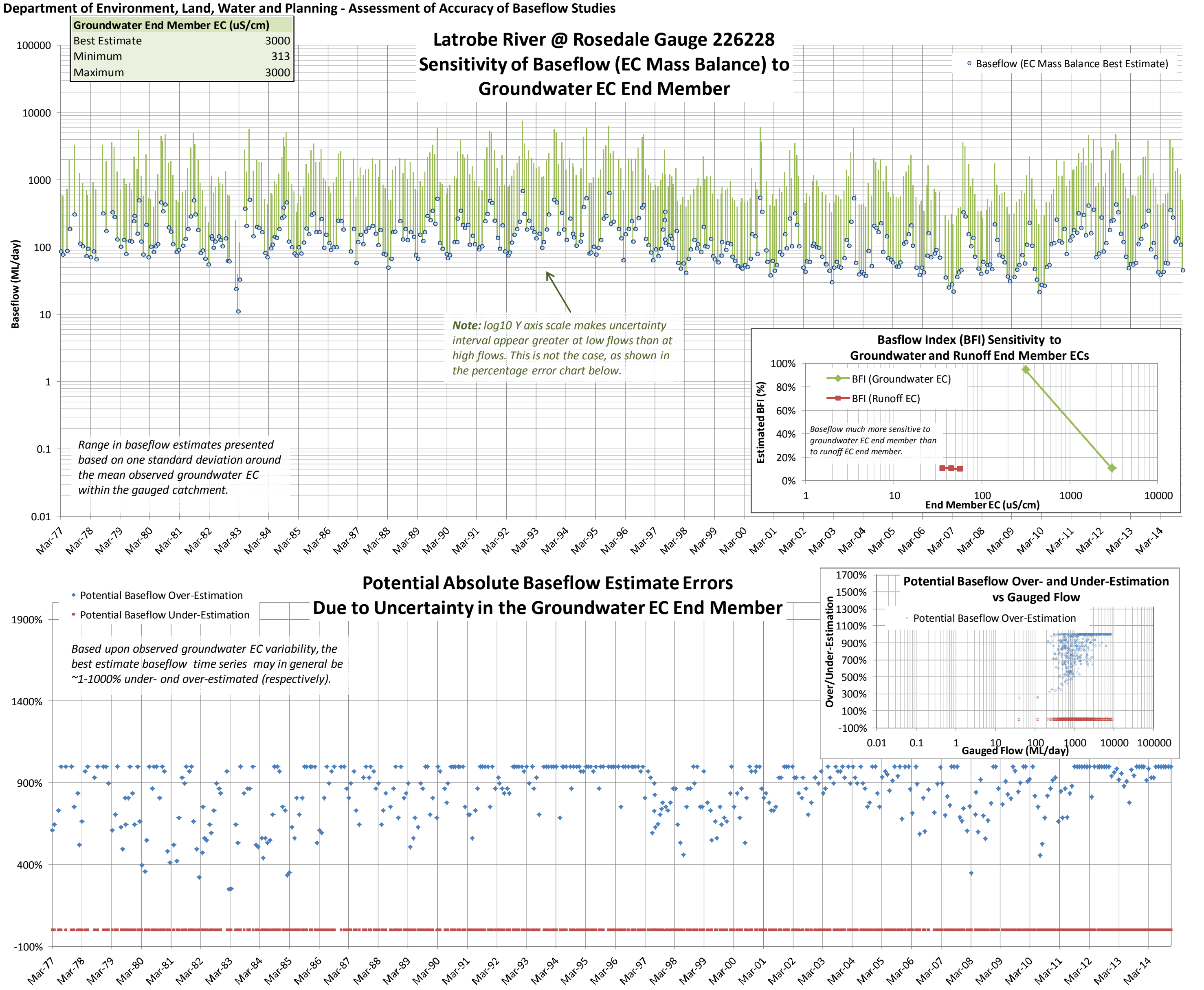


Potential Absolute Baseflow Estimate Errors Due to Uncertainty in the Groundwater EC End Member and Flow Gauging Error

Based upon observed groundwater EC variability and flow gauging error, the best estimate baseflow time series may be ~6 under-estimated, and ~550% over-estimated in general.

Potential Baseflow Over- and Under-Estimation vs Gauged Flow

Figure D6-2Baseflow Estimation Sensitivity to Flow Gauge Uncertainty and EC End Members for the Latrobe River at Kilmany South



Groundwater End Member EC (uS/cm)	
Best Estimate	3000
Minimum	313
Maximum	3000

Latrobe River @ Rosedale Gauge 226228 Sensitivity of Baseflow (EC Mass Balance) to Groundwater EC End Member

Note: log10 Y axis scale makes uncertainty interval appear greater at low flows than at high flows. This is not the case, as shown in the percentage error chart below.

Range in baseflow estimates presented based on one standard deviation around the mean observed groundwater EC within the gauged catchment.

Basflow Index (BFI) Sensitivity to Groundwater and Runoff End Member ECs

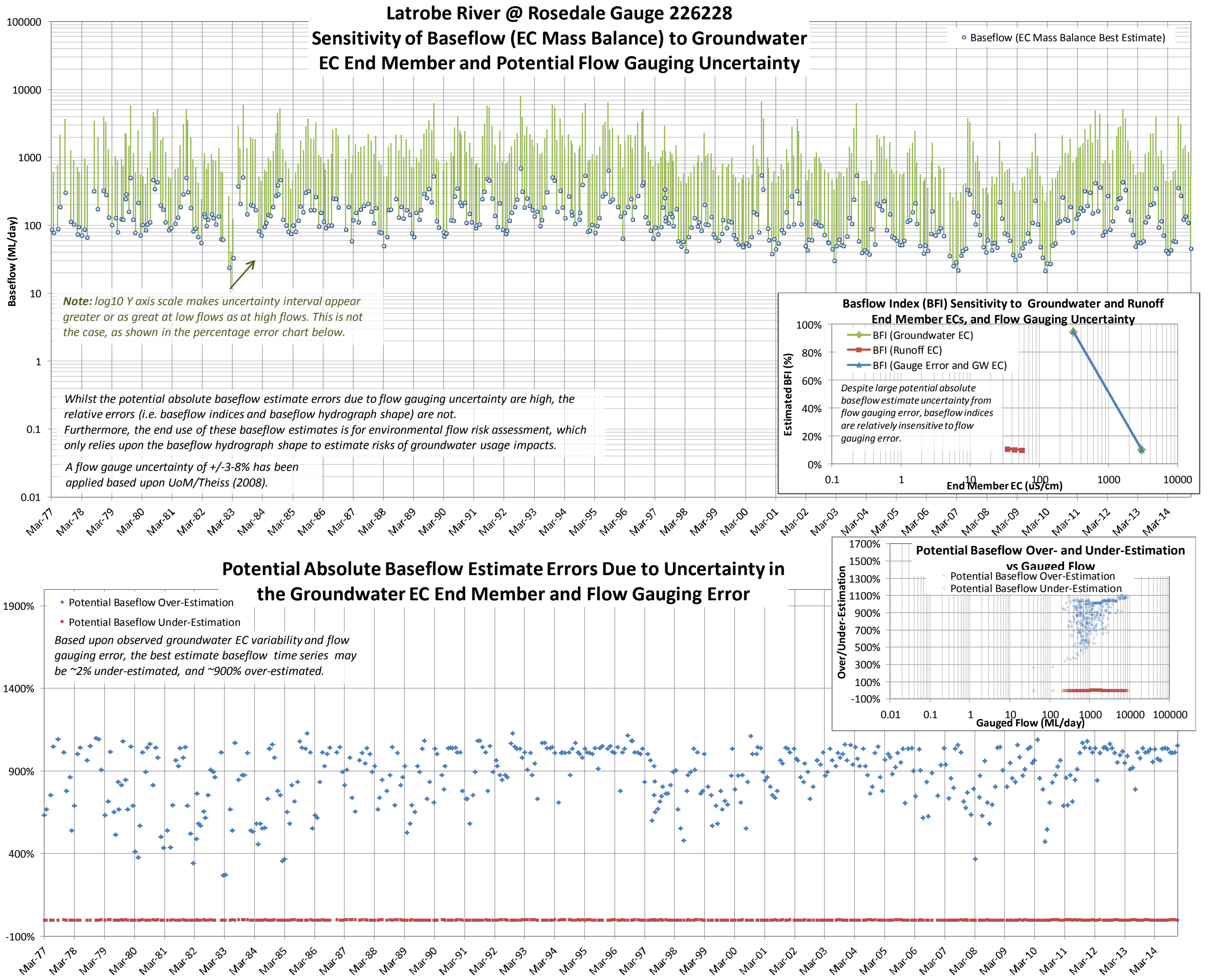
Baseflow much more sensitive to groundwater EC end member than to runoff EC end member.

Potential Absolute Baseflow Estimate Errors Due to Uncertainty in the Groundwater EC End Member

Based upon observed groundwater EC variability, the best estimate baseflow time series may in general be ~1-1000% under- ond over-estimated (respectively).

Potential Baseflow Over- and Under-Estimation vs Gauged Flow

Figure D7-1Baseflow Estimation Sensitivity to EC End Members for the Latrobe River at Rosedale



Latrobe River @ Rosedale Gauge 226228
Sensitivity of Baseflow (EC Mass Balance) to Groundwater EC End Member and Potential Flow Gauging Uncertainty

Note: *log10 Y axis scale makes uncertainty interval appear greater or as great at low flows as at high flows. This is not the case, as shown in the percentage error chart below.*

Whilst the potential absolute baseflow estimate errors due to flow gauging uncertainty are high, the relative errors (i.e. baseflow indices and baseflow hydrograph shape) are not.
Furthermore, the end use of these baseflow estimates is for environmental flow risk assessment, which only relies upon the baseflow hydrograph shape to estimate risks of groundwater usage impacts.

A flow gauge uncertainty of +/-3-8% has been applied based upon UoM/Theiss (2008).

Basflow Index (BFI) Sensitivity to Groundwater and Runoff End Member ECs, and Flow Gauging Uncertainty

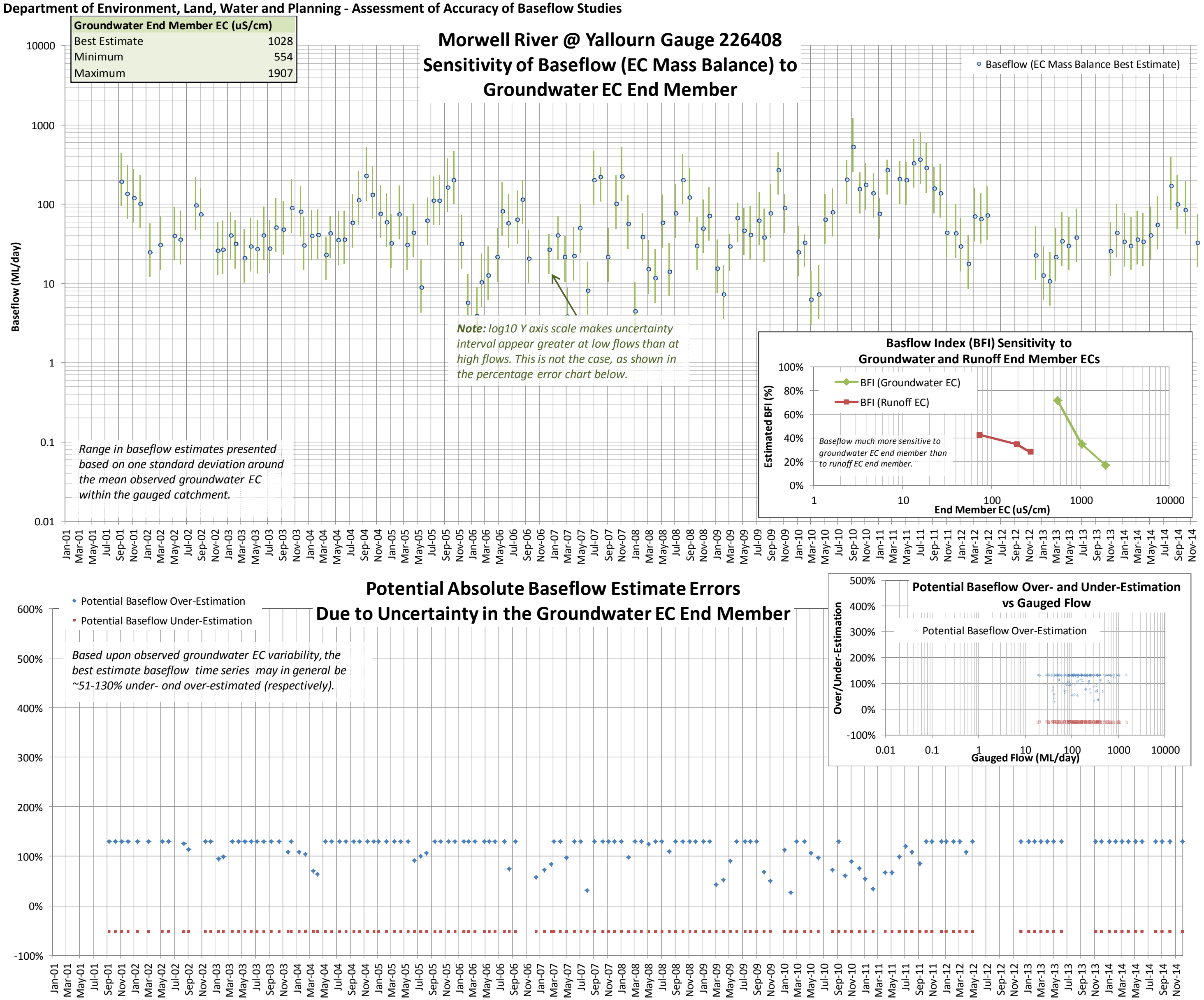
Despite large potential absolute baseflow estimate uncertainty from flow gauging error, baseflow indices are relatively insensitive to flow gauging error.

Potential Baseflow Over- and Under-Estimation vs Gauged Flow

Potential Absolute Baseflow Estimate Errors Due to Uncertainty in the Groundwater EC End Member and Flow Gauging Error

Based upon observed groundwater EC variability and flow gauging error, the best estimate baseflow time series may be ~2% under-estimated, and ~900% over-estimated.

Figure D7-2Baseflow Estimation Sensitivity to Flow Gauge Uncertainty and EC End Members for the Latrobe River at Rosedale



Groundwater End Member EC (uS/cm)	
Best Estimate	1028
Minimum	554
Maximum	1907

Morwell River @ Yallourn Gauge 226408
Sensitivity of Baseflow (EC Mass Balance) to Groundwater EC End Member

***Note:** log10 Y axis scale makes uncertainty interval appear greater at low flows than at high flows. This is not the case, as shown in the percentage error chart below.*

Range in baseflow estimates presented based on one standard deviation around the mean observed groundwater EC within the gauged catchment.

Basflow Index (BFI) Sensitivity to Groundwater and Runoff End Member ECs

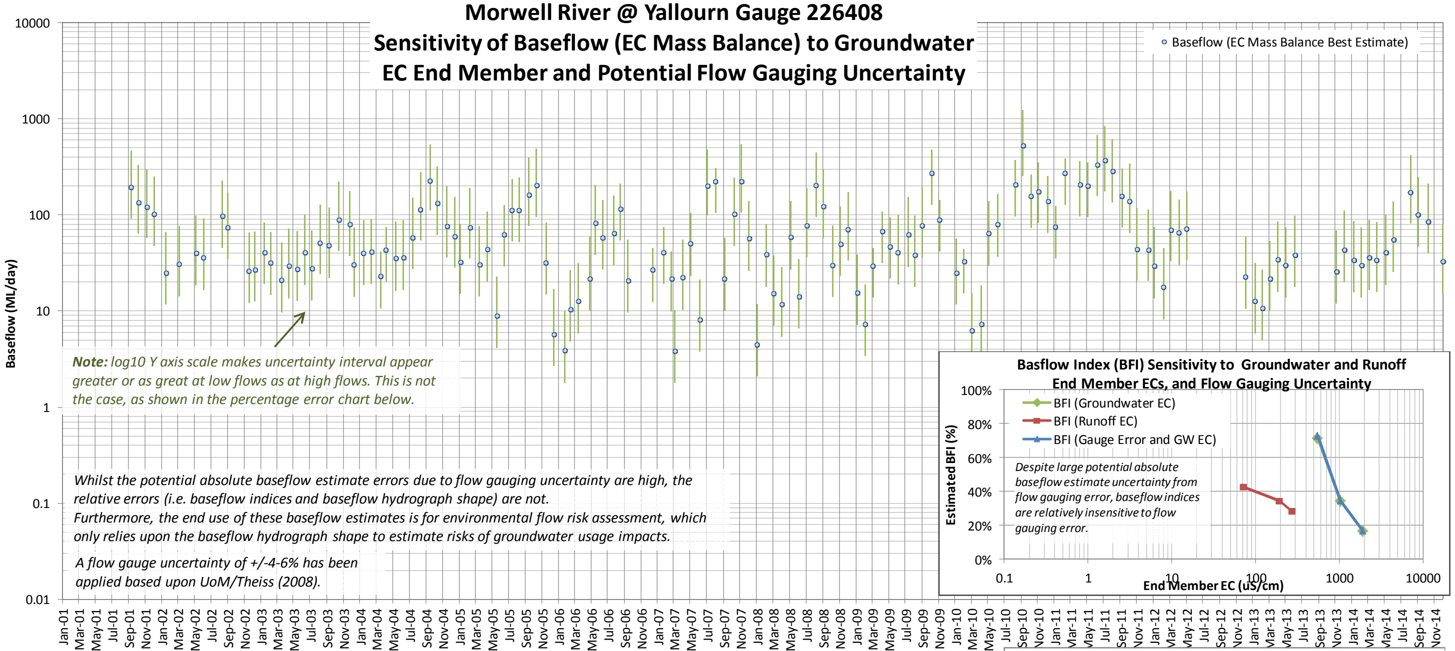
Baseflow much more sensitive to groundwater EC end member than to runoff EC end member.

