Methodology for the assignment of aquifers to bores in the Surat and southern Bowen basins

A technical note

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This document provides a technical summary of a current OGIA product which supports the assessment and management of resource development impacts. It is not a statutory document. Conclusions are subject to further review and changes ahead of the preparation of the next Underground Water Impact Report and other statutory reporting as needed.

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Terminology

Aquifer Attribution – the process of assigning source formations to water bores. The process does not discriminate whether a formation is an aquifer or an aquitard.

Area of Interest – the area that captures the entire active resource development footprint and extends to about 15 km from CSG development

Groundwater Intake Interval – the portion of the bore that is 'screened' or 'open' to the surrounding formations

Casing – the protective pipe around a borehole to prevent it from collapsing

RN-pipe – the combination of a bore's Registered Number (RN) and Pipe (A, B, C, D, etc.), used to create a unique identifier

Relative transmissivity – the rate at which groundwater moves through a screened section of a formation, relative to other formations intersected by the bore.

Hydraulic gradient – the rate of groundwater flow is driven by differences in hydraulic head over a given distance.

Abbreviations

AA........................ aquifer attribution

AOI .... Area of Interest

CMA .... Cumulative Management Area

CSG...................... coal seam gas

DNRM................... Department of Natural Resources and Mines (former)

DRDMW .... Department of Regional Development, Manufacturing and Water

GII......................... Groundwater Intake Interval

GSQ .... Geological Survey of Queensland

GWDB .... groundwater database

Kx .... horizontal permeability

OGIA .... Office of Groundwater Impact Assessment

QA/QC.................. quality assurance/quality control

REL_T .... relative transmissivity

RN .... Registration Number (refers to water bores)

UWIR.................... Underground Water Impact Report

WCM .... Walloon Coal Measures

WMS..................... Water Management Strategy

1 Introduction

1.1 The importance of aquifer attribution

Characterising extraction from aquifers within a regional geological context provides an understanding of where and to what extent groundwater is extracted, which informs the assessment and management of groundwater resources. The determination of aquifers accessed by a water bore depends on a comprehensive understanding of the full stratigraphy encountered, as well as the construction of the bore.

Aquifer attribution (AA) is the process of assigning formations to water bores. For the purposes of this report, this definition considers all formations, regardless of their hydrogeological characteristics and intended uses. The accurate assignment of aquifers to water bores is a key input to groundwater system conceptualisation and the modelling of groundwater impacts from resource development in the Surat Cumulative Management Area (CMA).

Information about water bore location, construction and source aquifers is crucial for the calibration of groundwater flow models. These datasets are also essential in understanding system response to principal stressors – a key component of impact assessment.

A range of conceptualisation activities are dependent on the accurate assignment of aquifers to water supply bores and monitoring bores. These activities include the analysis of groundwater level and hydrochemistry trends, the distribution of groundwater use and the identification of water supply bores potentially affected by resource development in the Surat CMA.

1.2 About this technical note

The Office of Groundwater Impact Assessment (OGIA) is an independent office responsible for the assessment and management of cumulative groundwater impacts from resource development within the Surat CMA. Comprehensive reporting is provided in the form of a statutory report – an Underground Water Impact Report (UWIR) – released every three years. The most recent assessment was completed in 2021.

Fundamental to the technical assessments carried out by OGIA is an understanding of the aquifers screened by monitoring points and water supply bores. This technical note describes OGIA's methodology for the assignment of aquifers to bores and a summary of each dataset used therein, from across the Surat CMA.

Since OGIA prepared the initial UWIR in 2012, the AA methodology has significantly evolved. The current methodology is designed to account for changes to input datasets – such as revised geological models – and to allow for the identification of dominant and secondary contributing aquifers where a bore is screened across more than one aquifer.

The AA workflow was applied to all water bores irrespective of their status – existing or decommissioned – or bore type – water supply or monitoring. This ensured that all bores and associated historical data were included in the AA process.

Aquifer attributions may change over time because of changes to input datasets, such as corrections to bore records, and ongoing improvement to geological modelling. Since the UWIR 2012, OGIA's methodology for assigning aquifers has also continued to evolve to address limitations of bore data and improvements in underlying information. Changing attributions are reported in the next UWIR, with changes to the workflow reported in subsequent research updates.

1.3 Context

This section provides an overview of the major groundwater systems in the Surat CMA, a summary of the key challenges in assigning aquifers to water bores and the evolution of OGIA's approach.

1.3.1 Groundwater flow systems

There are three primary groundwater systems in the Surat CMA, as shown in Figure 1-1 and discussed further in OGIA (OGIA 2021a).

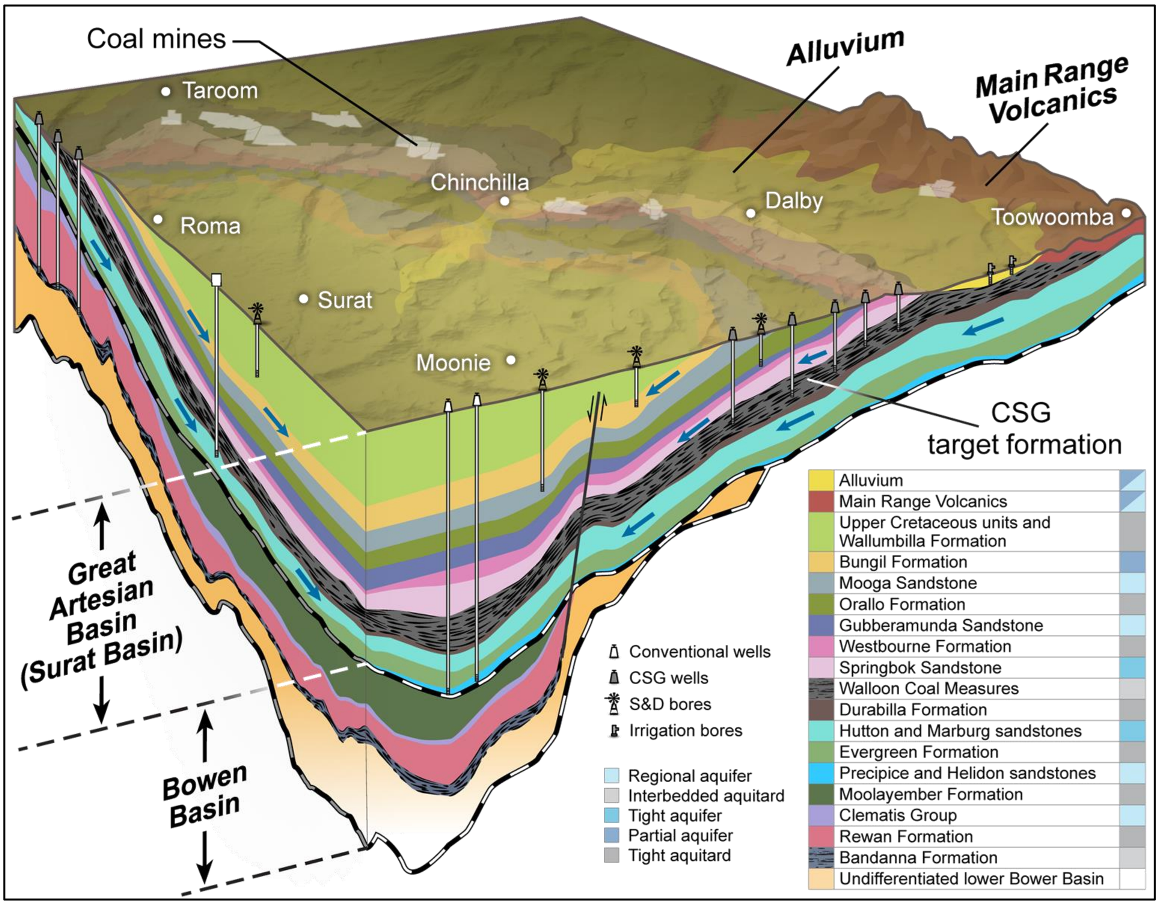

Figure 1-1: Representation of the geology of the Surat CMA (after OGIA 2021a)

Results in this technical note are reported based on these three groundwater systems:

- Surat Basin: a Jurassic to Cretaceous hydrogeological basin comprising alternating aquifers and aquitards of various geologic formations of Surat Basin sediments and their equivalents, including the Walloon Coal Measures – a coal seam gas (CSG) and coal mining resource.
- Bowen Basin: Permian to Triassic aquifers and aquitards of the Bowen Basin formations, underlying the Surat Basin. This includes the Bandanna Formation – a CSG reservoir.
- Alluvium and basalt:
    - Basalt: Cenozoic consolidated surficial aquifers, the most prominent being the Main Range Volcanics, overlying the Surat Basin sediments along the Great Dividing Range in the southeast of the Surat CMA.

