Murray-Darling Basin Authority

Methods for determining annual permitted take (groundwater)

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CDM Smith

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Glossary of terms

Term	Definition
Annual permitted take	The Basin Plan (s6.10) defines annual permitted take for an SDL resource unit for a water accounting period as: *The sum of the maximum quantity of water permitted to be taken by each form of take for consumptive use from the SDL resource unit, determined in accordance with the method for section 10.10*
Annual actual take	The Basin Plan (s6.10) defines annual actual take for a water accounting period as: (The) *sum* (of*) the quantity of water actually taken by each form of take for consumptive use from the SDL resource unit*. And in s10.15, the Basin plan outlines how the determination of actual must be specified, including: *A water resource plan must set out how the quantity of water actually taken for consumptive use by each form of take from each SDL resource unit will be determined after the end of a water accounting period using the best information available at the time.*
Compliance with the long-term annual diversion limit	The method for determining compliance with the long-term annual diversion is outlined in Part 4, Chapter 6 of the Basin Plan. It involves: Step 1: calculation of annual permitted take and annual actual take (s6.10) Step 2: record the difference between annual actual take and annual permitted take (s6.11), in which the difference is recorded on the register of take as a credit or a debit or a zero, and a cumulative balance is calculated. Step 3: Determine whether there is non-compliance (s6.12) in which: *There is non-compliance with a long-term annual diversion limit for an SDL resource unit in a water accounting period if:* *(a) the cumulative balance for an SDL resource unit, adjusted to account for any disposal or acquisition of held environmental water, is a debit amount equal to or greater than 20% of the long-term annual diversion limit for the SDL resource unit; and* *(b) the Basin State does not have a reasonable excuse for the excess.*
Groundwater SDL resource unit	A groundwater SDL resource unit is the spatial unit over which sustainable diversion limits are specified for groundwater resources in each water resource plan area, in accordance with s6.03 and Schedule 4 of the Basin Plan.
Held environmental water	From the Water Act 2007, *held environmental water means water available under: (a) a water access right; or (b) a water delivery right; or (c) an irrigation right;* *for the purposes of achieving environmental outcomes (including water that is specified in a water access right to be for environmental use).*
Long-term annual diversion limit	Under the Basin Plan, see note in s6.08(2), the long-term annual diversion limit is the same as the long-term average sustainable diversion limit.
Register of take	Under the Basin Plan, the MDBA must establish, maintain (s6.08(1)) and publish (s6.08(7)) a register of take annually. There are specific requirements for reporting in the register of take outlined in the Basin Plan that are designed to maintain the quality and integrity of the compliance process. The register of take is the formal record of all take in the Basin and *is to assist with determining, for each water accounting period, whether there has been compliance with the long-term annual diversion limit for an SDL resource unit and the extent of any failure to comply with that limit. Basin Plan s6.08(2)* A register of take will be established for both surface water and ground water SDL resource units, based on the annual data reported by the states in accordance with s71 of the Water Act. The register of take must include (s6.08(3)) a debit, when the annual actual take is greater than the permitted take, and conversely, a credit, where the annual actual take is less than the permitted take.

Term	Definition
Sustainable diversion limit	The Water Act 2007 defines the long-term average sustainable diversion limit (SDL) in item 6 of the table in subsection 22(1) as: *The maximum long term annual average quantities of water that can be taken, on a sustainable basis, from:* *(a) the Basin water resources as a whole; and* *(b) the water resources, or particular parts of the water resources, of each water resource plan area.*
Water-allocation	Water-allocation is defined in the Water Act 2007 as: *The specific volume of water allocated to water access entitlements in a given water accounting period*

Section 1 Introduction

A permitted take method is required for water resource plan accreditation under the Murray-Darling Basin Plan (the Basin Plan). The purpose of this report is to provide information and a description of the permitted take requirements and the possible methods to determine the annual permitted take for groundwater SDL resource units.

The scope of the project included:

- Consultation with jurisdictions to determine whether there are methods for determining permitted take that currently exist or are in development and to gather state-specific issues that may affect the development of appropriate methods;
- Development of example methods and a demonstration of how to relate them to the Basin Plan requirements;
- Presentation of the draft information paper to the Groundwater Advisory Panel (GAP) for consideration; and
- Facilitation of discussion of the permitted take methodology at a meeting of the GAP.

Section 2 Purpose and requirements of permitted take method

2.1 Permitted take purpose

The annual permitted take (permitted take) is used for water accounting and management purposes and is applied to each Sustainable Diversion Limit (SDL) resource unit. Permitted take is recorded on the register of take, where it is compared to actual take to indicate whether the level of actual take complies with SDL over the long-term.

The permitted take is closely related but not equivalent to the SDL. The SDL is a long-term average-annual limit to the actual take. The permitted take is the annual expression of the limit on actual take that would, over a repeat of the historical conditions (1895–2009), meet the SDL (MDBA 2017). Where the SDL is a fixed quantity of water, the Basin Plan has provisions which could allow the permitted take to vary from year to year and potentially exceed the SDL in a given year, as long as it is demonstrated (as per s10.10(4) of the Basin Plan) that '…if applied over a repeat of the historical climate conditions, it would result in meeting the SDL for the resource unit …'.

Similarly, permitted take should not be confused with allocated water, which may be more broadly termed as 'water lawfully accessible for take' and is defined as meaning: "the granting of permission, either annually or on a long-term basis, to take water from a water source under a form of take in a Basin state in accordance with that state's legal frameworks" (MDBA 2018). The volume of water lawfully accessible for take is determined ahead of a water use period, is not used to assess compliance against the relevant SDLs and is not required to be recorded in the register of take under s6.08 of the Basin Plan. In contrast, the permitted take is determined retrospectively for the previous water use period and is used for SDL compliance purposes within the register of take.

Under the Basin Plan (s6.08 to s6.11), the MDBA must keep a register of take for each SDL resource unit, with the purpose of determining whether there has been compliance with the SDL over the long term. The register records water account data including the permitted take and the actual take for each SDL resource unit and each water accounting period. An account is kept of the difference between these two volumes, with the credits and debits accumulating over water accounting periods. For each SDL resource unit, compliance is assessed with reference to the size of any accumulated debits on the register of take (the threshold is set as debit amount equal to or greater than 20% of the SDL) and whether there is a reasonable excuse for the debit (s6.12).

2.2 Permitted take method requirements

Part 3 of Chapter 10 in the Basin Plan requires that a water resource plan (WRP) must set out a method for deriving the permitted take. The Basin Plan does not prescribe the exact form of the method, but outlines a series of requirements and considerations that the method must address. Thus, there is some flexibility in how permitted take is derived, as long as the method meets the requirements that are outlined in s10.10 and s10.12.

Section 10.10 sets out that a method for deriving permitted take must be included in a WRP and then sets out the following constraints on the form of the permitted take method:

- *For each SDL resource unit in a water resource plan area, and for each form of take, the water resource plan must set out the method for determining the maximum quantity of water that the plan permits to be taken for consumptive use during a water accounting period* (s10.10(1));
- The method *may include modelling, and must be designed to be applied after the end of the relevant water accounting period, having regard to the water resources available during the period* (s 10.10(2));
- The method *must account for matters in s10.12(1) (s10.10(3)(a)) and be consistent with the other provisions of the WRP* (s10.10(3) (b));
- The WRP *must also set out a demonstration that the method relates to the SDL of each resource unit in such a way that, if applied over a repeat of the historical climate conditions, it would result in meeting the SDL for the resource unit, including as amended under section 23B of the Act* (s10.10(4)); and

- Section 23B of the Water Act 2007 allows adjustments to SDLs and Part 4 of Chapter 7 of the Basin Plan makes this applicable to groundwater. If a Basin state intends to adjust SDLs under this mechanism, then the Basin state must consider how s10.10(5) applies to the permitted take method. The provisions allowing this under Part 4 of Chapter 7 are not enactable unless the relevant text to amend the SDLs for groundwater SDL resource units is included in the WRP.

Given that s10.10(2) requires that the method has *regard to the water resources available during the period*, the method must have regard to the climate conditions of that water year in determining the permitted take. As well, it must demonstrate that it would meet the SDL if applied over the historical climate conditions (s10.10(4)). These two clauses require the method be linked to a consideration of climate, but do not specify how. One possible approach is to derive permitted take as a function of the rainfall that occurred during the water year, such that the permitted take would be less than or equal to the SDL if the method were applied to the average annual rainfall over the historical climate sequence. However, other approaches may also be considered. For instance, it is possible to set permitted take as a fixed volume (with no inter-annual variability) equivalent to the SDL, as this would satisfy s10.10(4) explicitly and s10.10(2) implicitly. Alternatively, more complex methods may be developed that represent climate and water availability more intricately (e.g. through the inclusion of factors related to surface water availability, such as flow, in SDL resource units where both surface water and groundwater are used).

All matters listed under s10.12(1) must be considered in the permitted take method where applicable. Further interpretation of s10.12 matters is summarised in Table 1. In some cases, the matter may not be applicable to the SDL resource unit. Where it is applicable, the matter may be considered for explicitly or implicitly by the permitted take method. The permitted take method should outline how each matter is considered.

The applicability of each of the matters will vary depending on the circumstances that operate for a WRP area. Matter (a) will always have application, as will matter (e). Where a matter is 'not applicable', the WRP must provide an explanation. If the circumstances are uncertain, the explanation must be substantiated by supporting evidence. The specified matters must be included in the method where they are relevant. If the method is a model, the matters must be considered in the model or be able to be adjusted for outside of the model.