Potential Absolute Baseflow Estimate Errors
Due to Uncertainty in the Groundwater EC End Member

Based upon observed groundwater EC variability, the best estimate baseflow time series may in general be ~51-130% under- ond over-estimated (respectively).

Potential Baseflow Over- and Under-Estimation vs Gauged Flow

Figure D8-1Baseflow Estimation Sensitivity to EC End Members for the Morwell River at Yallourn

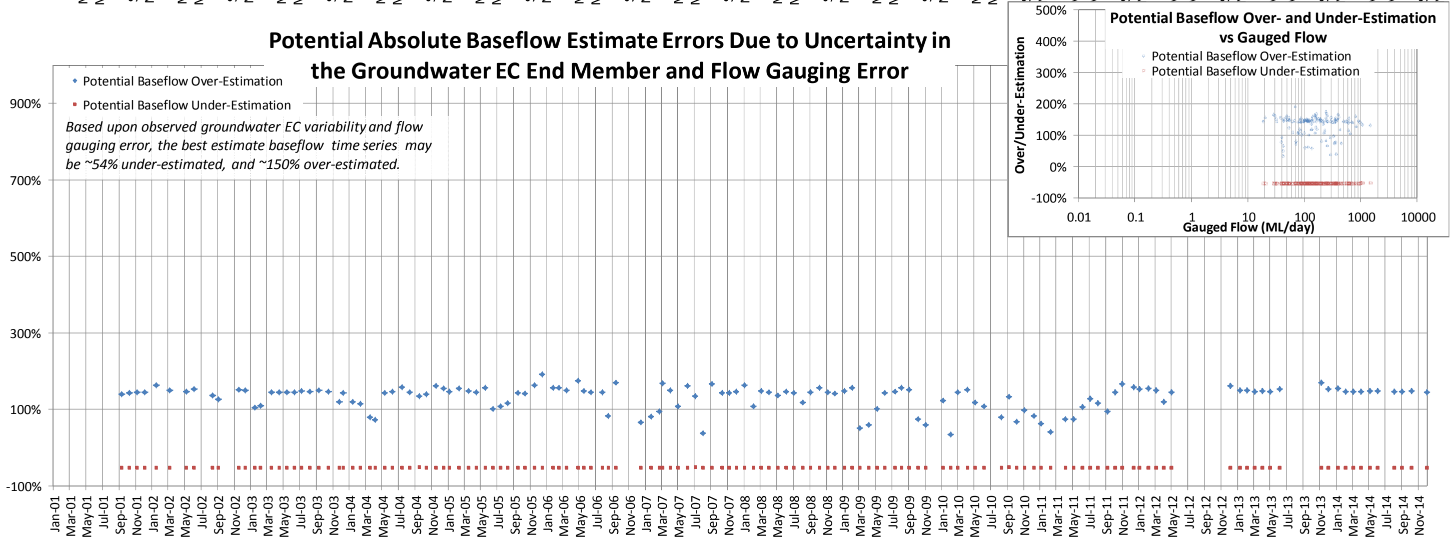


Note: log10 Y axis scale makes uncertainty interval appear greater or as great at low flows as at high flows. This is not the case, as shown in the percentage error chart below.

Whilst the potential absolute baseflow estimate errors due to flow gauging uncertainty are high, the relative errors (i.e. baseflow indices and baseflow hydrograph shape) are not.
Furthermore, the end use of these baseflow estimates is for environmental flow risk assessment, which only relies upon the baseflow hydrograph shape to estimate risks of groundwater usage impacts.

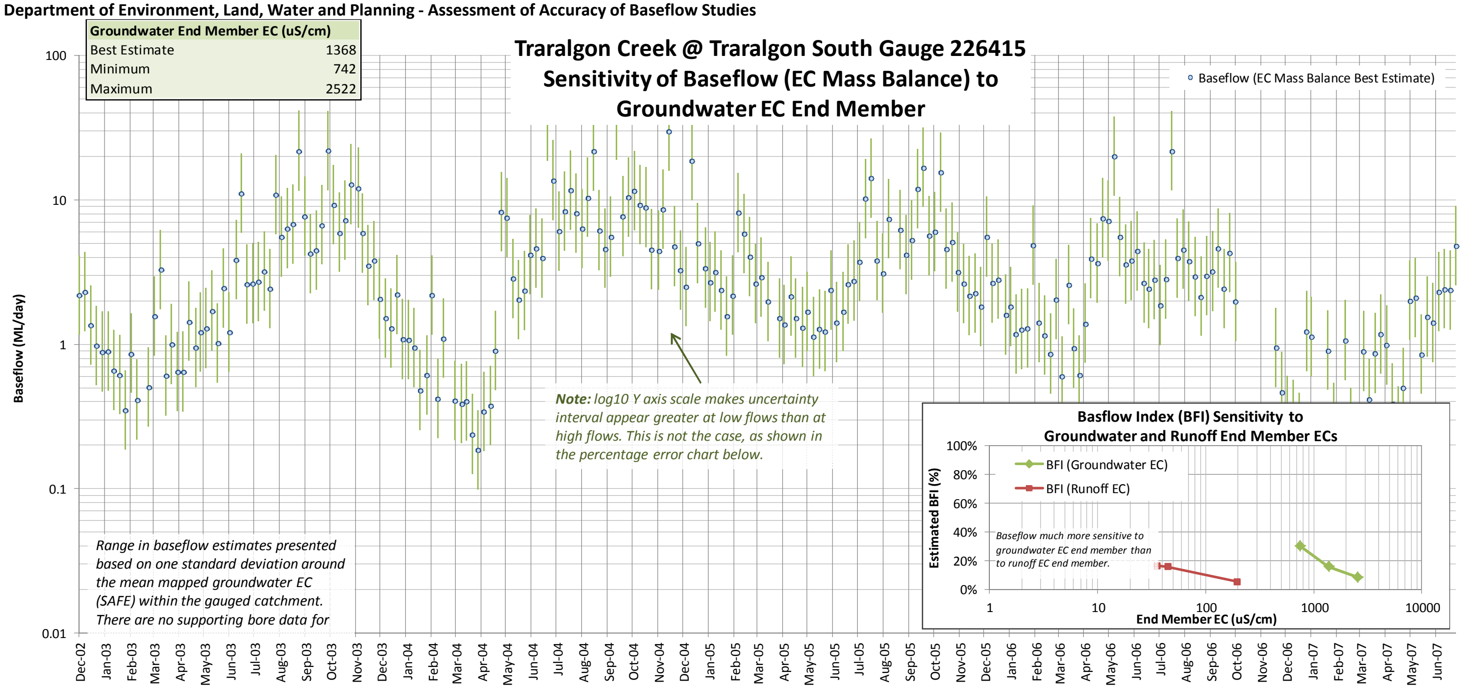
A flow gauge uncertainty of +/-4-6% has been applied based upon UoM/Theiss (2008).

Despite large potential absolute baseflow estimate uncertainty from flow gauging error, baseflow indices are relatively insensitive to flow gauging error.



Based upon observed groundwater EC variability and flow gauging error, the best estimate baseflow time series may be ~54% under-estimated, and ~150% over-estimated.

Figure D8-2Baseflow Estimation Sensitivity to Flow Gauge Uncertainty and EC End Members for the Morwell River at Yallourn



Groundwater End Member EC (uS/cm)	
Best Estimate	1368
Minimum	742
Maximum	2522

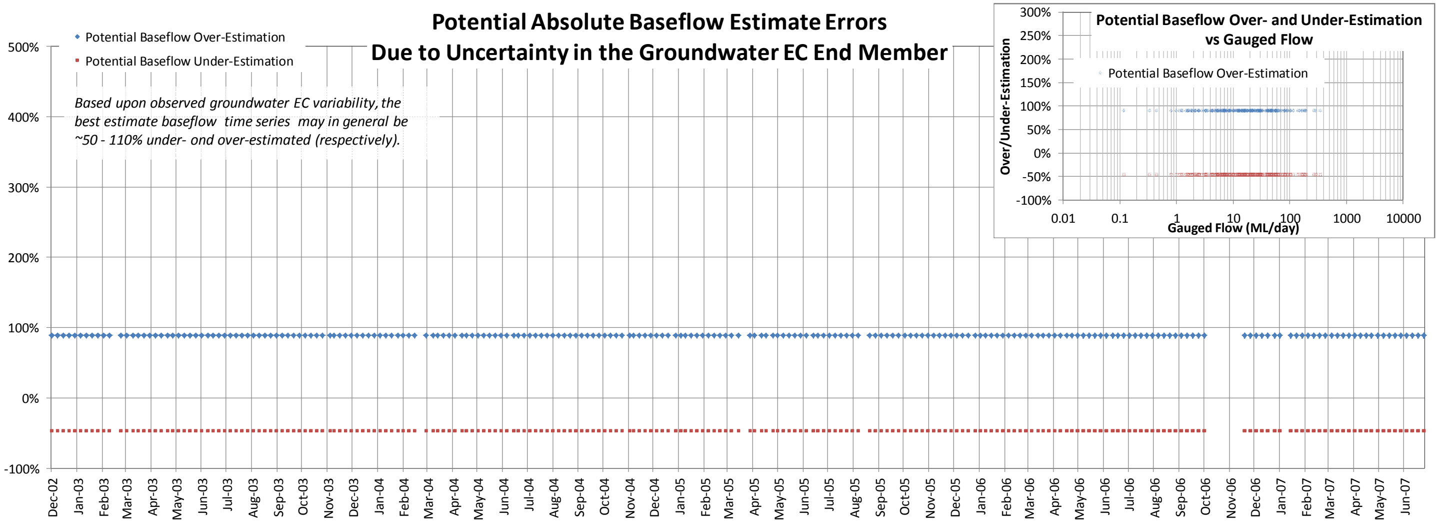
Traralgon Creek @ Traralgon South Gauge 226415 Sensitivity of Baseflow (EC Mass Balance) to Groundwater EC End Member

Note: log10 Y axis scale makes uncertainty interval appear greater at low flows than at high flows. This is not the case, as shown in the percentage error chart below.

Range in baseflow estimates presented based on one standard deviation around the mean mapped groundwater EC (SAFE) within the gauged catchment. There are no supporting bore data for

Basflow Index (BFI) Sensitivity to Groundwater and Runoff End Member ECs

Baseflow much more sensitive to groundwater EC end member than to runoff EC end member.

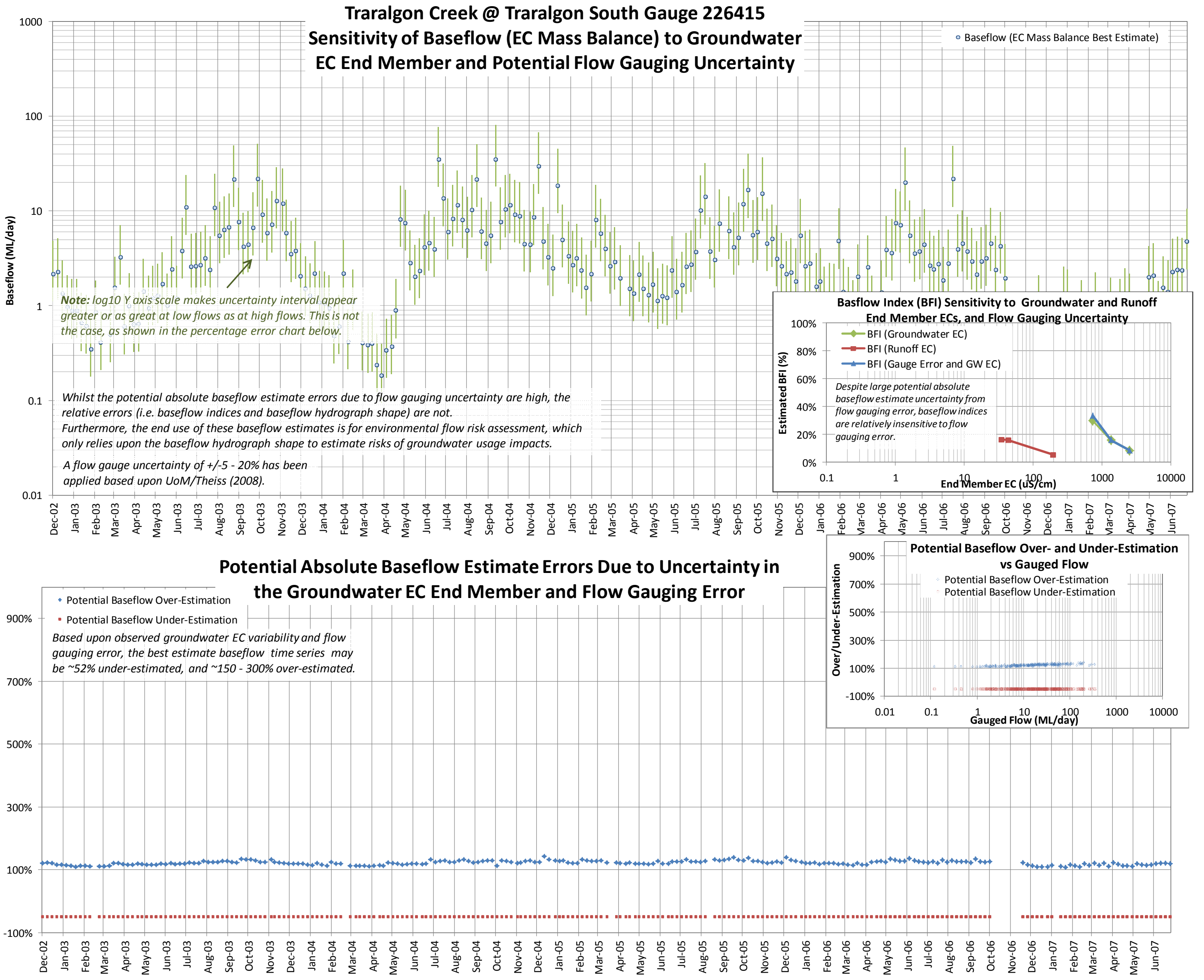


Potential Absolute Baseflow Estimate Errors Due to Uncertainty in the Groundwater EC End Member

Based upon observed groundwater EC variability, the best estimate baseflow time series may in general be ~50 - 110% under- ond over-estimated (respectively).

Potential Baseflow Over- and Under-Estimation vs Gauged Flow

Figure D9-1Baseflow Estimation Sensitivity to EC End Members for the Traralgon Creek at Traralgon South



Traralgon Creek @ Traralgon South Gauge 226415
Sensitivity of Baseflow (EC Mass Balance) to Groundwater EC End Member and Potential Flow Gauging Uncertainty

Note: log10 Y axis scale makes uncertainty interval appear greater or as great at low flows as at high flows. This is not the case, as shown in the percentage error chart below.

Whilst the potential absolute baseflow estimate errors due to flow gauging uncertainty are high, the relative errors (i.e. baseflow indices and baseflow hydrograph shape) are not.
Furthermore, the end use of these baseflow estimates is for environmental flow risk assessment, which only relies upon the baseflow hydrograph shape to estimate risks of groundwater usage impacts.

A flow gauge uncertainty of +/-5 - 20% has been applied based upon UoM/Theiss (2008).

Basflow Index (BFI) Sensitivity to Groundwater and Runoff End Member ECs, and Flow Gauging Uncertainty

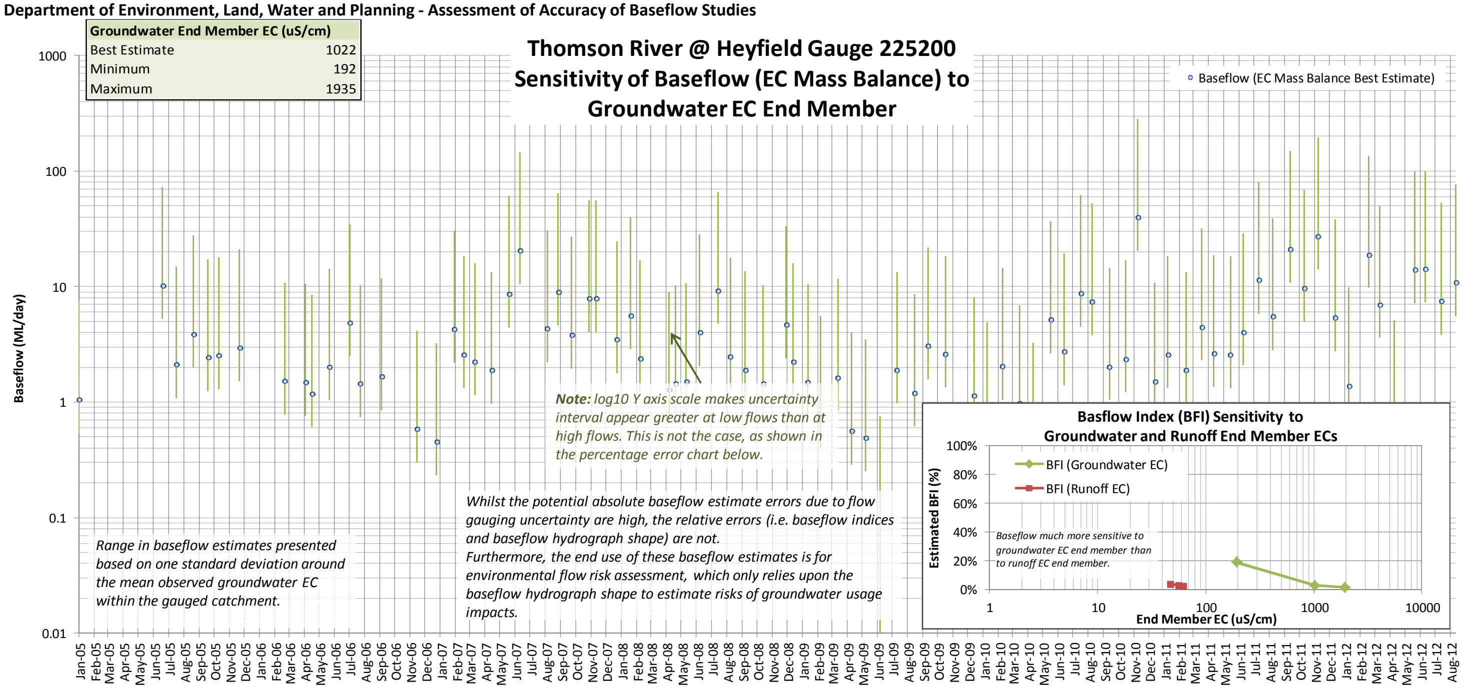
Despite large potential absolute baseflow estimate uncertainty from flow gauging error, baseflow indices are relatively insensitive to flow gauging error.

