6.3 Water

6.3.1 Hydrological Processes

Within the CPP Area, ground elevations range from approximately 220 m to 265 m AHD. The predicted 1 in 100-year flood level is approximately 226 m AHD in the vicinity of the well pads in this segment of the catchment system. The Carpentaria Highway bisects the CPP Area from east to west and generally aligns following topographic high points in the local landscape at approximately 250 m AHD.

In the CPP Area, this topographic crest feature, known locally as the Favenc Range, can be seen on the northern side of the Carpentaria Highway (**Figure 6.2—1**). The Favenc Range forms the headwaters of this portion of the Limmen Bight River catchment to the north of CPP and the McArthur River catchment to the east of the CPP Area.

The drainage lines in CPP Area correspond with the upper catchment, riverine morphological zone in Australian riverine topographic sequences described in [S Capon et al., 2016]. Below a defined catchment elevation, the streams are categorised as anabranch and distributary functional process zones, and community richness is relatively high.

Above that elevation, the streams are categorised as being in armoured, meandering, confined and mobile zones, with relatively high slopes, moderate to high stream power, active drainage networks and coarse, unstable sediments, and community richness is relatively lower.

6.3.1.1 Stream Mapping

Ordered mapping of streams that intersect the CPP Area are shown in **Figure 6.3—1** to **Figure 6.3—6**. The proposed CPP Area layout demonstrates avoidance of streams and observance of riparian buffers. The highest stream order (3) in the CPP Area occurs at the headwaters of Relief Creek and reflects the general site elevation at the top of two catchments, coincidental with the crest of the Favenc Range, which is generally just north of the Carpentaria Highway at this location.

In this region, the drainage channels cut through alluvium and are bounded on both sides by one or more deposition-erosion benches. The larger channels (e.g., Stream Order 3) develop benches because the drainage channel represents flooding by average storms, and the benches are flooded only by low-frequency episodic events.

Examples of ephemeral streams in the savannah country in the CPP Area are shown in **Figure 6.3—7**.

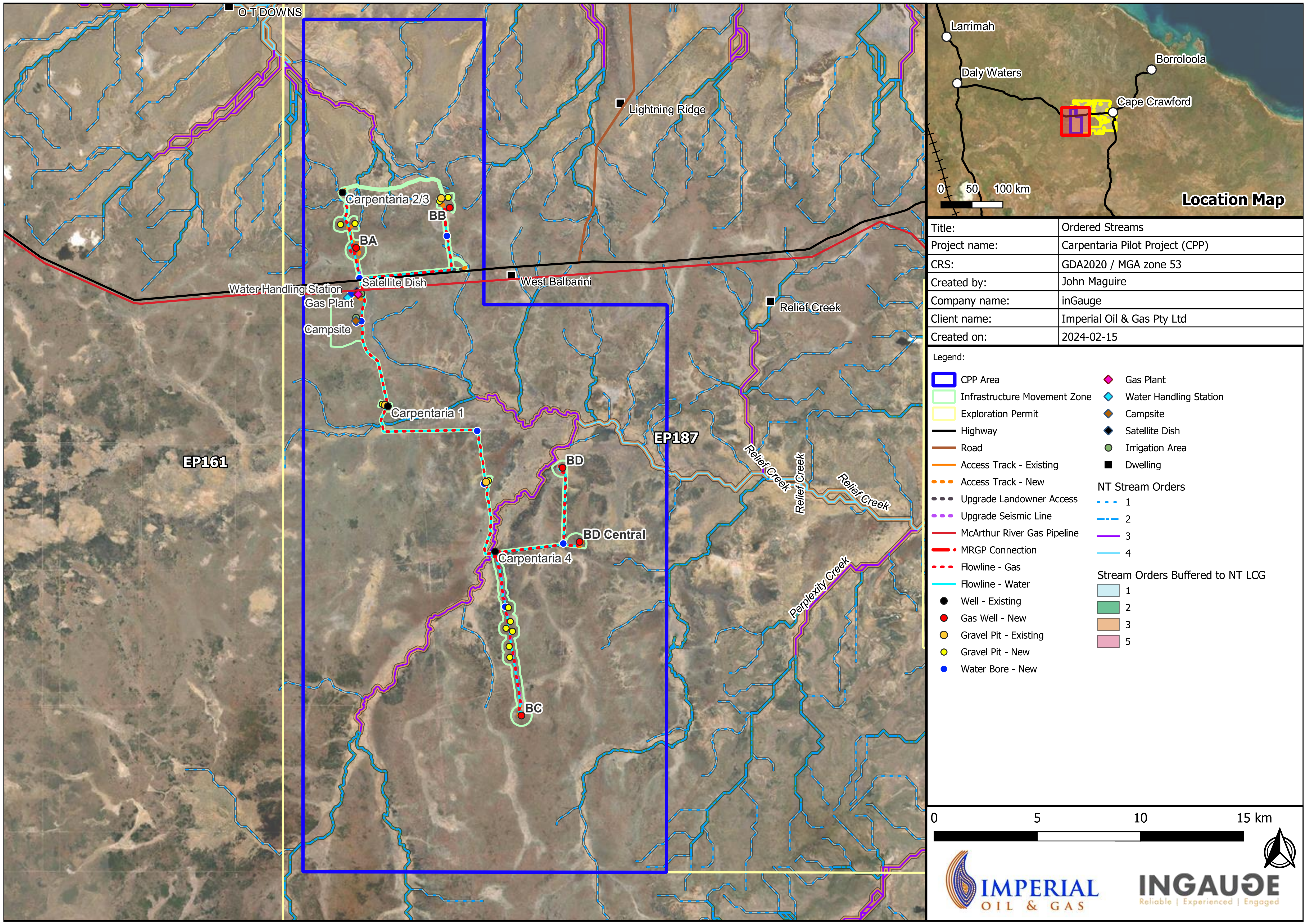

Figure 6.3—1 Ordered Streams in the CPP Area and Environs Draining from the Favenc Range (Overview)

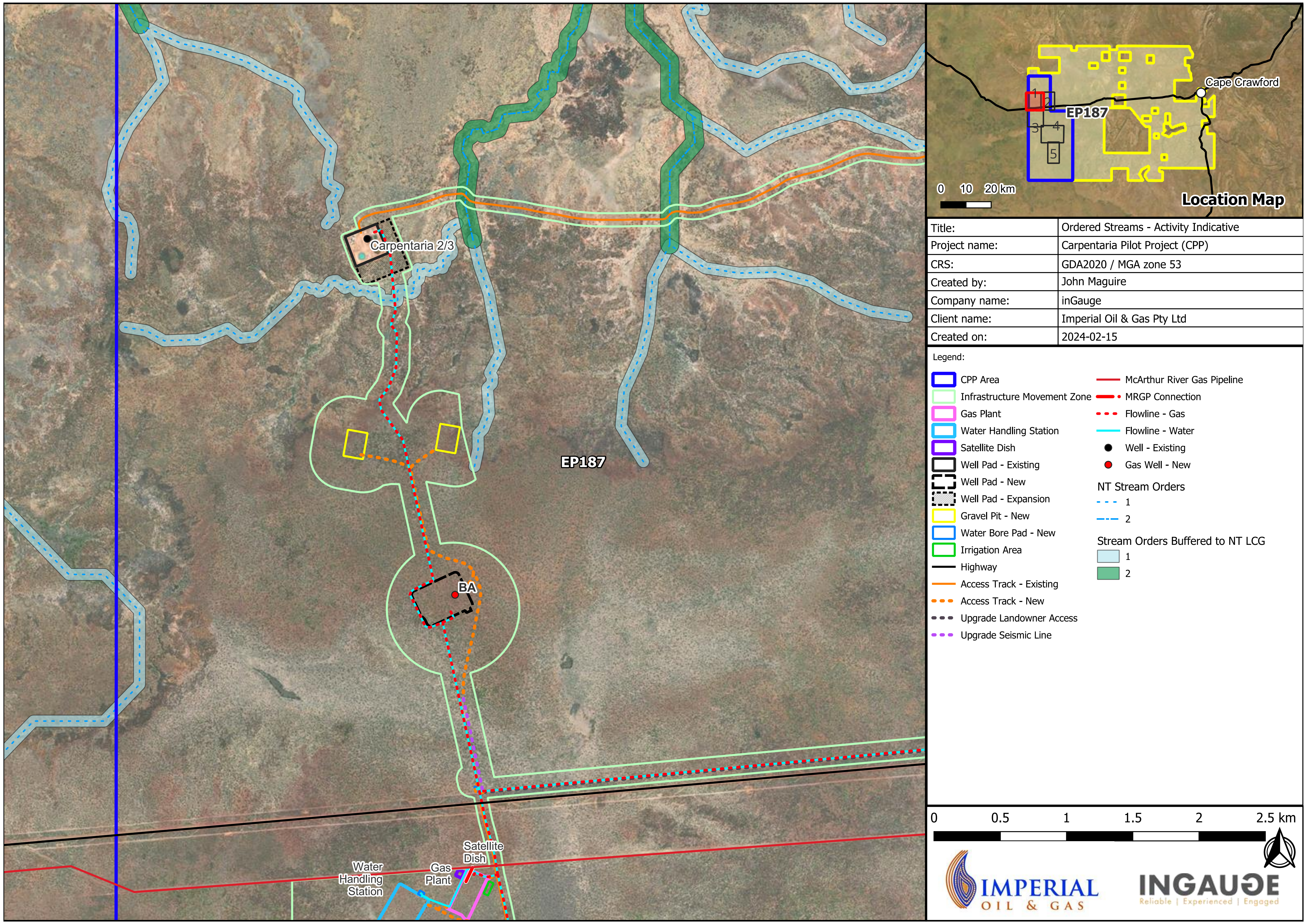

Figure 6.3—2 Ordered Streams in the CPP Area and Environs Draining from the Favenc Range - Map 1

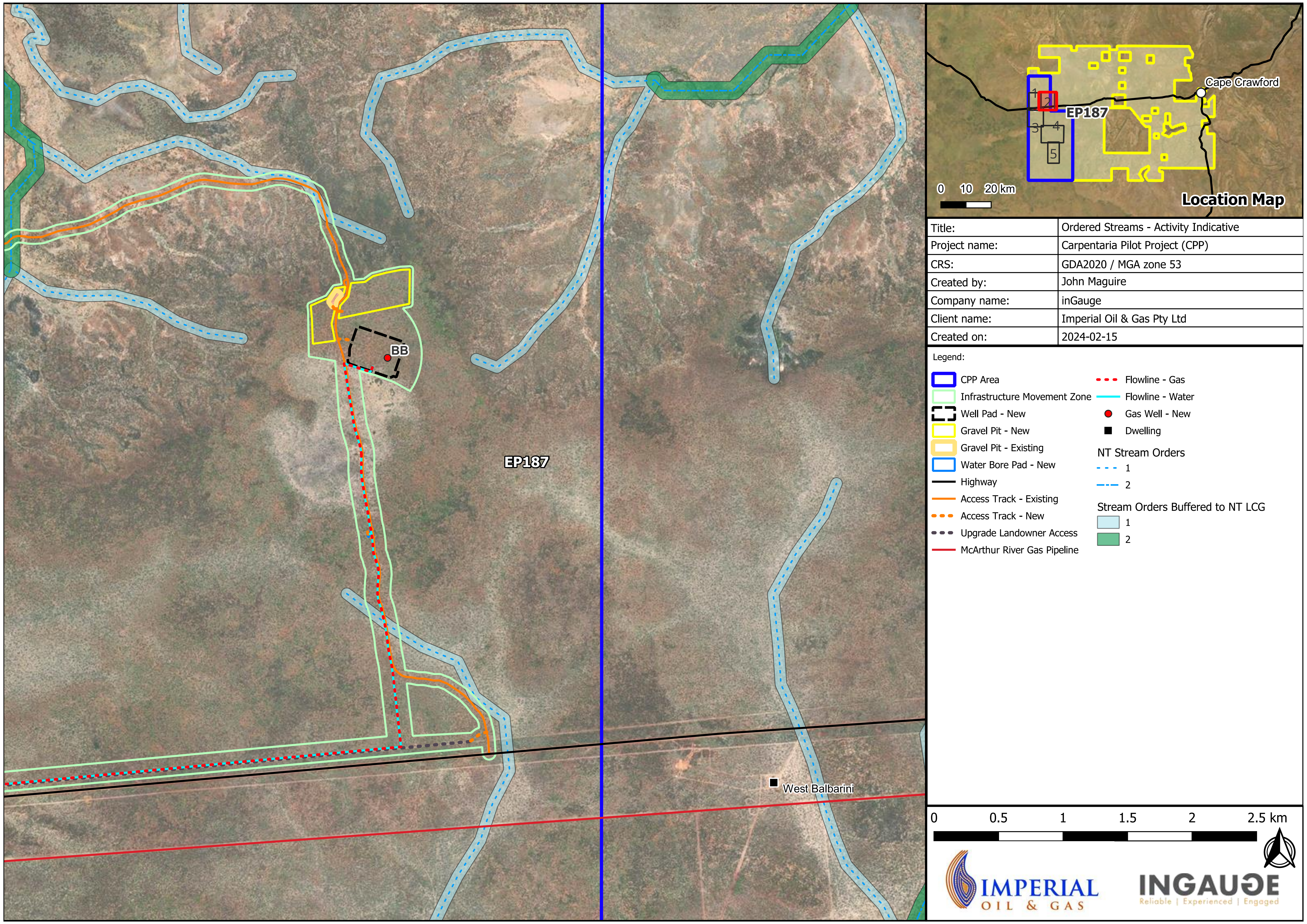

Figure 6.3—3 Ordered Streams in the CPP Area and Environs Draining from the Favenc Range - Map 2