Table 1 Interpretation of the matters outlined in section 10.12 with respect to the permitted take method

Section 10.12	Interpretation of ways to consider matter
(1)(a) all forms of take from the SDL resource unit and all classes of water access right;	List the forms of take and classes of water access right that are included within the SDL resource unit.
(1)(b) water allocations that are determined in one water accounting period and used in another, including water allocations that are carried over from one water accounting period to the next;	The method should consider existing carryover provisions and the likelihood of their influence on inter-annual variability in actual take. If carryover volumes are not allowed within an SDL resource unit, this could be used as the basis of having a fixed permitted take method where the permitted take is not allowed to exceed the SDL in any given water year, unless there are other mechanisms within the WRP which would allow take to exceed the SDL on a temporary basis. If carryover volumes are allowed and the uptake of carryover provisions is shown to influence actual take, this could be used as the basis for having a method that is used to derive a variable permitted take volume to allow for temporary exceedances of the SDL due to the influence of carryover. It is interpreted that carryover volumes are to be considered implicitly by a permitted take method rather than being explicitly accounted for. For example, if it can be shown that there is a relationship between actual take (of which carryover is a component) and a climate variable then this relationship could be used as the basis of the permitted take method.
(1)(c) for a surface water SDL resource unit—return flows, in a way that is consistent with arrangements under the Agreement immediately before the commencement of the Basin Plan;	This subsection is not applicable for groundwater as it only applies to surface water SDL resource units.
(1)(d) subject to subsection (3)—trade of water access rights;	Intra-SDL resource unit trade has no bearing on the permitted take method, as it has a net effect of zero on water availability at the SDL resource unit scale. At this time, there are very few examples, if any, where trade into or out of a groundwater SDL resource unit is allowed. However, this may change in the future and there may be a need to consider trade within the permitted take method. Trade into an SDL resource unit will cause no change to the SDL, with which the actual take must comply. In most cases, it is expected the WRP rules will be sufficient in limiting the actual take associated with trade so it does not exceed the SDL. However, if there are no such rules in place then there could be a case for adjusting the permitted take method as it will likely affect the relationship between actual take and the climatic conditions on which the permitted take is based.
(1)(e) water resources which have a significant hydrological connection to the water resources of the SDL resource unit;	For water resources which have a significant hydrological connection, the permitted take method should consider whether take from the connected water resource has an influence on the water resources available during the period, as per s10.10(2).
(1)(f) circumstances in which there is a change in the way water is taken or held under a water access right;	This subsection is applicable where there is a change in water access rights that are available in a groundwater system. If changes in the way groundwater is taken or held is not allowed for under the WRP, the Basin state may state that such changes will not alter permitted take. An example of such a change is the phasing out of NSW supplementary access licences under the ASGE program.

Section 10.12	Interpretation of ways to consider matter
(1)(g) changes over time in the extent to which water allocations in the unit are utilised; *Note: Paragraph (g) includes what is commonly known as a growth-in-use strategy.*	This provision is about identifying the rules for how the permitted take method adjusts if there was a negative impact of growth i.e. if actual take exceeds the compliance threshold and a growth-in-use strategy is implemented. Alternatively, if the actual take is below the SDL but there is an increase and/or changes to the extent that water allocations are used, there may be a need to adjust the permitted take method. In consideration of these matters, the permitted take method should be reviewed periodically to assess if there have been any changes in the extent to which water allocations are used (i.e. actual take) and especially in areas where the volume of entitlement is greater than the SDL. For example, if the permitted take method is based on the relationship between actual take and a climatic variable, then this should be reviewed periodically to determine whether changes are occurring and an adjustment to the method is required; noting that while these reviews are encouraged, a periodic revision to the permitted take method is not mandated.
(1)(h) water sourced from the Great Artesian Basin and released into a Basin water resource, by excluding that water; and	This subsection is applicable to surface water when water is co-produced (dewatered) from a GAB resource and then released into rivers, causing water availability in the surface water resource to increase. It is therefore not applicable to groundwater SDL resource units. Note s1012(1)(i) deals with the injection of water into a groundwater resource (managed aquifer recharge) and s10.14 deals with interceptions of groundwater between Basin and non-Basin resources.
(1)(i) water resources which are used for the purpose of managed aquifer recharge.	An adjustment to the permitted take method may be required in cases where managed aquifer recharge (MAR) is implemented. The nature of this adjustment should be based on the source of water used for MAR. For example, if the source water is surface water and accounted for as take from surface water then it should not be 'double' counted in the groundwater permitted take method. However, if there is a known mining of groundwater as a result of MAR, then it may be factored into the method. If non-Basin resources (i.e. GAB) are the source water for MAR, then consideration needs to be given if it will significantly affect the actual take such that an adjustment to the permitted take method is required.
(2) Subject to this section, the method may account for other matters.	This subsection might include other factors that could be considered in the method and used in calculating the permitted take that are not considered in s10.12(1). For example, a rule that has an effect across the SDL resource unit, such as a trigger level reduction leading to an allocation announcement
(3) For paragraph (1)(d), the water resource plan must account for the disposal and acquisition of held environmental water separately and in a way that does not affect the method under section 10.10.	The way the method accounts for trade of water access rights must separate out trade of HEW. In the method to determine annual permitted take, HEW must be excluded. Please note that disposed/acquired HEW must be stated under a separate line item to ensure it is identified. However, HEW must not be included as an item in the permitted take method. An example of the disposal and acquisition of HEW is provided in the Handbook for Practitioners Water Resource Plan Requirements (MDBA 2013).

2.3 SDL Compliance and permitted take

Compliance with the SDL is tested by whether the register of take cumulative balance for an SDL resource unit at the end of an accounting period is in debit by more than 20% of the annual SDL volume for that SDL resource unit. If there is an exceedance of this threshold, a potential non-compliance is flagged and further investigations are triggered to see if there is a reasonable excuse for the exceedance or if a real growth in use has been detected and requires the states to make good on the excess. Further information regarding compliance with SDLs can be found in the MDBA SDL Reporting and Compliance Framework.

If the permitted take method underestimates permitted take, i.e. if it returns a volume that underestimates the true annual expression of the SDL for the given climatic conditions in the water year, then there is greater probability that actual take will exceed the permitted take and a greater probability that a potential non-compliance will be flagged unnecessarily. In statistics, this is known as a Type 1 error or it is more commonly called a false alarm. An example of a Type 1 error occurring would be if the permitted take was a set as a fixed volume equivalent to the SDL (without any allowance for inter-annual variability) and actual take exceeded this volume due to the legitimate use of carry over provisions, which caused the cumulative balance to exceed the 20% threshold. The occurrence of Type 1 errors means more effort being needed to investigate a reasonable excuse for compliance and can lead to the false perception of a problem. If Type 1 errors occur for several SDL resource units or persistently with the one unit, this may not only mean an increased effort in dealing with and reporting the causes, but could undermine the credibility of the process amongst stakeholders.

If the permitted take method overestimates permitted take, i.e. if it returns a volume that overestimates the true annual expression of the SDL for the given climatic conditions in the water year, then there is greater probability that actual take will be less than the permitted take and a greater probability that a real growth in use may not be detected by the register of take. In statistics, this is known as a Type 2 error. An example of a Type 2 error occurring in this context, would be if errors in the permitted take method allowed actual take to exceed the SDL due to assumptions around the interannual variability in take as driven by climate but were in fact caused by a real growth in use that was not detected by the methodology. Type 2 errors are problematic because they may limit the identification of SDL resource units where actual take is not in compliance with the SDL and require management. It is understood that there are several checks and balances within the water resource planning requirements that minimise the likelihood of Type 2 errors occurring; however, it is recommended that they be given consideration during the development of permitted take methods due to their associated risks.

Given the problems associated with Type 1 and Type 2 errors, an objective of the permitted take method should be to reduce their occurrence.

Section 3 Potential methods to determine permitted take

3.1 Introduction

This section contains a description and analysis of possible methods for the determination of permitted take for groundwater SDL resource units and implications of errors in those methods. This section aims to demonstrate how methods could be applied to different SDL resource unit settings to meet the requirements described in the previous section.

It should be stressed that the methods presented in this report are not a requirement of the Basin Plan, rather this material is for guidance. Its purpose is to provide an example of how methods could be developed and meet the requirements of the Basin Plan and to gain an insight into the constraints required to maintain model acceptability. The Basin states are able to put forward their own methods for determining permitted take within the water resource plans (WRPs) as long as they meet the Part 3, Chapter 10 Basin Plan requirements. The methods presented may not be universally applicable and a Basin state has the opportunity to determine a method that is appropriate to the issues relevant to a particular SDL resource unit.

3.2 Guiding principles

The approach taken should be to balance the complexity of the method with the likelihood of SDL exceedance in the future, and where possible electing to use the simplest method, subject to ensuring that the requirements of the Basin Plan are met.

The following principles are put forward to guide the development of the permitted take method:

- The method must satisfy the requirements of the Basin Plan, as discussed in Section 2.2 of this report.
- The likelihood of the actual take exceeding the SDL can be determined probabilistically based on the record of historical take.
- The method should focus on minimising model uncertainty, to reduce the occurrence of Type 1 and Type 2 errors in compliance determinations.
- The complexity in the method to determine permitted take should be based on the likelihood of actual take exceeding the SDL, subject to there being mechanisms in the water resource plan (such as carry over) that would allow these temporary exceedances to occur. Where there are no such mechanisms in place, the permitted take method may be time invariant and equivalent to the SDL.
- The method could be regularly reviewed (nominally every five years) as a health-check and be updated if required, noting that periodic revisions to the permitted take method are not mandated and a formal revision would necessitate re-accreditation of the WRP.
- Each Basin state should consider the most applicable method given the circumstances of a particular SDL resource unit.

3.3 Method complexity

One issue to consider within this context is how complex does the permitted take method/model need to be to satisfy both the requirement of the Basin Plain and to minimise the errors according to the guiding principles.

There has been considerable effort to date in determining the SDL volumes in the Basin Plan and in developing allocation rules for groundwater SDL resource units. This allows groundwater users to operate their commercial activities, while providing constraints to ensure sustainability. Because of the large buffers associated with groundwater resources (that is, their storage characteristics), the active management of the annual variation in groundwater use appears to have been a lower priority. Some limits have been placed on carryover and other provisions to encourage the resource to be used more sustainably across years. However, this does not require regulators to fully understand the factors influencing the annual use of groundwater. Whilst it is understood that demand will be greater in drier years, other factors are less clear. An understanding of such factors may be useful for the determination of permitted take.

Permitted take is the annual expression of the SDL to be applied retrospectively based on climate and other factors that influence groundwater use. The explicit relationship between groundwater use and different factors is likely to vary across different groundwater units depending on climatic conditions, potential for surface water to be used and crop types.

The concept of permitted water is readily applicable to surface water resource management, for which the circumstances are somewhat different to the groundwater case. For surface water, the storage is much smaller than for groundwater and the available water is more constraining. Hence, the emphasis is to best fit demand to available water and to understand the annual variations in the use of surface water. In contrast to groundwater, use tends to be higher in wetter years. The nature of surface water means that more data is available to understand annual variations in use. Such relationships have been developed and incorporated in models over a period of time.

The permitted take method may vary in complexity along with the characteristics of the SDL resource unit. While some resource units could adopt a simple method of permitted take being equal to the SDL, it may not be suitable for all SDL resource units. For example, in SDL resource units with actual take close to the SDL and utilisation of carryover and other factors considered in s10.12 mean that the actual take exceeds the SDL in dry years and be compensated for in wetter years. In this example, if the permitted take was set at the SDL, over time a cumulative debit may exceed 20% of the SDL and this would trigger a need for the Basin state to claim a reasonable excuse for the excess or be determined as non-compliant. As discussed above, there is a cost for this to occur on a regular basis. Hence, for some systems where there is a likelihood of the SDL to be exceeded on an annual basis in accordance with the provisions of the relevant WRP, there is a need for something more comprehensive than setting the permitted take equal to the SDL. This is more likely to be the case where the mean groundwater take is close to the SDL.