    - Alluvium: Quaternary unconsolidated surficial aquifers, the most prominent being the Condamine Alluvium, overlying the Surat Basin sediments in the southeast of the Surat CMA in the central plain of the Condamine River.

1.3.2 Key challenges

There are a number of significant challenges to assigning source aquifers to water bores across the Surat CMA. These include:

- Dataset size – there are around 37,000 water bores across an area of approximately 600×500 km. The degree of automation versus manual verification presents a significant challenge.
- Reliability – source aquifer information from publicly available datasets and tenure holder datasets is often of variable quality. Assumptions have been made about the completeness and reliability of these datasets, to assign a confidence ranking to the data.
- Incompleteness and inconsistency – due to variable reporting standards, the quality and completeness of bore records in the Surat and Bowen basins varies. There is often incomplete or limited construction information available for some bores. Furthermore, data may include inconsistent information about source aquifers.

Overcoming these challenges requires the development of a workflow that encompasses a deep understanding of the input datasets and their limitations, the development of sound assumptions where data is incomplete, and the balancing of automation and manual verification, given the scale of the datasets.

1.3.3 Historical approach

OGIA's AA methodology has experienced significant transformation since the initial UWIR in 2012. Over time, OGIA has adopted a more systematic and data-driven approach for assigning aquifers, as summarised below.

- In 2012:
    - Attributions were primarily sourced from the Queensland Government’s Groundwater Database (GWDB) and water licensing information from the then Department of Natural Resources and Mines’ (DNRM) Water Management System.
    - In key areas, manual verification of source aquifer assignments was used to improve water bore attribution.
- Between 2016 and 2021:
    - The methodology was redeveloped for the UWIR 2016, ranking each data source to create a confidence-based hierarchy reflecting aspects such as data resolution, age of data, coverage and known level of accuracy. The redeveloped approach integrated a way of selecting for the best data source, where multiple options were available when assigning aquifers to bores.
    - Input datasets included bore assessments by tenure holders, the Queensland Government’s Murray-Darling Basin stock-and-domestic bore dataset, stratigraphic surfaces extracted from the revised OGIA regional geological model, bore screen information, and OGIA project and bore assessment databases.

- Where a borehole intersected multiple confined aquifers or aquitards in the OGIA groundwater flow model, the shallowest confined aquifer or aquitard – within the range of model layers available at the bore location – was assigned.
- Where multiple aquifers were assigned to a bore in the GWDB ‘Aquifer’ table, the deepest was assumed to be the target aquifer. This assumed that the bore was likely drilled until the most productive aquifer was reached and then screened in that zone.
- In cases where a bore was located outside the extent of model layers, the main aquifer accessed by nearby bores was assigned to the bore.

A more detailed overview of the progression of earlier methods for determining source aquifers is available in OGIA (2016).

2 Methodology

This chapter provides an overview of the current methodology for assigning aquifers to all monitoring and water supply bores within the Surat CMA.

2.1 Data sources

Key input datasets applied in the AA workflow are summarised in Table 2-1.

2.2 Methodology

Numerous data sources inform the identification of the screened aquifer(s) for an individual water bore. The approach used by OGIA's AA methodology integrates two primary elements: water bore construction information – location, depth and construction data – and hydrostratigraphic information.

There are significant challenges in implementing this fundamental process, such as uncertainties in recorded bore location; lack of information on bore depth and screened depths; and lack of sufficient construction information. In addition, the boundaries between geological formations near outcrop areas may be uncertain, which leads to uncertain aquifer attribution.

To overcome some of these challenges, the current methodology – in contrast to previous approaches, prior to 2019 – acknowledges areas where there is lower confidence in geological models due to limited stratigraphic control. In these areas, alternative datasets with higher confidence are used.

For the workflow, the latest data sources (Table 2-1) were collated and processed for use in a Python environment. This includes direct connection to a Structured Query Language (SQL) database with a monthly download of GWDB tables, as well as various static tables to capture data from other sources – such as the DRDMW water licensing system. Many of the attributes of individual datasets are standardised within the workflow, such as the various stratigraphic nomenclature used between the input datasets.

The workflow collates and prepares bore construction and aquifer information from a range of sources, calculates groundwater intake intervals (GII) where possible and applies the rulesets to assign an aquifer to the intake based on the degree of confidence in available datasets. Where multiple aquifers have been assigned, the workflow also determines dominant and secondary contributing aquifers. In cases where bores may not have all information needed to carry out these steps, the information that is available is used and applied in order of confidence.

Table 2-1: Summary of data sources

Theme	Dataset	Year	Description	Data source
Bore construction	GWDB	2023	Registered bore location, water levels, construction details, strata log and water quality from water supply and monitoring bores	https://www.data.qld.gov.au/dataset/groundwater-database-json
	Geological Survey of Queensland (GSQ) borehole database	2023	A digital representation of the distribution or locations of drilled bore holes	https://www.data.qld.gov.au/dataset/queensland-borehole-series
Hydrostratigraphy	OGIA Water Monitoring Strategy (WMS)	2023	Monitoring points constructed by tenure holders to target specific formations	OGIA dataset
	OGIA regional geological model	2021	Geological models to support conceptualisation and modelling activities	OGIA dataset
	OGIA sub-regional geological models (New Acland & Northern Coal Areas)	2021		OGIA dataset
	GWDB	2023	Strata log, stratigraphy and aquifer tables	https://www.data.qld.gov.au/dataset/groundwater-database-json
	Department of Regional Development, Manufacturing and Water (DRDMW) Water Management System	2023	Water entitlement and works information (including aquifers) for both groundwater and surface-water extraction in Queensland	https://www.data.qld.gov.au/dataset/water-entitlements

2.2.1 Data collation and preparation

The key input datasets for this workflow are tables from the GWBD, as listed in Table 2-2.

Table 2-2: GWDB tables used in the AA workflow

GWDB table	Description
Aquifer	Aquifers encountered during drilling of the bore; in some cases, contributing and non-contributing aquifers are flagged
Casing	Construction information about the bore
Registration	Every registered water bore in Queensland, including the location and date of construction
Strata logs	Transcription of the strata encountered in a bore, as described on the strata log section of a completed bore report
Stratigraphy	Interpreted stratigraphy of the bore and depth

2.2.1.1 Bore construction

Fundamental to the determination of a bore's physical attributes is the portion of the bore that is 'screened' or 'open' to the surrounding formations – termed the 'groundwater intake interval' (GII) in this technical note (Figure 2-1).