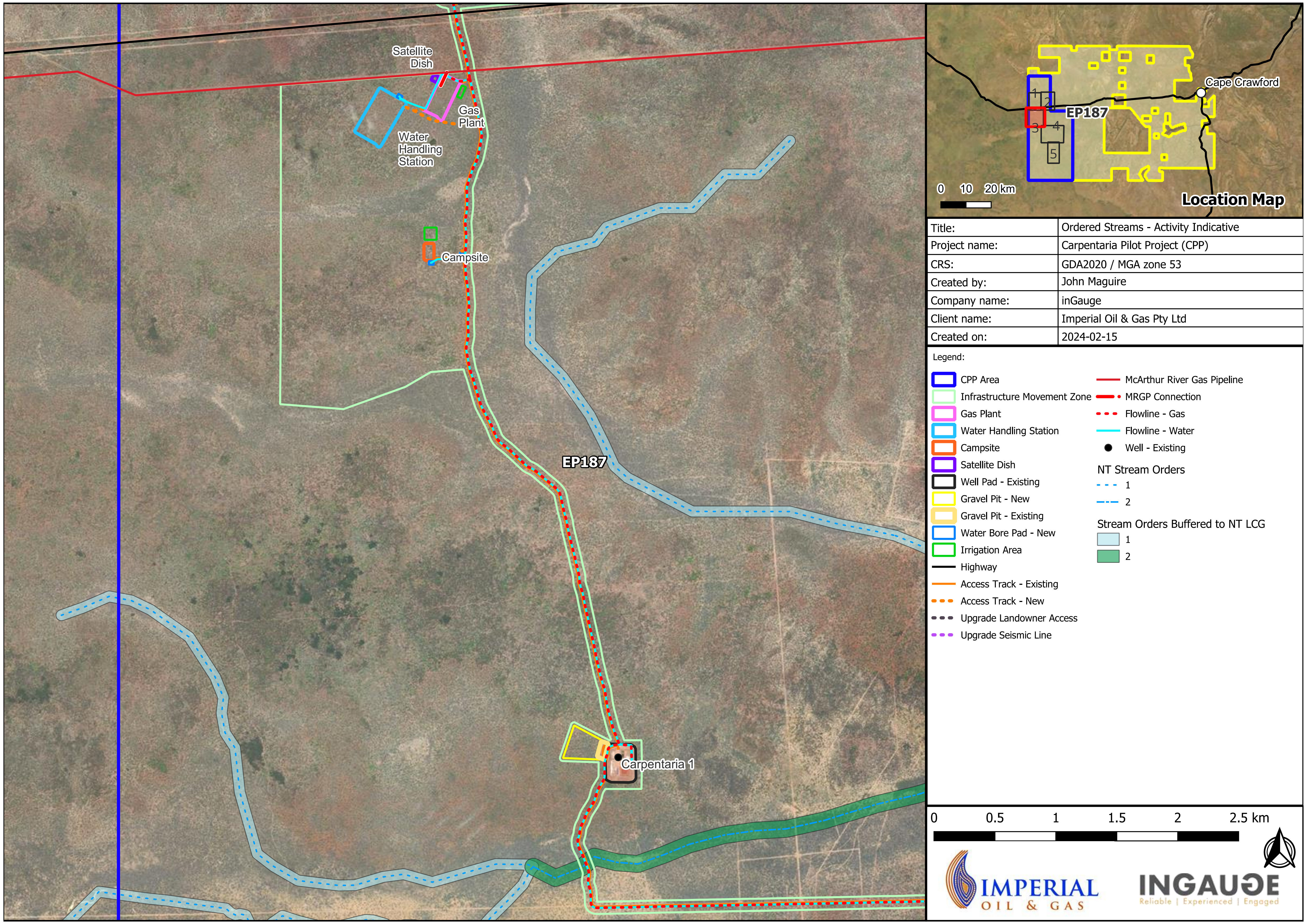

Figure 6.3—4 Ordered Streams in the CPP Area and Environs Draining from the Favenc Range - Map 3

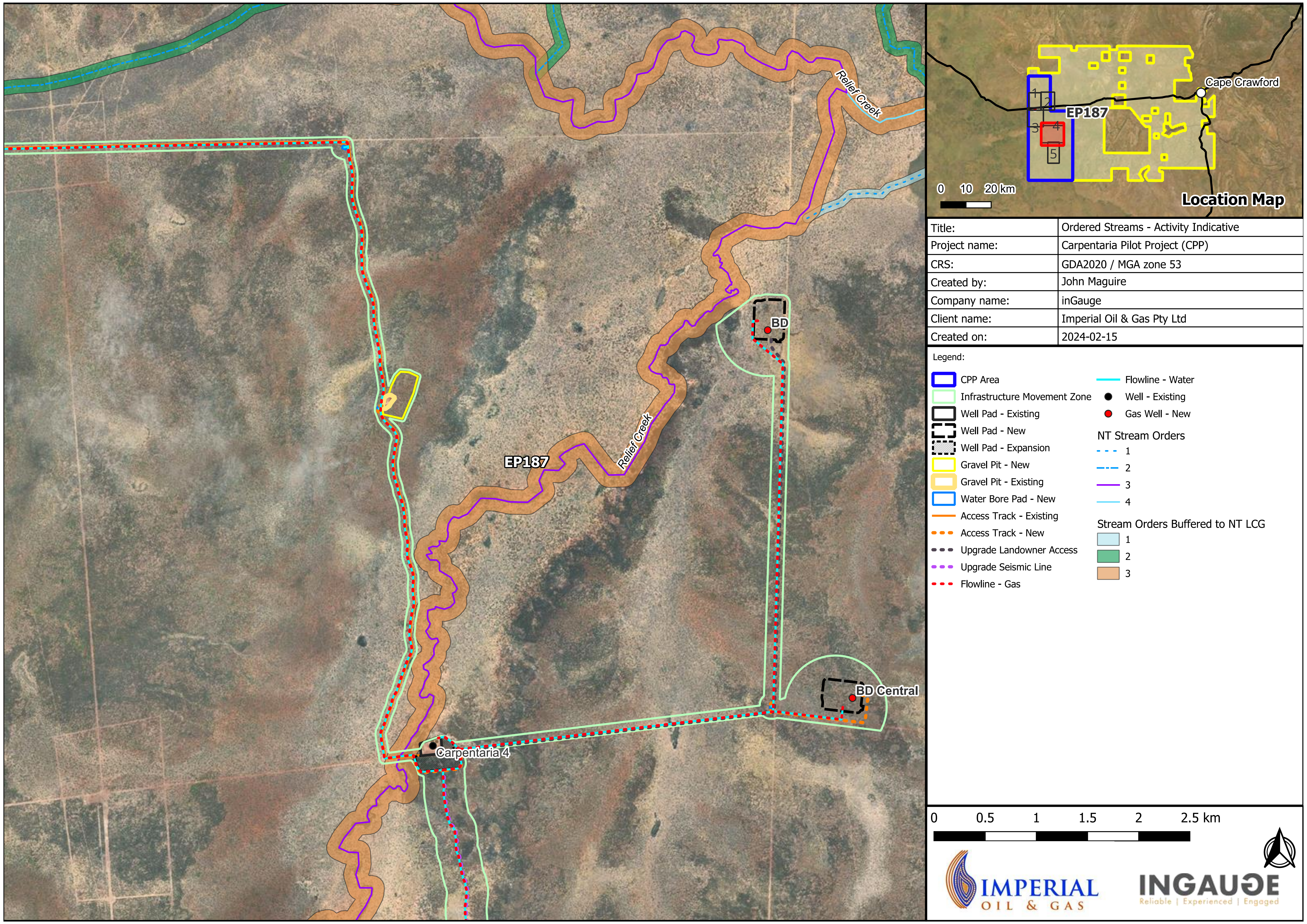

Figure 6.3—5 Ordered Streams in the CPP Area and Environs Draining from the Favenc Range - Map 4

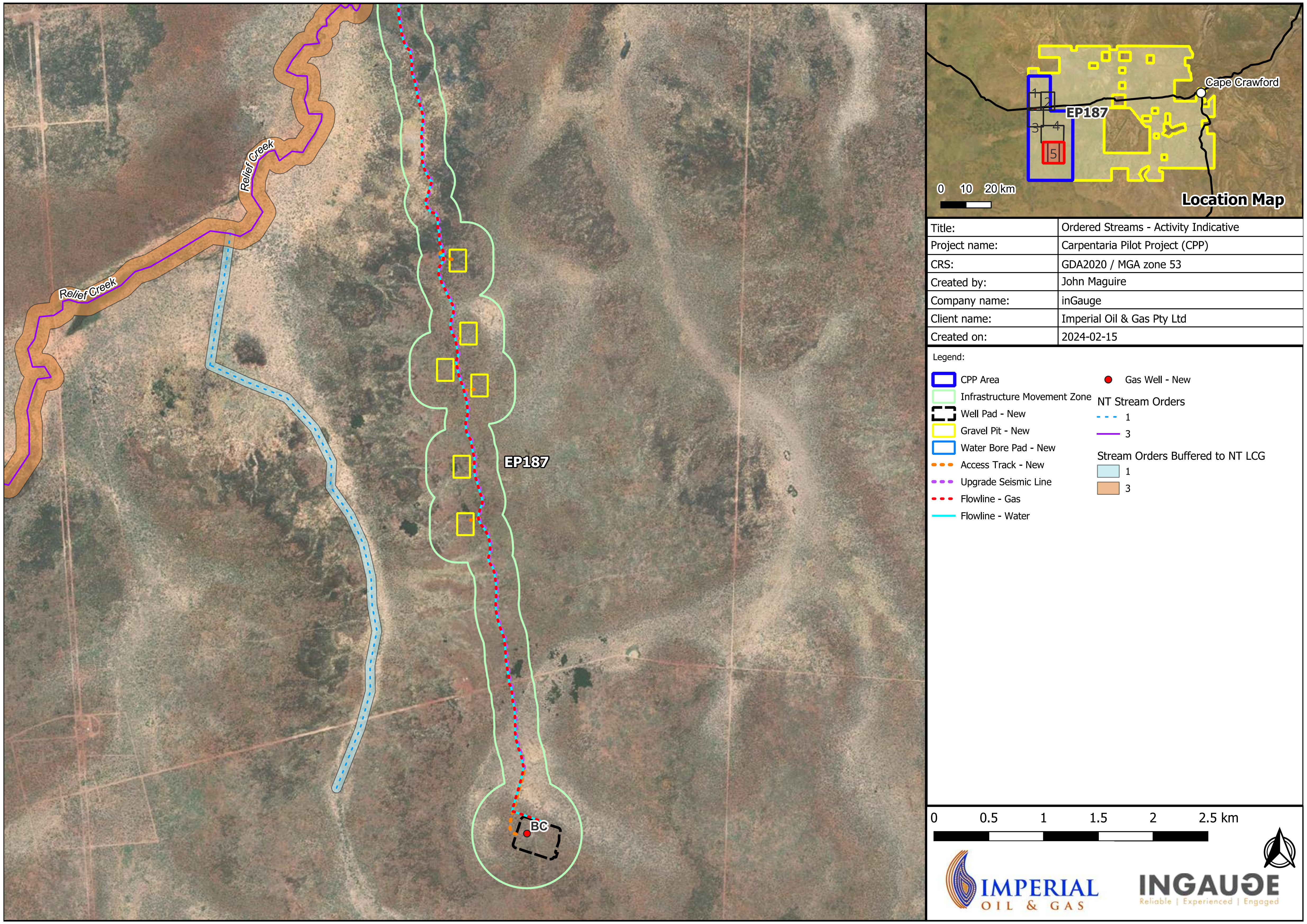

Figure 6.3—6 Ordered Streams in the CPP Area and Environs Draining from the Favenc Range - Map 5

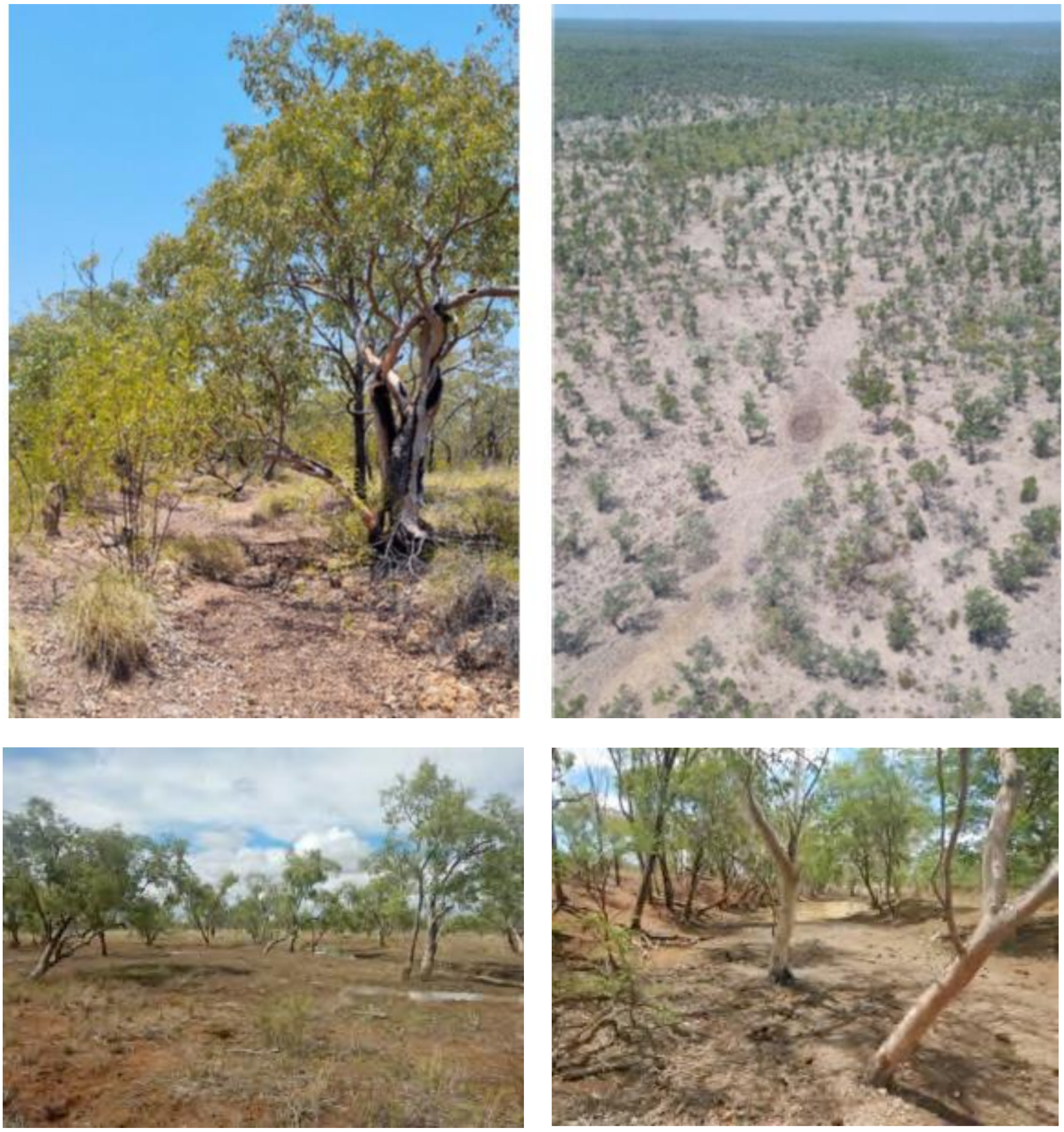

Figure 6.3—7 Views of Ephemeral Streams in the Savannah Region
(Left images – a drainage line in the CPP Area. Right images – aerial and ground view of Relief Creek)

6.3.1.1 Flood Modelling

Flood modelling of the CPP Area has been undertaken and is shown in **Figure 6.3—8** to **Figure 6.3—13**. As noted previously, the flood modelling has been based on SRTM elevation model that has been calibrated in the CPP Area using known benchmarks, such as existing CPP wells AHD elevations. The flood predictions are therefore relatively coarse, particularly at the boundaries of CPP area. In each case the well pad locations have been ground truthed to confirm avoidance of flood prone areas. **Figure 6.3—12** shows the well pad BD within the predicted 1-100 year flood event. A site inspection confirmed the mapped location is above flood prone area (EMP – Section 3).