As outlined in one of the guiding principles, it is recommended that the likelihood of actual take exceeding the SDL be determined probabilistically as the basis for whether or not a simple method is used. To illustrate how this approach may be put into practice, historical actual take data has been collated for five groundwater SDL resource units and the sample statistics for each is shown in Figure 1. The five SDL resource units represent case studies that have been selected for the purposes of this discussion paper. The box and whiskers plot shows the distribution of the historical data as follows:

- the median is shown by the central line;
- the mean is shown by the cross;
- the 25th and 75th percentiles are shown by outer dimensions of the box;
- the minimum and maximum values are shown by whiskers; and
- the upper 95% confidence limit of the mean is labelled as a percentage and is calculated as,

  upper 95% confidence limit = mean + 1.96(standard error of the mean).*

Where the upper 95% confidence limit approaches or exceeds the SDL, as in the case of the Lower Gwydir Alluvium and the Central Condamine Alluvium SDL resource units, there is a reasonable likelihood that the actual take may exceed the SDL in the immediate planning timeframe and there may a need to consider a more complex permitted take method that allows for permitted take to vary between years.

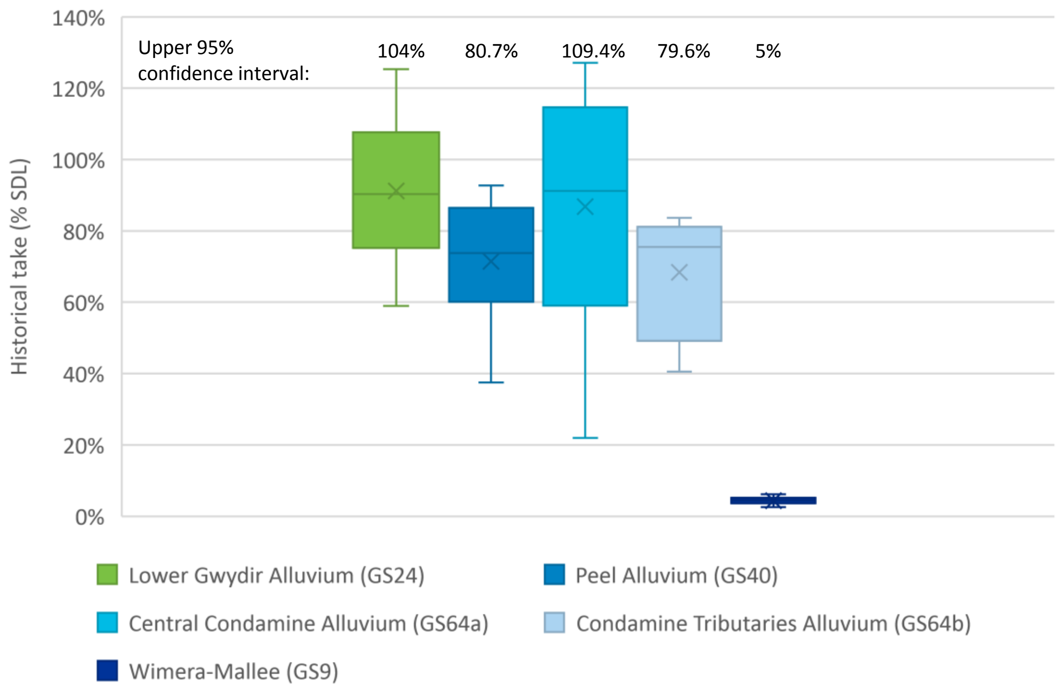

Figure 1 Historical take data for case study areas

For many groundwater units in the MDB, the distribution of actual use is such that there is over 95% confidence that numerical compliance holds and the use of SDL for permitted take appears reasonable. The above provides an approach for testing this. If the level of confidence for numerical compliance is too low, there may be a need to consider a more complex model of permitted take.

In some cases, testing may not be required, for instance, if the previous maximum actual take is below an agreed threshold of the SDL then there may be no need to consider adopting a complex method. At this stage, the threshold is suggested to be set arbitrarily at 80% of the SDL, but this should be agreed by relevant stakeholders.

In reality, the notion of complexity is not binary (that is either its simple or its complex), but variable (perhaps complexity levels 0, 1, 2 etc.). The lowest level of complexity for the permitted take model is for annual permitted take to be equal to the SDL volume. In this case, we consider the annual actual take being part of a population of historical take and that there is an associated probability distribution function that describes that. The probability of the annual take being greater than the SDL can be calculated, especially if the distribution of historical take is normally distributed. Similarly, we can calculate the probability that the cumulative deviation from the SDL is greater than 20% of the SDL (the threshold used in the register of take). Thus, we can estimate the probability of a Type 1 or Type 2 error and calculate the relevant confidence levels. If the historical take is less than 80% of the SDL, it could be reasonably assumed without any analysis that equating permitted take with the SDL should avoid Type 1 errors because take would need to increase by a sufficiently large percentage (>25%) for potential non-compliance events to be triggered.

If the required confidence level is insufficient (i.e. the probability of Type 1 or Type 2 error occurring is too large), we might then consider the next level of complexity, for example, a linear regression model with a constant bias so that the average annual permitted take over the set historical period is the SDL. The linear regression model can be with respect to any climatic variable that can be estimated over the set historical period. Generally, this is often rainfall for a period relevant to the annual take. As before, the probability of a Type 1 or Type 2 error can be calculated. If confidence levels are exceeded, we could consider more complex models. This could be in the form of non-linear regression, a multivariate regression, a regression with a bias dependent on rainfall or any other that is thought to minimise the probability of a Type 1 error. As before, the intention of moving to a more complex method is to reduce model uncertainty and the associated likelihood of Type 1 or Type 2 error occurring.

This consideration of model complexity relative to model error is analogous to a risk management framework, where we are concerned with the risk of Type 1 and Type 2 errors. It also uses the principle that the effort should be commensurate with risk. Each Basin state will have their own risk management approach and models be developed that set appropriate confidence levels within this context.

The historical take needs to be collated to apply this framework. Any external factors that may have influenced the actual take should be documented (e.g. reduction in SDL or equivalent, growth in use). Any factors that might further alter the actual take for the planning period 2019-28 should also be documented. Adjustments may be needed to the historical take to account for these factors before assessing probabilities and estimated errors may need to be adjusted with respect to further use as a precautionary measure in the risk framework.

3.4 The simple permitted take method

There are many groundwater SDL resource units where the historical take and/or sum of entitlement is significantly less than the SDL, and it is highly unlikely that actual take will exceed the SDL over the interim planning horizon (the next 10 years). In these cases (and in cases where there are no mechanisms within the water resource plan, such as carryover, that would allow the actual take to exceed the SDL) it is proposed that permitted take is simply equal to the SDL volume.

A framework has been outlined in Section 3.3 to determine whether this simple method is sufficient, and it is also proposed that a nominal cut-off for deciding whether an SDL resource unit falls into this simplest category is whether the historical use is less than 80% of the SDL. For this category of SDL resource unit, the likelihood of actual take being greater than the SDL in a water year and therefore possibly accumulating a debit that is greater than 20% of the SDL value is considered low (unlikely). The main advantage of this method is that it is straightforward to develop, administer and report against.

Section 10.10 (2) requires that the permitted take method be applied retrospectively having regard to the water resources available during the relevant water accounting period. While the simple method does not explicitly have regard the water resources available during the period, it does so implicitly on the basis that the SDL has been established having regard to the long-term availability of water resources. SDLs have been set in accordance with recharge estimates and/or existing state limits/caps and were tested against the preliminary extraction limit with the most conservative volume adopted under a range of climate scenarios.

The simple method meets s10.10 (4) requirements explicitly by ensuring that permitted take is equal to the SDL over the historical climate.

The means by which matters outlined in s10.10 (3) and s10.12 are considered by the method would need to be documented on a case-by-case basis.

If over time the actual take for an SDL resource unit increases above 80% of the SDL, then a different (more complex) method may be developed to avoid unnecessary accumulation of debits and potential compliance investigations associated with an exceedance of 20% of the SDL. Note though that permitted take is a component of an accredited WRP and that updating a method would require re-accreditation.

Case study #1: Wimmera-Mallee (groundwater) water resource plan area (GW3)

The SDL resource units within the Wimmera-Mallee (groundwater) WRP area were examined as a case study for determining permitted take in a situation where the historical take is low relative to the SDL. The Wimmera-Mallee (groundwater) WRP area comprises three SDL resource units: Highlands (GS9), Sedimentary Plain (GS9) and Deep (GS9). In all three units, the historical take is less than 80% of the SDL. The actual take measured over the five-year period from 2012-13 to 2016-17 was about 30% of the SDL in the Highlands SDL resource unit, about 5% of the SDL in the Sedimentary Plain SDL resource unit and was negligible in the Deep SDL resource unit (see Figure 2). With current levels of actual take being substantially less than the SDL, it is unlikely that take will approach or exceed the SDL over the immediate 10-year planning timeframe and the development of a complex method for determining the annual permitted take is not warranted. Thus, the adoption of a simple approach in which the permitted take is equivalent to the SDL is recommended.

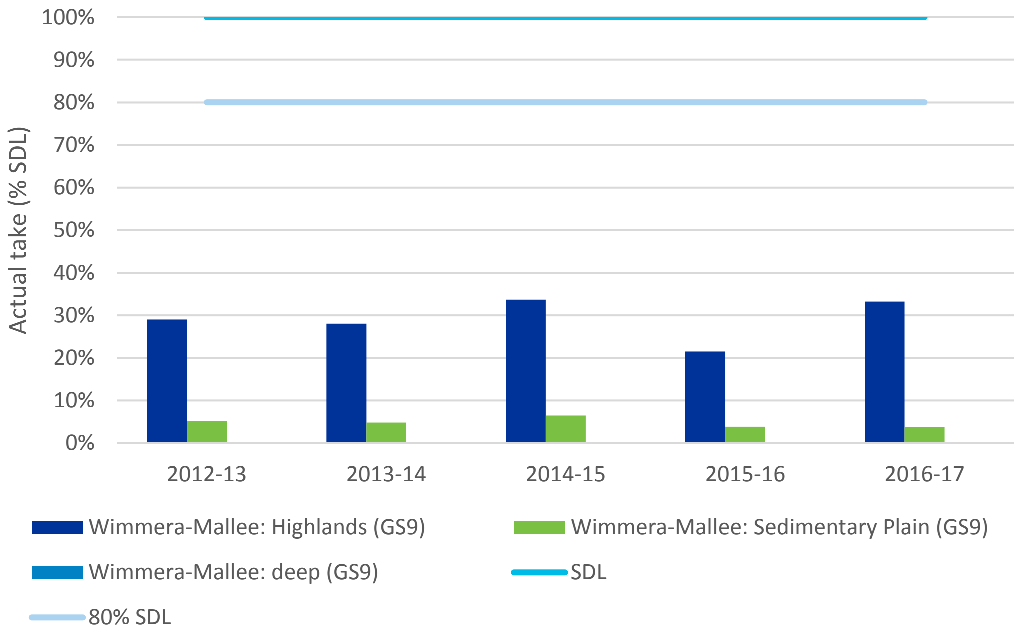

Figure 2 Actual take measured in the Wimmera-Mallee (groundwater) WRP area as a proportion of SDL

3.5 A modelling (regression) method

For SDL resource units where the historical use is equal to or greater than 80% of the SDL volume, the likelihood of actual take being higher than the SDL in a given water year is considered to be higher (possible). The likelihood of this occurrence is also dependent on management rules within the WRP, for instance whether carryover provisions exist, and can be determined probabilistically using the approach outlined in Figure 1.