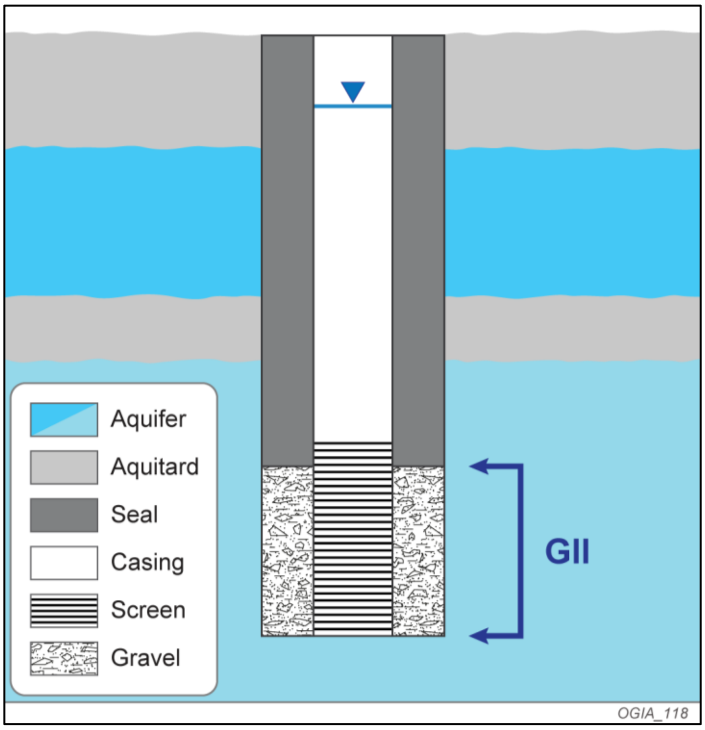

Figure 2-1: Example of determining the Groundwater Intake Interval

As individual bores – especially monitoring bores – may be nested and monitor water levels in multiple different aquifers using separate pipes, the combination of a bore's Registered Number (RN) and Pipe (A, B, C, D, etc.) has been used to create a unique identifier for each interval, termed the 'RN-pipe'. Under this convention, bores with pipe A indicate the deepest position, while subsequent letters source from progressively shallower depths.

A GII was generated based on construction information from the GWDB ‘Casing’ table, using the top and bottom of the zone from which groundwater enters the bore. A description of the key fields used from the ‘Casing’ table is provided in Table 2-3.

Table 2-3: GWDB ‘Casing’ table codes and categories applied in the workflow

Category	Code	Description
Open	PERF	Perforated or slotted casing section
	SCRN	Screen
	OPEN	Open hole (section of bore uncased)
	VWPZ	Vibrating-wire piezometer
Seals	GROU	Grout
	BNSL	Bentonite seal
	PLUG	Cement or grout plug
Base	ENDD	Open end pipe considered as an entry point
Casing	MDPP	Medium Density Polythene Pipe
	FRP	Fibreglass Reinforced Plastic
	PLAS	Plastic Casing
	PVC	Polyvinyl Chloride
	SBS	Slimline Black Steel
	SGS	Slimline Galvanized Steel
	SSL	Stainless Steel
	SSSB	Standard Screwed Swelled Black
	SSSG	Standard Screwed Swelled Galvanised
	TIMB	Timber Lining for Wells
	WES	Welded Steel Casing or Tubing

Using these codes (Table 2-3), the following logic has been applied to determine the GII for each individual bore:

- Open sections were identified with the following codes:
  - PERF, SCRN, OPEN or VWPZ
  - GRAV is used where none of the above codes are recorded (only applied when those listed in Table 2-3 are not present).
- Where a single open section is identified, the top and bottom are applied as the GII.
- Where multiple open sections are identified and these sections are not separated by a seal, the top of the uppermost open section and base of the lowermost open section are applied as the GII.
- Where an open section is not recorded but a blank interval is recorded between the bottom of the casing and base of the bore, this section is applied as the GII, noting:

    - blank interval must be greater than 1 metre
    - this logic uses the code ‘ENDD’.
- Where a GII material code – PERF, SCRN, OPEN or VWPZ – is incomplete, missing the top depth, bottom depth, or both, a default inlet of 10 m is applied. This value approximately corresponds to the median GII length for bores with complete construction information.
- Where a seal material occurs at a depth that is coincident with the GII, only the section completely open to the formation is selected as the GII.
- Where a bore does not contain a GII material code (PERF, SCRN, OPEN or VWPZ), only contains GRAV and this is not restricted by a seal material, this section is applied as the GII.
- For converted petroleum wells, the base of the bore is assumed to be the top of the first plug and the synthetic inlet is applied to these bores.

Maximum bore depth is also applied in the workflow. This information is extracted from the ‘Casing’, ‘Strata logs’, ‘Aquifer’ and ‘Stratigraphy’ tables of the GWDB. The depth of the casing is extracted using the GWDB codes FRP, MDPP, PLAS, PVC, SBS, SGS, SSL, SSSB, SSSG, TIMB and WES (Table 2-3). A summary of completions and the resulting GII are provided in Appendix A. The results from the application of this logic are provided in Table 2-4.

Table 2-4: Summary of bore construction categories for RN-pipes in the Surat CMA

Construction information type	Count	Percent of total (%)
Complete GII information	23,079	64
Depth only (synthetic applied)	9,106	25
Location only	3,095	9
Incomplete GII information (default of 10 m applied)	905	2
Total	**36,185**	**100**

Of the 36,185 RN-pipe combinations in the Surat CMA, there was sufficient construction information to determine the GII for 23,079 RN-pipes – approximately 64%. For around 900 bores (2%), construction information was incomplete for either the top or the base of the open interval. In these cases, an inlet of 10 m has been applied.

For the 25% of bores where a depth only is recorded, a synthetic GII has been generated using complete construction information of GIIs for other bores within the Surat CMA. In these situations, bores without construction details are characterised using their total depths and periods of construction.

Two depth ranges are considered: less than and greater than 100 metres. This depth threshold has been selected as a generalised transition from confined to unconfined conditions. Deeper bores are likely to have been constructed to standards different from those of shallow bores.

In terms of the period of construction, construction standards have evolved over time, reflecting improved drilling technology and regulatory requirements. Three time periods are applied, which generally align to evolution in construction standards or drilling techniques: 1900–1960; 1960–2000;

and 2000–2023. For each period, the percentage of GII to total bore depth is generated, as presented in Table 2-5. This percentage is then applied as a synthetic inlet to bores for which there is depth information but insufficient construction information to generate a stand-alone GII.

Table 2-5: Inlet statistics for bores with only depth information

Year range	Depth scenario (m)	Average GII from mBGL (m)	Average GII to mBGL (m)	Average GII length, as percent of total bore depth (%)
1900–1960	≤100	50	74	35
	>100	248	427	36
1960–2000	≤100	29	50	40
	>100	264	605	44
2000–2023	≤100	26	51	50
	>100	397	473	17

There are more than 3,000 (11%) bores that only have locations and therefore cannot be used to intersect with OGIA's geological models. Additional methods are required to assign source aquifers to these bores.

2.2.1.2 Geological model

OGIA has developed regional and sub-regional geological models of the Surat CMA for conceptualisation and modelling purposes (OGIA 2021b). These models were interrogated to identify the likely formations intercepted by the GIIs for bores located within the model extents.

The confidence in a geological model layer at a given location relates to the availability of data to control the model surfaces – such as bore logs and seismic lines. For each layer identified as intercepted by a GII, a confidence in the formation is assigned based on the distance to the nearest control point for that layer, as described in Table 2-6.

Table 2-6: Model confidence and criteria

Distance to nearest control point	OGIA model confidence
≤15 km	High
>15 km	Low

For the Surat CMA, there are three geological models: one regional and two sub-regional. Due to their varying construction, reflecting their purposes, the models were used differently in the AA workflow:

- **Regional model** – represents the lithostratigraphic-based conceptualisation of the Surat and Bowen basins. It incorporates key geological features, such as outcropping areas of Surat Basin units, regional faults and the unconformity at the Springbok Sandstone base. Features included in this model include the onlap of Surat Basin units against basal Jurassic unconformity, subcrop of Bowen Basin units and geological conceptualisation – at springs and contacts between the Bandanna Formation and Surat Basin units.

- **Northern coal geological model** – includes formations from the Springbok Sandstone to the Hutton Sandstone and has a surficial layer (top 35 m) that is a combination of formations, making this model unsuitable for aquifer attribution at shallow depths. This model was used where bores have inlet tops deeper than 35 m and inlet bottoms shallower than the Hutton Sandstone, i.e. where the GII falls within the model domain.
- **New Acland geological model** – focuses on surficial formations and the Taroom Coal Measures – the target formation for the New Acland coal mine. This model was used in place of the regional model within this model extent.

Where a GII intersects formations of both high and low confidence, both formations are assigned under the higher-confidence ruleset, which assumes a greater degree of stratigraphic control.