As noted above, stream flow in the area is to the north and south of a topographic crest feature that runs approximately east-west, known locally as the Favenc Range. The Favenc Range forms the headwaters of this portion of the Limmen Bight River catchment to the north of the CPP and the McArthur River to the east of the CPP Area.

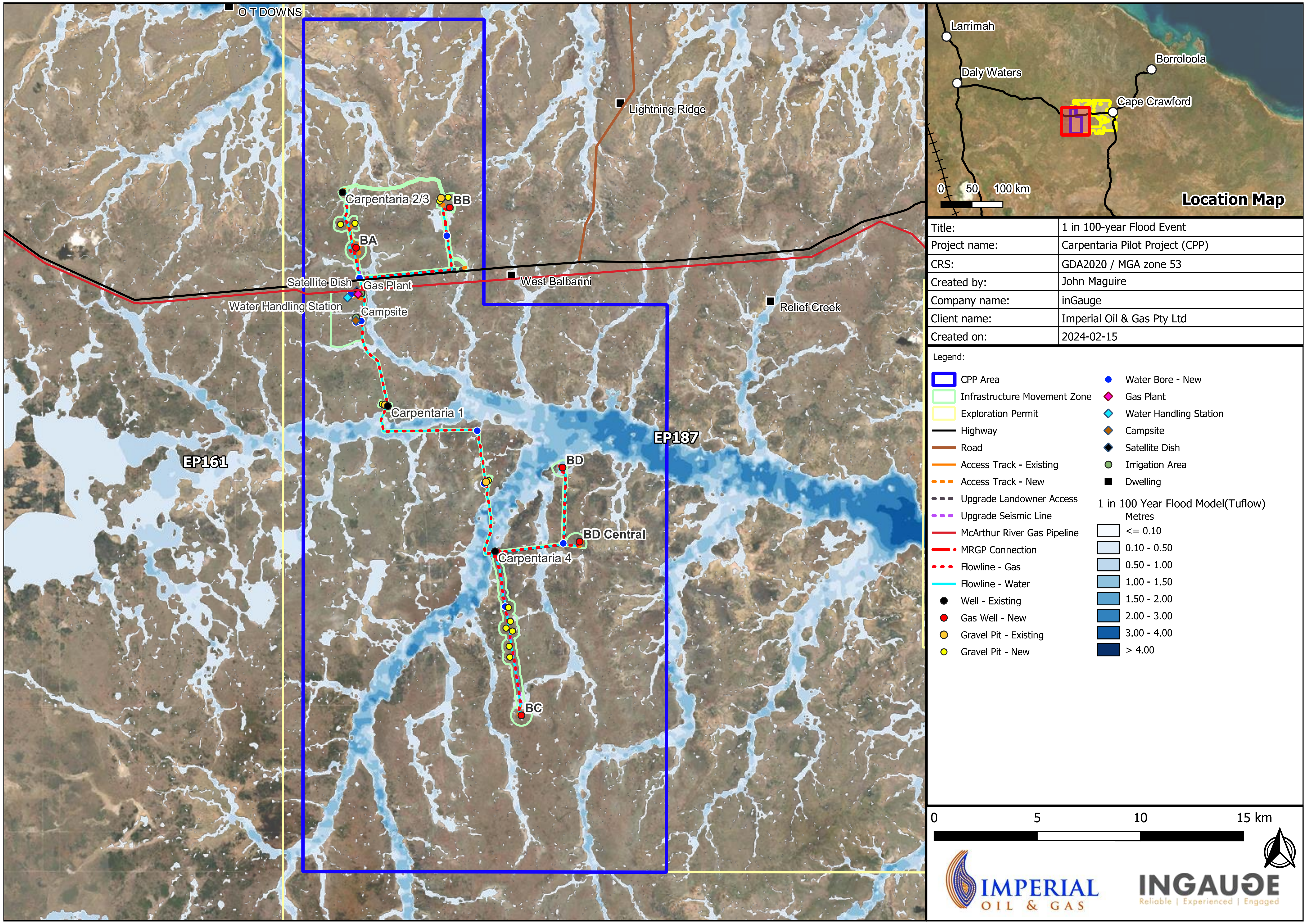

Figure 6.3—8 Flood Modelling Within the CPP Area (Overview)