Potential Absolute Baseflow Estimate Errors Due to Uncertainty in the Groundwater EC End Member and Flow Gauging Error

Based upon observed groundwater EC variability and flow gauging error, the best estimate baseflow time series may be ~52% under-estimated, and ~150 - 300% over-estimated.

Potential Baseflow Over- and Under-Estimation vs Gauged Flow

Figure D9-2Baseflow Estimation Sensitivity to Flow Gauge Uncertainty and EC End Members for the Traralgon Creek at Traralgon South



Groundwater End Member EC (uS/cm)	
Best Estimate	1022
Minimum	192
Maximum	1935

Thomson River @ Heyfield Gauge 225200 Sensitivity of Baseflow (EC Mass Balance) to Groundwater EC End Member

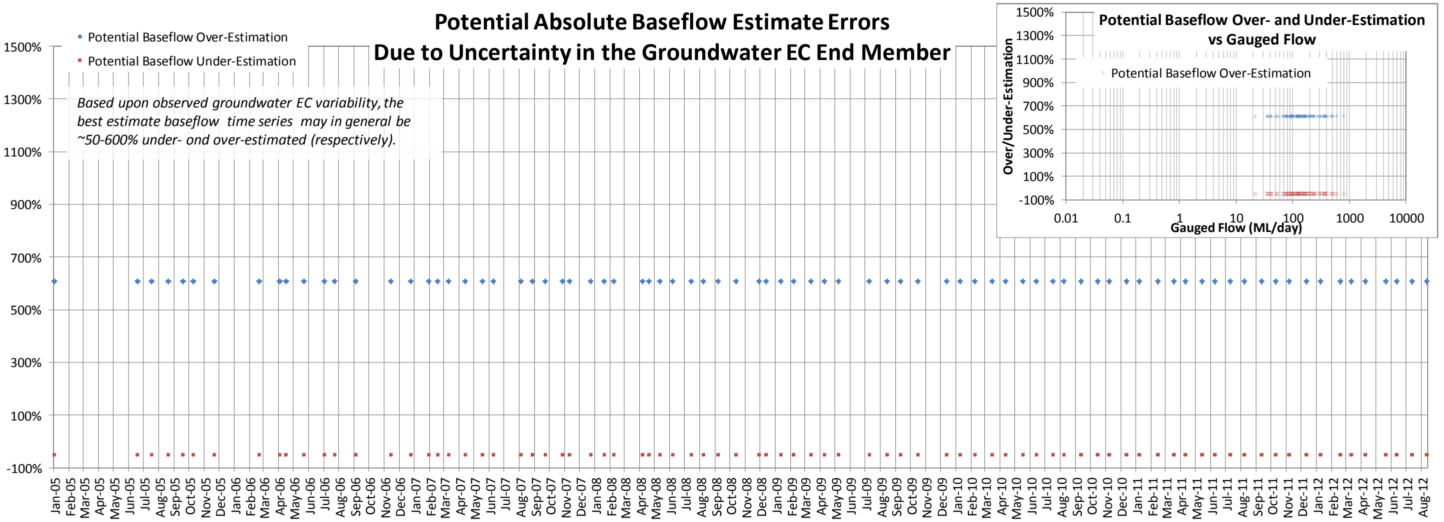
Note: *log10 Y axis scale makes uncertainty interval appear greater at low flows than at high flows. This is not the case, as shown in the percentage error chart below.*

Whilst the potential absolute baseflow estimate errors due to flow gauging uncertainty are high, the relative errors (i.e. baseflow indices and baseflow hydrograph shape) are not.
Furthermore, the end use of these baseflow estimates is for environmental flow risk assessment, which only relies upon the baseflow hydrograph shape to estimate risks of groundwater usage impacts.

Range in baseflow estimates presented based on one standard deviation around the mean observed groundwater EC within the gauged catchment.

Basflow Index (BFI) Sensitivity to Groundwater and Runoff End Member ECs

Baseflow much more sensitive to groundwater EC end member than to runoff EC end member.

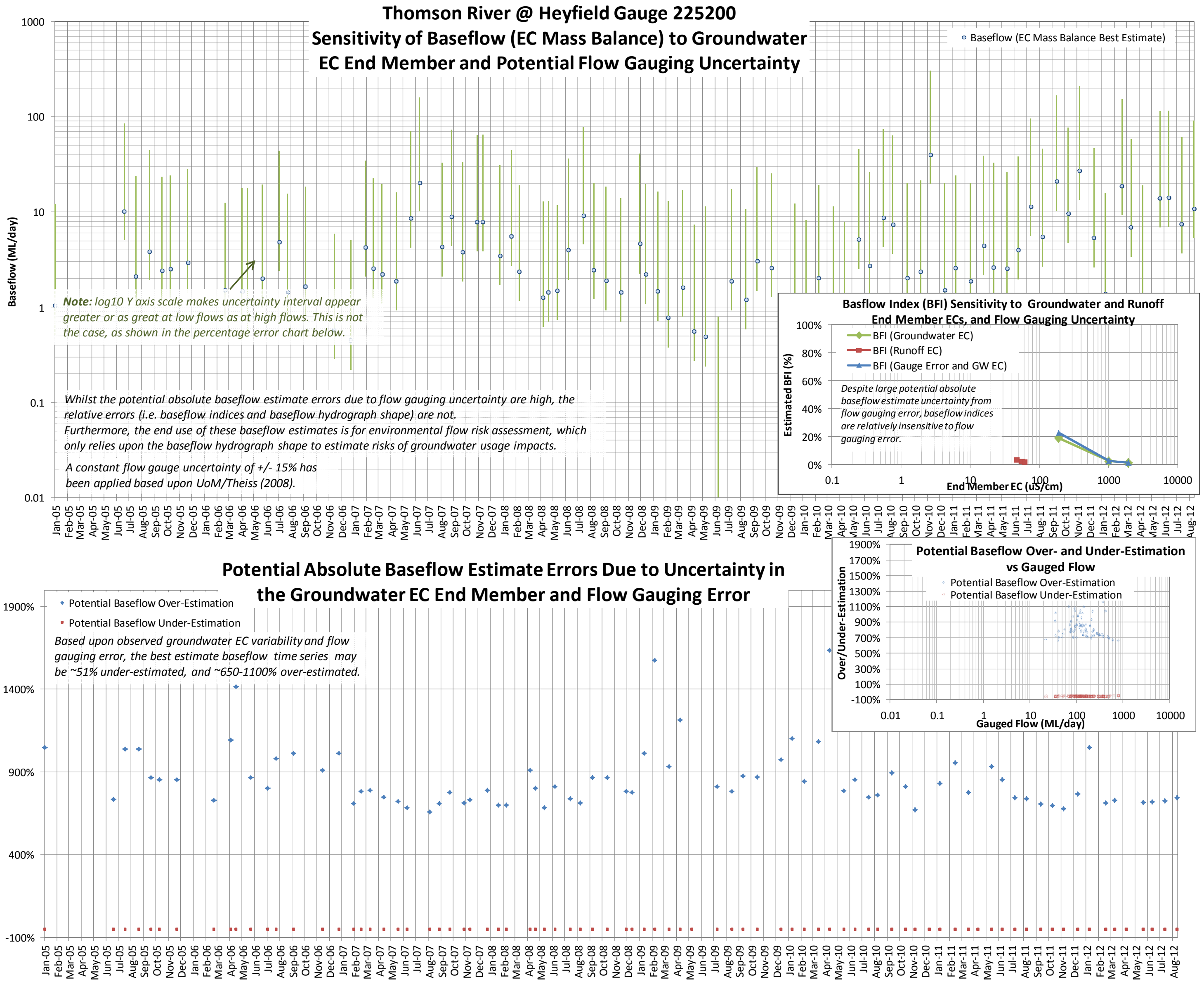


Potential Absolute Baseflow Estimate Errors Due to Uncertainty in the Groundwater EC End Member

Based upon observed groundwater EC variability, the best estimate baseflow time series may in general be ~50-600% under- ond over-estimated (respectively).

Potential Baseflow Over- and Under-Estimation vs Gauged Flow

Figure D10-1Baseflow Estimation Sensitivity to EC End Members for the Thomson River @ Heyfield



Thomson River @ Heyfield Gauge 225200
Sensitivity of Baseflow (EC Mass Balance) to Groundwater EC End Member and Potential Flow Gauging Uncertainty

Note: *log10 Y axis scale makes uncertainty interval appear greater or as great at low flows as at high flows. This is not the case, as shown in the percentage error chart below.*

Whilst the potential absolute baseflow estimate errors due to flow gauging uncertainty are high, the relative errors (i.e. baseflow indices and baseflow hydrograph shape) are not.
Furthermore, the end use of these baseflow estimates is for environmental flow risk assessment, which only relies upon the baseflow hydrograph shape to estimate risks of groundwater usage impacts.

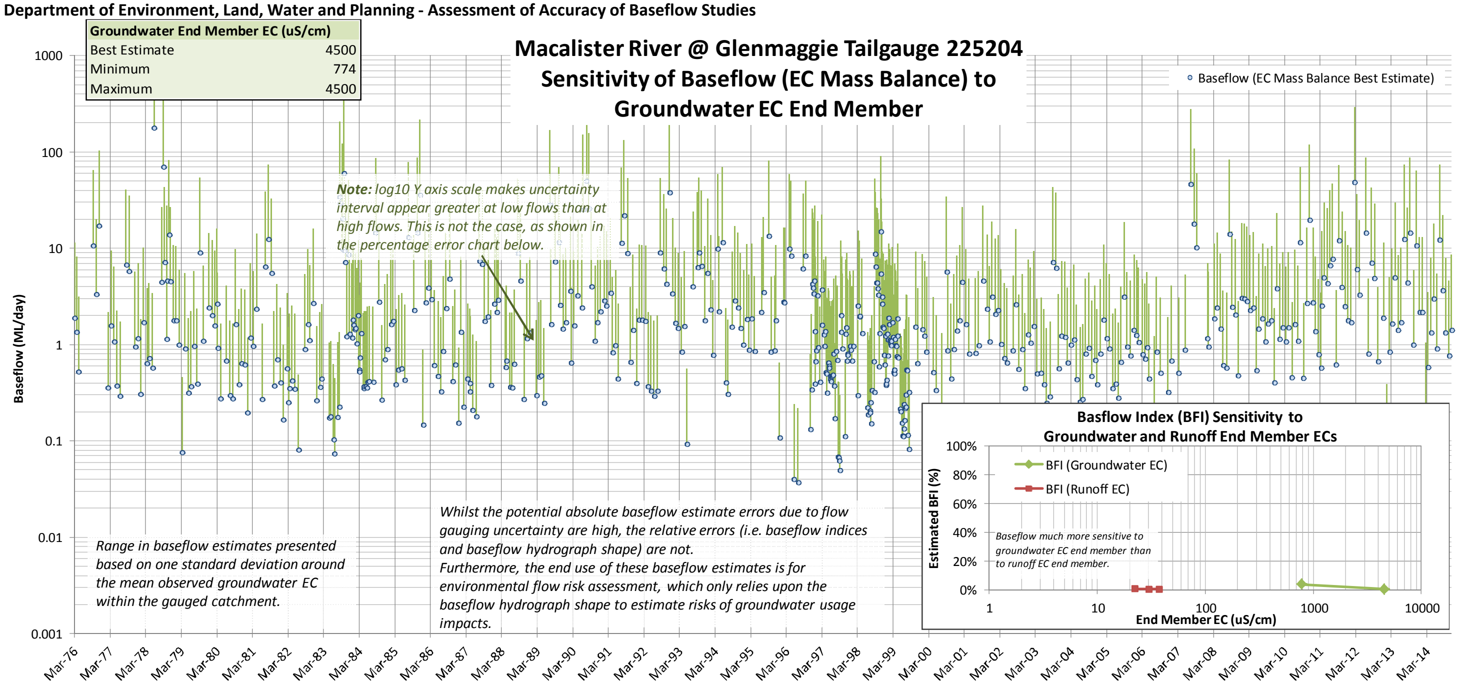
A constant flow gauge uncertainty of +/- 15% has been applied based upon UoM/Theiss (2008).

Despite large potential absolute baseflow estimate uncertainty from flow gauging error, baseflow indices are relatively insensitive to flow gauging error.

Potential Absolute Baseflow Estimate Errors Due to Uncertainty in the Groundwater EC End Member and Flow Gauging Error

Based upon observed groundwater EC variability and flow gauging error, the best estimate baseflow time series may be ~51% under-estimated, and ~650-1100% over-estimated.

Figure D10-2Baseflow Estimation Sensitivity to Flow Gauge Uncertainty and EC End Members for the Thomson River @ Heyfield



Groundwater End Member EC (uS/cm)	
Best Estimate	4500
Minimum	774
Maximum	4500

Macalister River @ Glenmaggie Tailgauge 225204 Sensitivity of Baseflow (EC Mass Balance) to Groundwater EC End Member

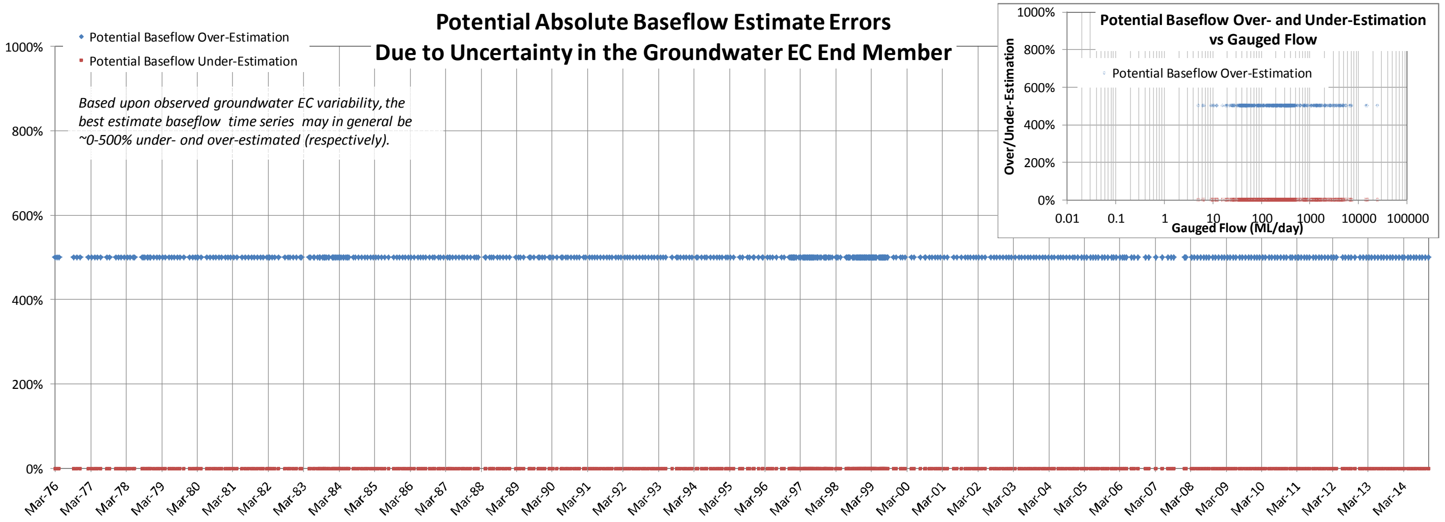
Note: log10 Y axis scale makes uncertainty interval appear greater at low flows than at high flows. This is not the case, as shown in the percentage error chart below.

Range in baseflow estimates presented based on one standard deviation around the mean observed groundwater EC within the gauged catchment.

Whilst the potential absolute baseflow estimate errors due to flow gauging uncertainty are high, the relative errors (i.e. baseflow indices and baseflow hydrograph shape) are not. Furthermore, the end use of these baseflow estimates is for environmental flow risk assessment, which only relies upon the baseflow hydrograph shape to estimate risks of groundwater usage impacts.

Basflow Index (BFI) Sensitivity to Groundwater and Runoff End Member ECs

Baseflow much more sensitive to groundwater EC end member than to runoff EC end member.