2.2.1.3 Formation standardisation

The recorded name of a formation may vary across the input datasets listed in Table 2-1. Such variations may be attributable to the level of experience of the person who created each record or the evolution of nomenclature for some formations in the Surat CMA – for example, the Injune Creek Group, which is now subdivided into several distinct formations. To integrate the primary datasets, it is therefore necessary to standardise formations names.

Standardised formations were compared with OGIA's regional and sub-regional geological models to subdivide the assigned source aquifers for each RN-pipe. This involved intersecting the GII with the geological layers and comparing the intersected formation to the original dataset's assigned source formation. If any inconsistencies were found, the original dataset's assigned aquifers were retained. Table 2-7 illustrates an example where a bore is screened across the Springbok Sandstone and Walloon Coal Measures. In this example, the assigned aquifer determined by complementary datasets aligns with OGIA's geological model, which enables additional granularity by identifying the Lower Springbok Sandstone and Juandah Coal Measures as source formations (shaded in grey in Table 2-7). Formations represented by multiple model layers or formation groupings (such as the Injune Creek Group) are limited to layers that are common between the original dataset and the OGIA geological model.

Table 2-7: Example intersection to standardise formation assignments

Formation recorded in an original dataset	OGIA geological model layer
Springbok Sandstone	Upper Springbok Sandstone
	Lower Springbok Sandstone
Walloon Coal Measures	Upper Juandah Coal Measures
	Lower Juandah Coal Measures
	Taroom Coal Measures

2.2.1.4 Master dataset compilation

The sections above describe the methodology to process and standardise the input data, which is then compiled into a master dataset. This compilation provides the following benefits:

- a comprehensive summary of the available data, enabling a considered assessment of source aquifers across all input datasets
- efficient manual review of attributions in key areas that require further verification
- improved data management to reduce errors in duplication and processing
- increased transparency, by providing a record of data sources in the attribution process.

2.2.2 Ruleset application

Nine rulesets have been developed using the available construction and aquifer information available for each RN-pipe combination. Appendix B provides a full description of the rules and assumptions and the proportion of RN-pipes to which each rule is applied.

For this workflow, a hierarchical approach was used in applying the rulesets to each RN-pipe combination. The process ranked data first by high-confidence datasets, then progressively lower confidence model data, with the lowest confidence level assigned to data with depth and location data only.

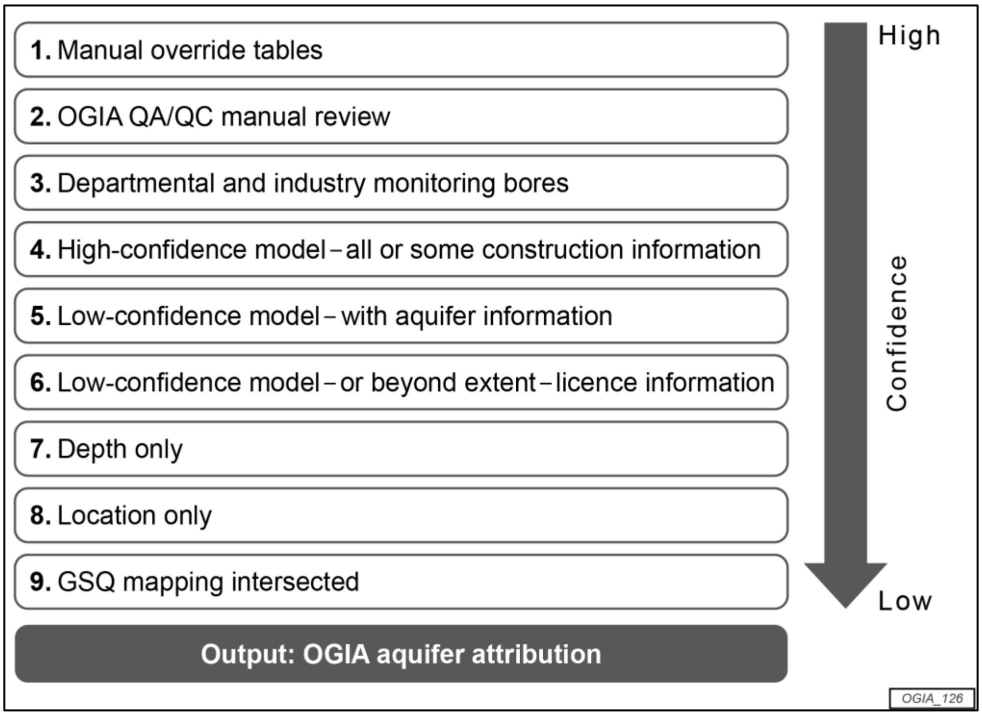

Figure 2-2: Flow chart illustrating the application of rulesets

There are three categories of rulesets based on confidence in the available datasets. The distribution of bores assigned to high-, medium- and low-confidence categories are based on assumed source dataset verification and quality, as discussed below.

2.2.2.1 High-confidence rulesets

The methodology implemented by OGIA was designed to ensure accuracy and reliability of attributions. High-confidence rulesets 1, 2, 3 and 4 are listed in order of application:

- Approximately 15,000 RN-pipes have been manually reviewed (desktop investigation) for the UWIR 2021 and prior to the UWIR 2019 (rulesets 1 and 2).

- For bores in the UWIR 2021 WMS, the assigned source aquifer was assumed to be of high confidence. For bores identified as DRDMW monitoring bores, the aquifer intersected by the GII in the GWDB ‘Aquifer’ table is retained (ruleset 3).
- Bores were intersected with OGIA's regional and sub-regional geological models in high-confidence areas, with priority given to bores with complete construction information (valid top and bottom GII information) (ruleset 4).
- A synthetic inlet was applied to bores with incomplete construction data (ruleset 4).
- Additionally, model intersections occurring within 15 km of stratigraphic control points are designated as high-confidence and adopted accordingly (ruleset 4).

2.2.2.2 Medium-confidence rulesets

To assign aquifers to bores that have not had aquifers assigned through the high-confidence ruleset, a systematic approach is applied, as follows:

1. Analysis of the GWDB ‘Aquifer’ table using the GII. The table lists aquifers that have both tops and bottoms. Formations containing an "N" flag in the "CONT" field were excluded, as they do not contribute to the water in the bore (ruleset 5).
2. Where no information was obtained from the GWDB ‘Aquifer’ table, the GII was applied to the GWDB ‘Stratigraphy’ table, if available (ruleset 5).
3. If primary data is not available from these tables, the aquifer specified on the water entitlement and development approval was applied where available. The entitlement data took precedence over works data, as it includes information on the aquifer to be accessed by a specific bore (ruleset 6).
4. The geological model intersection was taken for low-confidence model locations (>15 km from stratigraphic control) (ruleset 6).
5. Bores for which the GWDB ‘Aquifer’ table includes only a top or bottom of aquifer were excluded from ruleset 5 and all aquifers with such incomplete information were assigned to the RN-Pipe (ruleset 6).

2.2.2.3 Low-confidence rulesets

The lower confidence rulesets were designed to attribute bores where there was little to no information available and where they have not been captured by the high- or medium-confidence rulesets. In these cases, the following logic has been applied:

1. For low-confidence geological model locations (>15 km away from stratigraphic control), all bores were intersected with the GWDB ‘Stratigraphy’ table using a synthetic inlet (ruleset 7).
2. Where the GWDB ‘Stratigraphy’ table is unavailable, the geological model layers were used (ruleset 7).
3. For areas with low confidence as defined by the distance from stratigraphic control, the screened model layers were then applied (ruleset 7).
4. Bores were assigned source aquifers based on the dominant formation of nearby bores within a 5-km radius. This was done separately for bores with construction information (ruleset 7) and without this information (ruleset 8). Nearby bores are restricted to those used for water

supply purposes and the assigned formation must occur in the assigned model extent at the bore location.

5. Remaining assignments were derived by intersecting the GSQ detailed surface geological mapping dataset (ruleset 9).

2.2.3 Primary and secondary contributing formations

The aquifer attribution process may result in more than one formation identified as contributing to a single bore. Approximately 23% of RN-pipes were identified to be open to multiple formations. In these cases, an additional workflow was developed to both identify the primary and secondary contributing aquifers and quantify their relative contributions. This is important for a number of dependent datasets – such as groundwater use or groundwater level trends – where data may relate to more than one aquifer.