Actual take can exceed the SDL in a given year for the reasons stated above. A reason for this in groundwater SDL resource units is carry-over. If permitted take for a groundwater plan was set as the SDL, carry-over provisions could lead to exceedance of the 20% threshold on a regular basis and further lead to reporting requirements in instances where take is authorised by provisions of the WRP. A proposed method to reduce potential non-compliance associated with Type 1 errors is to use a method for deriving the permitted take that accounts for the climatic influence on diversions. This is similar (but less complex) than the approach used for surface water SDL resource units.

A reasonable starting point for a more complex method is to develop a mathematical predictor (e.g. a linear regression) for take and then deliberately adjust this so that its average is equal to the SDL (to satisfy s10.10 (4)). This would lead to a permitted take that is aligned closely to the predicted actual take but with a bias to avoid debits. The predictor would be based on pre-2019 data and then used to calculate permitted take retrospectively in each water year from 2019 based on the climatic conditions of each year (to satisfy s10.10 (2)). There are several ways to develop such a mathematical predictor and different ways to adjust the bias.

In developing a predictor, it is generally necessary to use a historical groundwater diversions time series. There are several attributes of the diversions time series that need to be considered:

- all forms of take need to be included in the data (this comprises all license types, including stock and domestic) in accordance with s10.15 (the determination of actual take);
- the data should be of the highest possible quality and a report should be prepared that outlines how the data are derived (to satisfy s10.15 (2));
- the data are stationary (that is, data whose mean, variance, autocorrelation, etc., are constant over time) and do not reflect actions that violate the relevant WRP; and
- the data should be adjusted to account for the relevant parts of s10.12.

The use of a linear regression model as a predictor as a step towards determining annual permitted take has been examined in three case studies:

- the Upper Condamine Alluvium (consisting of the Central Condamine Alluvium and Tributaries SDL resource units (GS64a and GS64b));
- the Lower Gwydir Alluvium SDL resource unit (GS24); and
- the Peel Valley Alluvium SDL resource unit (GS40).

As outlined in Section 3.3, an analysis of the historical take data indicates a reasonable likelihood that the actual take could exceed the SDL in the Central Condamine Alluvium and the Lower Gwydir Alluvium SDL resource units which provides some justification for considering a more complex model. While the likelihood of actual take exceeding the SDL is lower in the Peel Valley Alluvium and the Condamine Tributaries SDL resource units and a more complex method may not be deemed as necessary, they were still included in this analysis to illustrate some of the considerations required in developing a more complex permitted take method.

In all cases, the regression models developed use rainfall during the water year as the climate variable from which permitted take is derived. However, this is not meant to imply that rainfall is the only factor that a permitted take method should use. Indeed, there are several options that a Basin state may consider using in the development of a permitted take model and their inclusion may lead to a more robust method.

There were several reasons as to why rainfall was selected for the case study analysis:

- It has a causative basis in providing a measure of demand (i.e. the more rainfall during a growing season the lower the demand for irrigation water and vice versa);
- The data is readily available, which includes the historical data so that s10.10 (4) can be easily applied.

In undertaking this analysis, the following questions were considered:

1. What statistical tests are available to evaluate the robustness of a regression model and do the regression models developed meet these criteria in providing a robust model?
2. How can the regression models be developed satisfy the requirements of s10.10 (4)?
3. What measures of model uncertainty are available and how can these be translated to register of take determinations?

The main test of the applicability of the regression method is whether it meets the requirements of s 10.10 (4), which states permitted take must not be higher than the SDL when averaged over the historical climate sequence (1895 to 2009). If the predicted average annual actual take derived from the historical record is lower than the SDL volume for a specific SDL resource unit, then there may be opportunity for the permitted take formulation to be derived from a scaling of the linear regression so the requirement of s 10.10 (4) is met exactly (a bias adjustment). This allows for more bias and hence opportunity to avoid Type 1 errors. Fortunately, the linear regression allows the long term averaged predicted take to be calculated easily by inserting the long-term average rainfall into the relationship. The simplest scaling of the regression is to modify the intercept so that the s.10.10 (4) is met exactly. The amount to be added is the difference between the SDL and the predicted long-term average annual actual take. However, other scaling methods exist. For example, the entire relationship could be scaled. The following case studies are used to show how this works.

3.5.1 Lower Gwydir Alluvium SDL resource unit (GS24) case study

Figure 3 illustrates the approach and how it can be applied to derive permitted take for the Lower Gwydir Alluvium SDL resource unit. This SDL resource unit has been selected because it represents a situation where recent actual take data has been noted to approach or exceed the SDL.

Step 1: obtain and review data

As a first step, a time series of groundwater actual take was obtained. For the Lower Gwydir Alluvium SDL resource unit, this covered the period of 2007 to 2017 (where 2007 represents the 2006-07 water year, 2008 represents the 2007-08 water year and so on). Because this period is coincident with the structural adjustments of the NSW Government's Achieving Sustainable Groundwater Entitlements (ASGE) program, the raw actual take data was adjusted to account for this as follows:

$$Actual\ take\ (adjusted) = Actual\ take(unadjusted)\ \times \frac{SDL}{Transitional\ Diversion\ Limit}$$

This adjustment normalises the dataset against the SDL to remove the influence of the ASGE program and its potential to distort the relationship between actual take and rainfall.[1]

Rainfall data was obtained for the equivalent time period from the Bureau of Meteorology (BoM), and this dataset was expanded by accessing a SILO patched point for the entire historical sequence. The average annual rainfall for the baseline period is shown in Figure 3, along with an indication of its variance provided by the standard deviation.

To derive a regression model, only the data from 2007 to 2014 has been used, with the last three years of data (2015-17) set aside to test the model for the purposes of this discussion paper. When testing a model in a predictive capacity, it is not scientifically valid to use the same data from which it was derived. If applying this approach in practice, use of the complete dataset (2007 to 2017) is recommended.

[1] The adjustment relies on the assumption that the ASGE program has influenced actual take and, if applied, such an adjustment would need to be supported by evidence that actual take has been influenced by the reduction in entitlements; however, it is noted that scaling the actual take data in this manner produces a flatter regression relationship and ultimately a more conservative estimate of permitted take during years of below average rainfall.

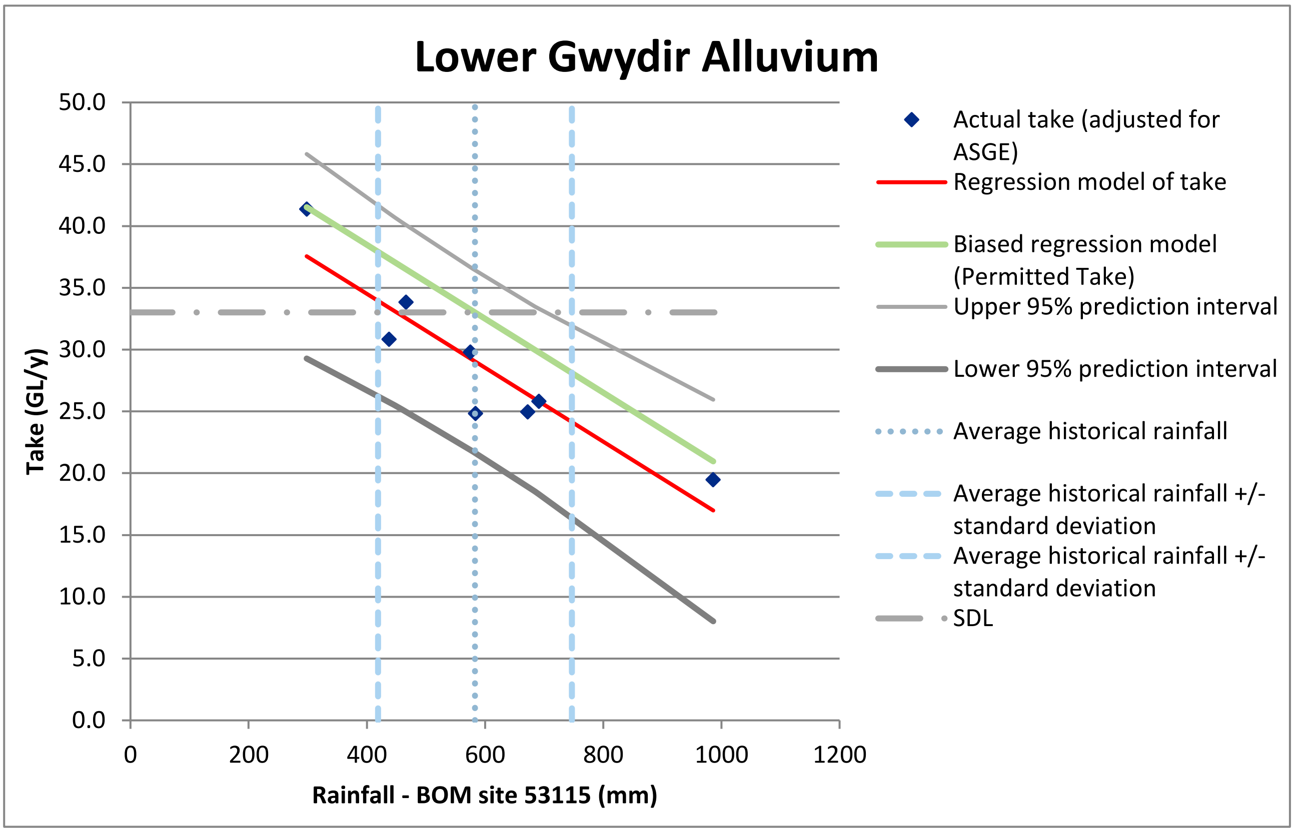

Figure 3 **Regression model used to derive permitted take for the Lower Gwydir Alluvium SDL resource unit**