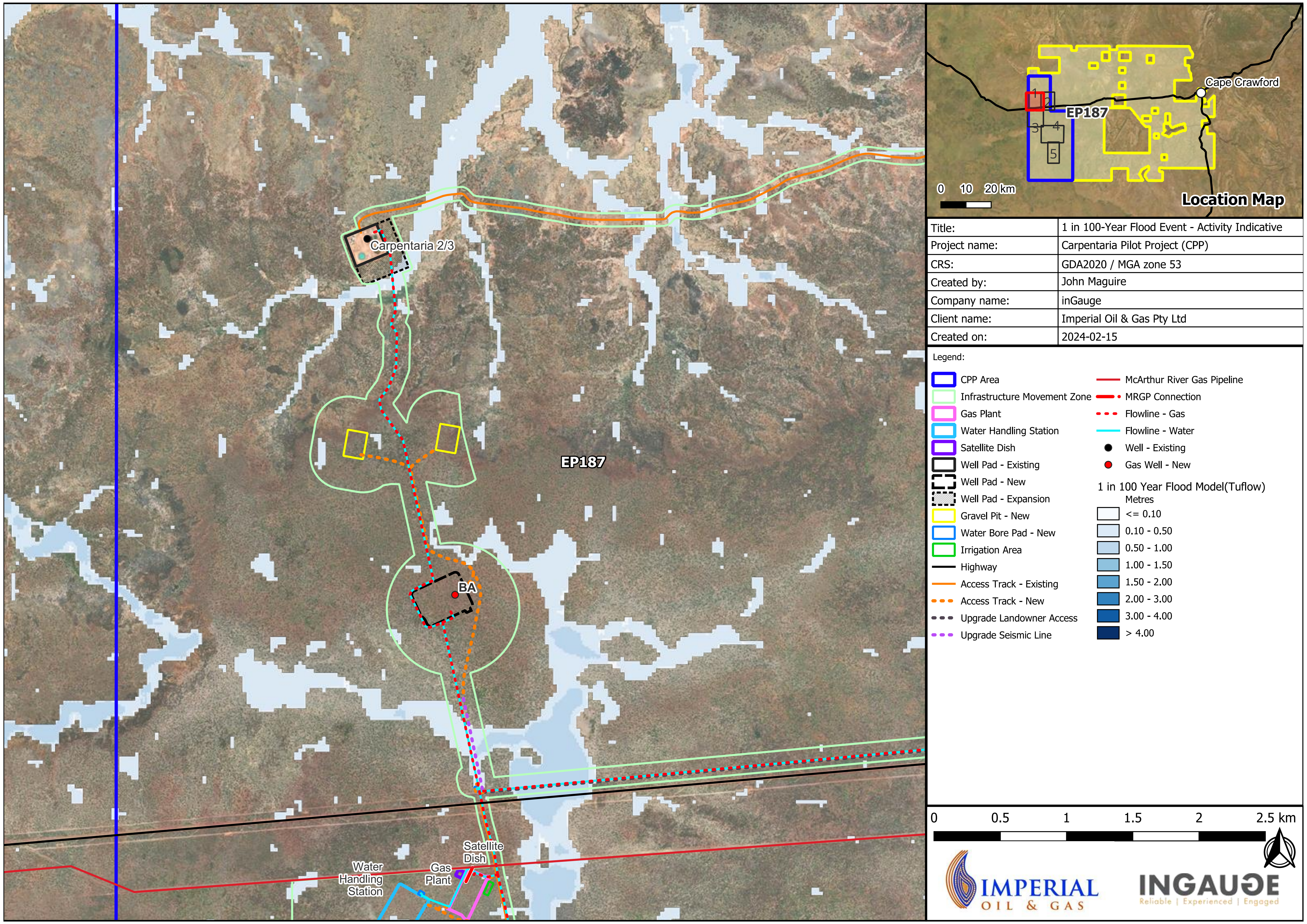

Figure 6.3—9 Flood Modelling Within the CPP Area - Map 1

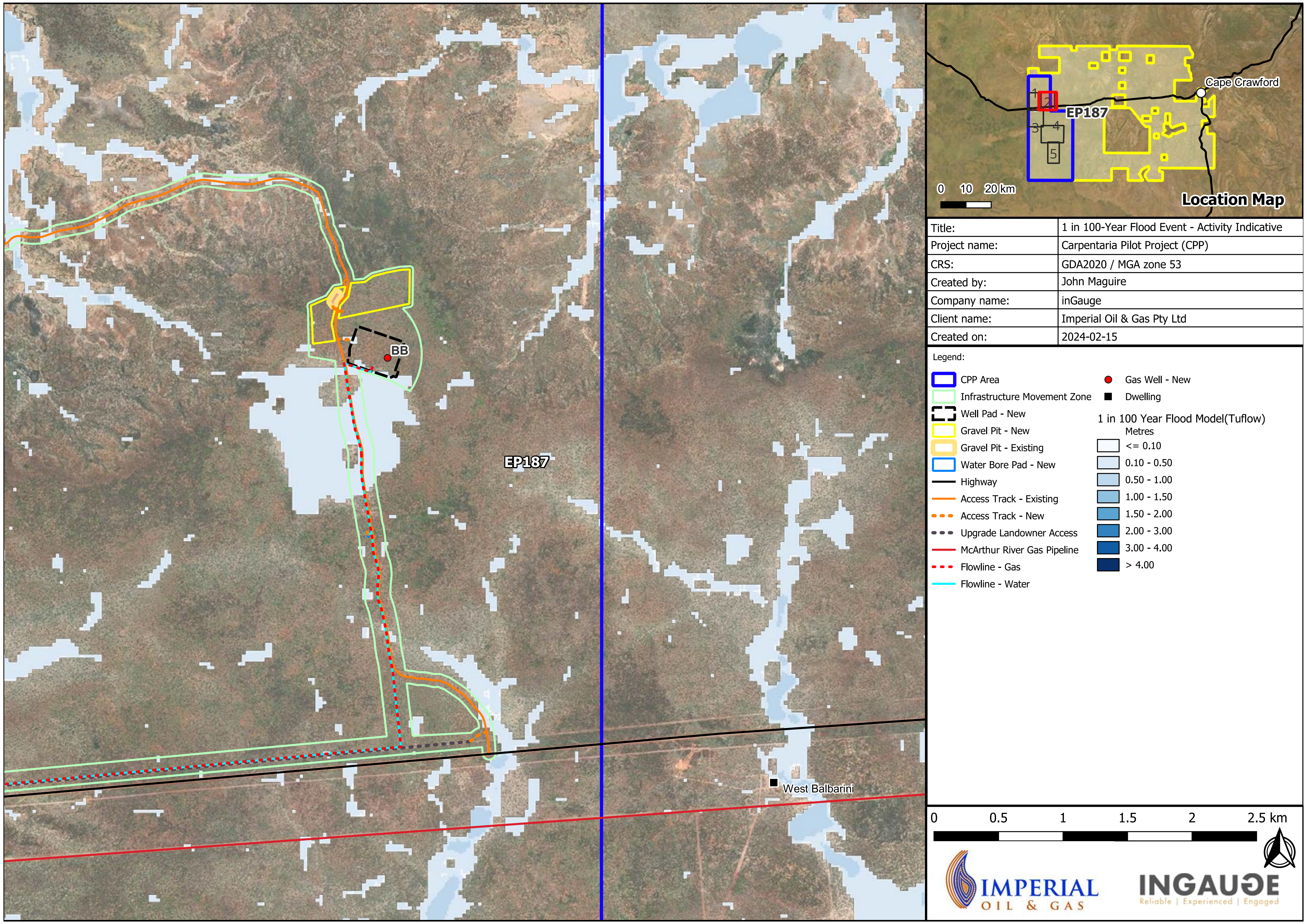

Figure 6.3—10 Flood Modelling Within the CPP Area – Map 2

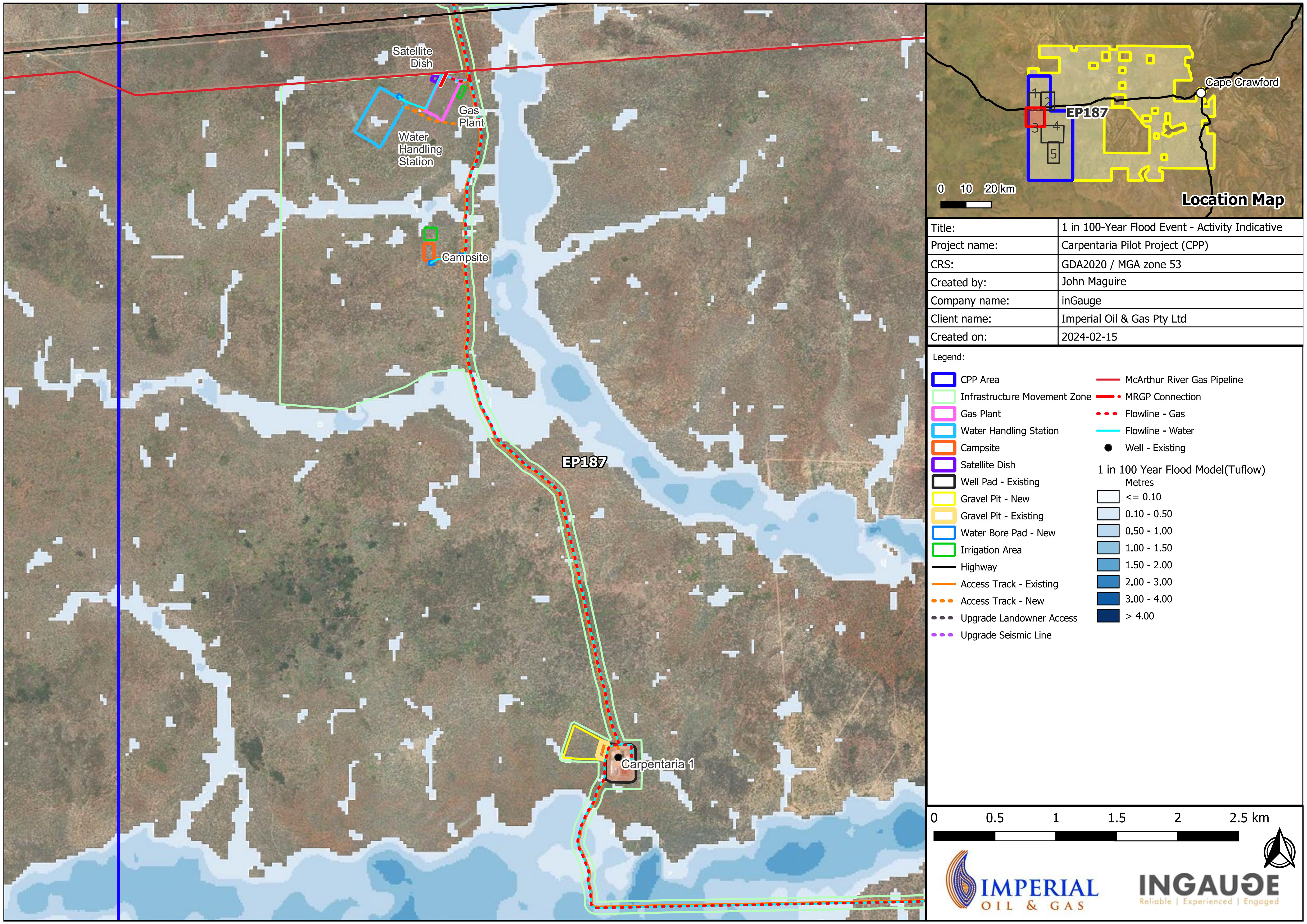

Figure 6.3—11 Flood Modelling Within the CPP Area - Map 3

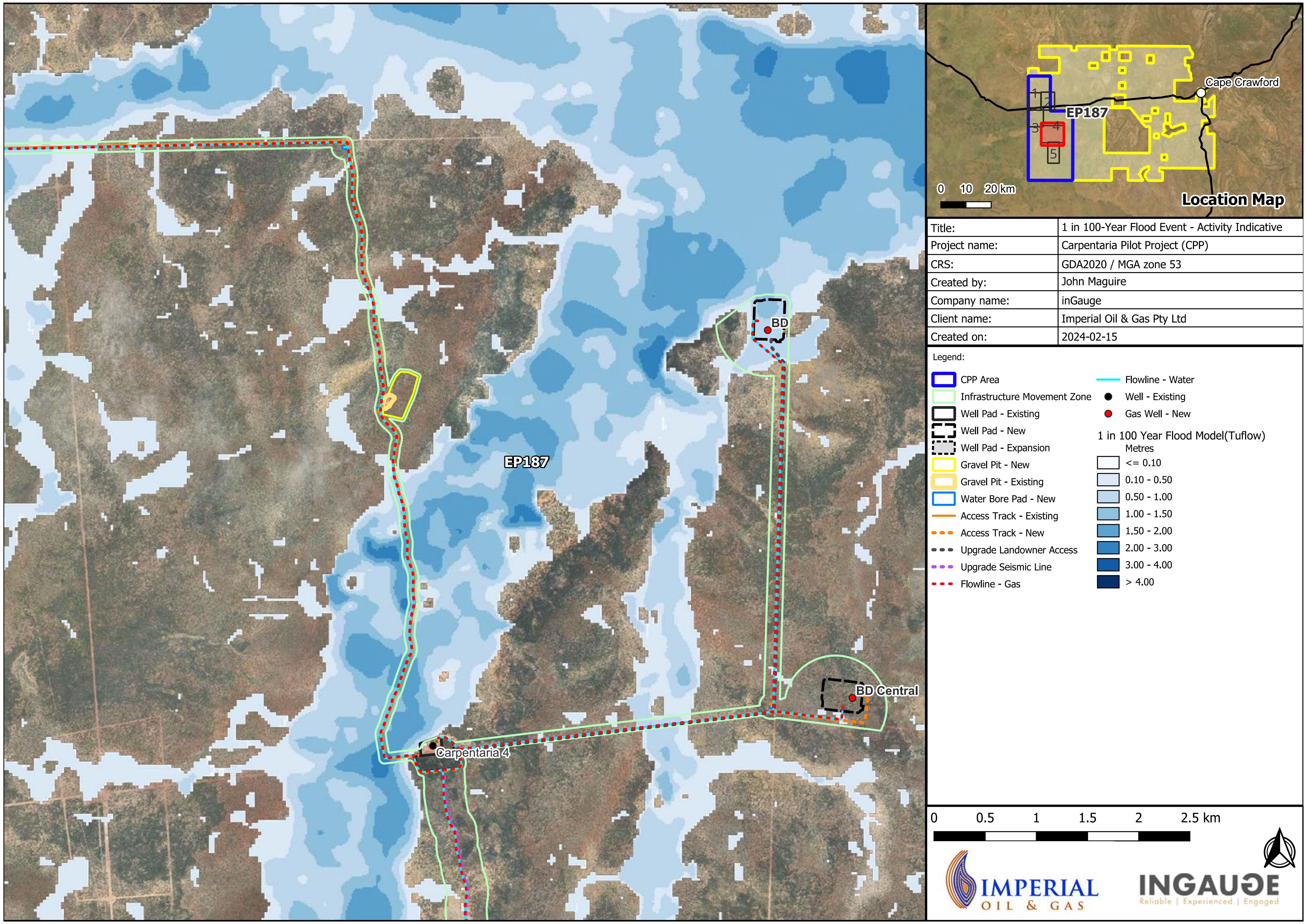

Figure 6.3—12 Flood Modelling Within the CPP Area - Map 4

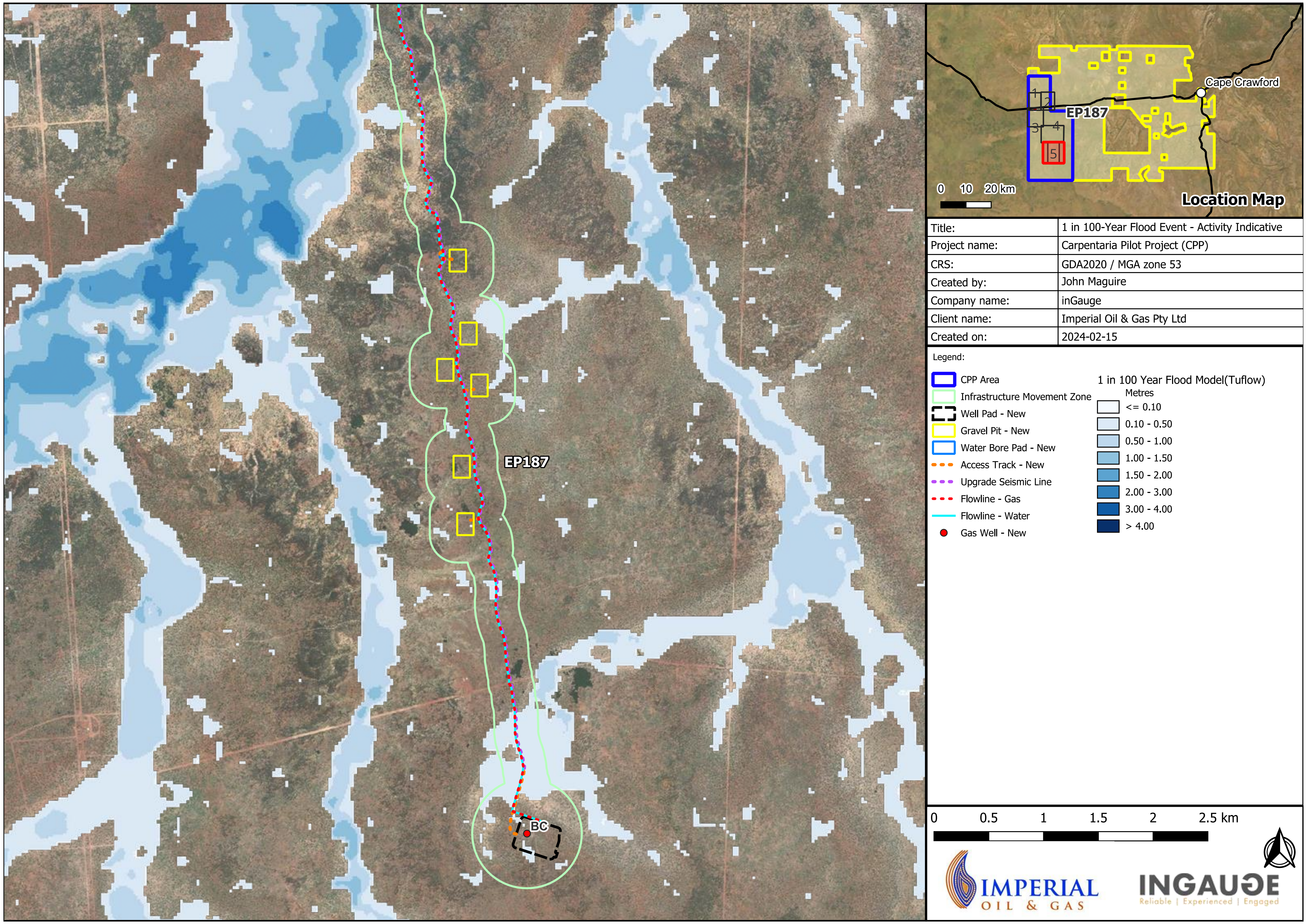

Figure 6.3—13 Flood Modelling Within the CPP Area - Map 5

Average monthly stream flow at the Baileys Grave stream gauging station on Tablelands Highway, is shown in **Figure 6.3—14**. This station is located in the McArthur River downstream and 60 km east of the headwaters of Relief Creek/Tooganginie Creek, where the Activity is located. Dry season flows typically register near zero.

At this location the ground level elevation is approximately 83 m AHD. This is about 140 m lower than the CPP Area and drains a vast network of topographic regional sub-catchments, including Relief Creek. The average monthly stream flow is highest in February at this location and exceeds 70 m^3/s.

The average flow from year to year may vary considerably (**Figure 6.3—14**) reflecting the erratic nature of rainfall quantity in the region and associated inter-decadal "pulse events", discussed further in the EMP (**Section 4.2.3**).

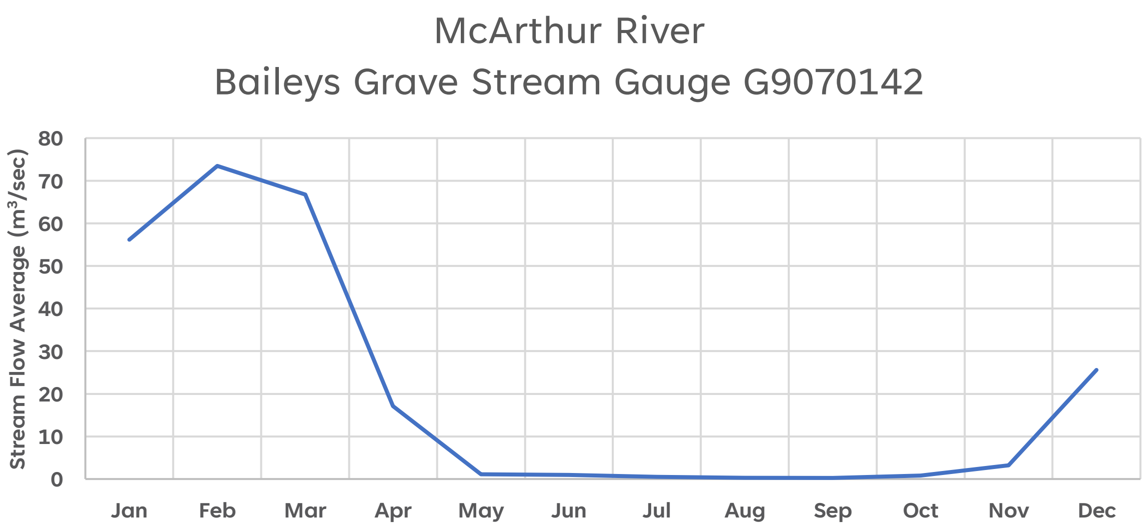

Figure 6.3—14 Average Monthly Stream Flow – Elevation 83 m AHD

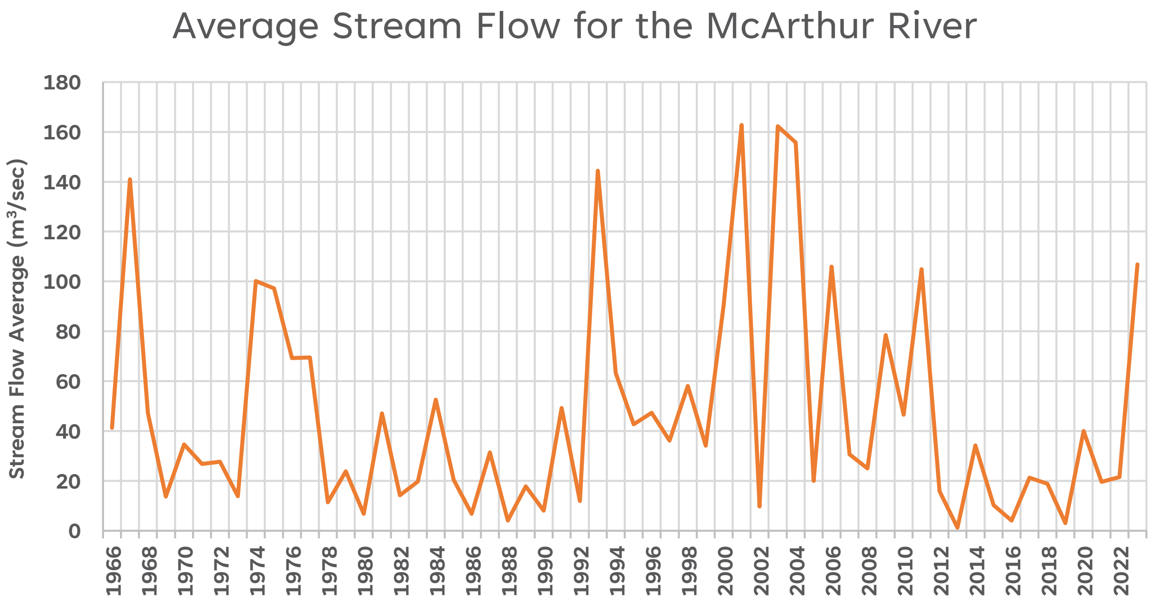

Figure 6.3—15 Average Measured Annual Stream Flow in McArthur River – East of CPP Area