The following approach was used to determine the relative contribution of the screened aquifers. This involves calculating the transmissivity (T) of each screened model layer and determining its relative contribution relative to the total T across the screened model layers.

Relative transmissivity (REL_T) is the rate at which groundwater moves through an aquifer under a hydraulic gradient and is calculated as follows:

$$REL_T = \frac{T}{Tsum}$$

where:

T = transmissivity of an aquifer/layer of interest (screened thickness × horizontal permeability (Kx))

Tsum = sum of transmissivities for all screened model layers.

Figure 2-3 illustrates the treatment of a bore screened within a single formation across multiple groundwater flow model subdivisions. In this example, the bore sources predominantly from the central layers (70% in total). The uppermost and lowermost layers contribute the other 10% and 20%, respectively. This methodology can also be used when a bore is screened across multiple formations.

To assign relative transmissivities to bores under the current methodology, it was necessary to consider assignments that may occur beyond the extent of the model – noting the extent of the permeability arrays is less than the model layer extents. Scenarios and actions for bore assignments in this scenario are summarised in Table 2-8 and further described below.

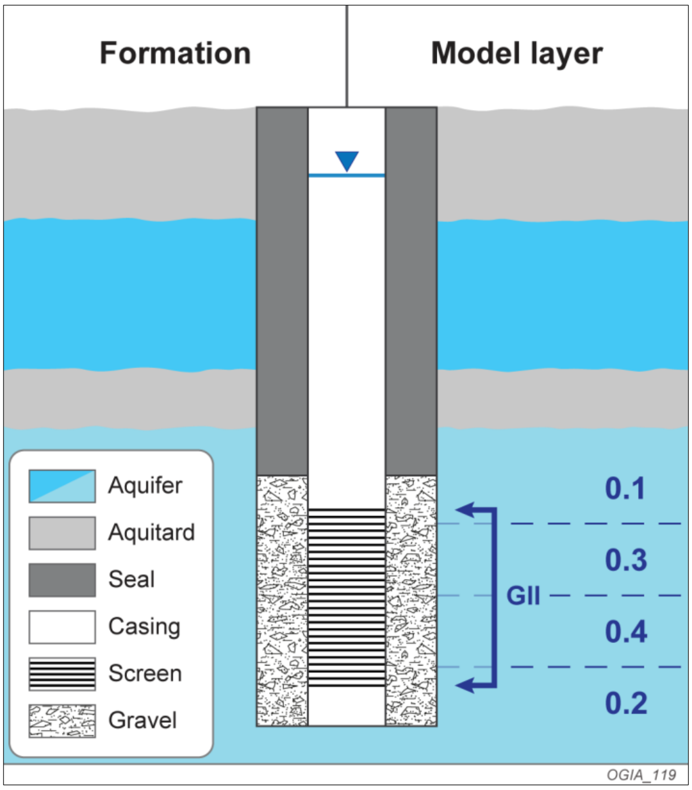

Figure 2-3: Bore diagram illustrating the calculation of relative transmissivity (dark blue lines indicate model subdivisions)

Table 2-8: Methodology for assigning relative transmissivities to water bores.

Kx value available	Thickness available	Action
Yes	Yes	Calculate REL_T
No	Yes	Formation represented by multiple model layers: • neighbouring constituent layer Kx value • radius search for Kx value within 15 km • median formation transmissivity Formation represented by a single model layer: • radius search for Kx value within 15 km • median formation transmissivity
Yes/No	No	Assigned using a median formation transmissivity value

- Where a calibrated Kx value and layer thickness are available at the bore location for the assigned model layer, transmissivity has been calculated based on the screened layer thickness, if available, or full layer thickness if the GII is unknown.
- Where a calibrated Kx value is not available but a model layer thickness is known, several approaches are used to attribute a permeability value. For formations with multiple numerical model layer subdivisions – such as the Walloon Coal Measures – the workflow steps vertically downwards through Kx values ascribed to model layers at the bore location within the attributed formation – as deeper formations will have Kx values. A radius search is conducted

within 15 km to assign a Kx value. If a Kx value is not available, transmissivity statistics are calculated for an assumed thickness of 10 m at every model node location, unless the layer thickness reduces to less than this value.

- Where a screened or layer thickness was unknown regardless of the availability of a Kx value, transmissivity cannot be determined. In this case, the bulk formation transmissivity has been assigned for the bore, based on an assumed thickness of 10 m, as per the approach described in scenario two.

2.3 Assumptions and limitations

Given the substantial number of water bores in the Surat CMA, OGIA has developed a methodology that is largely automated, complemented with manual site-specific review in specific areas of interest – such as where impacts are predicted in the short term. The following assumptions are applied in the workflow:

- Tenure holder attributions of monitoring bores are assigned a high level of confidence, due to their assumed higher level of verification relative to water supply bores.
- In areas where the geological model has very limited or no control points, the aquifer recorded in the GWDB, entitlement or development approval is retained.
- Where no depth information is available, a bore is assumed to be screened in the aquifer that is frequently intersected by other water bores within five kilometres.
- Where all previous rulesets have been applied and no aquifer has been assigned, GSQ detailed surface geological mapping (1:100,000) is assumed to represent the target formation.
- Where the bore is screened or open across multiple formations, the formations' relative transmissivity (a product of intercepted thickness and permeability) is used to assign the dominant and secondary contributing aquifers.

3 Outputs

The workflow described above provides a hierarchical dataset detailing the assignment of aquifers to each bore within the Surat CMA. Table 3-1 and Table 3-2 summarise the dominant formations assigned to all RN-pipes based on the ruleset hierarchy, irrespective of their status and purpose (existing or abandoned; water supply or monitoring). To provide a more relevant contextual number of water bores, the number of water bores is also reported for the area of interest (AOI). This is an area that captures the entire active resource development footprint and extends to about 15 km from CSG development (Figure 3-1).

For both the Surat CMA and the AOI, the majority (81-85%) of RN-pipe records were assigned a dominant formation based on high-confidence rulesets. Formations for about 11% of RN-pipe records in the Surat CMA were assigned based on medium-confidence rulesets, while 6% were assigned using the low-confidence rules. In the AOI, 9% of RN-pipes were assigned using low-confidence rules and 6% were assigned based on medium-confidence rules. Overall, the results indicate that there is a high degree of confidence in the rulesets used to assign source aquifers to the majority of the water bores in both areas.

In the Surat CMA, the largest percentage of RN-pipes were assigned to alluviums and basalts (Table 3-1), with approximately 44% of bores being assigned to the Main Range Volcanics, Condamine Alluvium or other alluvium or basalts. These formations tend to have irregularly shaped outcrop areas, the intricate details of which are not always captured accurately in the resolution provided by the models. In the AOI, which excludes certain areas of Main Range Volcanics, the largest proportion (60%) of RN-pipes were assigned to the Condamine Alluvium. A map illustrating the distribution of water bores by geological basins in the Surat CMA is presented in Figure 3-1 and Appendix 2 provides a summary of metadata for the OGIA aquifer attribution dataset.