Step 2: develop regression model and assess its robustness

A standard linear regression model was derived and is shown as the red line in Figure 3. The model takes the form of a two-parameter linear equation (y = A*x + B) where y represents modelled/predicted take, x represents the rainfall recorded in the water year, A represents the slope of the equation and B the intercept. In developing the regression model, a number of statistical tests can be applied to evaluate its robustness, as follows:

- The residuals (the difference between the measured and modelled values of take) can be plotted with respect to rainfall to test that they are randomly scattered and show no obvious trend with respect to rainfall. The regression model for the Lower Gwydir Alluvium passes this test.
- The same plot of residuals can be examined to assess whether their variance (magnitude of scatter) appears constant with respect to rainfall. The regression model for the Lower Gwydir Alluvium passes this test.
- To test that residuals are normally distributed, a normal probability plot of the residuals can be produced and a linear trend is indicative of a normal probability distribution. The regression model for the Lower Gwydir Alluvium passes this test.
- The r^2 value reports the percentage of variance about the average actual take value that can be explained by rainfall. The regression model for the Lower Gwydir Alluvium reports an r^2 of 85% to indicate that rainfall is a strong predictor of take.
- The standard error of the regression model provides a measure of the accuracy of the predictions. The standard error of the regression model for the Lower Gwydir Alluvium is 2.8 GL or 8.5% of the SDL.
- A regression model relies on the assumption that the data points are independent; i.e. actual take measured in a given year of the time series is not influenced by the actual take measured in any other year of the time series. This criterion is probably not satisfied because carry-over provisions mean that actual take in a given year is

related to not only the rainfall for that year, but those in previous years. If the regression approach is to be accepted, it is important that this flaw in the approach is acknowledged because it may lead to perverse outcomes if the sequence of rainfall recorded during the development regression model is typical for the SDL resource unit.

- A regression model relies on the assumption of stationarity, which requires that the conditions experienced during the time series in which the model is developed are stationary (actual take and/or rainfall are not gradually increasing or decreasing to make the modelled relationship spurious). This criterion is difficult to satisfy given natural fluctuations in climate, underlying climate change trends, or development trends in actual take. In the case of the Lower Gwydir Alluvium, efforts have been made to normalise an underlying trend in actual take associated with the ASGE program. While it is possible some other underlying trends have not been detected, the duration of the time series data used to develop the model is relatively short (8 years) for this assumption to be reasonable.

In summary, the regression model developed for the Lower Gwydir Alluvium is satisfactory, but it is noted that the data points are not strictly independent, and it is recommended that the regression model be periodically updated and revised as more data is collected. The data for two years (for the very wet and very dry years) has a strong influence on the regression and, ideally, one would use a much longer historical time series; however, for many SDLs resource units this may be influenced by changes in regulation, markets, technology and surface water availability. Hence, there is a balance between having data that represents unchanging (stationary) conditions and having sufficient data to create a good regression. Because of this, there may generally be only 5–15 data points used to create the regression and this should be updated periodically.

Step 4: adjust the regression model to form a model of permitted take

To form a model of permitted take, the regression model is adjusted to minimise the potential for Type 1 errors and to meet the requirements of s10.10 (4); i.e. that the permitted take is not higher than the SDL when averaged over the historical climate sequence. This adjustment can be made in two steps, as follows:

a. The model is applied to the average annual rainfall of the historical climate to determine a modelled/predicted take for that level of rainfall, which in the case of the Lower Gwydir Alluvium is 29 GL.

b. The difference between the modelled/predicted take determined in step a) and the SDL is used to adjust the intercept of the regression model. In the case of the Lower Gwydir Alluvium, the difference between the SDL (33 GL) and modelled/predicted take is 4 GL, meaning that the intercept of the regression model can be shifted upwards (biased) by 4 GL (or 12 % of the SDL) to create a model of permitted take shown by the green line in Figure 3, and it is noted that the permitted take for the average historical rainfall is equivalent to the SDL.

Step 5: compare to simple method

The variance in the regression method can be compared to that of a simple permitted take method (in which the permitted take is equivalent to the SDL) by calculating the difference between the permitted take and actual take during the period of record and comparing these two population distributions, as shown in Figure 4. The y-axis of this figure is representative of possible credit (positive) or debit (negative) entries in the register of take, and the lower 95% confidence interval (calculated as the mean minus 1.96*(the standard error of the mean)) shows the point above which the mean is most likely to occur. It can be seen in Figure 4 that the variance is much smaller when the regression method is applied, and where debits are possible due to the uncertainty of the simple method (the lower 95% confidence limit is negative), they are very unlikely to occur due to the uncertainty of the regression method (the lower 95% confidence limit is 2.14 GL). Thus, the likelihood of Type 1 errors is minimised by using the regression method, and the likelihood of Type 2 errors is also reduced because the uncertainty of the model is lower. These considerations provide some justification in moving to the more complex method.

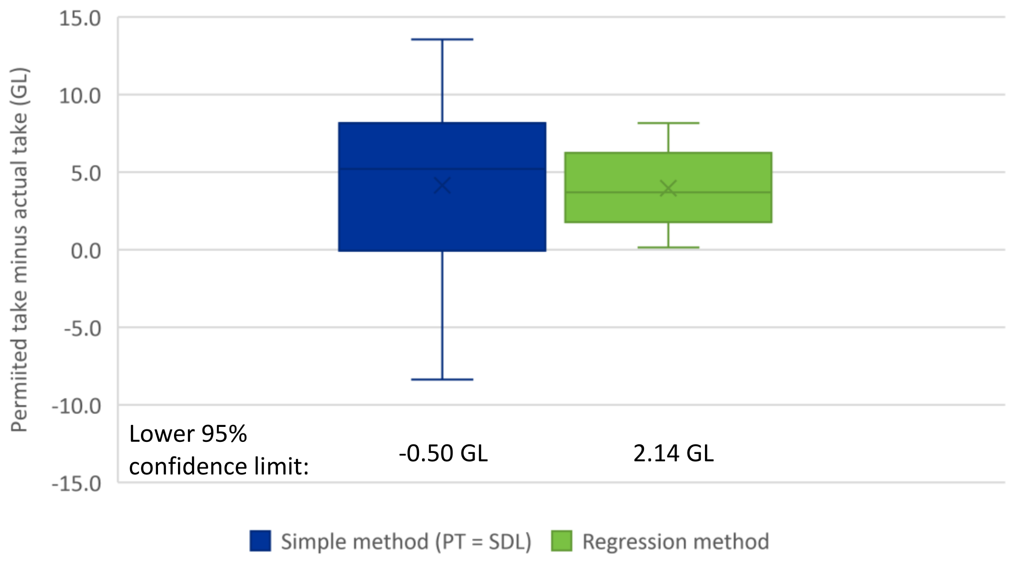

Figure 4 Comparison of permitted take methods for the Lower Gwydir Alluvium SDL resource unit

3.5.2 Peel Valley Alluvium SDL resource unit (GS40) case study

Figure 5 illustrates how the approach can be applied to derive permitted take for the Peel Valley Alluvium SDL resource unit. The Peel Valley Alluvium SDL resource unit has been selected for analysis because it represents a situation where groundwater use occurs in a highly connected surface water-groundwater system.

Step 1: obtain and review data

As a first step, a time series of groundwater actual take was obtained. For the Peel Valley Alluvium SDL resource unit this covered the period of 2004 to 2017 (where 2004 represents the 2003-04 water year, 2005 represents the 2004-05 water year and so on). Unlike the Lower Gwydir Alluvium SDL resource unit, no adjustments to the actual data are required to normalise for the effects of the ASGE program. Rainfall data was obtained as per the method employed for the Lower Gwydir Alluvium SDL resource unit.

To derive a regression model, only the data from 2004 to 2014 has been used, with the last three years of data (2015-17) set aside to test the model for the purposes of this discussion paper. If applying this approach in practice, use of the complete dataset (2004 to 2017) is recommended.

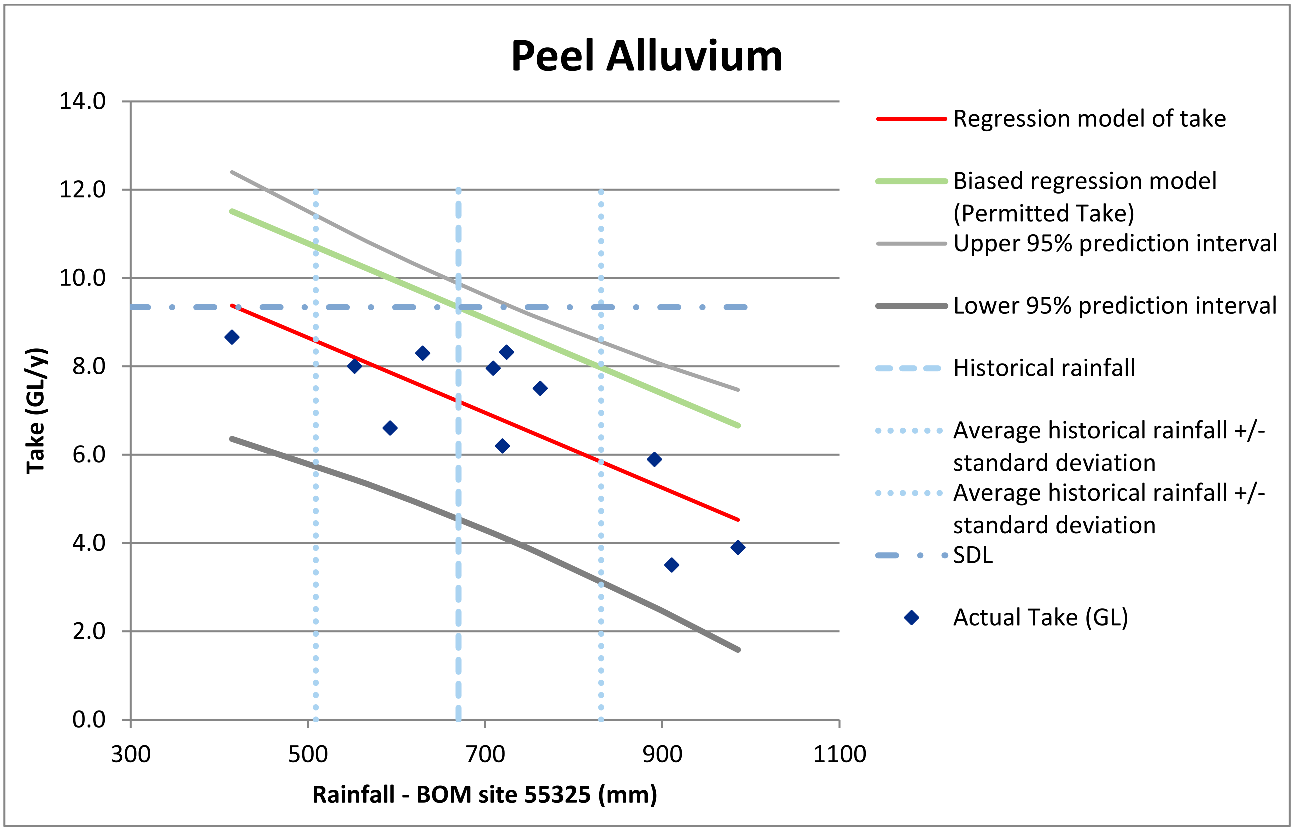

Figure 5 Regression model used to derive Permitted Take for the Peel Valley Alluvium SDL resource unit