(Source: Baileys Grave Stream Gauge G9070142)

6.3.2 The Georgina Wiso Water Allocation Plan

The Hydraulic Fracturing Inquiry (HFI) [Pepper, R et al (2018)] made recommendations for the NT Government's management of water in areas of onshore petroleum development. These recommendations were as follows:

- Implement recent amendments to the Water Act 1992 (NT) so that a groundwater extraction license (GWEL) is required for NT onshore petroleum activities to legally access water for their operations.
- The Georgina Wiso WAP, the Government's primary water resource management mechanism, be developed for the Beetaloo Sub-basin region prior to the granting of any production-level groundwater extraction licences for the petroleum industry that control the rate and volume of any water extraction by petroleum companies.

The Georgina Wiso WAP 2023-2031 Report 12/2023 [DEPWS, 2023a] relates to the management of the groundwater resources of the Georgina and Wiso Basins underlying the southern Sturt Plateau and north-western Barkly region, including for the CPP Area in the Georgina Basin.

The estimated sustainable yield is based on the understanding the inflows and outflows of the water resource, including the volumes of water in storage, combined with the inputs (recharge, inflow) and outputs (discharge, outflow, and evapotranspiration) and throughflow. However, the contribution of recharge to the GRF aquifer from sinkholes, which are common in the Beetaloo region and can provide rapid recharge pathways to aquifers, is poorly documented and likely underestimated [A Knapton, 2020]. Recharge via sinkholes was considered by Yin Foo and Matthews (2001) to be a major source of recharge on the Sturt Plateau.

The Georgina Basin petroleum allocation of 8 GL/a in the WAP is less than 5% of the ESY. The present GWEL in the GRF aquifer (part of the Georgina Basin) are listed in **Table 6.3—1**. The ESY in the WAP for the Georgina Wiso basins is 210 GL per year, and for the Georgina Basin is 186 ML/a. The overall ESY of the basin is shown diagrammatically in **Figure 6.3—16**.

Table 6.3—1 GWEL Issued for the Gum Ridge Formation Aquifer

Company	GWEL #	Volume, ML/a
Santos	GRF 10280	193.5
Origin	GRF 10285	175
Sweetpea	GRF 10346	299
Imperial	GRF 10316 (current)	85
TOTAL Petroleum		750
Power & Water	~	400
Imperial Proposed Increased Allocation	GRF 10316 (amendment not yet approved)	750

6.3.3 Groundwater Requirements

The WAP details the requirements for the management of the groundwater resources of the Wiso Basin (to the west of the Stuart Highway) and Georgina Basin (to the east of the Stuart Highway) to the south of Larrimah including the CLA. The Georgina Basin underlies the southern Sturt Plateau and north-western Barkly region and includes the CPP Area. The Georgina Basin includes the Gum Ridge Formation [S Tickell, 2022].

The WAP establishes the proportion of water from the water resource that can be sustainably allocated for drinking water, a range of commercial uses, including petroleum, and reserve water for Aboriginal economic development.

The estimated sustainable yield (ESY) of the Georgina Basin that will be accessed for groundwater for the Activity, is approximately 186 GL/a, approximately 0.03% of the estimated Georgina Basin storage volume of 660,000 GL.

The WAP groundwater extraction allocation for petroleum in the Georgina Basin is capped at 8 GL/a, which is approximately 4.3% of the ESY. The overall ESY of the Georgina Basin is shown in **Figure 6.3—16**.

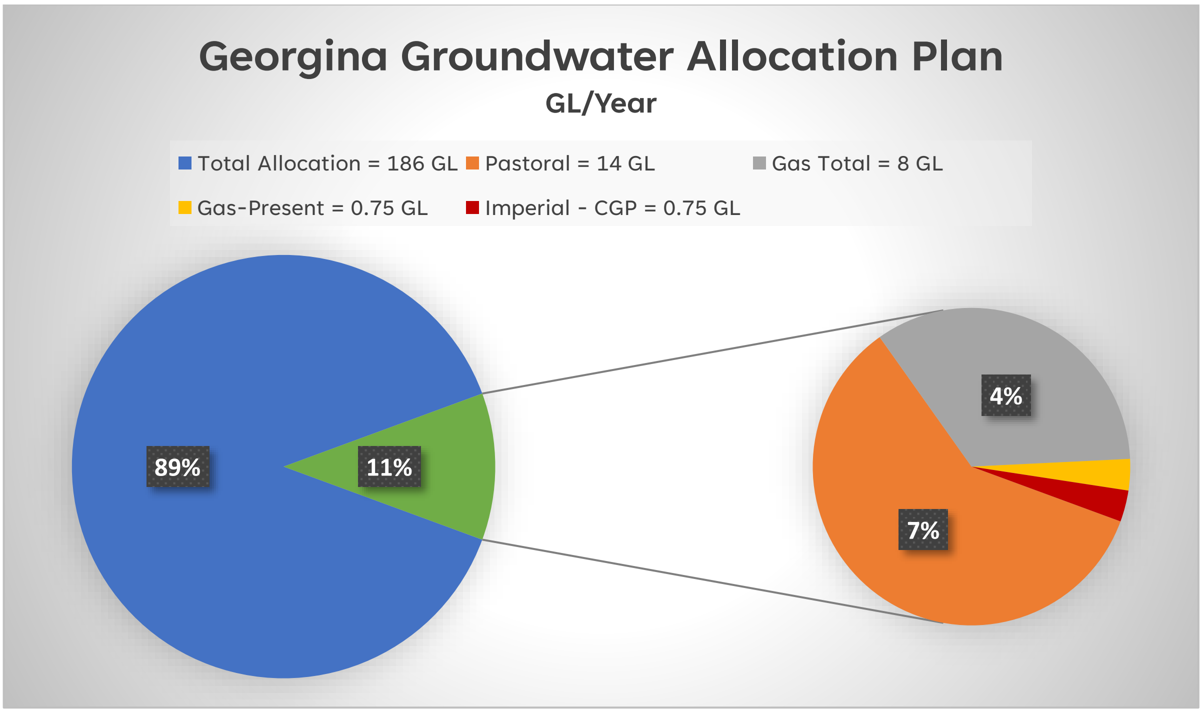

Figure 6.3—16 Estimated Sustainable Yield – Georgina Water Allocation Plan

Imperial will apply for an increased water allocation in Ground water Extraction Licence (GWEL) GRF10316 from 85 ML/a to 750 ML/a for the proposed Activity. This is less than 10% of the Georgina Basin petroleum activity cap of 8 GL/a, and about 0.4% of the Georgina Basin beneficial groundwater allocation of approximately 186 GL/a.

The overall maximum ground water total to be extracted over the CPP EMP 5-year period is estimated to be approximately 950 ML. Imperial does not consider this to be a significant impact to the available groundwater of the GRF aquifer. It is noted that the reuse of HF flowback could reduce the overall potential annual groundwater extraction requirements of the Activity by up to 40%.

The contribution of recharge to the GRF aquifer from sinkholes that are common in the Beetaloo region during inter-decadal "pulse" events of cumulative rain (discussed in **EMP Section 4**) is poorly documented and likely under-estimated. Open sinkholes can provide pathways for rapid recharge to aquifers [S Tickell, 2022]. Recharge via sinkholes was considered to be a major source of recharge on the Sturt Plateau [D. Yin Foo et al., 2000].

The estimated monthly average and cumulative annual groundwater usage for the proposed Activity is provided in **Figure 6.3—17**. This is conservatively estimated at approximately 46 ML/a on average, and to be to be 950 ML over the 5-year Activity period. An additional margin factor in the proposed GWEL (750 ML/a) provides for years when the ground water extraction may exceed this estimated overall annual average.

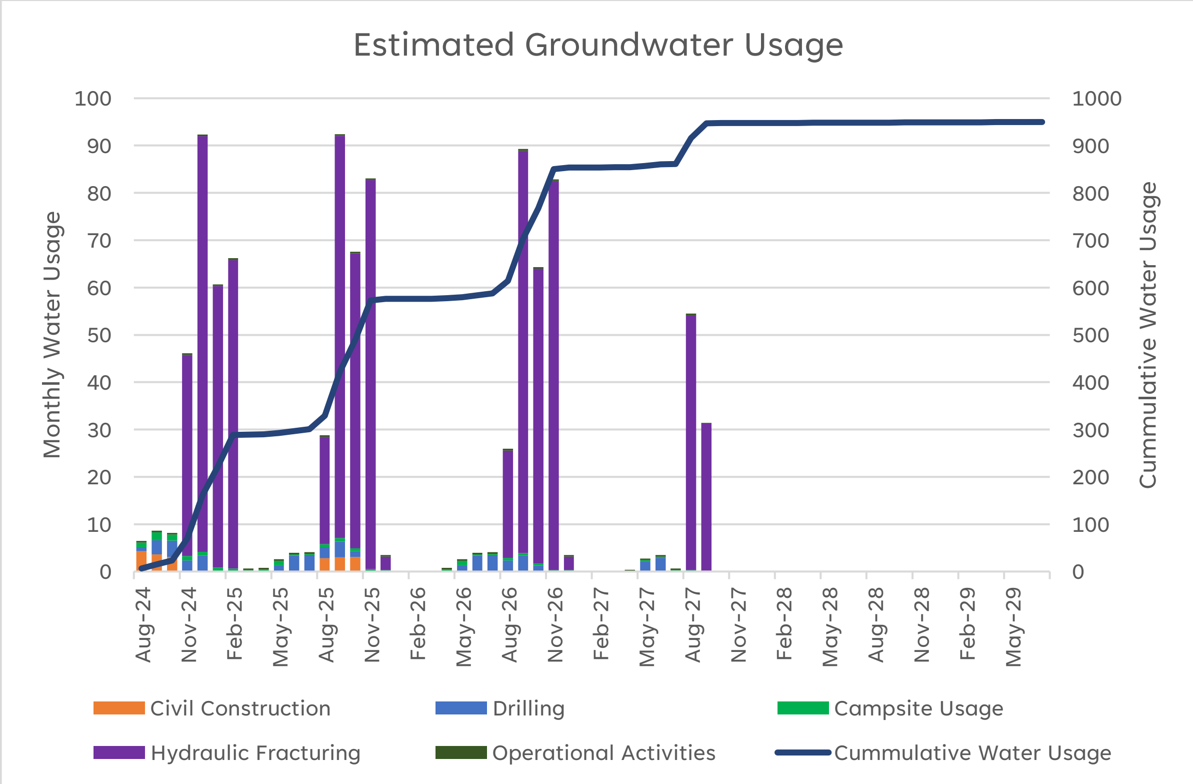

Figure 6.3—17 Estimated CPP Potential Water Extraction Requirements (ML)

6.3.4 Inland Water Quality

The CLA system is the most documented and significant aquifer in the Beetaloo sub-basin and is used as a resource for the pastoral industry and communities [P Meyer, 2023]. The CLA is vast and covers an area of approximately 570,000 km^2.

The CLA comprises two groundwater flow systems: the minor and shallower Anthony Lagoon aquifer and the more substantial, deeper GRF aquifer. Despite the large area of the CLA in the arid south including the Beetaloo, its contribution to the total throughflow to the rivers to the north (e.g. Roper) is minor compared to the areas north of the Beetaloo [S Tickell, 2022].

As discussed in EMP **Section 4.10**, the estimated volume of groundwater stored in the CLA is very significant: between 1,819,000 GL and 3,690,000 GL [A Knapton, 2020]. The great majority of that volume (96%) is in the GRF, which occurs as a vast cavernous limestone aquifer across the Beetaloo with an average inferred thickness of 24 m in the CPP Area, as discussed below. Because of this massive karstic water storage, measured GRF groundwater levels are very stable, including at existing well pads.

Time-series groundwater levels in both Anthony Lagoon and GRF measured at five locations in the Beetaloo showed a variance of less than ± 0.1m over a 3-year period and no clear trends within or between hydrograph sites [S Tickell, 2022].

6.3.4.1 Gum Ridge Formation Aquifer

A key requirement of *the Code* in relation to groundwater monitoring in the Beetaloo is the guideline requirement for an accurate lithological log of rock from the water supply bore at a well pad during the implementation of the required well pad monitoring bore layout. The water bore should be drilled to the base of the Gum Ridge Formation.

The measured top and base of the aquifer interval and measured standing water level relative to ground level at different existing CPP well pads is shown in **Table 6.3—2**.

The main area of CPP activity is in the fractured and karst area of the CLA aquifer, extending into the fractured and weathered area in the north (**Figure 6.3—18**).