Table 3-1: Number of bores* in the Surat CMA by ruleset category

Group	Formation	Number of bores by ruleset confidence			Total
		High	Medium	Low	
Alluvium and basalts	Condamine Alluvium	4,479	64	333	4,876
	Main Range Volcanics	8,310	146	304	8,760
	Other Alluvium	3,391	220	304	3,915
	Other Basalts	1,210	69	54	1,333
	Alluvium and basalts subtotal	*17,390*	*499*	*995*	*18,884*
Great Artesian Basin	Upper Cretaceous formations	403	5	29	437
	Wallumbilla Formation	84	116	64	264
	Bungil Formation	133	173	22	328
	Mooga Sandstone	593	184	78	855
	Orallo Formation	838	120	108	1,066
	Gubberamunda Sandstone	1,197	149	134	1,480
	Westbourne Formation	131	19	16	166
	Upper Springbok Sandstone	274	13	41	328

Group	Formation		Number of bores by ruleset confidence			Total
			High	Medium	Low	
	Lower Springbok Sandstone		240	13	21	274
	Walloon Coal Measures	Upper Juandah Coal Measures	641	31	55	727
		Lower Juandah Coal Measures	962	178	103	1,243
		Taroom Coal Measures	879	130	60	1,069
	Durabilla Formation		165	17	4	186
	Upper Hutton Sandstone		2,304	922	463	3,689
	Lower Hutton Sandstone		327	547	207	1,081
	Upper Evergreen Formation		104	62	98	264
	Boxvale Sandstone Member		68	25	4	97
	Lower Evergreen Formation		145	61	29	235
	Precipice Sandstone		648	135	21	804
	GAB subtotal		*10,136*	*2,900*	*1,557*	*14,593*
Bowen Basin	Moolayember Formation		65	121	45	231
	Clematis Group		155	47	8	210
	Rewan Group		524	-	19	543
	Upper Bandanna Formation		157	38	35	230
	Lower Bandanna Formation		66	11	4	81
	Upper Cattle Creek Formation		12	11	17	40
	Lower Cattle Creek Formation		2	3	-	5
	Upper Permian		378	210	99	687
	Lower Permian		232	56	72	360
	Metamorphic/igneous/old basement rocks		138	116	66	321
	Bowen Basin subtotal		*1,729*	*613*	*365*	*2,708*
Total			**29,255**	**4,012**	**2,917**	**36,185**
Percentage of total (%)			81	11	6	100

Note:
* All bores, irrespective of their status (existing or abandoned) or purpose (water supply or monitoring).

Table 3-2: Number of bores in the area of interest by ruleset category

Group	Formation	Number of bores by ruleset confidence			Total
		High	Medium	Low	
Alluvium and basalts	Condamine Alluvium	3,511	31	282	3,824
	Main Range Volcanics	428	11	38	477
	Other Alluvium	891	14	72	977

Group	Formation		Number of bores by ruleset confidence: High	Medium	Low	Total
	Other Basalts		67	-	5	72
	Alluvium and basalts subtotal		4,897	56	397	5,350
Great Artesian Basin	Upper Cretaceous formations		186	4	26	216
	Wallumbilla Formation		23	51	36	110
	Bungil Formation		68	97	14	179
	Mooga Sandstone		330	105	63	498
	Orallo Formation		579	72	99	750
	Gubberamunda Sandstone		816	45	110	971
	Westbourne Formation		114	11	15	140
	Upper Springbok Sandstone		237	2	41	280
	Lower Springbok Sandstone		200	3	19	222
	Walloon Coal Measures	Upper Juandah Coal Measures	598	4	44	646
		Lower Juandah Coal Measures	722	40	49	811
		Taroom Coal Measures	534	13	30	577
	Durabilla Formation		87	-	1	88
	Upper Hutton Sandstone		1,073	132	137	1,342
	Lower Hutton Sandstone		167	167	58	392
	Upper Evergreen Formation		33	3	9	45
	Boxvale Sandstone Member		15	4	-	19
	Lower Evergreen Formation		74	4	7	85
	Precipice Sandstone		417	12	14	443
	GAB subtotal		1,866	322	226	2,414
Bowen Basin	Moolayember Formation		31	-	-	31
	Clematis Group		39	-	1	40
	Rewan Group		119	-	4	123
	Upper Bandanna Formation		45	-	1	46
	Lower Bandanna Formation		29	-	-	29
	Upper Cattle Creek Formation		5	-	-	5
	Lower Cattle Creek Formation		2	-	-	2
	Upper Permian		39	4	-	43
	Lower Permian		16	-	-	16
	Metamorphic/igneous/old basement rocks		22	5	-	27
	Bowen Basin Total		347	9	6	362
Total			**11,517**	**834**	**1,175**	**13,526**
Percentage of total (%)			85	6	9	100%

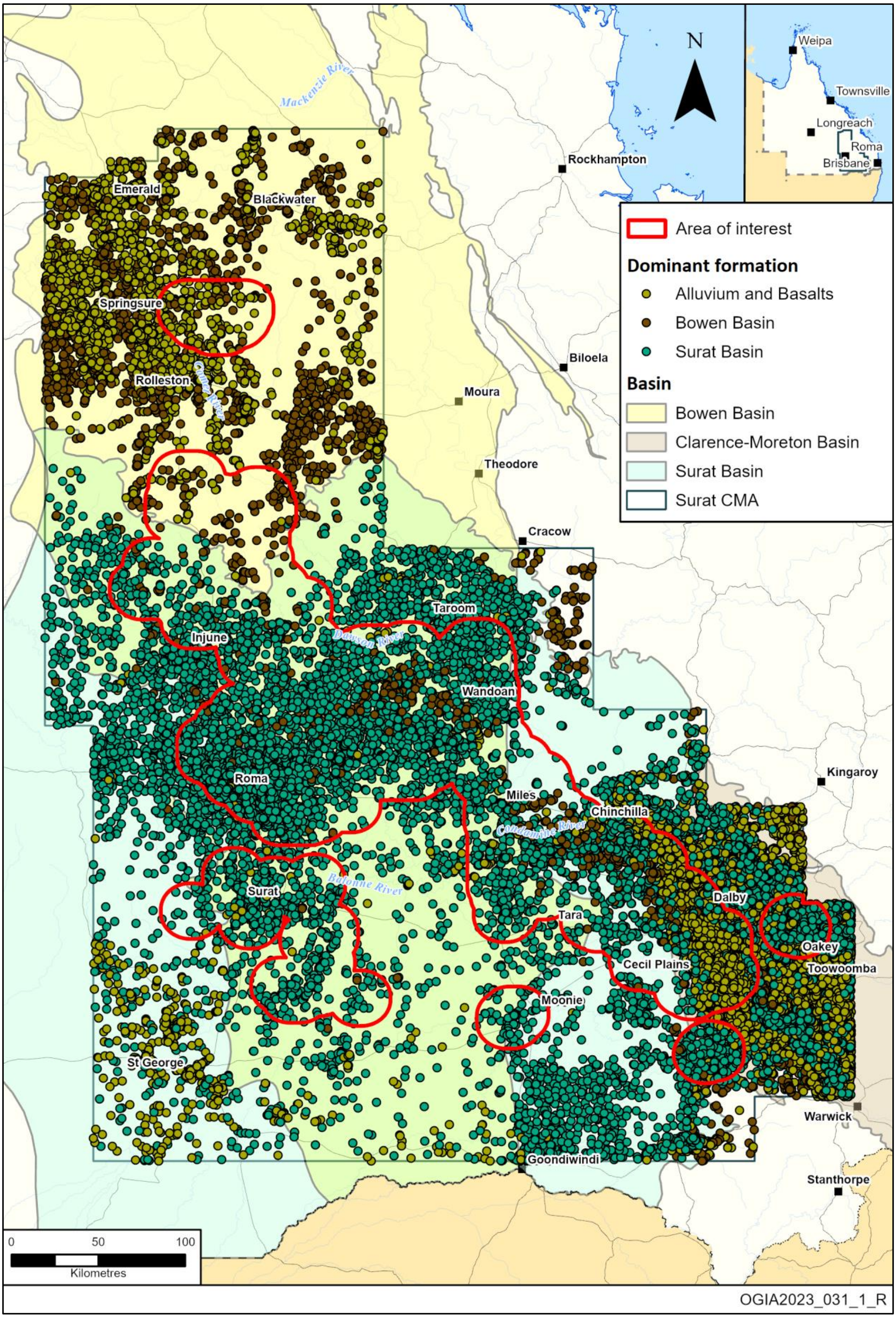

Figure 3-1: Distribution of water bores by geological basin in the Surat CMA

4 Conclusions

4.1 Application

The assignment of aquifers to bores serves as a critical input to conceptualisation and modelling. This is foundational information for analysing groundwater levels and hydrochemical trends, distributing water extraction volumes and identifying bores that may be affected by resource development.