Step 2: develop regression model and assess its robustness

A standard linear regression model was derived and is shown as the red line in Figure 5. In developing the regression model, a number of statistical tests can be applied to evaluate its robustness, as follows:

- The residuals (the difference between the measured and modelled values of take) can be plotted with respect to rainfall to test that they are randomly scattered and showing no obvious trend with respect to rainfall. The regression model for the Peel Valley Alluvium passes this test.
- The same plot of residuals can be examined to assess whether their variance (magnitude of scatter) appears constant with respect to rainfall. The regression model for the Peel Valley Alluvium passes this test.
- To test that residuals are normally distributed, a normal probability plot of the residuals can be produced and a linear trend is indicative of a normal probability distribution. The regression model for the Peel Valley Alluvium passes this test.
- The r^2 value reports the percentage of variance about the average actual take value that can be explained by rainfall. The regression model for the Lower Gwydir Alluvium reports an r^2 of 64% to indicate that rainfall is a reasonable predictor of take.
- The standard error of the regression model provides a measure of the accuracy of the predictions. The standard error of the regression model for the Lower Gwydir Alluvium is 1.1 GL or 12 % of the SDL.
- A regression model relies on the assumption that the data points are independent; i.e. actual take measured in a given year of the time series is not influenced by the actual take measured in any other year of the time series. Like the Lower Gwydir Alluvium, this criterion is probably not satisfied and it is acknowledged because it may lead to perverse outcomes if the sequence of rainfall recorded during the development regression model is atypical for the SDL resource unit.

- A regression model relies on the assumption of stationarity, which requires that the conditions experienced during the time series in which the model is developed are stationary (actual take and/or rainfall are not gradually increasing or decreasing to make the modelled relationship spurious). While it is possible some other underlying trends have not been detected, the duration of the time series data used to develop the model is relatively short (11 years) for this assumption to be reasonable.

In summary, the regression model developed for the Peel Valley Alluvium is satisfactory, but it is noted that the data points are not strictly independent, and it is recommended that the regression model be periodically updated and revised as more data is collected. From a certain perspective, there would be benefits in using a much longer historical time series to improve model robustness; however, for many SDLs resource units this may be influenced by changes in regulation, markets, technology and surface water availability. Hence, there is a balance between having data that represents unchanging (stationary) conditions and having sufficient data to create a good regression. Because of this, there may generally be only 5–15 data points used to create the regression and this should be updated periodically. Thus, the 11 year period used to develop the regression model for the Peel Valley Alluvium is considered reasonable.

Step 4: adjust the regression model to form a model of permitted take

To form a model of permitted take, the regression model is adjusted to minimise the potential for false positives and to meet the requirements of s10.10 (4); i.e. that the permitted take is not higher than the SDL when averaged over the historical climate data. This adjustment can be made in two steps, as follows:

a. The model is applied to the average annual rainfall of the historical climate to determine a modelled/predicted take for that level of rainfall, which in the case of the Peel Valley Alluvium is 7.2 GL.

b. The difference between the modelled/predicted take determined in step a) and the SDL is used to adjust the intercept of the regression model. In the case of the Lower Gwydir Alluvium, the difference between the SDL (9.3 GL) and modelled/predicted take is 2.1 GL, meaning that the intercept of the regression model can be shifted upwards (biased) by 2.1 GL (or 23% of the SDL) to create a model of permitted take shown by the green line in Figure 5, and it is noted that the permitted take for the average historical rainfall is equivalent to the SDL.

Step 5: compare to simple method

The variance in the regression method can be compared to that of a simple permitted take method (in which the permitted take is equivalent to the SDL) by calculating the difference between the permitted take and actual take during the period of record and comparing these population distributions, as shown in Figure 6. The y-axis of this figure is representative of possible credit (positive) or debit (negative) entries in the register of take, and the lower 95% confidence interval (calculated as the mean minus 1.96*(the standard error of the mean)) shows the point above which the mean is most likely to occur

It can be seen in Figure 6 that the variance is lower when the regression method is applied; however there is little difference in the lower 95% confidence limits and because this is a positive value for the simple method, there is a very low likelihood of debits being returned due to uncertainty of the simple of method. Thus, on the basis of reducing Type 1 errors, there is little value in shifting to the regression method. The standard error of the mean is, however, lower under the regression method (0.3 GL c.f. 0.5 GL), which may provide for a more robust analysis of trends in actual take. So, there would be some justification in moving to the regression method as it would reduce, slightly, the probability of Type 2 errors occurring.

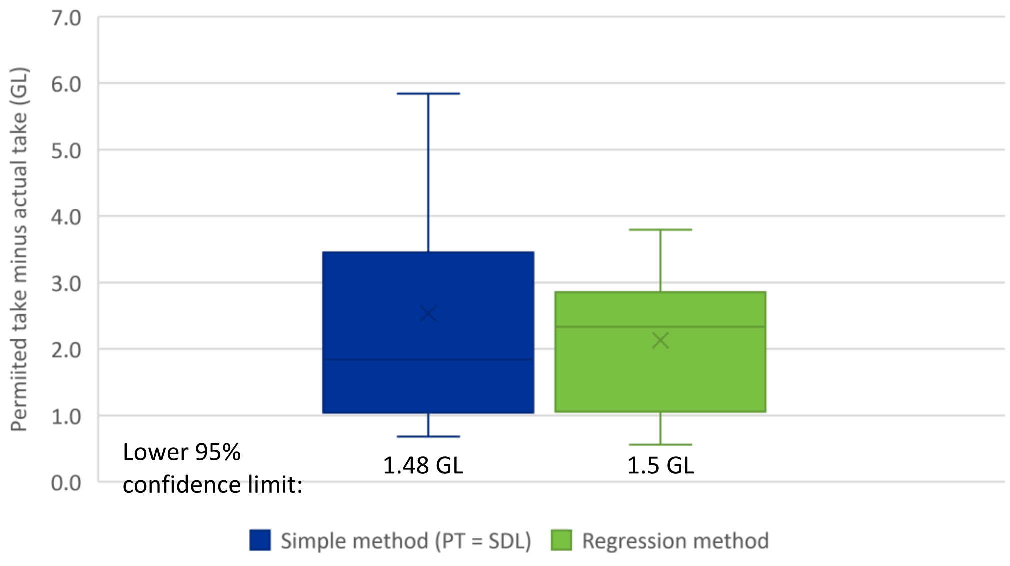

Figure 6 **Comparison of permitted take methods for the Peel Valley Alluvium SDL resource unit**

3.5.3 Upper Condamine Alluvium case study

Two SDL resource units were examined in the Upper Condamine Alluvium: the Upper Condamine Alluvium (Central Condamine Alluvium) (GS64a) and the Upper Condamine Alluvium (Tributaries) (GS64b) (Central Condamine Alluvium and Condamine Tributaries hereafter).

Step 1: obtain and review data

As a first step, a time series of groundwater actual take was obtained. For both of the Upper Condamine Alluvium SDL resource units this covered the period of 2009 to 2017 (where 2009 represents the 2008-09 water year, 2010 represents the 2009-10 water year and so on). Unlike the Lower Gwydir Alluvium, no adjustments were made in the actual data to normalise for the effects of structural adjustment. Rainfall data was obtained as per the method employed for the Lower Gwydir Alluvium.

To derive a regression model, only the data from 2009 to 2014 has been used, with the last three years of data (2015-17) set aside to test the model for the purposes of this discussion paper. If applying this approach in practice, use of the complete dataset (2009 to 2017) is recommended; however, it is noted that use of this data does not improve the robustness of the regression model appreciably in the dataset examined.

Step 2: develop regression model and assess its robustness

A standard linear regression model was derived and is shown as the red lines in Figure 7 and Figure 8. In developing the regression model, a number of statistical tests can be applied to evaluate its robustness, as follows:

- The residuals (the difference between the measured and modelled values of take) can be plotted with respect to rainfall to test that they are randomly scattered and showing no obvious trend with respect to rainfall. Both regression models pass this test, but there is a small number of data points (6).
- The same plot of residuals can be examined to assess whether their variance (magnitude of scatter) appears constant with respect to rainfall. Both regression models pass this test, but large residuals are noted.
- To test that residuals are normally distributed, a normal probability plot of the residuals can be produced and a linear trend is indicative of a normal probability distribution. Both regression models pass this test.
- The r^2 value reports the percentage of variance about the average actual take value that can be explained by rainfall. The regression model for the Central Condamine Alluvium reports an r^2 of 61% to indicate that rainfall is

a reasonable predictor of take, but an r^2 of 5% is derived for the Condamine Tributaries indicating that rainfall is a poor predictor of take.

- The standard error of the regression model provides a measure of the accuracy of the predictions. The standard error of the regression model for the Central Condamine Alluvium is 13.6 GL or 30 % of the SDL. The standard error of the regression model for the Condamine Tributaries is 8.42 GL or 21 % of the SDL. The accuracy of the predictions is also reflected in the upper and lower 95% prediction intervals and in both cases this range extends to negative values of take, indicating a low level of confidence in the accuracy of the predictions.
- A regression model relies on the assumption that the data points are independent; i.e. actual take measured in a given year of the time series is not influenced by the actual take measured in any other year of the time series. Like the other SDL resource units examined, this criterion is probably not satisfied and it is acknowledged because it may lead to perverse outcomes if the sequence of rainfall recorded during the development regression model is atypical.
- A regression model relies on the assumption of stationarity, which requires that the conditions experienced during the time series in which the model is developed are stationary (actual take and/or rainfall are not gradually increasing or decreasing to make the modelled relationship spurious). While the time series data used to develop the model is relatively short (6 years), Central Condamine Alluvium and Condamine Tributaries have been subject to structural adjustments in their allocation provisions and it is possible that some underlying trends in take have occurred over this period to invalidate this criterion.

The regression model developed for the Central Condamine Alluvium is not particularly robust. While the r^2 is reasonable, the model has a high degree of predictive uncertainty (a standard error equivalent to 30% of the SDL). This may be related to the small number of data points (6 years), but it may also be related to other factors not included in the model (e.g. the actual take has not been normalised for any structural adjustments).

The regression model developed for the Condamine Tributaries is not satisfactory. Its low r^2 (5%) indicates that rainfall is a poor predictor of take and it has a high degree of predictive uncertainty (a standard error equivalent to 21% of the SDL).