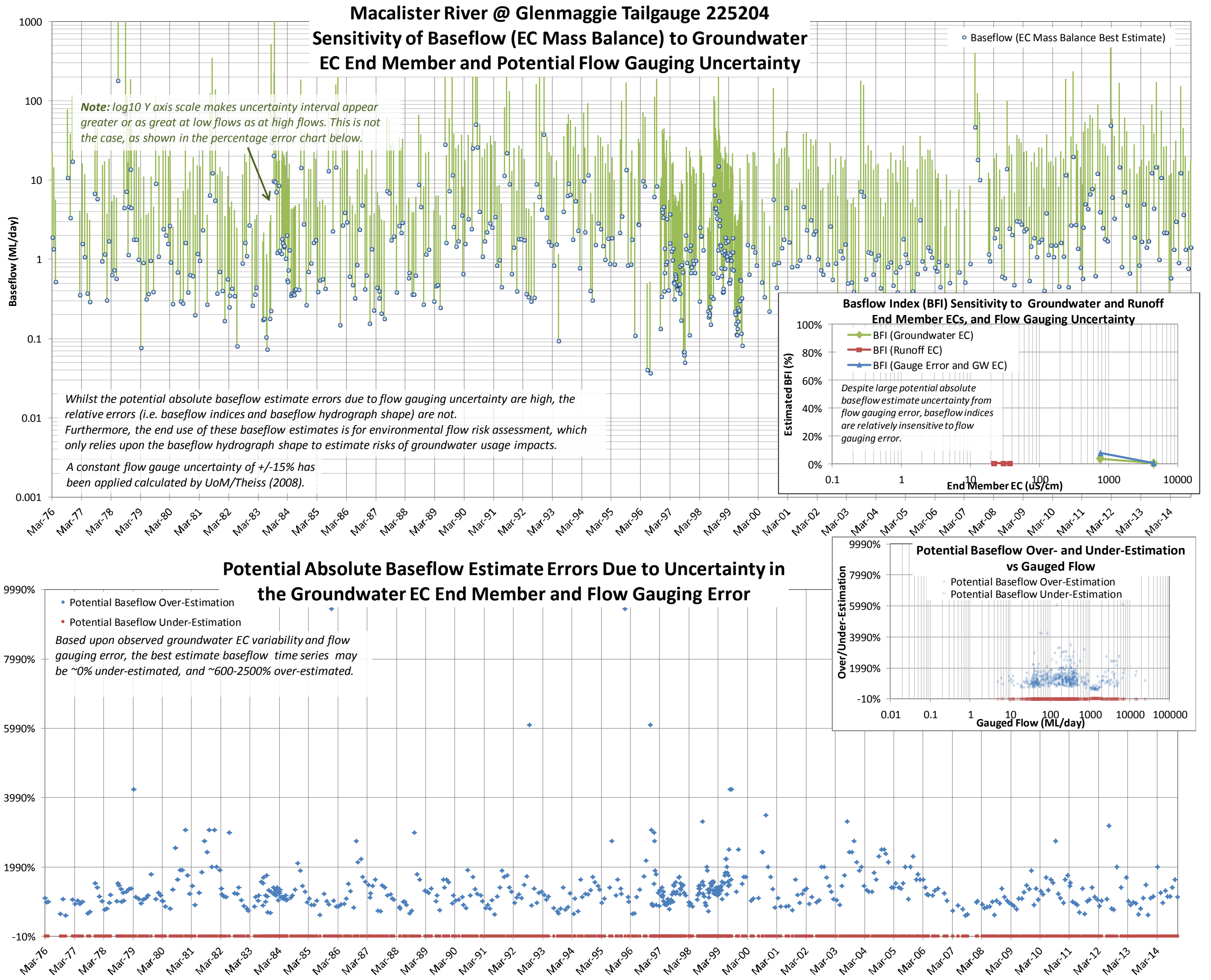


Potential Absolute Baseflow Estimate Errors Due to Uncertainty in the Groundwater EC End Member

Based upon observed groundwater EC variability, the best estimate baseflow time series may in general be ~0-500% under- ond over-estimated (respectively).

Potential Baseflow Over- and Under-Estimation vs Gauged Flow

Figure D11-1Baseflow Estimation Sensitivity to EC End Members for the Macalister River at Glenmaggie



***Note:** log10 Y axis scale makes uncertainty interval appear greater or as great at low flows as at high flows. This is not the case, as shown in the percentage error chart below.*

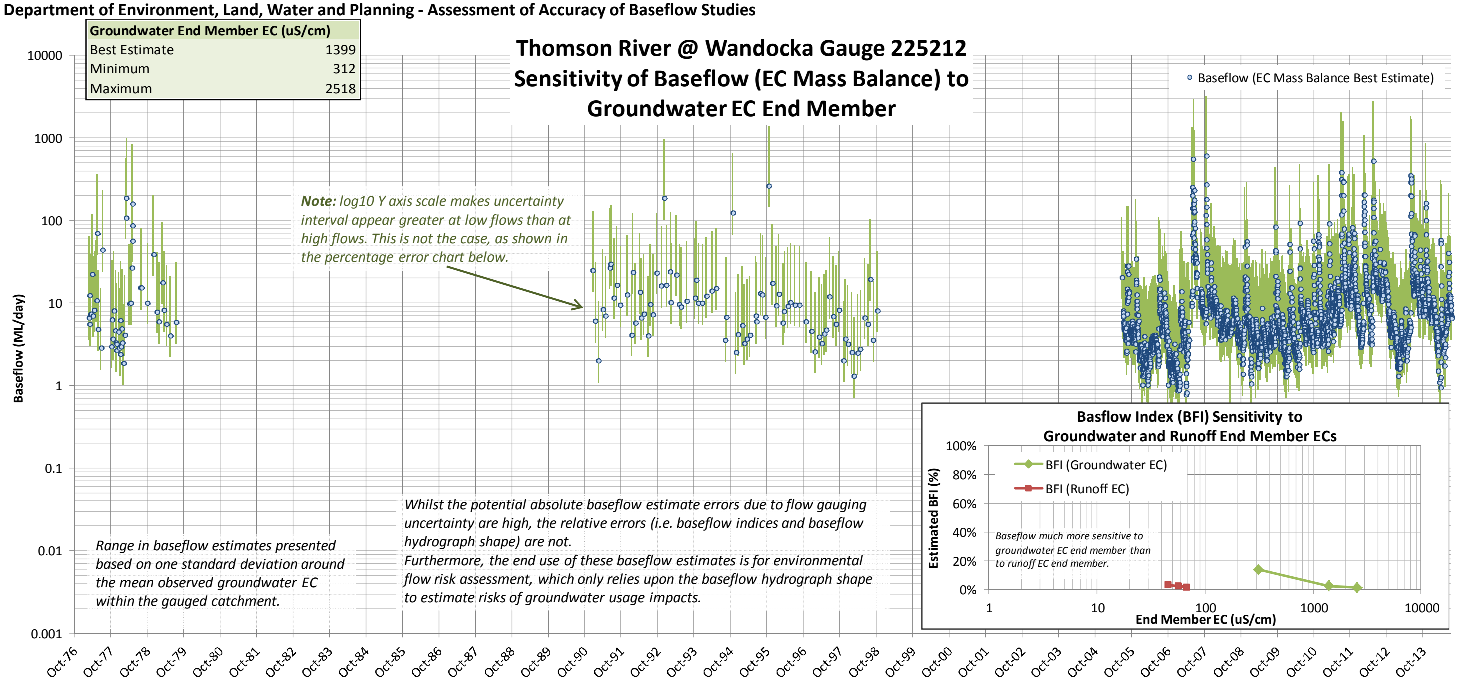
Whilst the potential absolute baseflow estimate errors due to flow gauging uncertainty are high, the relative errors (i.e. baseflow indices and baseflow hydrograph shape) are not.
Furthermore, the end use of these baseflow estimates is for environmental flow risk assessment, which only relies upon the baseflow hydrograph shape to estimate risks of groundwater usage impacts.

A constant flow gauge uncertainty of +/-15% has been applied calculated by UoM/Theiss (2008).

Despite large potential absolute baseflow estimate uncertainty from flow gauging error, baseflow indices are relatively insensitive to flow gauging error.

Based upon observed groundwater EC variability and flow gauging error, the best estimate baseflow time series may be ~0% under-estimated, and ~600-2500% over-estimated.

Figure D11-2Baseflow Estimation Sensitivity to Flow Gauge Uncertainty and EC End Members for the Macalister River at Glenmaggie



Groundwater End Member EC (uS/cm)	
Best Estimate	1399
Minimum	312
Maximum	2518

Thomson River @ Wandocka Gauge 225212 Sensitivity of Baseflow (EC Mass Balance) to Groundwater EC End Member

Note: *log10 Y axis scale makes uncertainty interval appear greater at low flows than at high flows. This is not the case, as shown in the percentage error chart below.*

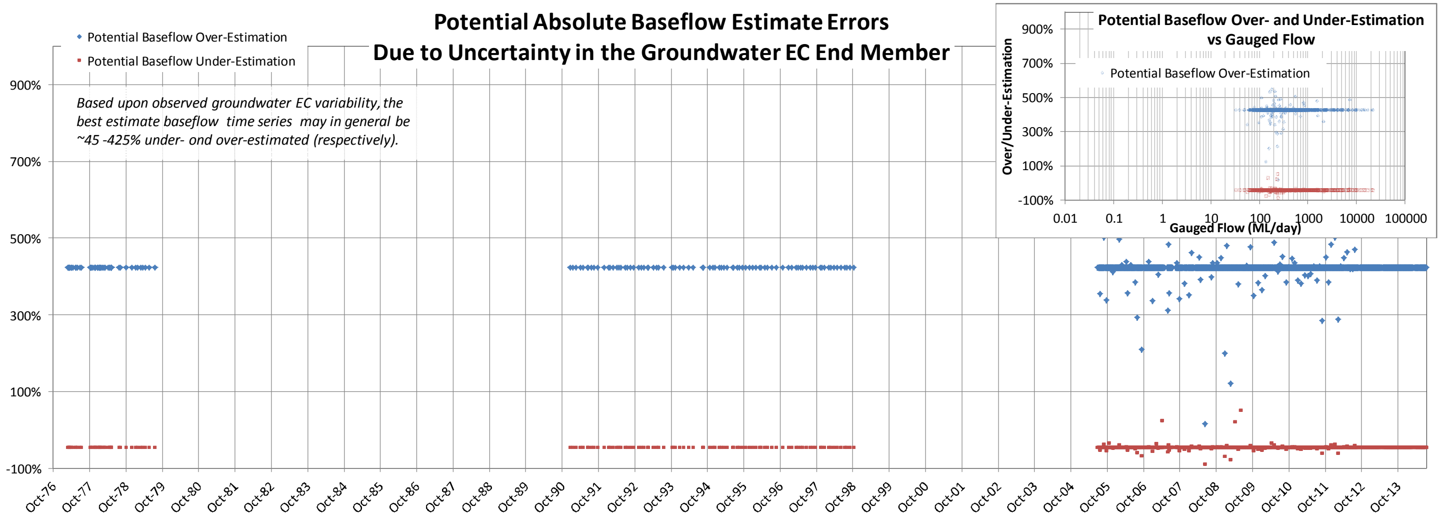
Range in baseflow estimates presented based on one standard deviation around the mean observed groundwater EC within the gauged catchment.

Whilst the potential absolute baseflow estimate errors due to flow gauging uncertainty are high, the relative errors (i.e. baseflow indices and baseflow hydrograph shape) are not.

Furthermore, the end use of these baseflow estimates is for environmental flow risk assessment, which only relies upon the baseflow hydrograph shape to estimate risks of groundwater usage impacts.

Basflow Index (BFI) Sensitivity to Groundwater and Runoff End Member ECs

Baseflow much more sensitive to groundwater EC end member than to runoff EC end member.

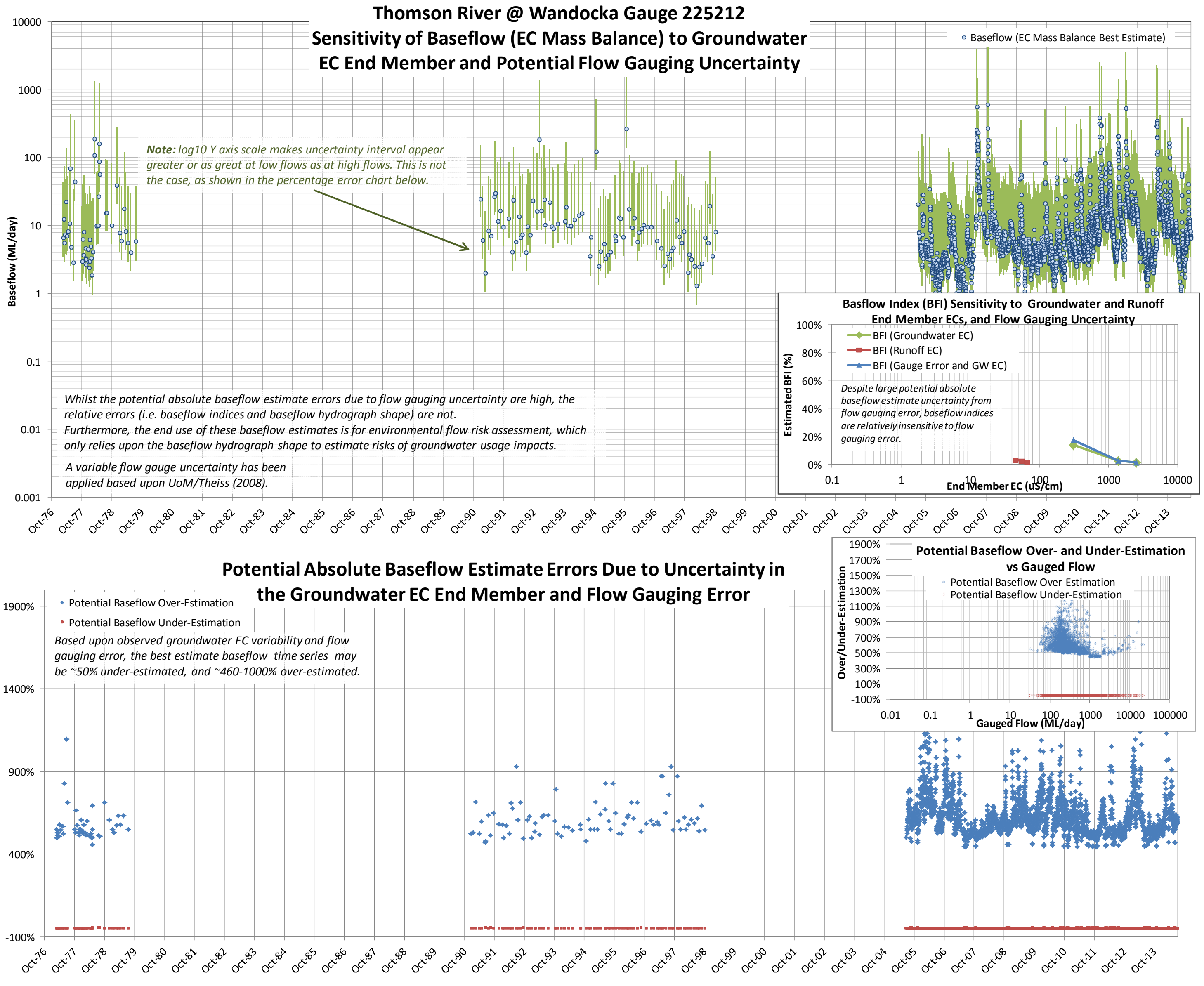


Potential Absolute Baseflow Estimate Errors Due to Uncertainty in the Groundwater EC End Member

Based upon observed groundwater EC variability, the best estimate baseflow time series may in general be ~45 -425% under- ond over-estimated (respectively).

Potential Baseflow Over- and Under-Estimation vs Gauged Flow

Figure D12-1Baseflow Estimation Sensitivity to EC End Members for the Thomson River @ Wandocka


Thomson River @ Wandocka Gauge 225212
Sensitivity of Baseflow (EC Mass Balance) to Groundwater
EC End Member and Potential Flow Gauging Uncertainty

Note: log10 Y axis scale makes uncertainty interval appear greater or as great at low flows as at high flows. This is not the case, as shown in the percentage error chart below.

Whilst the potential absolute baseflow estimate errors due to flow gauging uncertainty are high, the relative errors (i.e. baseflow indices and baseflow hydrograph shape) are not.
Furthermore, the end use of these baseflow estimates is for environmental flow risk assessment, which only relies upon the baseflow hydrograph shape to estimate risks of groundwater usage impacts.

A variable flow gauge uncertainty has been applied based upon UoM/Theiss (2008).

Basflow Index (BFI) Sensitivity to Groundwater and Runoff End Member ECs, and Flow Gauging Uncertainty

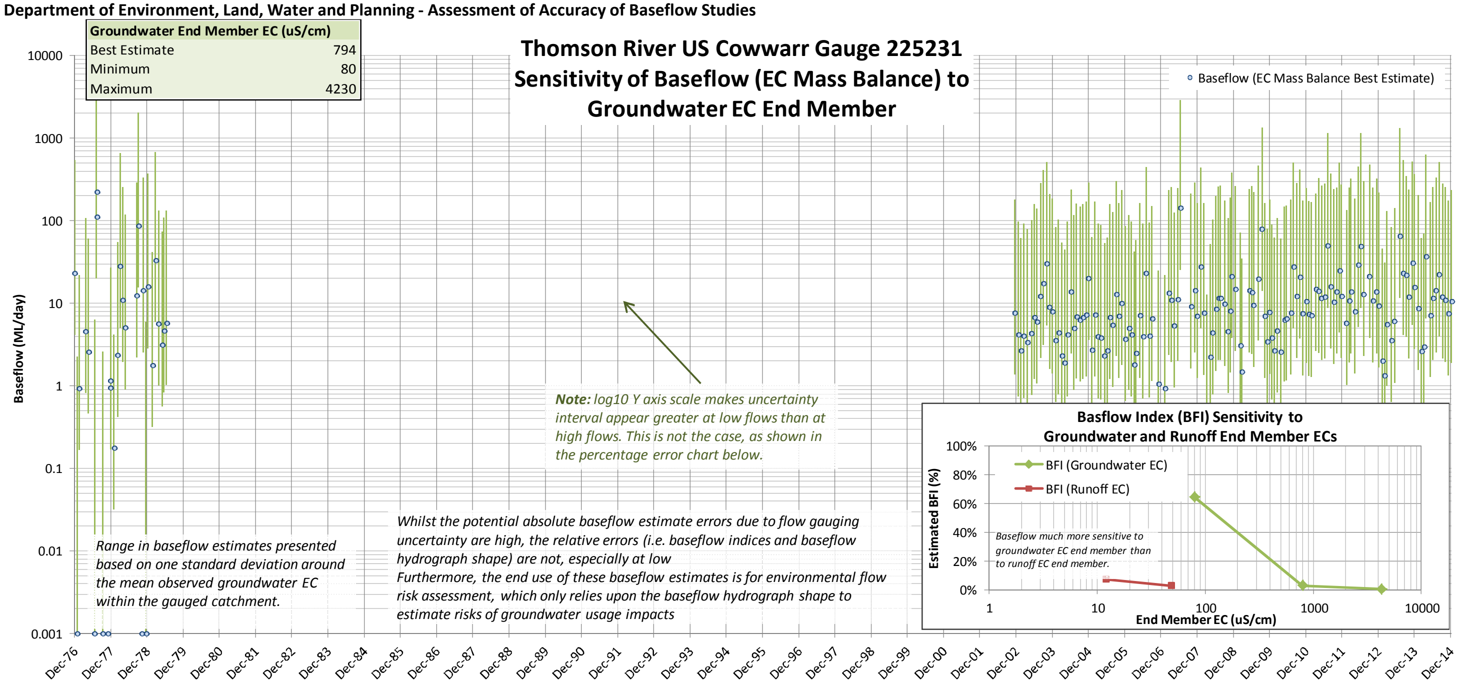
Despite large potential absolute baseflow estimate uncertainty from flow gauging error, baseflow indices are relatively insensitive to flow gauging error.