Table 6.3—2 CPP Well Pad Water Bores Aquifer Stratigraphy

Bore Owner	RN	Top (mbgl)	Base (mbgl)	Thickness (m)	Standing Water Level (mbgl)
Imperial	RN041800	72	96	24	69.3
Imperial	RN042461	64	76	12	68
Imperial	RN042463	74	90	16	65.5
Imperial	RN041678	60	96	36	69
Imperial	RN043012	47	82.5	35.5	65.5
AVERAGE		**63.4**	**88.1**	**24.7**	**68**

6.3.4.2 CPP Area Groundwater Baseline Assessment

The total dissolved solids (TDS) isopleth mapping of the CLA derived for the SREBA studies [CR Huddlestone-Holmes et al., 2020] has been overlaid with the CPP boundaries (**Figure 6.3—19**). The results of the Activity baseline groundwater monitoring are consistent with the eastern boundary of the SREBA in the TDS contour of 600-800 mg/L. The measured TDS level is 705 ± 80 mg/L.

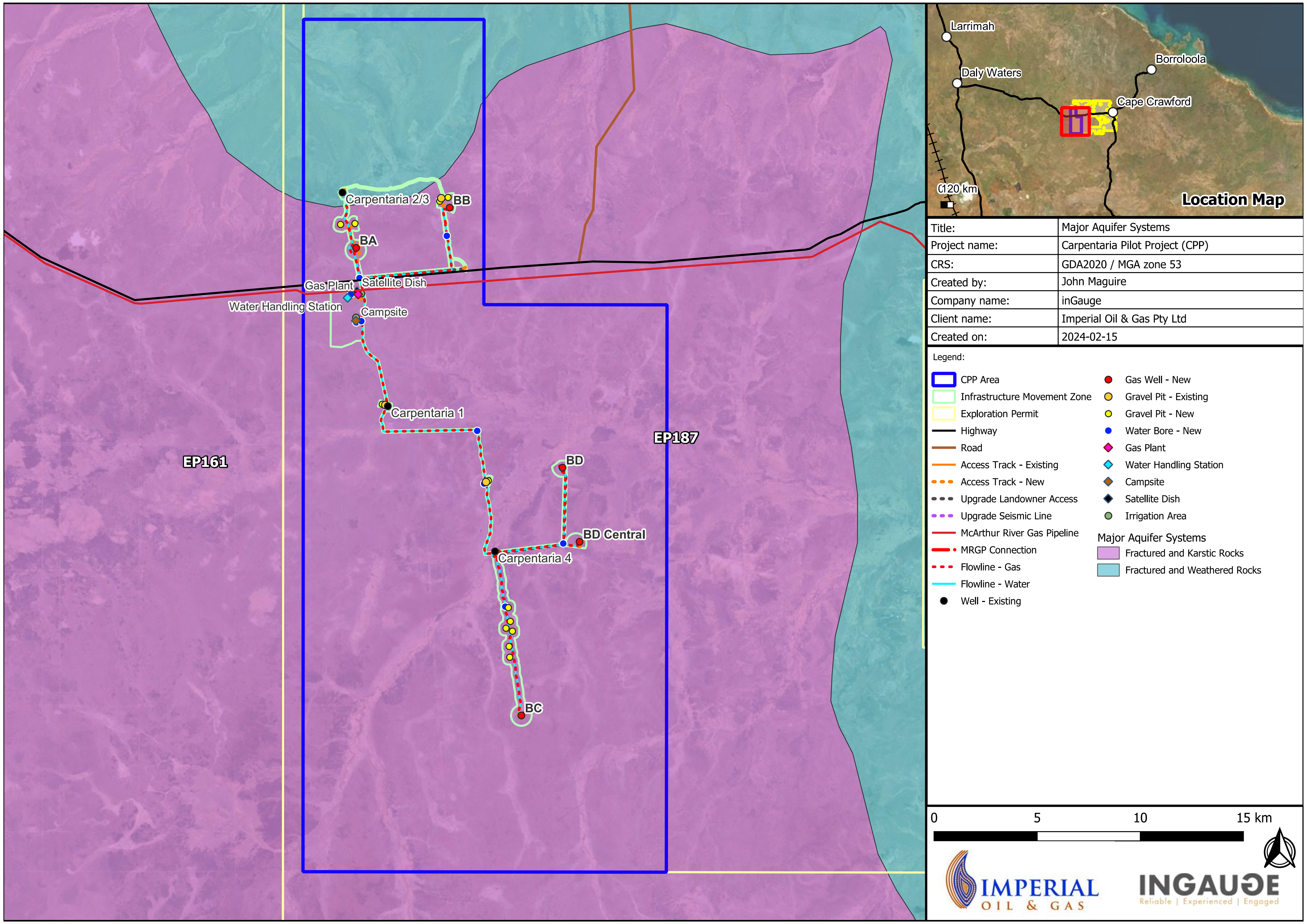

Figure 6.3—18 Cambrian Limestone Aquifer in the CPP Area

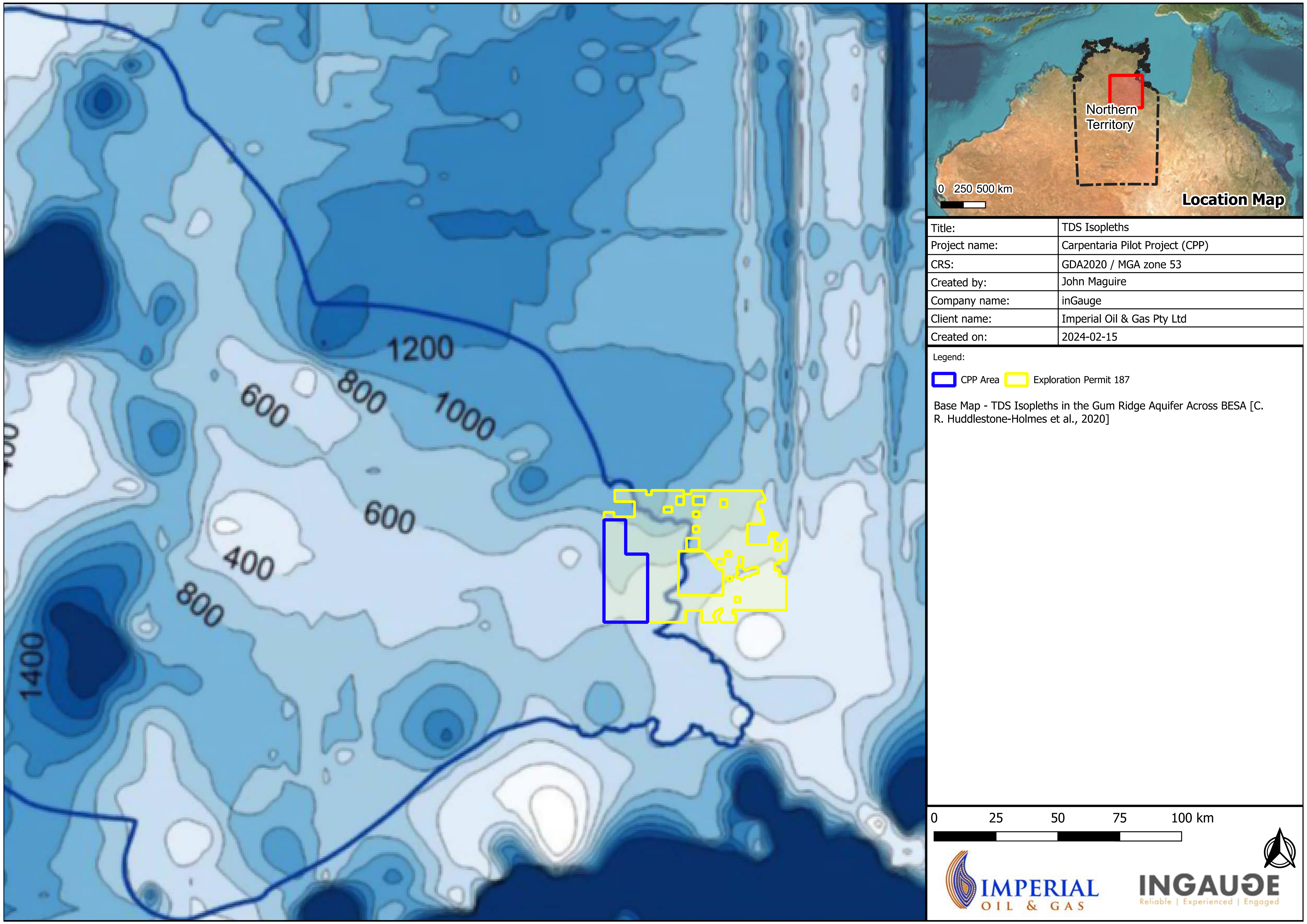

Figure 6.3—19 TDS Isopleths in the Gum Ridge Formation Aquifer at the CPP Area

A well pad baseline groundwater assessment has been conducted in compliance with *the Code* and the *Preliminary Guideline: Groundwater Monitoring Bores for Exploration Petroleum Wells in the Beetaloo Sub-Basin* [DENR, 2018] at all existing CPP well pads, shown in **Figure 6.3—20** to **Figure 6.3—25**. The design of the groundwater monitoring program is based on BACI (Before/After and Control/Impact) sampling, widely used in investigations of environmental impacts on water pollution, among others.

A statistical re-analysis and compilation of the time series data of groundwater quality sampling on 10 occasions at the Carpentaria 2 well pad, was undertaken on Control and Impact Bores (RN042461, RN042462 and RN042463, RN042464 – refer **Figure 6.3—20** to **Figure 6.3—25**) that intercept the Anthony Lagoon and Gum Ridge aquifers, respectively. The key results are presented in **Figure 6.3—26** to **Figure 6.3—29**.

The data for each bore and analyte that were above the Limits of Reporting (LoR) are presented as the mean and the confidence intervals computed as ± 1 standard deviation. The data shows that the measured levels of key analytes, major cations and anions, pH and metals, or trace metals are not statistically significantly different ($p > .05$) between any of the monitoring bores at the well pad. This confirms the efficacy of Imperial's aquifer protection methods (further discussed in **Section 6.3.6** of this document).

The results provide confidence in the statistical power to detect effects in groundwater across the CPP Area into the future and that a robust baseline for the 67 specified groundwater analytes is established at the well pads. Any anomalous variations to groundwater quality at well pads can, therefore, be detected by this method in the future.

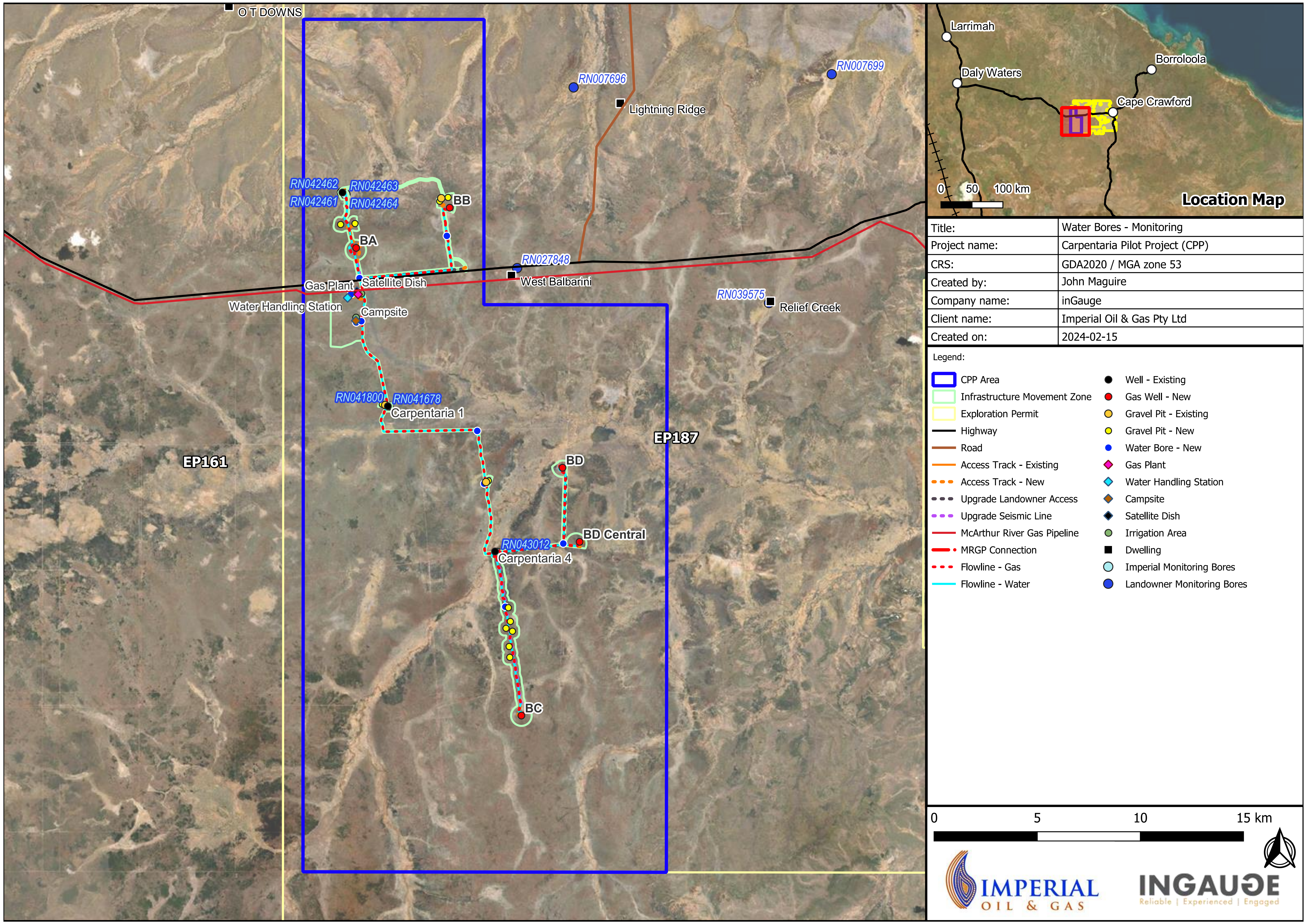

Figure 6.3—20 Groundwater Baseline Monitoring Bores in the CPP Area (Overview)