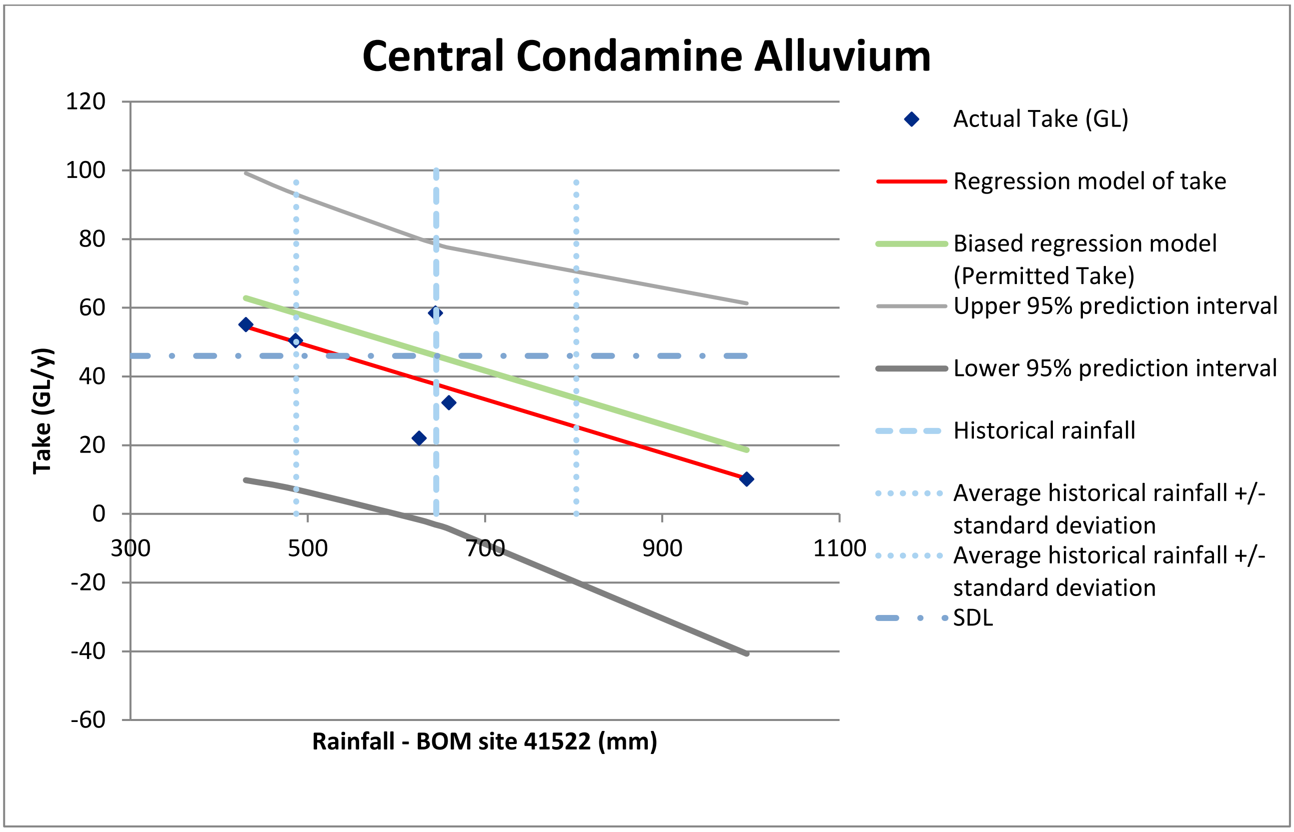

Figure 7 **Regression model used to derive permitted take for the Upper Condamine Alluvium (Central Condamine Alluvium) SDL resource unit**

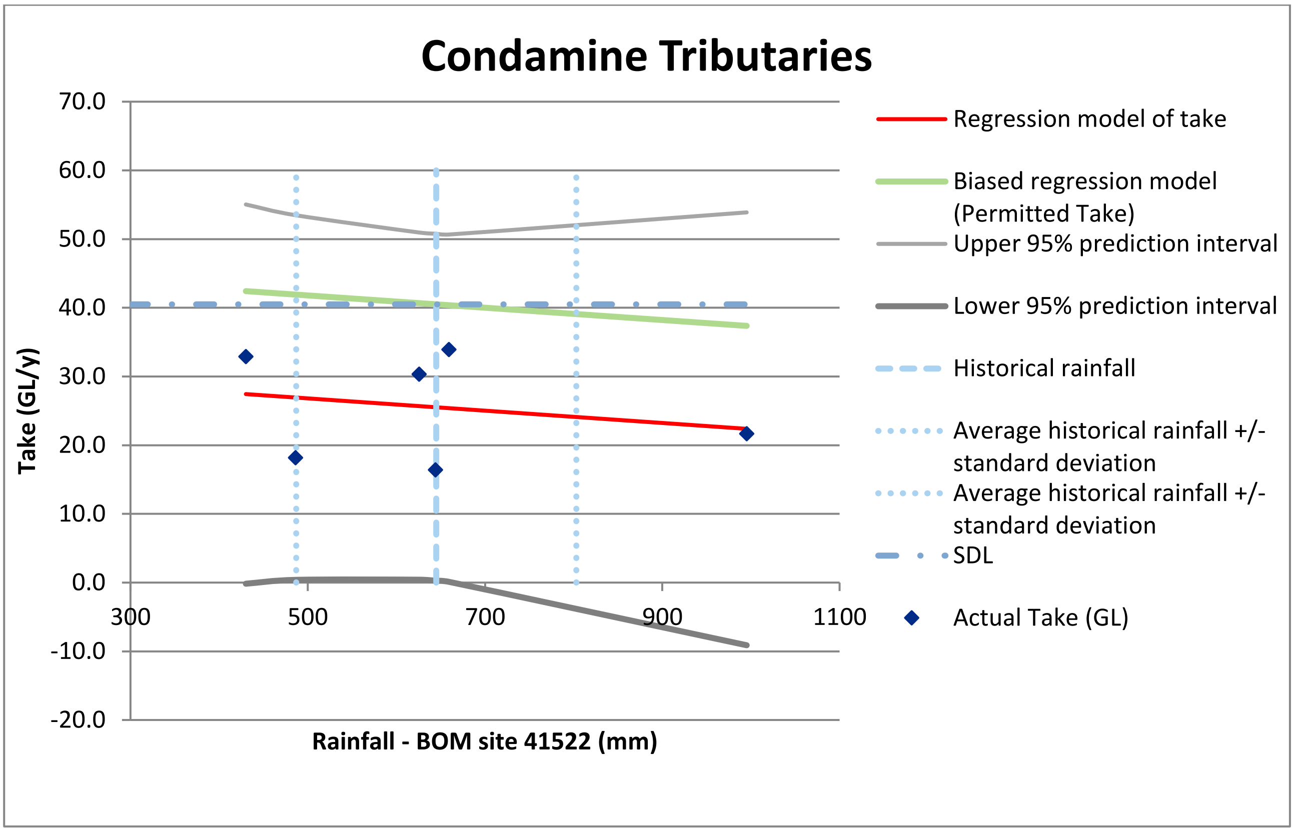

Figure 8 **Regression model used to derive permitted take for the Upper Condamine Alluvium (Tributaries) SDL resource unit**

Step 4: adjust the regression model to form a model of permitted take

If these regression models were to be used to develop a model of permitted take, the regression model can be adjusted to minimise the potential for Type 1 errors and to meet the requirements of s10.10 (4); i.e. that the permitted take is not higher than the SDL when averaged over the historical climate data. This adjustment can be made in two steps, as follows:

a. The model is applied to the average annual rainfall of the historical climate to determine a modelled/predicted take for that level of rainfall, which is 37.7 GL for the Central Condamine Alluvium and 25.5 GL for the Condamine Tributaries.

b. The difference between the modelled/predicted take determined in step a) and the SDL is used to adjust the intercept of the regression model, which allows for a shift of 8.3 GL (18% in the Central Condamine Alluvium) and 15 GL (37% in the Condamine Tributaries).

Step 5: compare to simple method

The variance in the regression method can be compared to that of a simple permitted take method (in which the permitted take is equivalent to the SDL) by calculating the difference between the permitted take and actual take during the period of record and comparing these population distributions, as shown in Figure 9. The y-axis of this figure is representative of possible credit (positive) or debit (negative) entries in the register of take, and the lower 95% confidence interval (calculated as the mean minus 1.96*(the standard error of the mean)) shows the point above which the mean is most likely to occur

It can be seen in Figure 9 that the variance is lower when the regression method is applied to the Central Condamine Alluvium but there is no improvement when it is applied to the Condamine Tributaries (reinforcing the results from the r^2 statistic). For the Central Condamine Alluvium, the uncertainty in the complex method is still, however, large and the lower 95% confidence limit of -1.44 GL indicates that Type 1 errors are still possible if it is used. In this instance, it would be of benefit to investigate ways to improve the model robustness (e.g. by including other factors, such as stream flow, or by determining whether the take data needs to be normalised to remove an underlying trend). As it stands, moving to the regression approach is still justified on the basis that the standard error is reduced and it would provide a more accurate determination of permitted take, reducing the likelihood of both Type 1 and Type 2 errors occurring but without ruling them out. The model could also be improved over time as more data is collected.