Potential Absolute Baseflow Estimate Errors Due to Uncertainty in the Groundwater EC End Member and Flow Gauging Error

Based upon observed groundwater EC variability and flow gauging error, the best estimate baseflow time series may be ~50% under-estimated, and ~460-1000% over-estimated.

Potential Baseflow Over- and Under-Estimation vs Gauged Flow

Figure D12-2Baseflow Estimation Sensitivity to Flow Gauge Uncertainty and EC End Members for the Thomson River @ Wandocka



Thomson River US Cowwarr Gauge 225231 Sensitivity of Baseflow (EC Mass Balance) to Groundwater EC End Member

Groundwater End Member EC (uS/cm)	
Best Estimate	794
Minimum	80
Maximum	4230

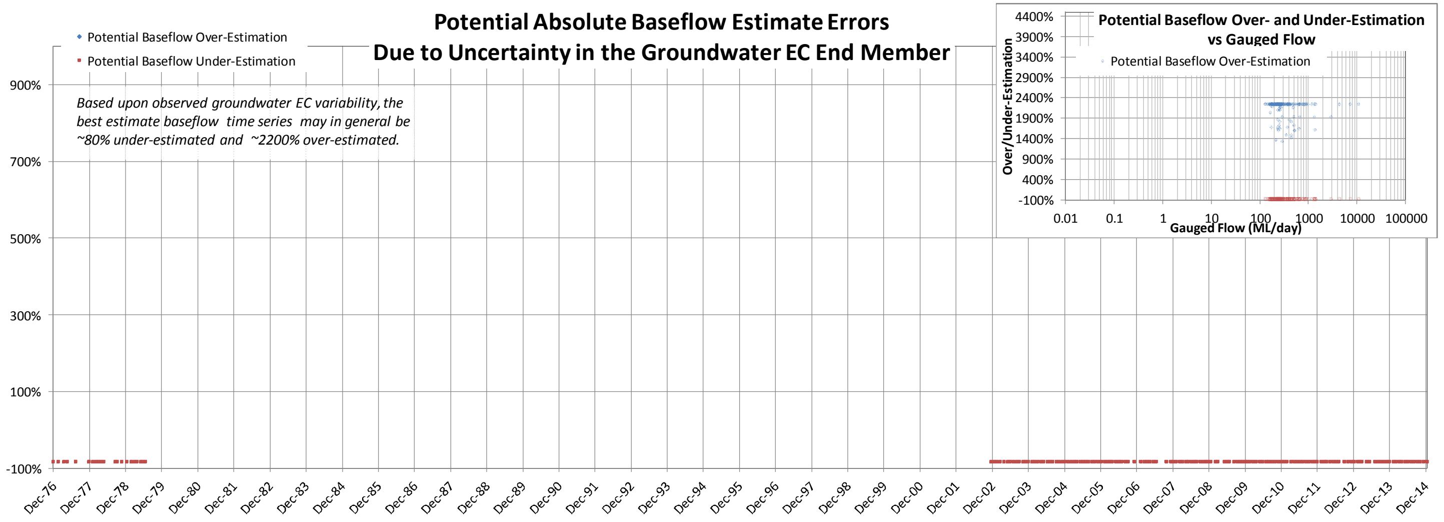
***Note:** log10 Y axis scale makes uncertainty interval appear greater at low flows than at high flows. This is not the case, as shown in the percentage error chart below.*

Range in baseflow estimates presented based on one standard deviation around the mean observed groundwater EC within the gauged catchment.

Whilst the potential absolute baseflow estimate errors due to flow gauging uncertainty are high, the relative errors (i.e. baseflow indices and baseflow hydrograph shape) are not, especially at low
Furthermore, the end use of these baseflow estimates is for environmental flow risk assessment, which only relies upon the baseflow hydrograph shape to estimate risks of groundwater usage impacts

Basflow Index (BFI) Sensitivity to Groundwater and Runoff End Member ECs

Baseflow much more sensitive to groundwater EC end member than to runoff EC end member.

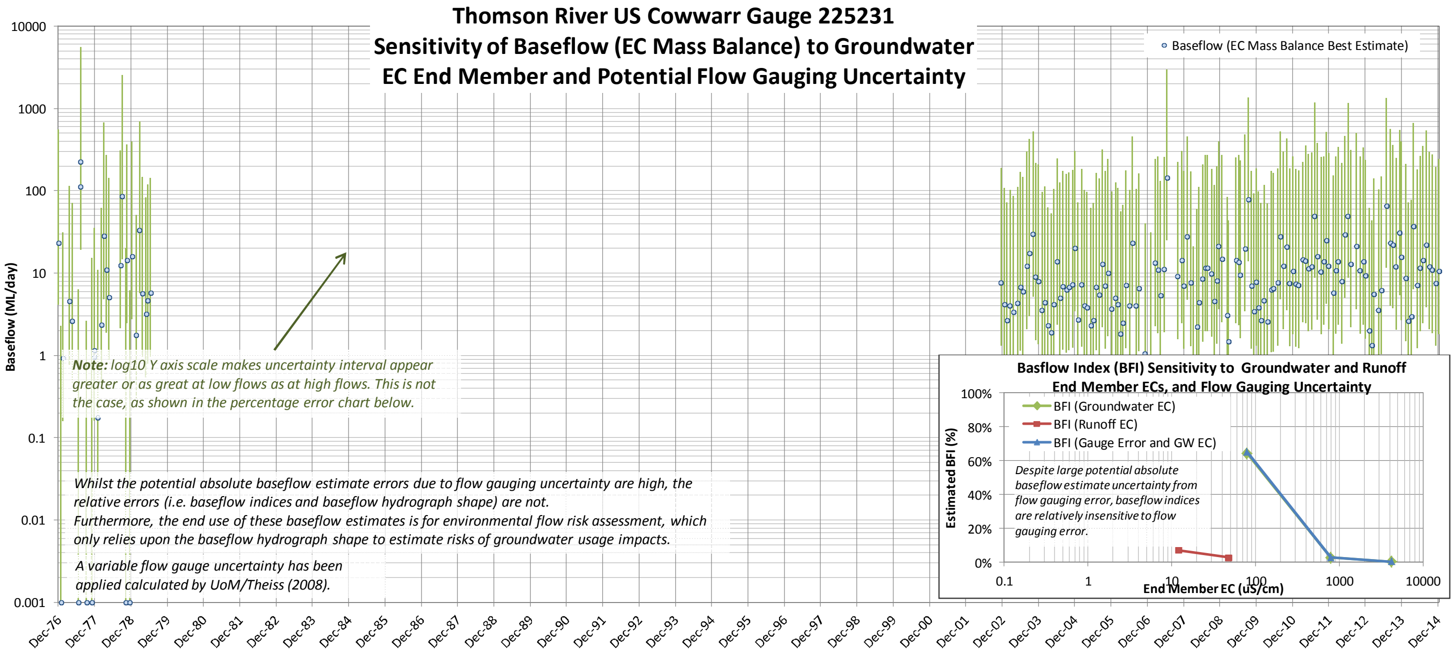


Potential Absolute Baseflow Estimate Errors Due to Uncertainty in the Groundwater EC End Member

Based upon observed groundwater EC variability, the best estimate baseflow time series may in general be ~80% under-estimated and ~2200% over-estimated.

Potential Baseflow Over- and Under-Estimation vs Gauged Flow

Figure D13-1Baseflow Estimation Sensitivity to EC End Members for the Thomson River U/S Cowwarr Weir


Thomson River US Cowwarr Gauge 225231
Sensitivity of Baseflow (EC Mass Balance) to Groundwater EC End Member and Potential Flow Gauging Uncertainty

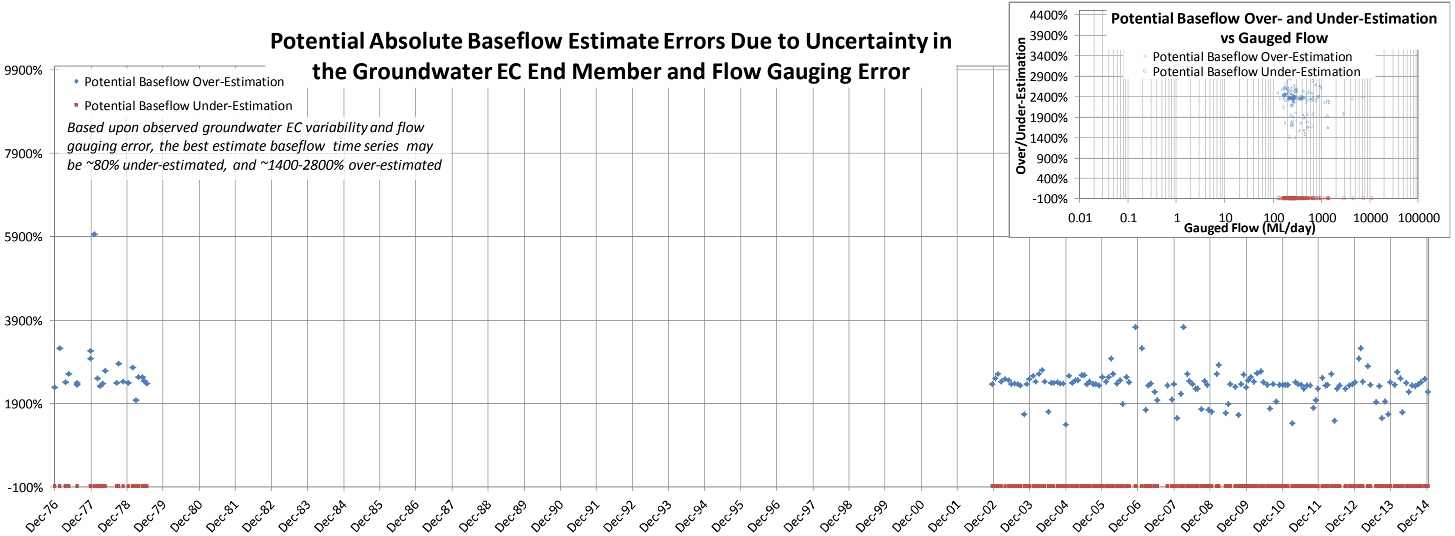
Note: *log10 Y axis scale makes uncertainty interval appear greater or as great at low flows as at high flows. This is not the case, as shown in the percentage error chart below.*

Whilst the potential absolute baseflow estimate errors due to flow gauging uncertainty are high, the relative errors (i.e. baseflow indices and baseflow hydrograph shape) are not.
Furthermore, the end use of these baseflow estimates is for environmental flow risk assessment, which only relies upon the baseflow hydrograph shape to estimate risks of groundwater usage impacts.

A variable flow gauge uncertainty has been applied calculated by UoM/Theiss (2008).

Basflow Index (BFI) Sensitivity to Groundwater and Runoff End Member ECs, and Flow Gauging Uncertainty

Despite large potential absolute baseflow estimate uncertainty from flow gauging error, baseflow indices are relatively insensitive to flow gauging error.

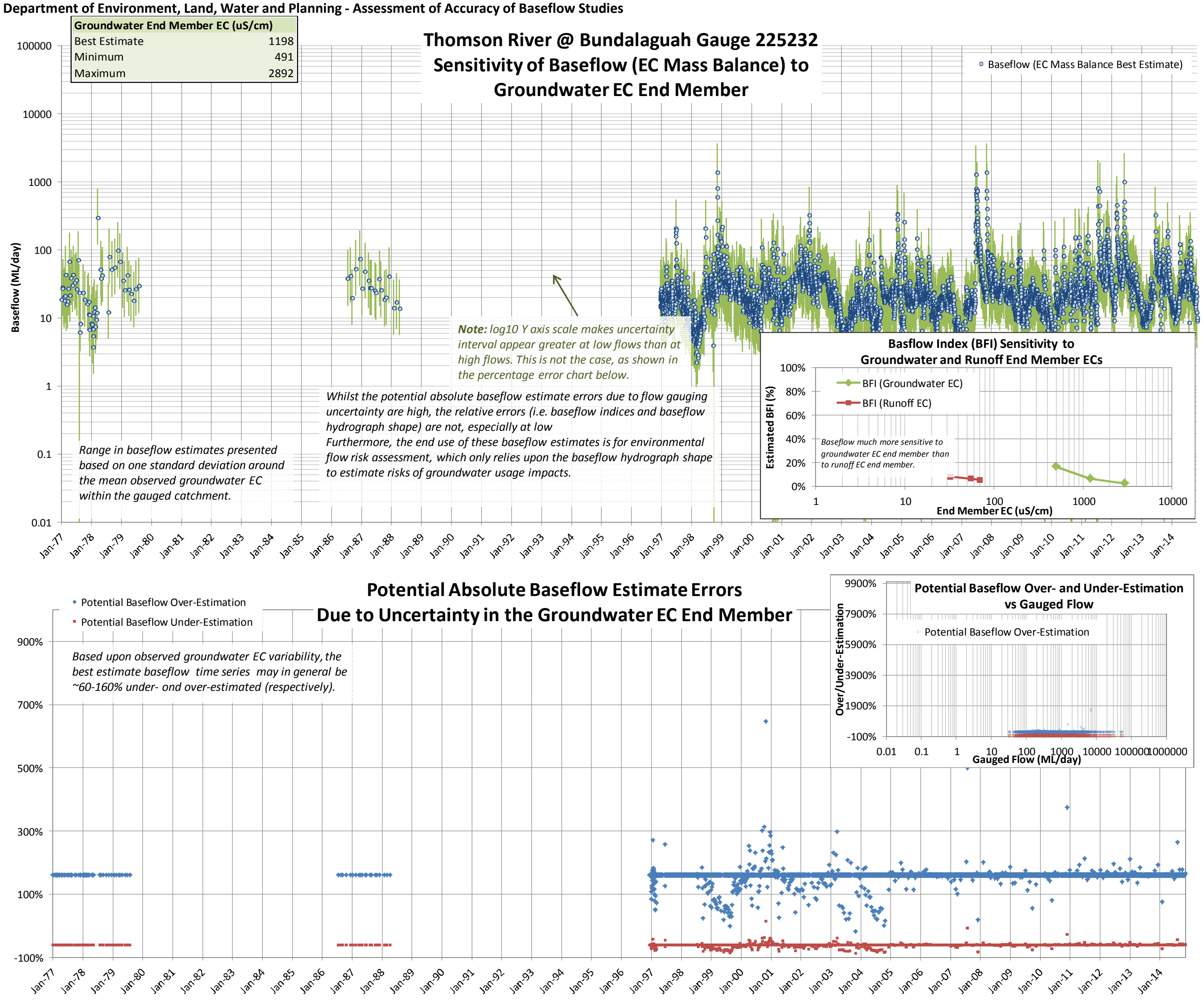

Potential Absolute Baseflow Estimate Errors Due to Uncertainty in the Groundwater EC End Member and Flow Gauging Error

Based upon observed groundwater EC variability and flow gauging error, the best estimate baseflow time series may be ~80% under-estimated, and ~1400-2800% over-estimated

Potential Baseflow Over- and Under-Estimation vs Gauged Flow

Figure D13-2Baseflow Estimation Sensitivity to Flow Gauge Uncertainty and EC End Members for the Thomson River U/S Cowwarr Weir

Department of Environment, Land, Water and Planning - Assessment of Accuracy of Baseflow Studies



Groundwater End Member EC (uS/cm)	
Best Estimate	1198
Minimum	491
Maximum	2892

Note: log10 Y axis scale makes uncertainty interval appear greater at low flows than at high flows. This is not the case, as shown in the percentage error chart below.

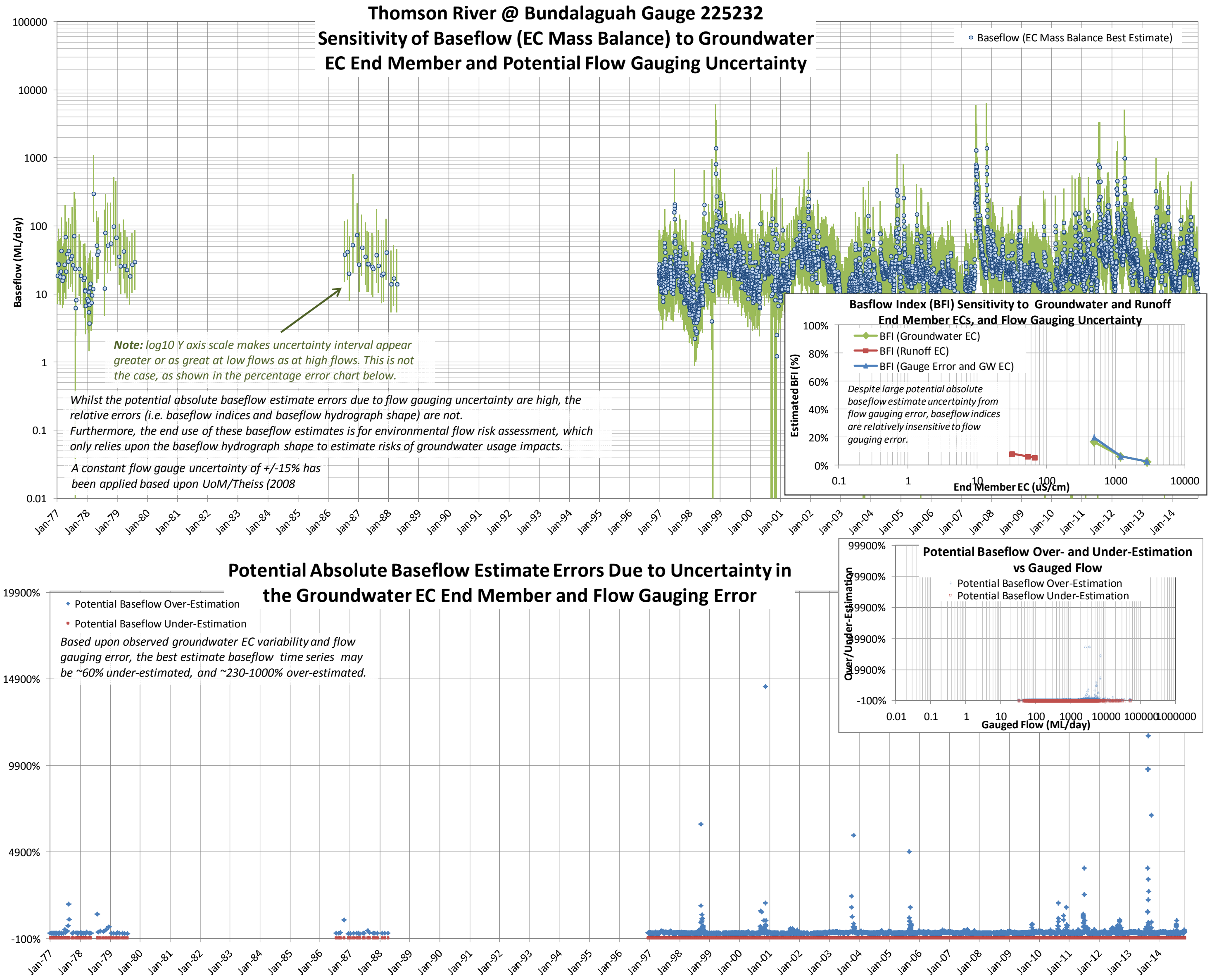
Whilst the potential absolute baseflow estimate errors due to flow gauging uncertainty are high, the relative errors (i.e. baseflow indices and baseflow hydrograph shape) are not, especially at low
Furthermore, the end use of these baseflow estimates is for environmental flow risk assessment, which only relies upon the baseflow hydrograph shape to estimate risks of groundwater usage impacts.