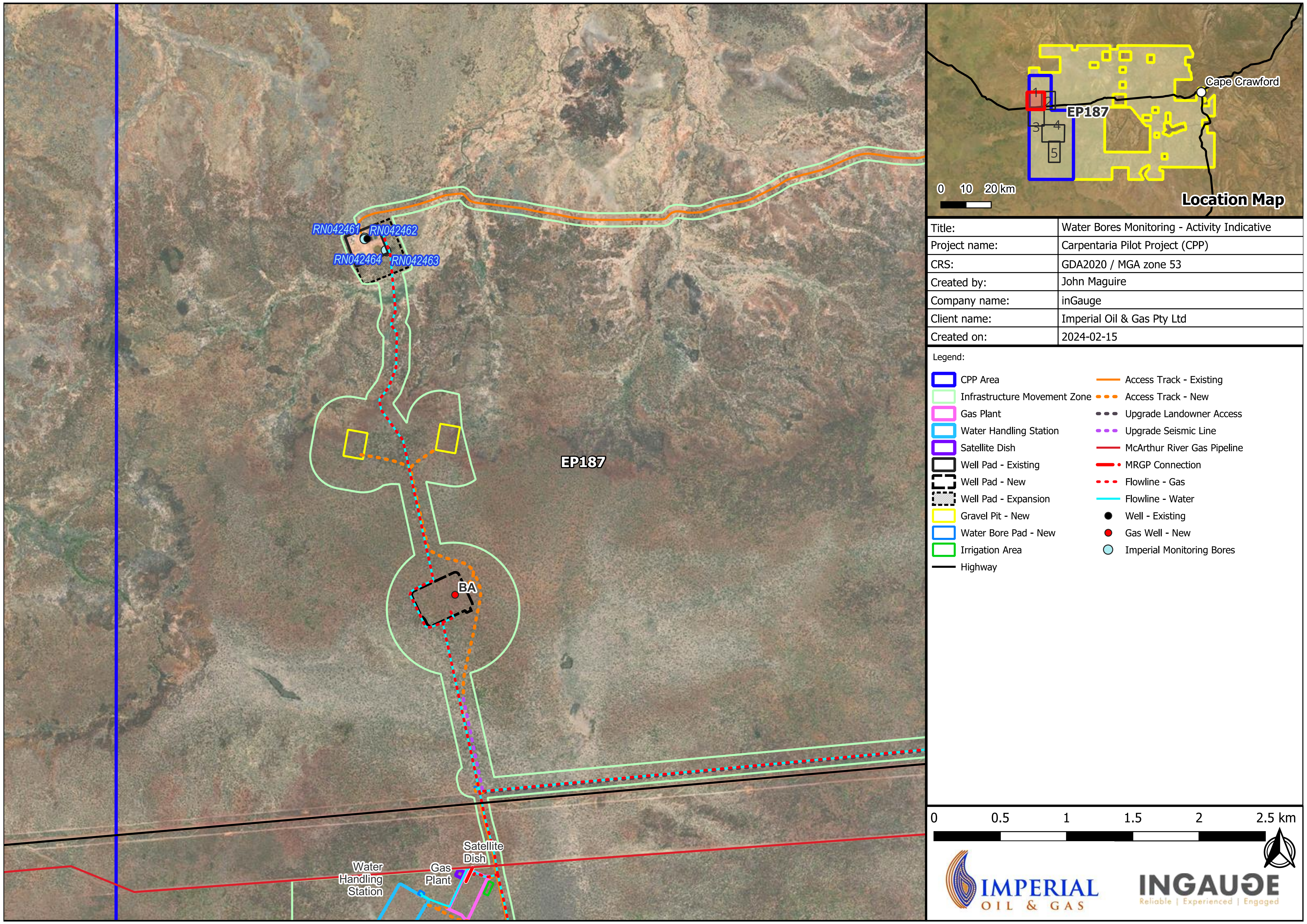

Figure 6.3—21 Groundwater Baseline Monitoring Bores in the CPP Area – Map 1

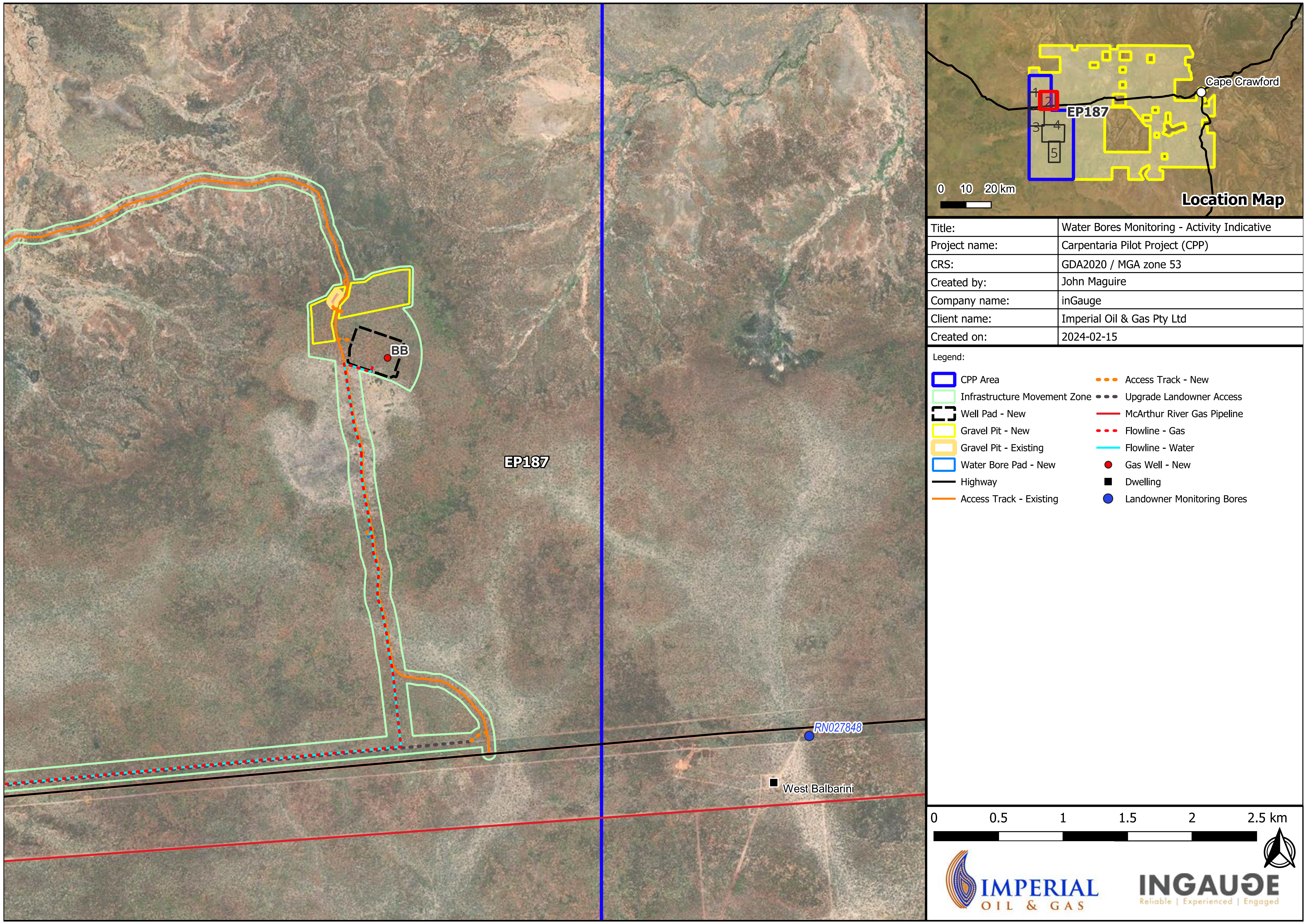

Figure 6.3—22 Groundwater Baseline Monitoring Bores in the CPP Area – Map 2

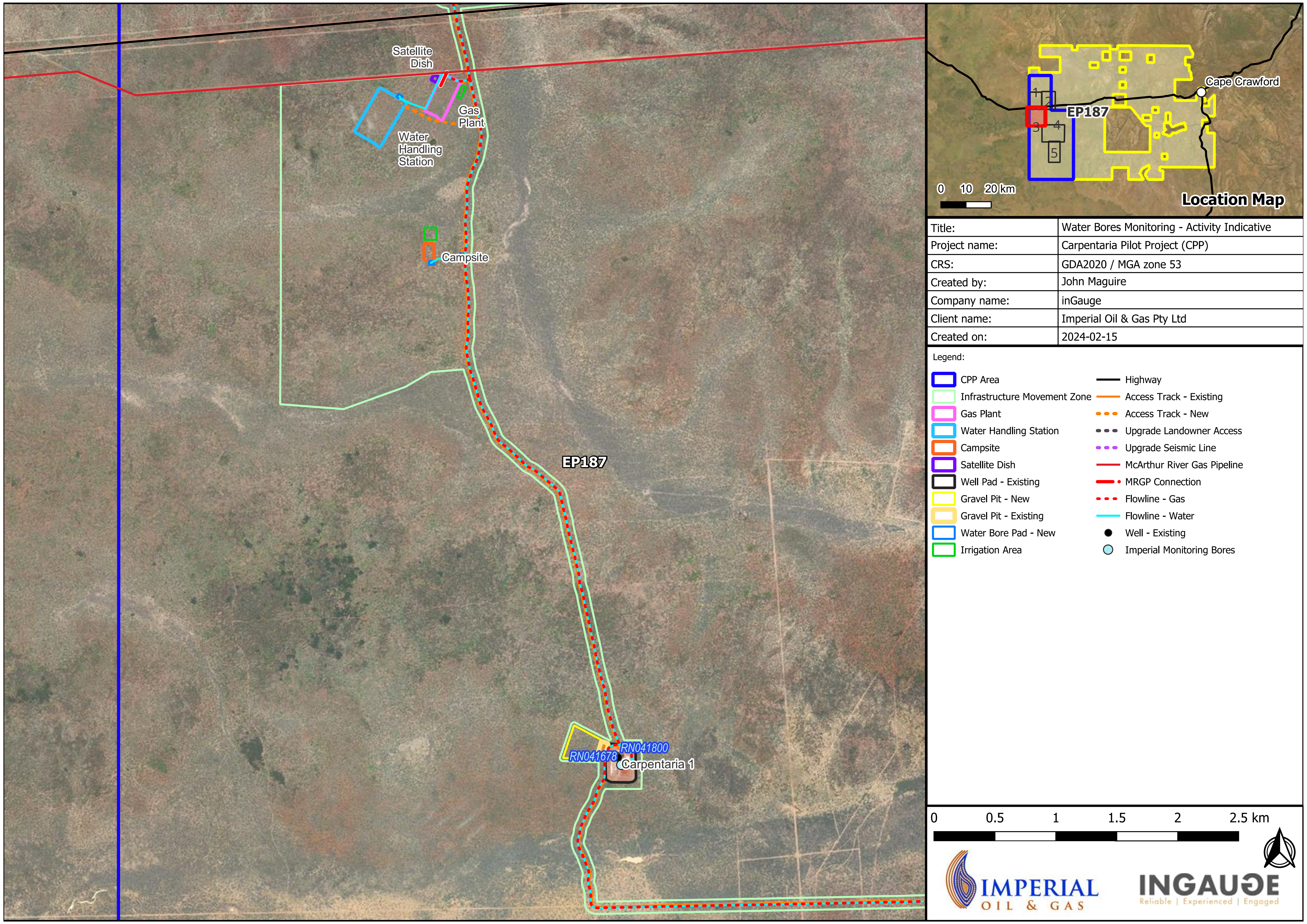

Figure 6.3—23 Groundwater Baseline Monitoring Bores in the CPP Area – Map 3

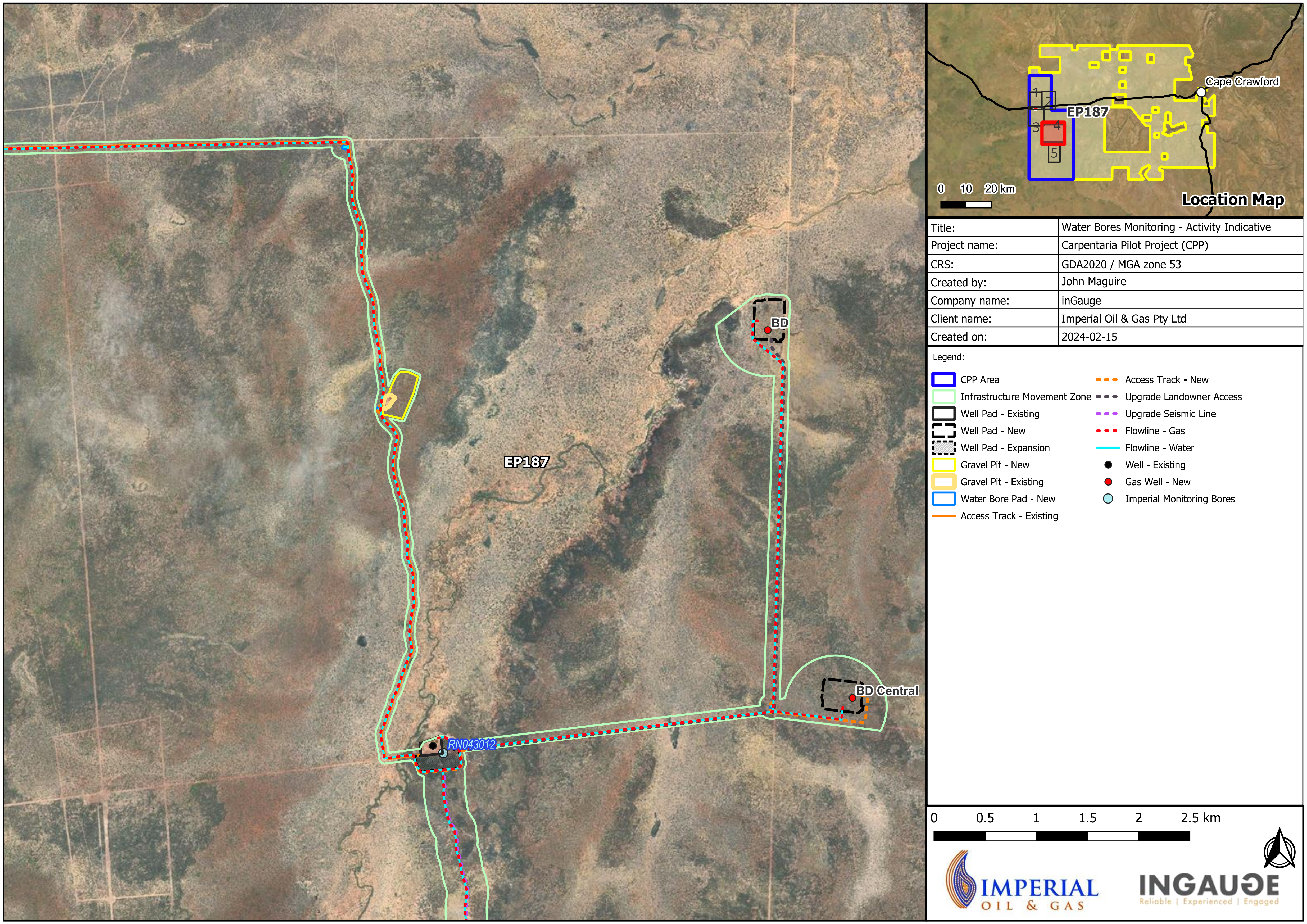

Figure 6.3—24 Groundwater Baseline Monitoring Bores in the CPP Area – Map 4

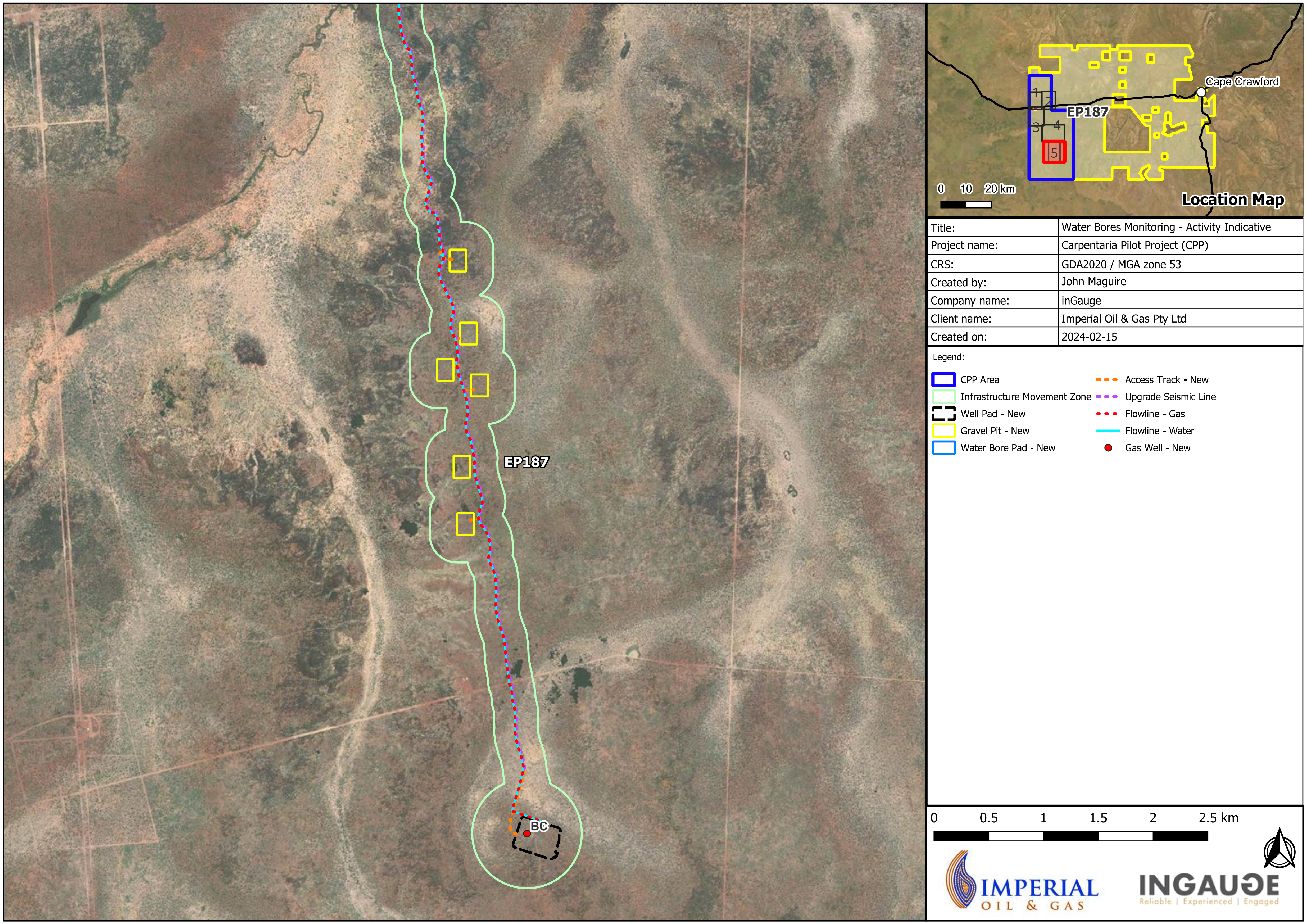