An important outcome of the aquifer attribution methodology is the assignment of a relative transmissivity value to each formation and groundwater flow model layer. This attribute enables the following to be applied in the Surat CMA:

- The proportional distribution of groundwater extraction to bores accessing multiple formations or layers within the groundwater flow model. This ensures that the extraction volumes are appropriately assigned to each aquifer for modelling and conceptualisation activities.
- The use of transmissivity values to identify thresholds for single-aquifer bore completions. As an example, a bore may access two formations with relative transmissivity values of 87% and 13% for the two aquifers screened. By adopting a threshold of 80%, only the bore accessing more than this value will be considered for further analysis. This threshold conservatively excludes bores that have significant contributions from secondary formations. This is important for establishing appropriate datasets for trend analysis, potentiometric surface mapping and hydrochemistry analysis.

4.2 Summary

Since the initial UWIR in 2012, OGIA has continued to evolve the methodology for the assignment of formations to bores in the Surat CMA. The current methodology integrates bore construction information and hydrogeological information in a hierarchical workflow across the regional and sub-regional model domains. The key elements of the methodology are as follows:

- rulesets that integrate confidence in the quality of source datasets
- GIIs generated that can be intersected with geological models and other hydrostratigraphic information available from a range of data sources
- integration of aquifers identified in water licensing and development permit databases and stratigraphy information maintained in the GWDB
- dominant and secondary contributing aquifers and their respective contributions
- workflow developed in Python and modularised to enable re-running when new data becomes available, such as updated geological models.

The updated workflow described in this technical note provides a more rigorous process in the assignment of dominant formations to individual bore holes, improving an important foundational dataset that is critical for assigning water extraction volumes to water bores and distributing water extraction based on numerical groundwater flow model layers.

References

OGIA 2016, *Hydrogeological Conceptualisation Report for the Surat Cumulative Management Area*, OGIA, Department of Natural Resources and Mines, Brisbane, accessed from <https://www.ogia.water.qld.gov.au/publications-reports>.

OGIA 2021a, ‘Underground Water Impact Report 2021 for the Surat Cumulative Management Area’, , no. December, p. 224, accessed from <https://www.ogia.water.qld.gov.au/publications-reports>.

OGIA 2021b, *Geology and 3D geological models for Queensland’s Surat and southern Bowen basins: stratigraphic framework, data, methods and results (OGIA21CD03)*, Brisbane, Queensland, accessed from <https://www.ogia.water.qld.gov.au/publications-reports>.