Range in baseflow estimates presented based on one standard deviation around the mean observed groundwater EC within the gauged catchment.

Baseflow much more sensitive to groundwater EC end member than to runoff EC end member.

Based upon observed groundwater EC variability, the best estimate baseflow time series may in general be ~60-160% under- ond over-estimated (respectively).

Figure D14-1Baseflow Estimation Sensitivity to EC End Members for the Thomson River at Bundalaguah



Thomson River @ Bundalaguah Gauge 225232
Sensitivity of Baseflow (EC Mass Balance) to Groundwater EC End Member and Potential Flow Gauging Uncertainty

Note: *log10 Y axis scale makes uncertainty interval appear greater or as great at low flows as at high flows. This is not the case, as shown in the percentage error chart below.*

Whilst the potential absolute baseflow estimate errors due to flow gauging uncertainty are high, the relative errors (i.e. baseflow indices and baseflow hydrograph shape) are not.
Furthermore, the end use of these baseflow estimates is for environmental flow risk assessment, which only relies upon the baseflow hydrograph shape to estimate risks of groundwater usage impacts.

A constant flow gauge uncertainty of +/-15% has been applied based upon UoM/Theiss (2008

Basflow Index (BFI) Sensitivity to Groundwater and Runoff End Member ECs, and Flow Gauging Uncertainty

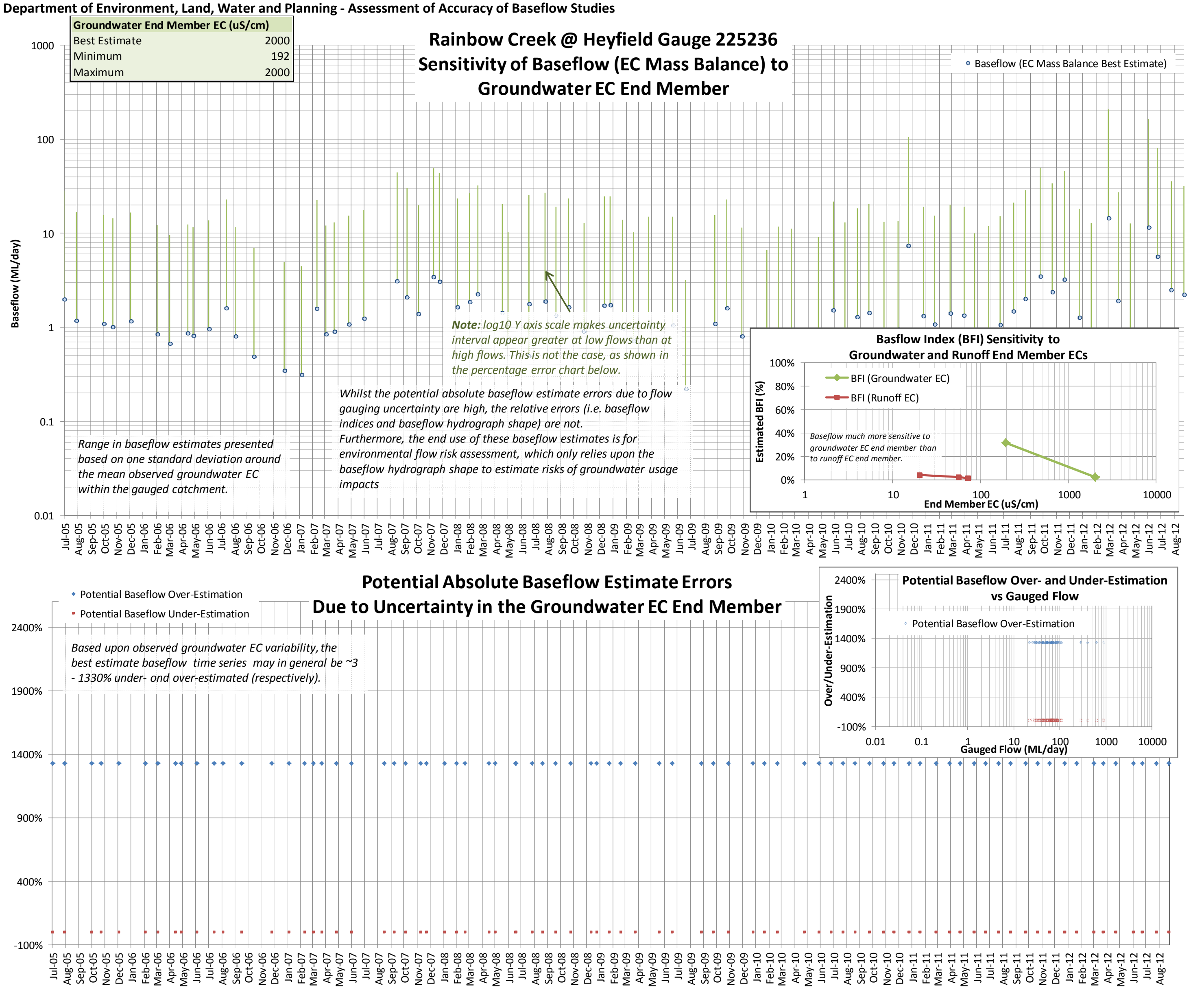
Despite large potential absolute baseflow estimate uncertainty from flow gauging error, baseflow indices are relatively insensitive to flow gauging error.

Potential Absolute Baseflow Estimate Errors Due to Uncertainty in the Groundwater EC End Member and Flow Gauging Error

Based upon observed groundwater EC variability and flow gauging error, the best estimate baseflow time series may be ~60% under-estimated, and ~230-1000% over-estimated.

Potential Baseflow Over- and Under-Estimation vs Gauged Flow

Figure D14-2Baseflow Estimation Sensitivity to Flow Gauge Uncertainty and EC End Members for the Thomson River at Bundalaguah



Groundwater End Member EC (uS/cm)	
Best Estimate	2000
Minimum	192
Maximum	2000

Rainbow Creek @ Heyfield Gauge 225236
Sensitivity of Baseflow (EC Mass Balance) to Groundwater EC End Member

Note: *log10 Y axis scale makes uncertainty interval appear greater at low flows than at high flows. This is not the case, as shown in the percentage error chart below.*

Whilst the potential absolute baseflow estimate errors due to flow gauging uncertainty are high, the relative errors (i.e. baseflow indices and baseflow hydrograph shape) are not.
Furthermore, the end use of these baseflow estimates is for environmental flow risk assessment, which only relies upon the baseflow hydrograph shape to estimate risks of groundwater usage impacts

Range in baseflow estimates presented based on one standard deviation around the mean observed groundwater EC within the gauged catchment.

Basflow Index (BFI) Sensitivity to Groundwater and Runoff End Member ECs

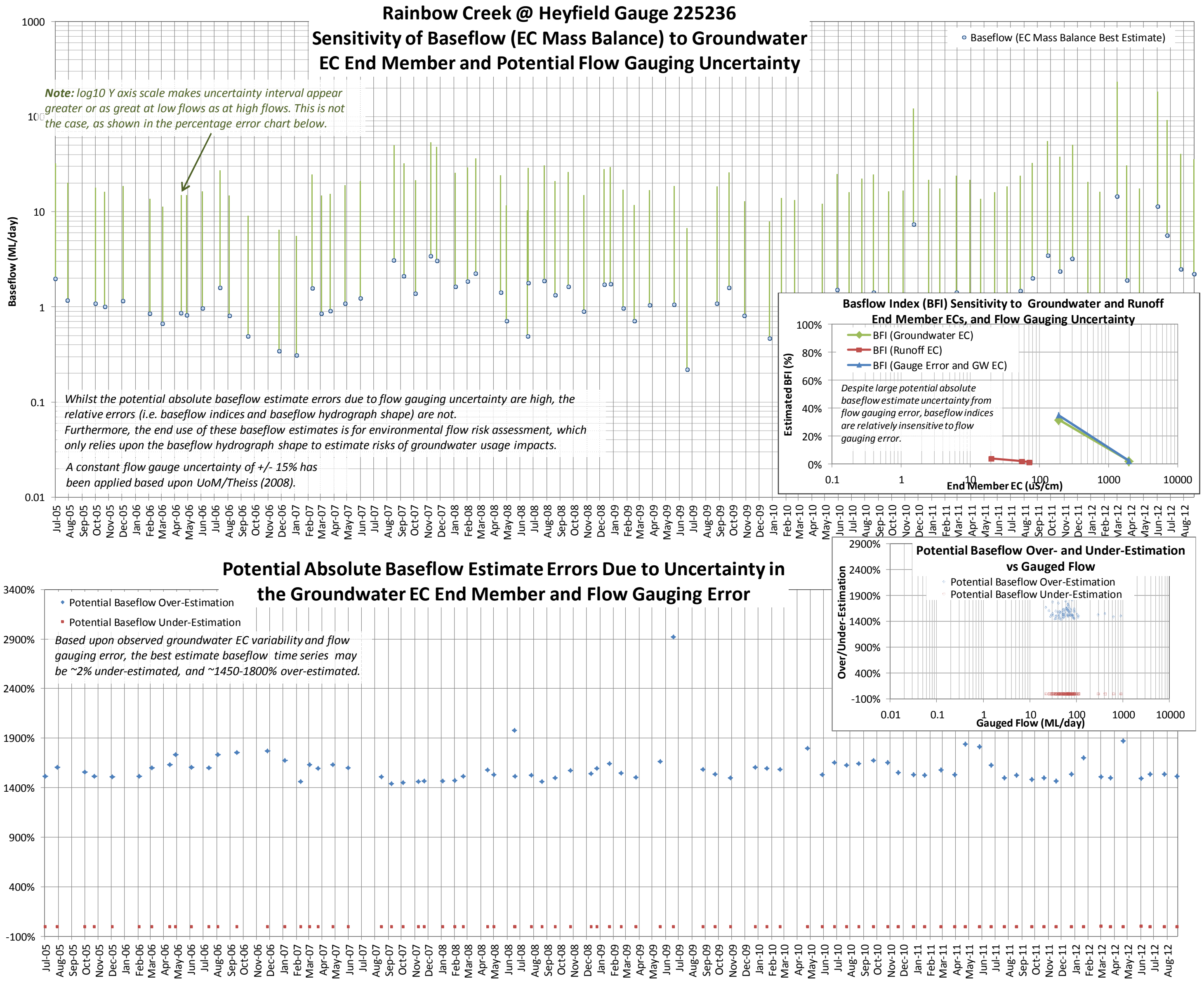
Baseflow much more sensitive to groundwater EC end member than to runoff EC end member.

Potential Absolute Baseflow Estimate Errors Due to Uncertainty in the Groundwater EC End Member

Based upon observed groundwater EC variability, the best estimate baseflow time series may in general be ~3 - 1330% under- ond over-estimated (respectively).

Potential Baseflow Over- and Under-Estimation vs Gauged Flow

Figure D15-1Baseflow Estimation Sensitivity to EC End Members for the Rainbow Creek @ Heyfield



Rainbow Creek @ Heyfield Gauge 225236
Sensitivity of Baseflow (EC Mass Balance) to Groundwater EC End Member and Potential Flow Gauging Uncertainty

Note: *log10 Y axis scale makes uncertainty interval appear greater or as great at low flows as at high flows. This is not the case, as shown in the percentage error chart below.*

Whilst the potential absolute baseflow estimate errors due to flow gauging uncertainty are high, the relative errors (i.e. baseflow indices and baseflow hydrograph shape) are not.
Furthermore, the end use of these baseflow estimates is for environmental flow risk assessment, which only relies upon the baseflow hydrograph shape to estimate risks of groundwater usage impacts.

A constant flow gauge uncertainty of +/- 15% has been applied based upon UoM/Theiss (2008).

Basflow Index (BFI) Sensitivity to Groundwater and Runoff End Member ECs, and Flow Gauging Uncertainty

Despite large potential absolute baseflow estimate uncertainty from flow gauging error, baseflow indices are relatively insensitive to flow gauging error.

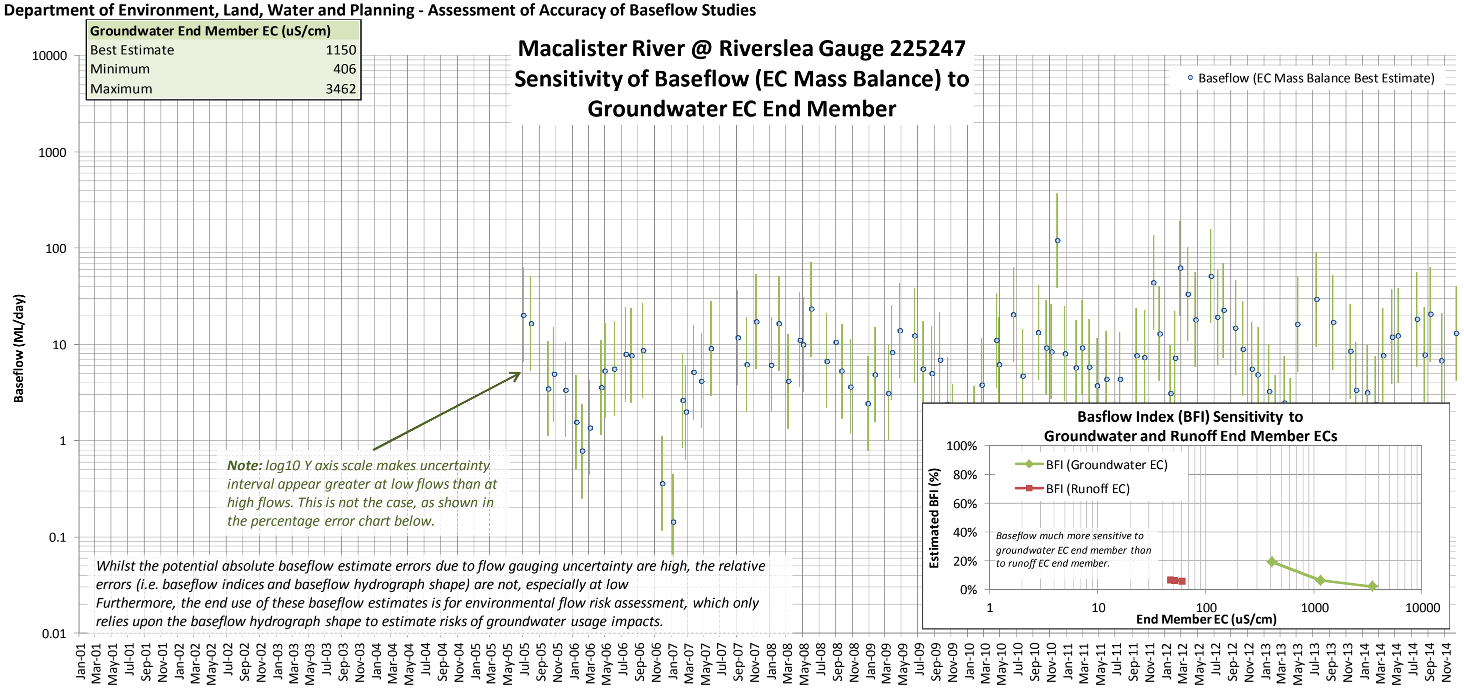
Potential Absolute Baseflow Estimate Errors Due to Uncertainty in the Groundwater EC End Member and Flow Gauging Error

Based upon observed groundwater EC variability and flow gauging error, the best estimate baseflow time series may be ~2% under-estimated, and ~1450-1800% over-estimated.