Figure 6.3—25 Groundwater Baseline Monitoring Bores in the CPP Area – Map 5

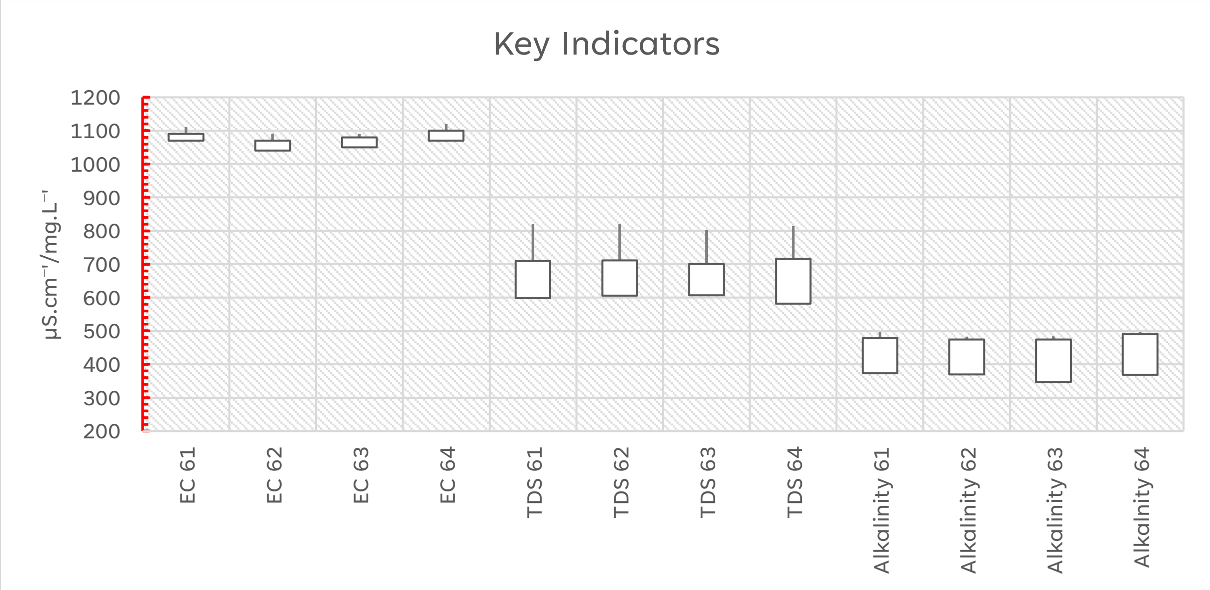

Figure 6.3—26 Salinity and Alkalinity Confidence Intervals at Each Bore (n = 10)

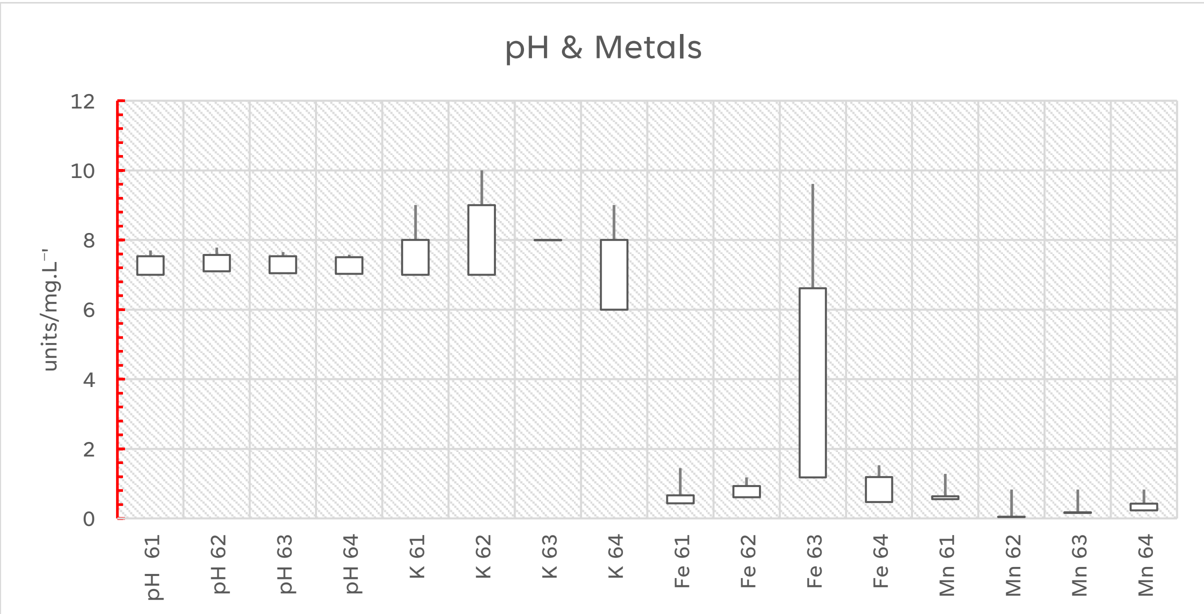

Figure 6.3—27 pH and Metals Confidence Intervals at Each Bore (n = 10)

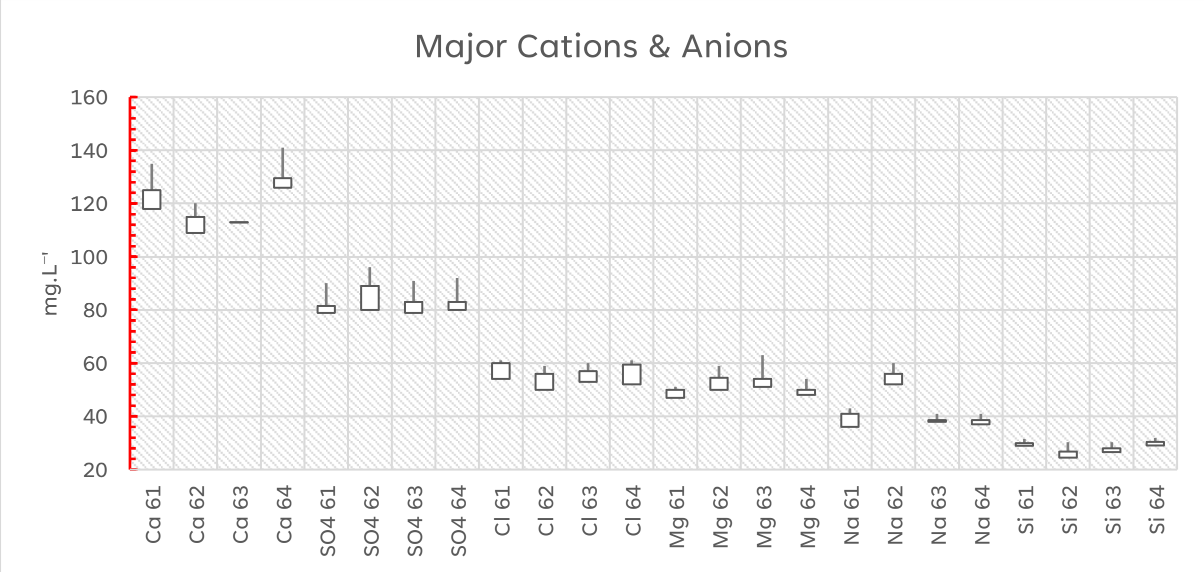

Figure 6.3—28 Major Cations and Anion Confidence Intervals at Each Bore (n = 10)

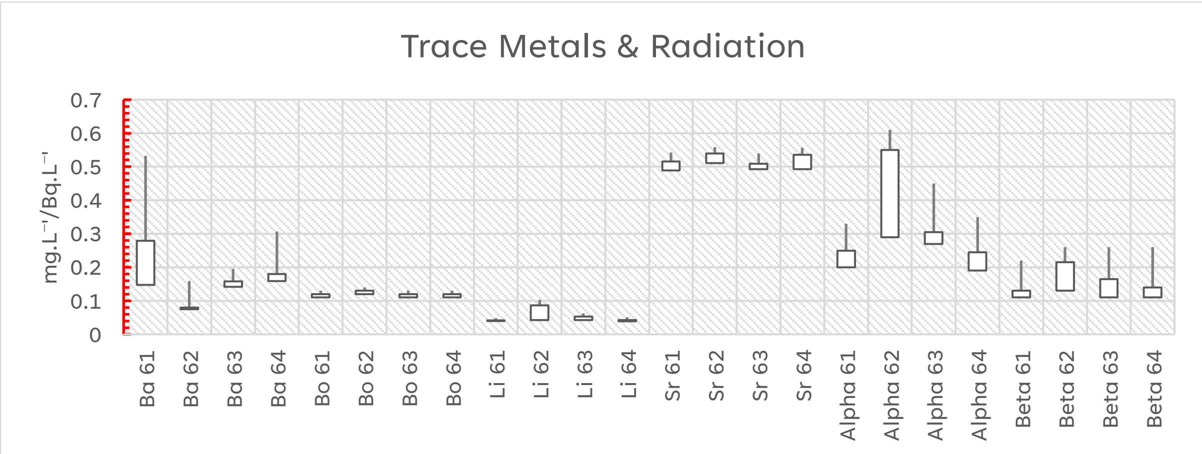

Figure 6.3—29 Trace Metals and Radiation Confidence Intervals at Each Bore (n = 10)