Appendix A GII schematics

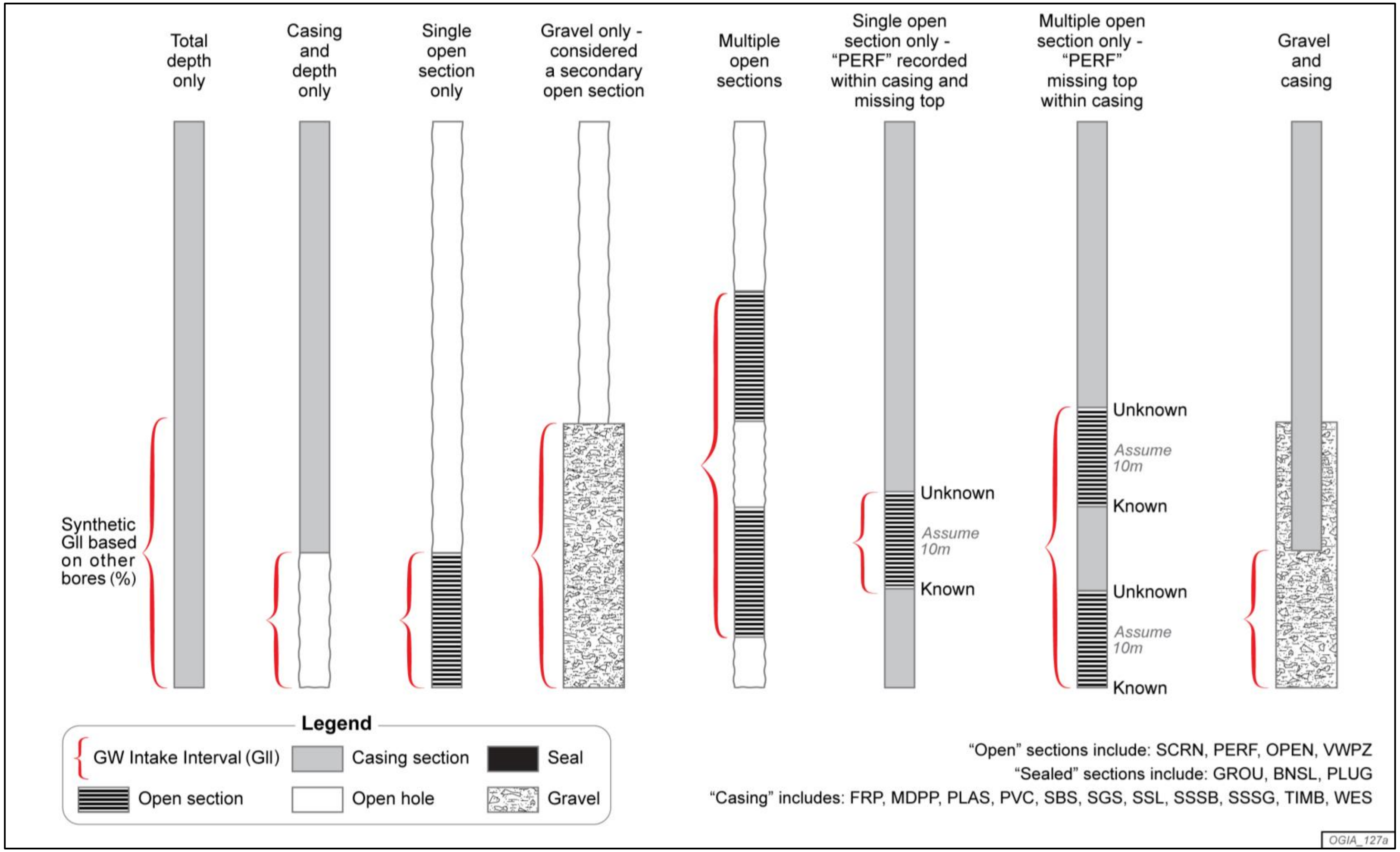

Figure A-1: Open sections and casing information

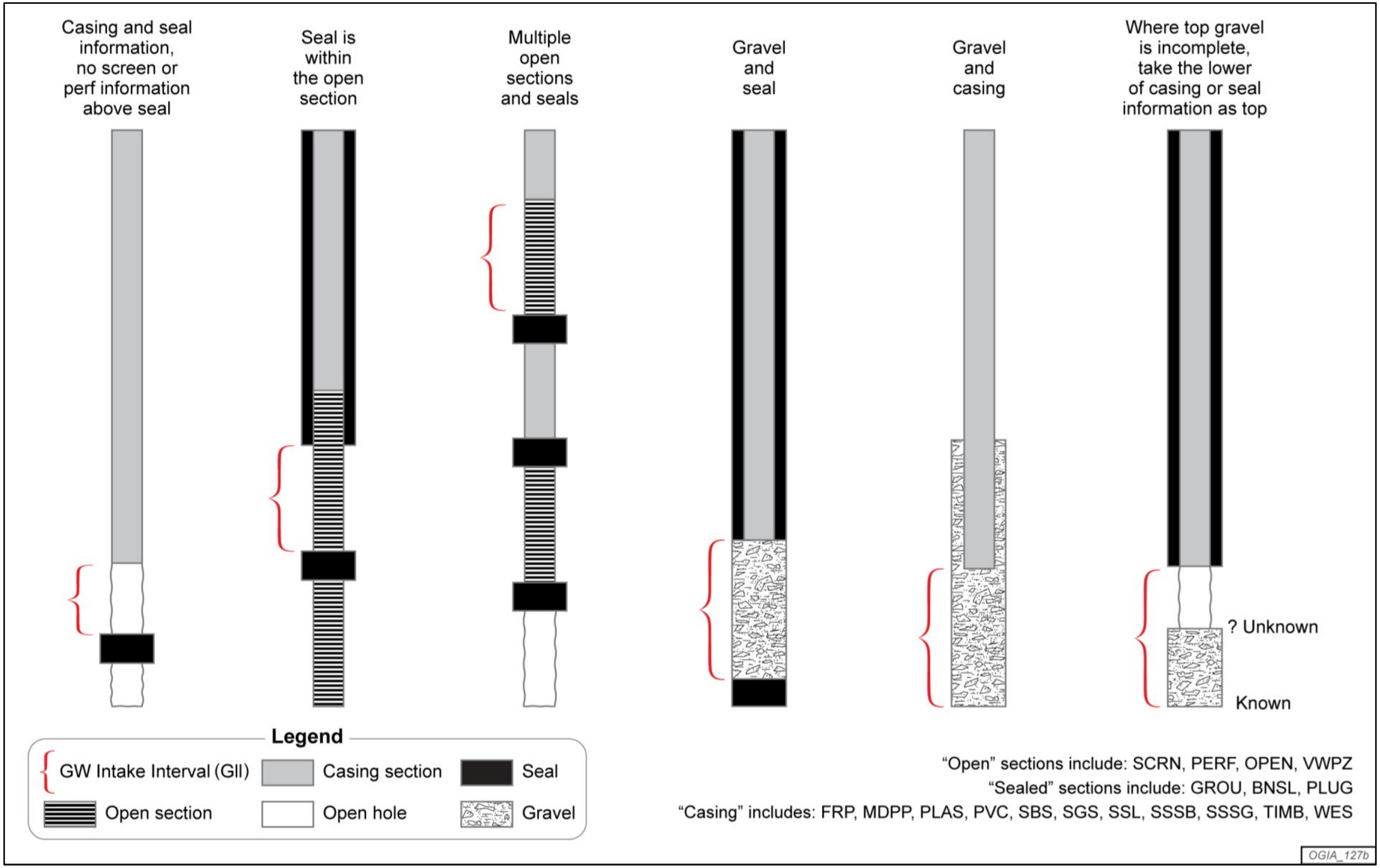

Figure A-2: Open sections, casing and seal information

Appendix B Detailed rulesets

Table B-1: High-confidence ruleset descriptions, assumptions and application in the Surat CMA

<table>
<tr><th>Ruleset</th><th>Description and assumption</th><th>RN-pipes assigned, Surat CMA</th></tr>
<tr><td>Ruleset 1: Manual override table</td><td>Table to allow manual interpretation of assigned aquifers, as well as dominant and secondary formations, to be fed back into the workflow.</td><td>8,534 (23%)</td></tr>
<tr><td rowspan="2">Ruleset 2: Formation assigned based on OGIA QA/QC manual review</td><td>Manual QC on formation attribution for part of the dataset, therefore considered the highest confidence rank in the workflow.</td><td rowspan="2">6,897 (19%)</td></tr>
<tr><td>This dataset has been filtered to include Rank 1, 2, and 3 data: where the GII intersects multi-layer formations (e.g. the WCM), the AA is restricted to only the common model layers. For all other formations, we carry through the manual QA.</td></tr>
<tr><td colspan="3">Ruleset 3: Departmental and industry monitoring bores</td></tr>
<tr><td>(a) Aquifer assigned in the OGIA WMS</td><td>Monitoring bores drilled by the department and industry, in accordance with minimum construction standards, to be screened across single aquifers.</td><td>893 (2%)</td></tr>
<tr><td>(b) For DRDMW (monitoring bores), the aquifer identified in the GWDB ‘Aquifer’ table</td><td rowspan="2">Where the GII intersects formation groupings (Kumbarilla Beds, Injune Creek Group etc.), the AA is restricted to only the common model layers. For all other formations, the aquifer assigned in the OGIA WMS, DRDMW or company monitoring is assigned.</td><td>904 (2%)</td></tr>
<tr><td>(c) Monitoring data received directly from coal mining companies</td><td>139 (<1%)</td></tr>
<tr><td>Ruleset 4: High-confidence geological model location with all or some construction information</td><td colspan="2">In these areas, the geological model has a high confidence with control points within 15 km of the bore. Note, where a GII intersects both high- and low-confidence formations, both are assigned.</td></tr>
<tr><td>(a) High confidence with construction – GII applied</td><td>The bore has GII and the latest model is considered the best available knowledge on system architecture.</td><td>7,858 (21%)</td></tr>
<tr><td>(b) High-confidence geological model. All formations intersected by the synthetic GII are assigned</td><td>As there is no screen information or cable tool construction, it is difficult to assign one aquifer with certainty. A synthetic GII has been generated and all high-confidence formations intersected with the model are assigned.</td><td>4,030 (11%)</td></tr>
</table>

Table B-2: Medium-confidence ruleset descriptions, assumptions and application in the Surat CMA

Ruleset	Description and assumption	RN-pipes assigned, Surat CMA
Ruleset 5: Low-confidence geological model or beyond geological model extent, with GWDB construction and aquifer information		
(a) Assign aquifer from the GWDB 'Aquifer' table, using the GII and limiting to only those formations where the CONT flag is not equal to 'N'	The principle of this rule is to apply primary data as the initial pick before works or water licence information is used in the workflow.	2,221 (6%)
(b) If 'Aquifer' table is incomplete, use the GWDB 'Stratigraphy' table formation(s), using the GII	Where the GII intersects multi-layer formations (e.g. the WCM), the AA is restricted to only the common model layers. Where the GII intersects formation groupings (Kumbarilla Beds, Injune Creek Group etc.), the AA is restricted to only the common model layers. For all other formations, aquifers assigned on the licence or works are assigned in (a), (b) and (c).	30 (<1%)
Ruleset 6: Low and high-confidence geological model or outside of the geological model extent, with other licence aquifer information		
(a) If the aquifer on the works and water licence is consistent, the aquifer is assigned	If no primary information is available from the GWDB tables, the aquifer identified on the water licence and works approval is used.	567 (1%)
(b) If the aquifers assigned are inconsistent, the water licence aquifer is assigned	Licensed data is considered higher confidence than works data as the aquifer assigned on the works authorisation is often assigned in advance of the water bore's completion	65 (<1%)
(c) Where only a works or a licence aquifer is available, the available aquifer is assigned	As the licensed data contains information on the aquifer that is registered to be screened by a particular bore, this supersedes the works data	115 (<1%)
(d) In areas of low-confidence geological model location with construction information (GII), the geological model intersect is assigned	The bore has GII and the latest geological model is considered the best available knowledge on system architecture	822 (2%)
(e) For bores where the GWDB 'Aquifer' table contains incomplete top and bottom information or contains only depth information, all aquifers are assigned where they do not have a 'CONT' flag equal to 'N'		192 (1%)

Table B-3: Low-confidence ruleset descriptions, assumptions and application in the Surat CMA

Ruleset	Description and assumption	RN-pipes assigned, Surat CMA
Ruleset 7: Depth-only bores		
(a) Low-confidence geological model with stratigraphy table information available, then assign all formations intersected in stratigraphy table by the synthetic GII (note: as above)	It is difficult to assign a single aquifer as no accurate assumptions can be made around the target of the drilling (no depth or construction information). For this reason, the synthetic GII is used to assign formations in the stratigraphy table.	56 (<1%)
(b) Low-confidence geological model, without stratigraphy table = assign all formations intersected using the synthetic GII and the geological model	If there is no information in the stratigraphy table, all formations intersected by the model using the synthetic GII are assigned as there is limited data to determine contributing formation.	872 (2%)
(c) Assign dominant formation of nearby bores (5 km)	The dominant formation sourced by nearby bores is used to assign contributing formation(s).	242 (<1%)
Ruleset 8: Location only	There is no construction information; assign dominant formation of nearby bores (5 km). If there is no subsurface information on the bore, the assumption is that the bore is screened in the dominant formation in the local area.	1,718 (5%)
Ruleset 9: GSQ mapping	Assign outcrop aquifer as identified by the GSQ mapping. These bores are outside of the model area and have no other bores within a 5-km radius.	30 (<1%)

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