Potential Baseflow Over- and Under-Estimation vs Gauged Flow

Figure D15-2Baseflow Estimation Sensitivity to Flow Gauge Uncertainty and EC End Members for the Rainbow Creek @ Heyfield

Department of Environment, Land, Water and Planning - Assessment of Accuracy of Baseflow Studies

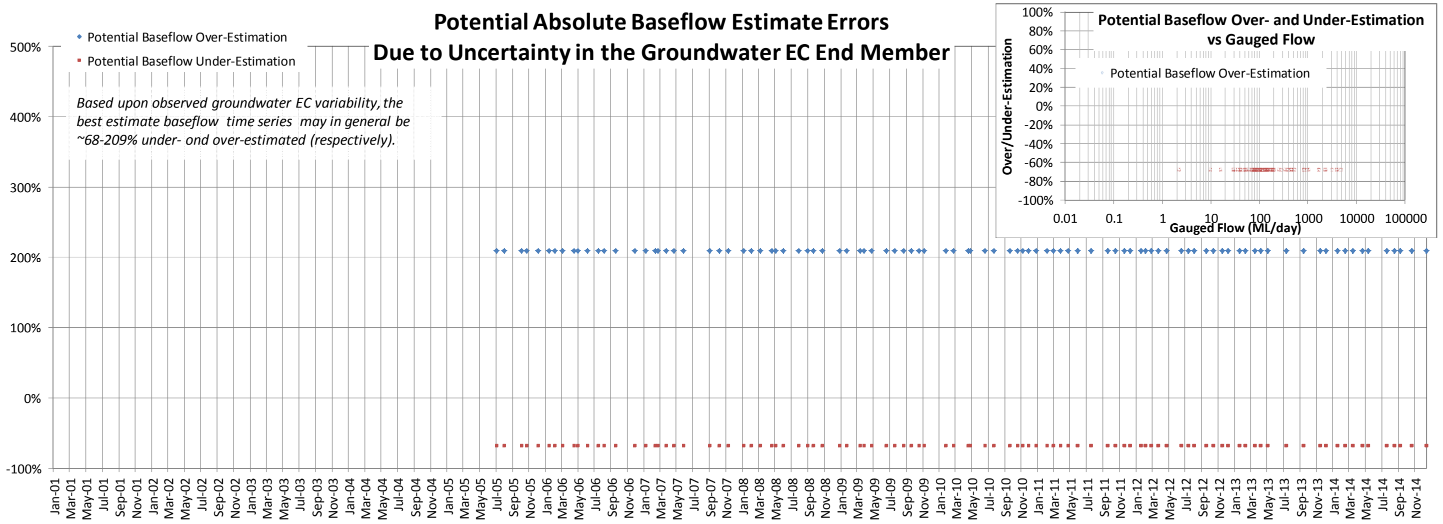


Groundwater End Member EC (uS/cm)	
Best Estimate	1150
Minimum	406
Maximum	3462

***Note:** log10 Y axis scale makes uncertainty interval appear greater at low flows than at high flows. This is not the case, as shown in the percentage error chart below.*

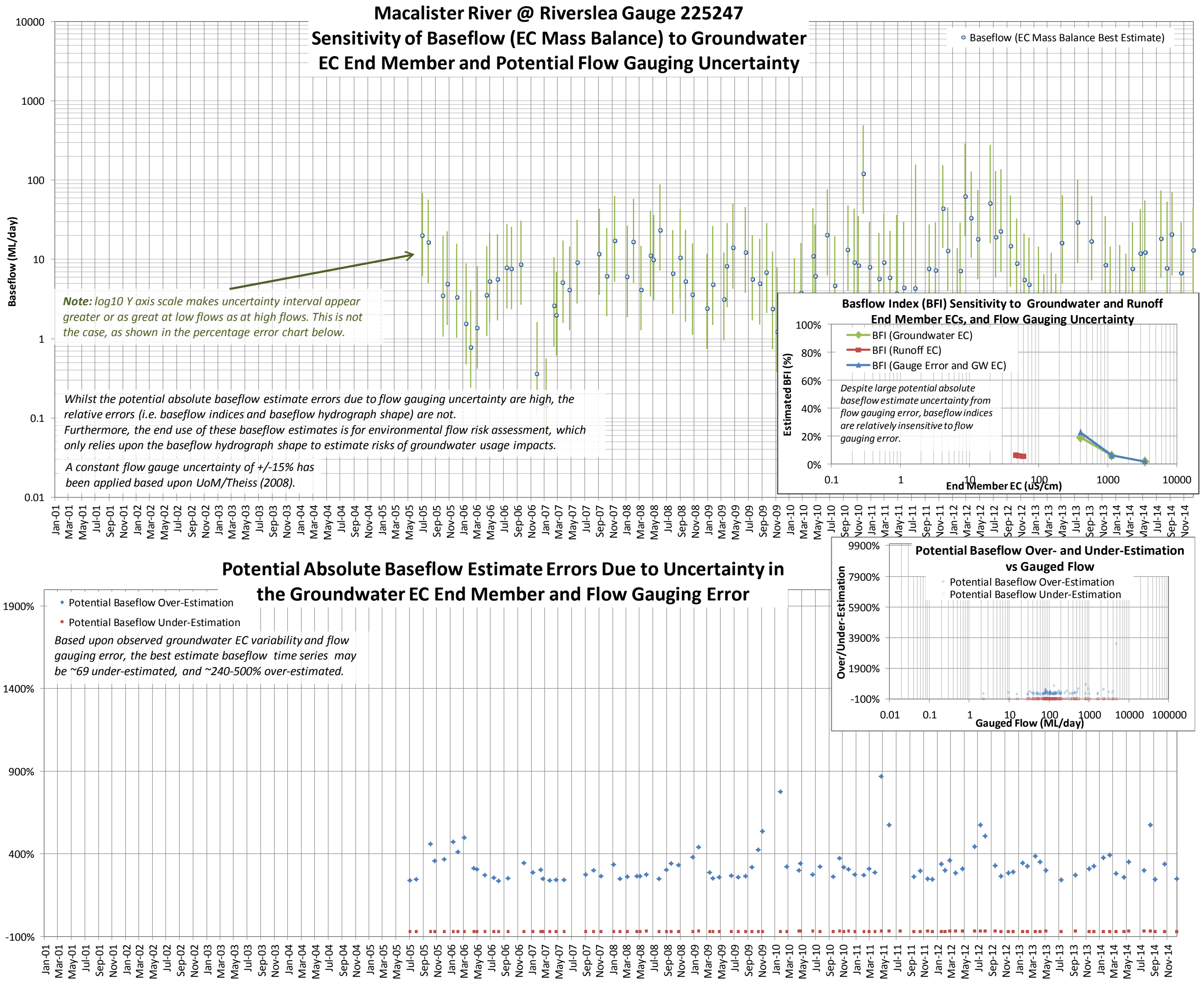
Whilst the potential absolute baseflow estimate errors due to flow gauging uncertainty are high, the relative errors (i.e. baseflow indices and baseflow hydrograph shape) are not, especially at low Furthermore, the end use of these baseflow estimates is for environmental flow risk assessment, which only relies upon the baseflow hydrograph shape to estimate risks of groundwater usage impacts.

Baseflow much more sensitive to groundwater EC end member than to runoff EC end member.



Based upon observed groundwater EC variability, the best estimate baseflow time series may in general be ~68-209% under- ond over-estimated (respectively).

Figure D16-1Baseflow Estimation Sensitivity to EC End Members for the Macalister River at Riversleigh



Macalister River @ Riverslea Gauge 225247
Sensitivity of Baseflow (EC Mass Balance) to Groundwater EC End Member and Potential Flow Gauging Uncertainty

Note: *log10 Y axis scale makes uncertainty interval appear greater or as great at low flows as at high flows. This is not the case, as shown in the percentage error chart below.*

Whilst the potential absolute baseflow estimate errors due to flow gauging uncertainty are high, the relative errors (i.e. baseflow indices and baseflow hydrograph shape) are not.
Furthermore, the end use of these baseflow estimates is for environmental flow risk assessment, which only relies upon the baseflow hydrograph shape to estimate risks of groundwater usage impacts.

A constant flow gauge uncertainty of +/-15% has been applied based upon UoM/Theiss (2008).

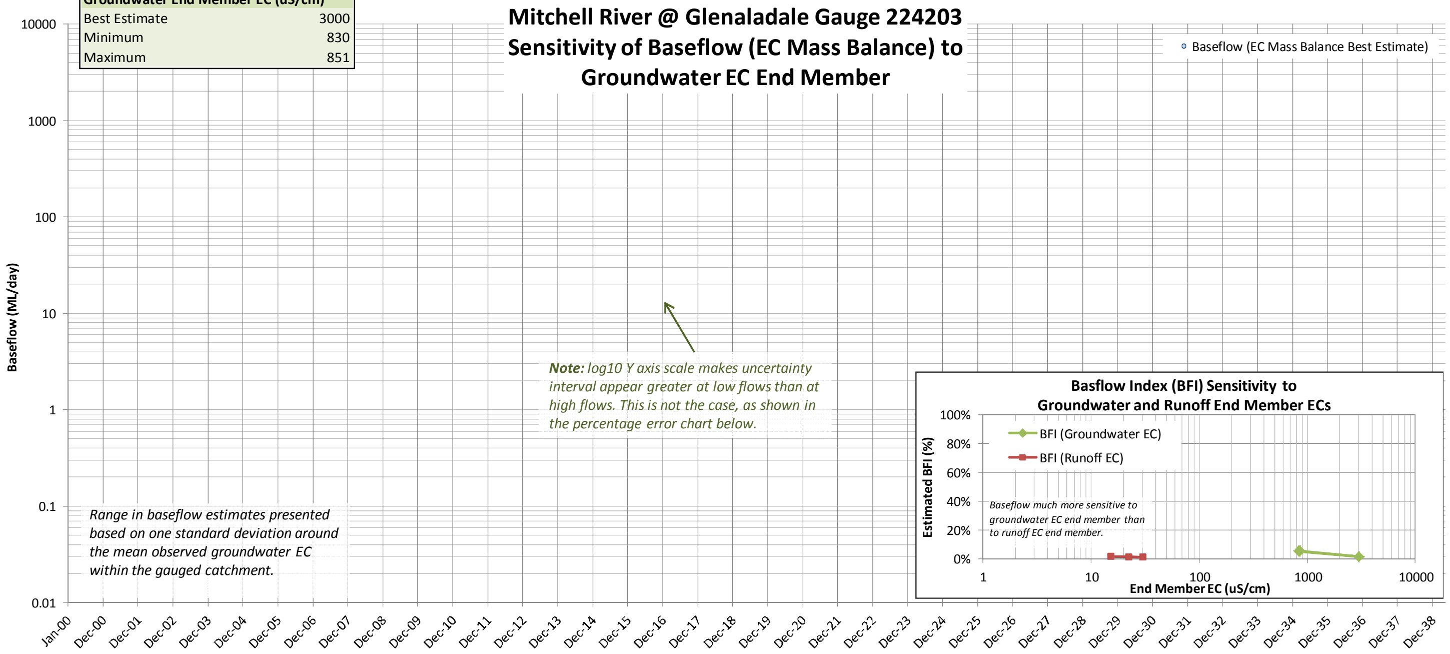
Despite large potential absolute baseflow estimate uncertainty from flow gauging error, baseflow indices are relatively insensitive to flow gauging error.

Potential Absolute Baseflow Estimate Errors Due to Uncertainty in the Groundwater EC End Member and Flow Gauging Error

Based upon observed groundwater EC variability and flow gauging error, the best estimate baseflow time series may be ~69 under-estimated, and ~240-500% over-estimated.

Figure D16-2Baseflow Estimation Sensitivity to Flow Gauge Uncertainty and EC End Members for the Macalister River at Riversleigh

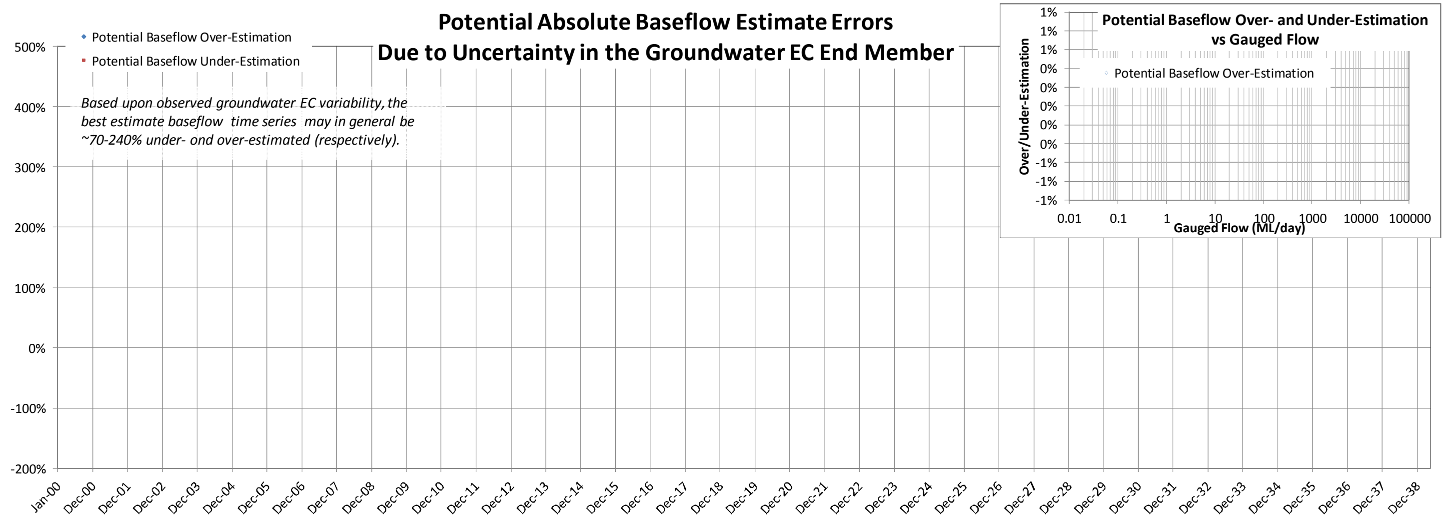
Groundwater End Member EC (uS/cm)	
Best Estimate	3000
Minimum	830
Maximum	851



Note: *log10 Y axis scale makes uncertainty interval appear greater at low flows than at high flows. This is not the case, as shown in the percentage error chart below.*

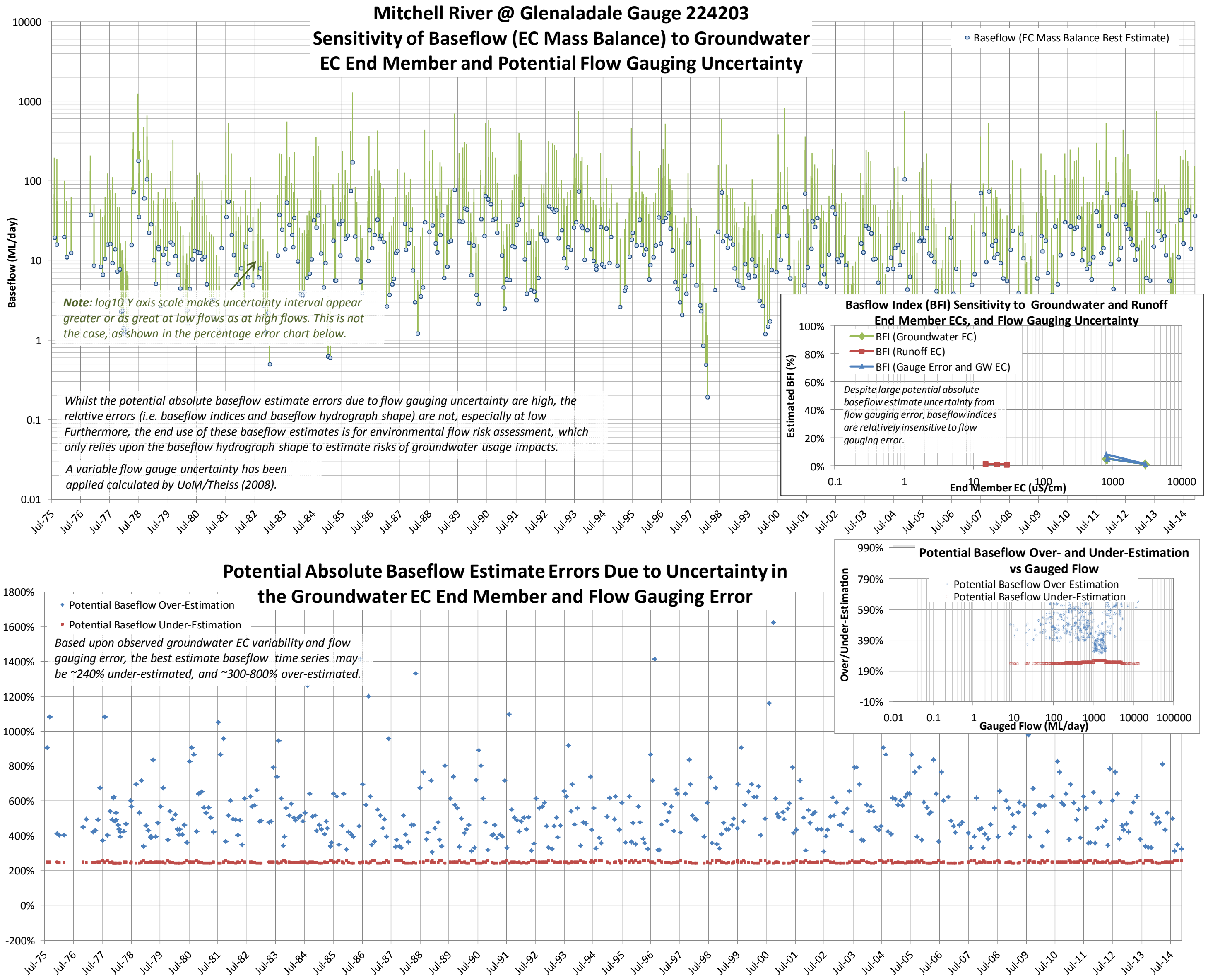
Range in baseflow estimates presented based on one standard deviation around the mean observed groundwater EC within the gauged catchment.

Baseflow much more sensitive to groundwater EC end member than to runoff EC end member.



Based upon observed groundwater EC variability, the best estimate baseflow time series may in general be ~70-240% under- ond over-estimated (respectively).

Figure D17-1 Baseflow Estimation Sensitivity to EC End Members for the Mitchell River @ Glenaladale



Mitchell River @ Glenaladale Gauge 224203
Sensitivity of Baseflow (EC Mass Balance) to Groundwater EC End Member and Potential Flow Gauging Uncertainty

Note: *log10 Y axis scale makes uncertainty interval appear greater or as great at low flows as at high flows. This is not the case, as shown in the percentage error chart below.*

Whilst the potential absolute baseflow estimate errors due to flow gauging uncertainty are high, the relative errors (i.e. baseflow indices and baseflow hydrograph shape) are not, especially at low Furthermore, the end use of these baseflow estimates is for environmental flow risk assessment, which only relies upon the baseflow hydrograph shape to estimate risks of groundwater usage impacts.