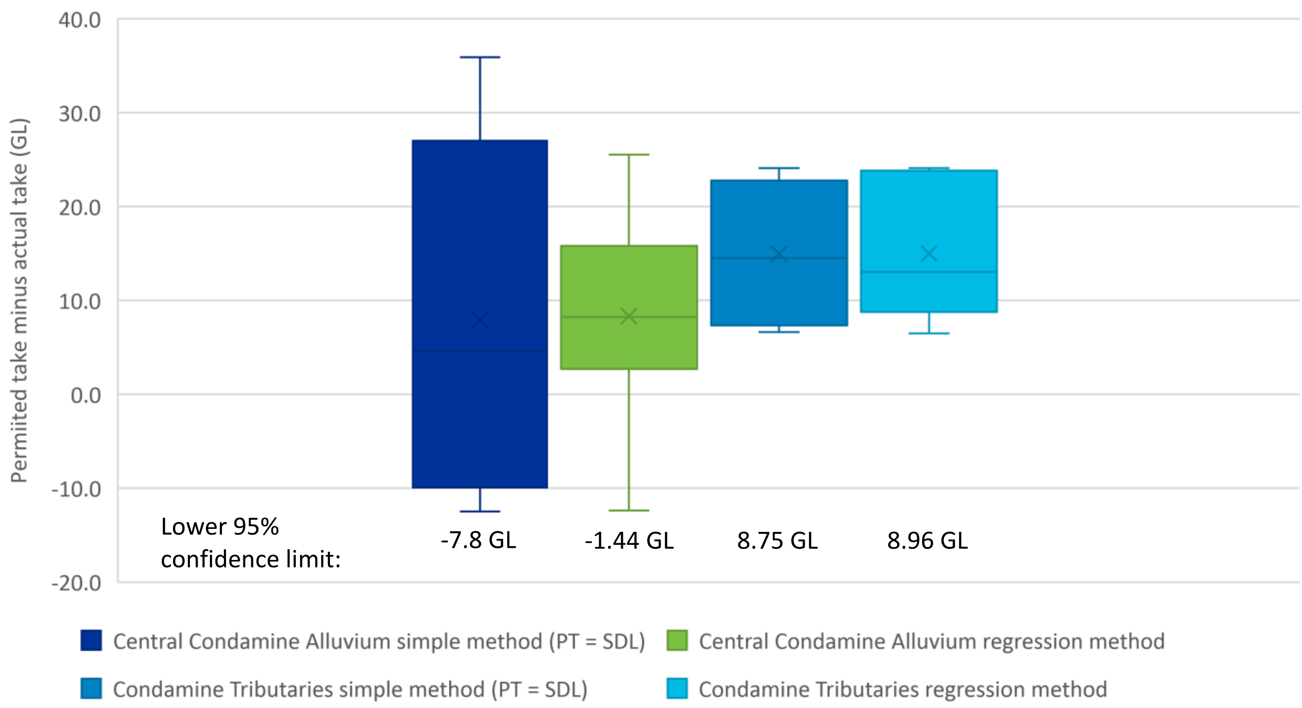

Figure 9 **Comparison of permitted take methods for the Central Condamine Alluvium and Condamine Tributaries**

By comparison, there is no benefit by moving to the regression method for the Condamine Tributaries; noting that Type 1 errors are considered unlikely even if the simple method is used (as evident by the lower 95% confidence limit being in credit, well above zero).

3.6 Evaluation of model errors and implications for accounting

The permitted take methods developed for the case study examples have been tested retrospectively using data from 2015-2017 to illustrate how they could be applied within the compliance assessment. Table 2 presents the results of this analysis which compares the use of a simple method (where permitted take is equivalent to the SDL) to the regression approach (complex method). A limitation of this analysis is that only 3 years of data is used, which represents a very small subset of the climatic sequence.

For the Lower Gwydir Alluvium SDL resource unit, the application of a simple permitted take method results in an exceedance of the 20% SDL threshold in the annual accounts undertaken for 2015 and 2016 (highlighted by the red shading in Table 2). If this exceedance is consistent with a legitimate level of actual take (e.g. through access to carry-over provisions), then the triggering of a potential non-compliance is regarded as a Type 1 error. Whereas if the complex permitted take method were used, which allows for actual take to exceed the SDL in years of low rainfall, the 20% SDL threshold is not breached.

No other exceedances were recorded using either the simple or the complex methods.

The 'cumulative errors' presented in the right-hand columns of Table 2 can be used to examine the significance of the errors and biases associated with the regression model for the compliance assessment.

The standard error is based on the standard error of the regression, and its value becomes larger over time when it is used to assess the cumulative balance. For example, the standard error for Year 3 of an assessment (2017 in the example shown) is related to the cumulative standard error over 3 years. This term does not grow linearly but can be approximated by the following formulation:

$$Cumulative\ S.E. = S.E.\, of\ Regression \times \sqrt{Number\ of\ years\ in\ cumulative\ assessment}$$

Thus, the error term increases with time but at a gradually reducing rate.

While the cumulative standard error is used to define model uncertainty, it is offset by the bias applied in the adjusted regression formulation to determine predicted take. For example, the model used for the Lower Gwydir Alluvium SDL resource unit has (in 2017) a standard error of 2.8 GL but a bias of 4.0 GL. Because the bias is larger than the standard error, we can be confident in the application of the model in the accounting process and if this model were to detect a 20% SDL exceedance, it is unlikely that such an exceedance is due to model uncertainty.

The model errors are larger for the case studies from the two Upper Condamine Alluvium SDL resource units. In the case of the Central Condamine Alluvium, the standard error is larger than the bias and the 20% threshold in 2015 and 2016 of the assessment. Therefore, its use in the compliance assessment would have a high degree of uncertainty in the early years of its application but would improve thereafter.

For the Condamine Tributaries, the bias applied to the model is large, but the regression model on which it is based is poor and the complex method is not recommended for compliance purposes. In this situation the simple method would be recommended, as outlined above.

Table 2 Test of permitted take methods over the 2015-2017 period

Year	AT (GL)	Rainfall (mm)	PT (simple); PT = SDL				PT (complex); Regression approach				Cumulative Errors (for complex method)		
			PT (simple) (GL)	PT - AT (GL)	Cumulative balance (GL)	Cumulative balance (% SDL)	PT (complex) (GL)	PT - AT (GL)	Cumulative balance (GL)	Cumulative balance (% SDL)	Standard error (GL)	Cumulative bias (GL)	20% SDL threshold (GL)
Lower Gwydir Alluvium SDL resource unit													
2015	40.9	499	33.0	-7.8	-7.8	-24%	35.5	-5.3	-5.3	-16%	2.8	4.0	6.6
2016	35.5	403	33.0	-2.5	-10.4	-31%	38.4	2.8	-2.5	-8%	4.0	7.9	6.6
2017	23.8	593	33.0	9.2	-1.1	-3%	32.7	8.9	6.4	19%	4.9	11.9	6.6
Peel Valley Alluvium SDL resource unit													
2015	7.2	747	9.3	2.2	2.2	23%	8.7	1.5	1.5	16%	1.1	2.1	1.9
2016	6.6	689	9.3	2.7	4.9	52%	9.2	2.6	4.1	44%	1.6	4.3	1.9
2017	4.8	820	9.3	4.5	9.4	101%	8.1	3.3	7.3	79%	1.9	6.4	1.9
Upper Condamine Alluvium (Central Condamine Alluvium) SDL resource unit													
2015	41.1	451	46.0	4.9	4.9	11%	61.2	20.1	20.1	44%	13.6	8.3	9.2
2016	42.0	396	46.0	4.0	9.0	19%	65.5	23.5	43.6	95%	19.3	16.6	9.2
2017	48.0	634	46.0	-2.0	6.9	15%	46.9	-1.2	42.4	92%	23.6	25.0	9.2
Upper Condamine Alluvium (Tributaries) SDL resource unit													
2015	30.6	451	40.5	9.9	9.9	24%	42.2	11.7	11.7	29%	8.4	15.0	8.1
2016	32.7	396	40.5	7.9	17.8	44%	42.7	10.1	21.7	54%	11.9	30.0	8.1
2017	32.8	634	40.5	7.7	25.4	63%	40.6	7.8	29.5	73%	14.6	45.0	8.1

Overall, the case studies show that for some of the SDL resource units, there is advantage in using a mathematical formulation of permitted take in order to minimize Type 1 errors. However, if the model uncertainty increases over time or the level of actual take is closer to the SDL, the probability of Type 1 errors will increase. Thus, lack of independence, non-stationarity, smaller sequences of historical data and the type of adjustment to create a bias could all increase model uncertainty and hence the likelihood of Type 1 errors occurring. A more complex regression involving more than one-year rainfall record may better reflect the relationship between actual take and rainfall. For example, a regression model could be built using actual take and rainfall over two-year increments rather than single year increments to better account for carryover influences. However, this is likely to lead to fewer degrees of freedom and hence greater errors. It may be feasible to take a longer groundwater diversion record, but the conditions due to drought, ASGE and reduced surface water diversions might affect the suitability of the regression as a predictor. The updating of the regression using newly obtained diversion data is important and updates to the model should be considered at 5-year intervals during the life of the Basin Plan. There may be other drivers for diversion other than rainfall, and these may be considered by jurisdictions.

The long-term rainfall record is important. The source of the rainfall data needs to be declared, and information on the mean and distribution need to be derived. If there is an understanding of the sequences of rainfall that lead to low and high groundwater diversions, then it would be important to better understand the occurrence of such sequences in the historical rainfall record.

Climate change is addressed in the SDL. However, higher temperatures and longer droughts may lead to changes in groundwater use. This provides another reason for regularly reviewing the mathematical formulations.

Section 4 Conclusions and recommendations

There are simple and more complex methods for determining permitted take. A simple method can work well where the annual actual take is likely to remain well below SDL value. A more complex method such as using a model (e.g. a linear regression) can be applied where there is greater chance that actual take can be greater than the SDL. The benefit of a more complex method is that it provides flexibility to allow for fluctuations in actual take when it is lawful but higher than SDL in a given year. The complex method offsets reduced actual take in other years and averages out to the SDL. The case study analysis demonstrates that by introducing a more complex method there can be fewer occurrences of permitted take exceeding actual take, thereby avoiding the problem of Type 1 errors and reducing the likelihood of Type 2 errors. As a general rule the approach taken should be to balance the complexity of the method with the likelihood of SDL exceedance in the future. And, where possible electing to use the simplest method, subject to ensuring that the requirements of the Basin Plan are met.

If a more complex method is used, and this relies on a model of the historical record of take, then care needs to be exercised in assessing the results. Historical data of groundwater take is not long or comprehensive. In these first stages of model development, the number of years with reliable data will be limited. In a statistical sense, the sample size will be small and this increases the standard error.

The reliability of the linear regression model depends on the validity of key assumptions (in particular, independence of data and stationarity within the relationship between actual take and rainfall) and these should be evaluated prior to use of this method.

There are a range of factors that might lead to these key assumptions not being valid, which creates errors in the regression such as use of management rules that breakdown the relationship between rainfall and actual take.

Under the scenario of a drying climate, a regression method may cause the permitted take to more frequently exceed the SDL compared to the historical climate sequence, placing additional pressure on the groundwater resource. Regular reviews of the regression method should be undertaken to determine whether such changes are occurring, and whether the permitted take method needs to be updated to avoid such a perverse outcome.

More complex relationships between actual take and rainfall may be more valid and it is not necessary to use a linear regression, but adopting such a method will make the relationship more reflective of the consequences of WRPs and will provide information that will allow the risk of potential non-compliance to be assessed. Basin states are able to bring forward their own methods for consideration within the WRP submitted for accreditation. Those methods will be reviewed against the relevant criteria.

Regression can be improved with collection of more data over time and it is recommended there is re-evaluation of the data and models at 5-yearly intervals.

Section 5 References

MDBA, 2013. Handbook for Practitioners – Water resource plan requirements. Murray-Darling Basin Authority, October 2013.

MDBA, 2017. Transitional Period Water Take Report 2012–13 to 2015–16: Report on cap compliance and transitional SDL accounting. Murray-Darling Basin Authority, November 2017.

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