A variable flow gauge uncertainty has been applied calculated by UoM/Theiss (2008).

Basflow Index (BFI) Sensitivity to Groundwater and Runoff End Member ECs, and Flow Gauging Uncertainty

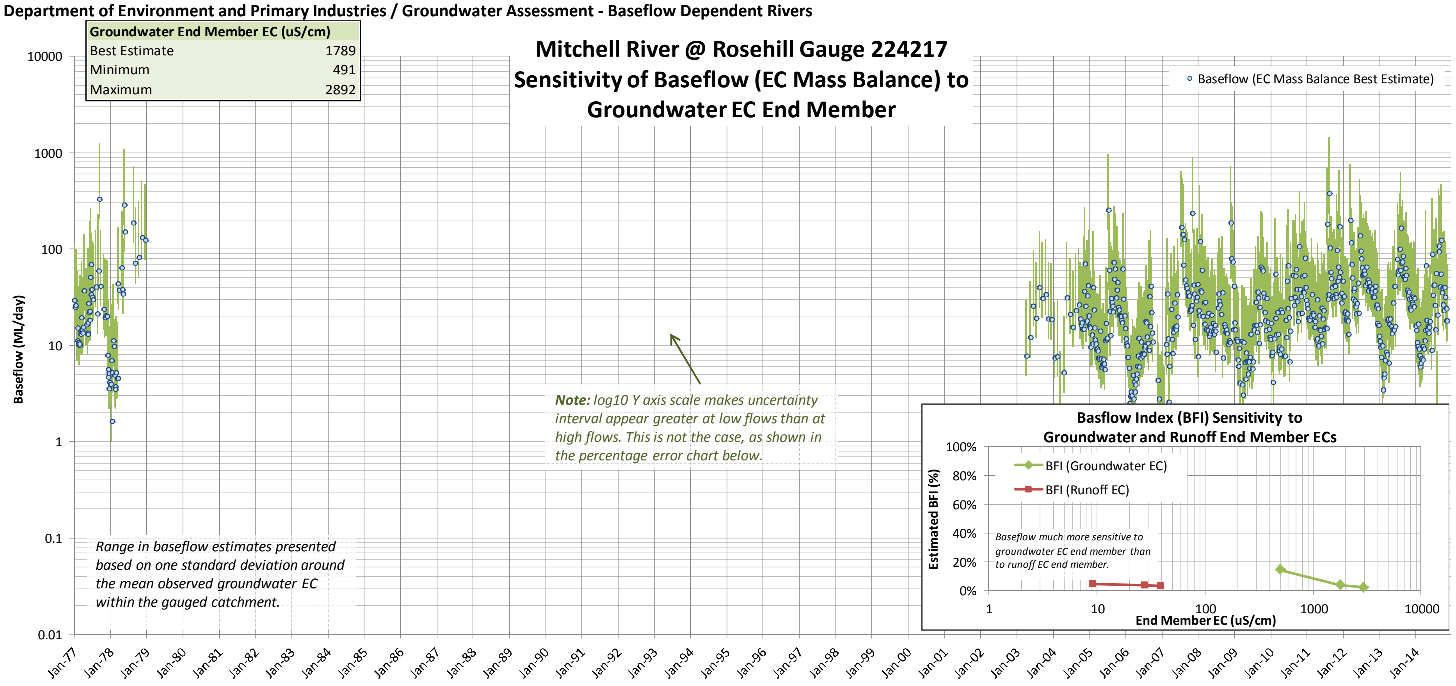
Despite large potential absolute baseflow estimate uncertainty from flow gauging error, baseflow indices are relatively insensitive to flow gauging error.

Potential Baseflow Over- and Under-Estimation vs Gauged Flow

Potential Absolute Baseflow Estimate Errors Due to Uncertainty in the Groundwater EC End Member and Flow Gauging Error

Based upon observed groundwater EC variability and flow gauging error, the best estimate baseflow time series may be ~240% under-estimated, and ~300-800% over-estimated.

Figure D17-2 Baseflow Estimation Sensitivity to Flow Gauge Uncertainty and EC End Members for the Mitchell River @ Glenaladale



Mitchell River @ Rosehill Gauge 224217 Sensitivity of Baseflow (EC Mass Balance) to Groundwater EC End Member

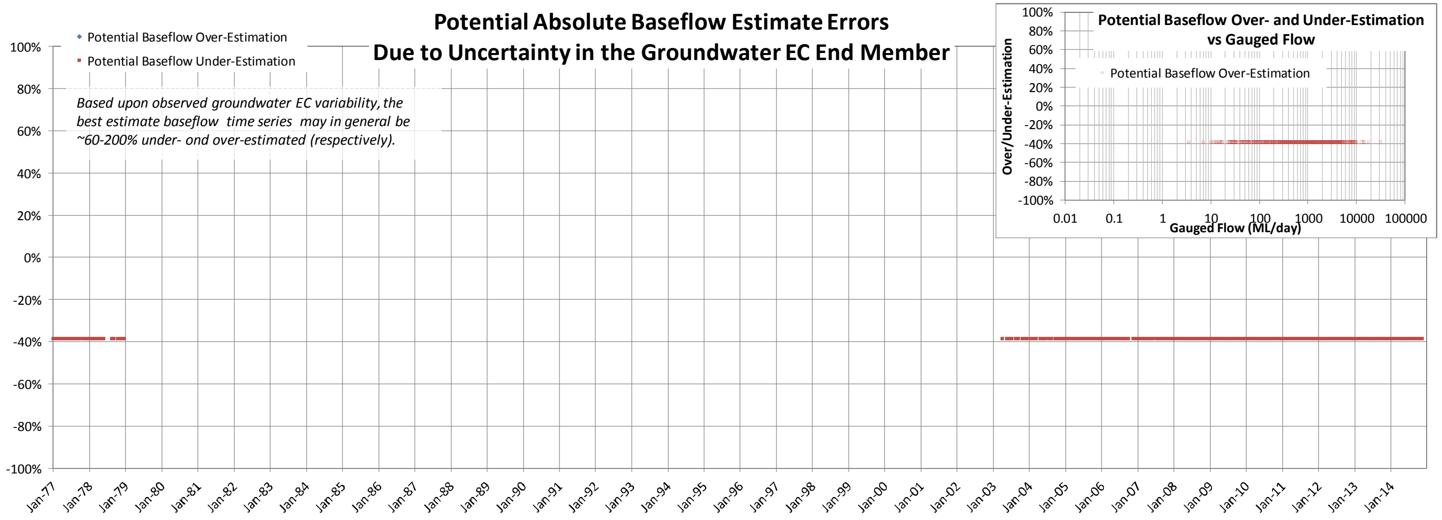
Groundwater End Member EC (uS/cm)	
Best Estimate	1789
Minimum	491
Maximum	2892

Range in baseflow estimates presented based on one standard deviation around the mean observed groundwater EC within the gauged catchment.

***Note:** log10 Y axis scale makes uncertainty interval appear greater at low flows than at high flows. This is not the case, as shown in the percentage error chart below.*

Basflow Index (BFI) Sensitivity to Groundwater and Runoff End Member ECs

Baseflow much more sensitive to groundwater EC end member than to runoff EC end member.

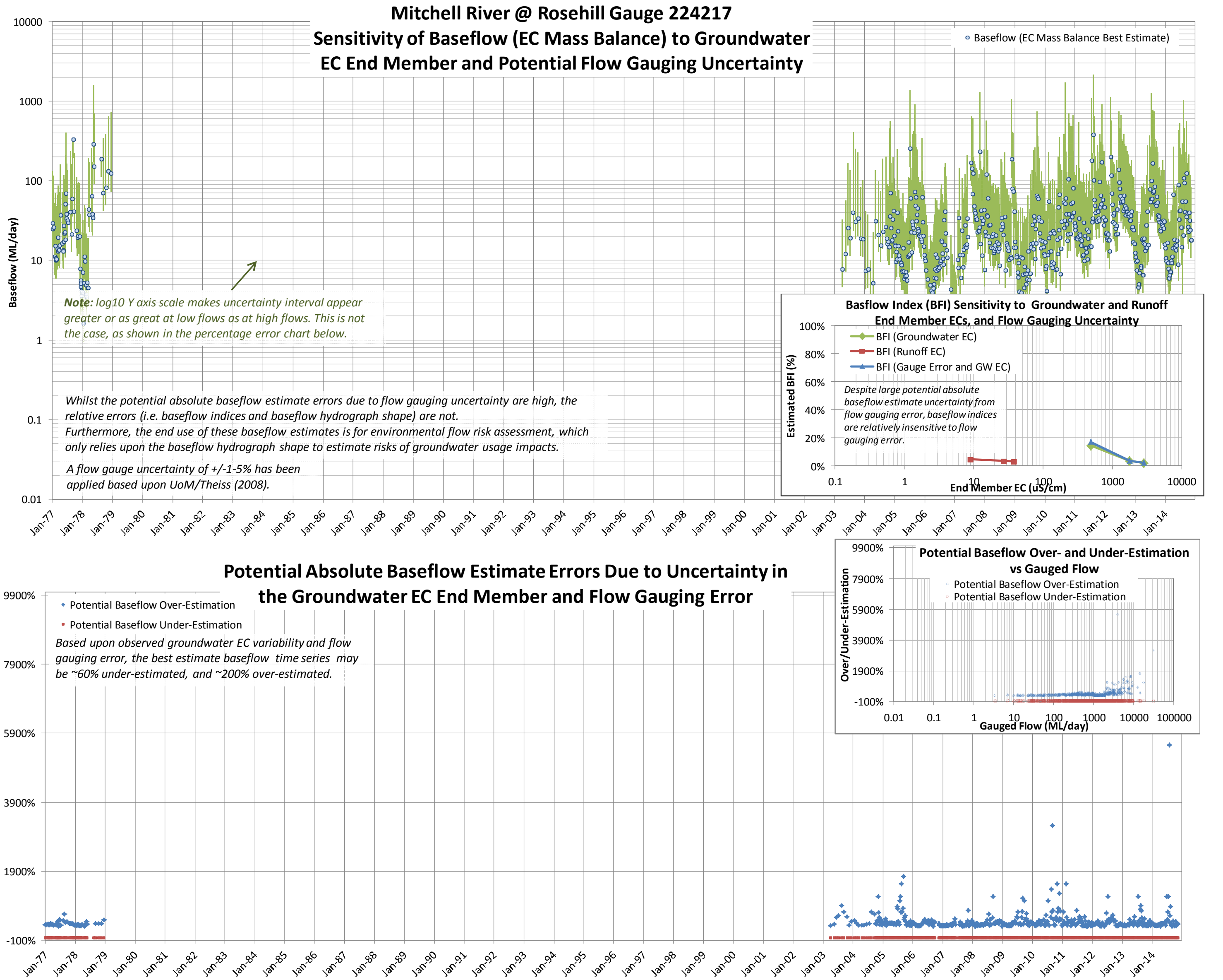


Potential Absolute Baseflow Estimate Errors Due to Uncertainty in the Groundwater EC End Member

Based upon observed groundwater EC variability, the best estimate baseflow time series may in general be ~60-200% under- ond over-estimated (respectively).

Potential Baseflow Over- and Under-Estimation vs Gauged Flow

Figure D18-1 Baseflow Estimation Sensitivity to EC End Members for the Mitchell



Mitchell River @ Rosehill Gauge 224217
Sensitivity of Baseflow (EC Mass Balance) to Groundwater EC End Member and Potential Flow Gauging Uncertainty

Note: log10 Y axis scale makes uncertainty interval appear greater or as great at low flows as at high flows. This is not the case, as shown in the percentage error chart below.

Whilst the potential absolute baseflow estimate errors due to flow gauging uncertainty are high, the relative errors (i.e. baseflow indices and baseflow hydrograph shape) are not.
Furthermore, the end use of these baseflow estimates is for environmental flow risk assessment, which only relies upon the baseflow hydrograph shape to estimate risks of groundwater usage impacts.

A flow gauge uncertainty of +/-1-5% has been applied based upon UoM/Theiss (2008).

Basflow Index (BFI) Sensitivity to Groundwater and Runoff End Member ECs, and Flow Gauging Uncertainty

Despite large potential absolute baseflow estimate uncertainty from flow gauging error, baseflow indices are relatively insensitive to flow gauging error.

Potential Absolute Baseflow Estimate Errors Due to Uncertainty in the Groundwater EC End Member and Flow Gauging Error

Based upon observed groundwater EC variability and flow gauging error, the best estimate baseflow time series may be ~60% under-estimated, and ~200% over-estimated.

Potential Baseflow Over- and Under-Estimation vs Gauged Flow

Figure D18-2 Baseflow Estimation Sensitivity to Flow Gauge Uncertainty and EC End Members for the Mitchell

Appendix E – Baseflow End Member Estimates

E1 – Previous Study End Member Estimates

E2 – Revised End Member Estimate

E1 - Baseflow EC End Member Summary – Previous Studies (GHD 2013a, 2013b)

Gauging station	Catchment	Runoff EC best estimate	Runoff EC min	Runoff EC max	Groundwater EC best estimate	Groundwater EC min	Groundwater EC max
Latrobe River at Thoms Bridge (226005)	Latrobe	150	75	225	709	336	1575
Morwell River at Yallourn (226408)	Latrobe	370	185	555	1028	555	1906
Narracan Creek at Moe (226021)	Latrobe	135	95	160	489	361	663
Tanjil River at Tanjil South (226216)	Latrobe	80	35	112	471	117	1897
Tyres River at Browns (226007)	Latrobe	38	20	63	320	80	800
Traralgon Creek at Traralgon South (226415)	Latrobe	180	110	275	1363	739	2515
Latrobe River at Scarns Bridge (226033)	Latrobe	250	180	350	934	436	2305
Latrobe River at Rosedale (226228)	Latrobe	220	110	330	1289	551	3313
Latrobe River at Kilmany South (226227)	Latrobe	270	190	370	1303	558	3324
Mitchell River at Glenaladale (224203)	Mitchell	22	11	33	460	150	1500
Mitchell River at Rosehill (224217)	Mitchell	19	10	29	898	442	1825
Thomson River at Wandocka (225212)	Thomson Macalister	25	13	38	565	337	1157
Macalister River at Riverslea (225247)	Thomson Macalister	25	13	38	1505	649	3490
Thomson River upstream of Cowwarr Weir (225231) *	Thomson Macalister	12	6	18	320	160	480
Thomson River at Bundalaguah (225232)	Thomson Macalister	25	13	38	672	365	1406
Macalister River at Lake Glenmaggie (tail gauge) (225204)	Thomson Macalister	25	13	38	649	329	1278
Rainbow Creek at Heyfield (225236)	Thomson Macalister	25	13	38	565	337	1157
Thomson River at Heyfield (225200)	Thomson Macalister	25	13	38	565	337	1157

E2 - Baseflow EC End Member Summary – Revised Estimates

Gauging station	Catchment	Runoff EC best estimate	Runoff EC min	Runoff EC max	Groundwater EC best estimate	Groundwater EC min	Groundwater EC max
Latrobe River at Thoms Bridge (226005)	Latrobe	44 (2)	44	150	639	282	1446
Morwell River at Yallourn (226408)	Latrobe	44 (2)	44	270	1028	554	1907
Narracan Creek at Moe (226021)	Latrobe	44 (2)	44	176	602	530	685
Tanjil River at Tanjil South (226216)	Latrobe	44 (1)	35	56	471	99	2237
Tyres River at Browns (226007)	Latrobe	34 (1)	33	35	828	814	843
Traralgon Creek at Traralgon South (226415)	Latrobe	44 (2)	44	194	1368	742	2522
Latrobe River at Scarns Bridge (226033)	Latrobe	44 (2)	44	236	3000 (8)	279	3000
Latrobe River at Rosedale (226228)	Latrobe	44 (2)	27	220	3000 (8)	313	3000
Latrobe River at Kilmany South (226227)	Latrobe	44 (2)	44	262	2807 (8)	491	3219
Mitchell River at Glenaladale (224203) *	Mitchell	22 (1)	15	30	3000 (8)	835	10462
Mitchell River at Rosehill (224217)	Mitchell	27 (1)	9	38	1789 (8)	491	2892
Thomson River at Wandocka (225212)	Thomson Macalister	56 (1)	45	67	1399	312	2518
Macalister River at Riverslea (225247)	Thomson Macalister	51 (1)	47	60	4500 (8)	406	3462
Thomson River upstream of Cowwarr Weir (225231) *	Thomson Macalister	48 (3)	12	48	794 (5)	80 (6)	4230 (7)
Thomson River at Bundalaguah (225232)	Thomson Macalister	54 (1)	32	68	1198 (8)	491	2892
Macalister River at Lake Glenmaggie (tail gauge) (225204)	Thomson Macalister	30 (1)	22	37	4500 (8)	1810	4500
Rainbow Creek at Heyfield (225236)	Thomson Macalister	56 (4)	20	71	2000 (8)	192	2000
Thomson River at Heyfield (225200)	Thomson Macalister	56 (1)	47	61	1022 (8)	192	1935

(1) Runoff best estimate EC end member estimated as the 1st percentile of gauged EC

(2) Runoff best estimate EC end member estimated based on Tanjil River at Tanjil South (226216) as gauged EC was considered too high for a runoff end member (>100 µS/cm)

(3) Runoff best estimate EC end member estimated as the 5th percentile of gauged EC

(4) Runoff best estimate EC end member estimated based on Thomson River at Heyfield (226200) as this gauge has a similar catchment and more data.

(5) Groundwater best estimate EC end member estimated based on Interpolated EC data mean

(6) Groundwater min EC end member defined by nearby Tyres River at Browns (226007) as this is the lowest min EC end member estimate of nearby gauges

(7) Groundwater max EC end member defined by nearby Macalister River at Lake Glenmaggie (tail gauge) (225204) as this is the highest max EC end member estimate of nearby gauges

(8) Groundwater best estimate EC end member estimated based on calibration to interstation reach scale mass balance

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