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Land and water resources for irrigated agriculture in the Pilbara

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Summary

This report documents the procedures used to identify suitable locations for irrigation development in the Pilbara region. It is the first study to investigate the potential for irrigated agriculture across the Pilbara. We used a desktop analysis to ascertain water availability and spatial data modelling to determine the potential of the land and soil resource to support irrigated agriculture. This study was part of the Pilbara Hinterland Agricultural Development Initiative (PHADI).

We used existing rangeland land inventory information augmented with digital spatial environmental data, in a process known as map disaggregation, to create soil and landform maps that had a quantified soil type prediction at every location on the ground. Soil type predictions were divided into 3 'irrigation suitability' classes to identify areas most capable of supporting irrigation. We identified 3 landscape-scale constraints likely to preclude the development of irrigation in this extreme climate: inland flooding and inundation, water erosion and coastal inundation. We used proprietary data from Landgate and new datasets that were developed during this project to identify areas at heightened risk of these hazards and then excluded these areas from assessment. The assessment identified:

- 2.1 million ha of class A1 land (8% of the PHADI area); Class A1 land has soil and landform characteristics that are rated as highly suited to irrigation making up more than 70% of its area
- other small areas with significant good land for irrigation, which should be able to support smaller-scale irrigation developments if water supplies can be secured.

The water assessment reviewed all publicly available data and information to assess potential water resources in the Pilbara that could support irrigated agriculture. Specifically, the water assessment reviewed:

- the volume of water that was available in areas with allocation limits
- mining areas having surplus dewater not used for mining operations or environmental purposes
- other sources of water potentially available, including underdeveloped non-target aquifers
- surface water flows that could be captured and stored through managed aquifer recharge systems.

The review identified 10 prospective areas that, combined, could have 100–120 GL/y of water resources available to support irrigated agriculture. Together, these 10 sites cover 5,000–12,000 ha across the Pilbara, with individual areas from 250–500 ha up to possibly 3,000 ha. These areas should be investigated in greater detail for water supply, water quality, landform and soil characteristics.

All prospective irrigation development, particularly large precinct-type development, must thoroughly assess social, environmental and economic impacts and consequences – we summarise some key considerations of these aspects in this report. Proponents considering smaller-scale development would benefit from considering these aspects early in their planning and should be aware of the regulatory processes that must be complied with.

1 Introduction

The PHADI area includes the western part of the Pilbara region and the northern part of the Gascoyne region. The area is a sparsely populated region of north-west Western Australia (WA), about 850 km north of Perth at its closest point. Major centres are Port Hedland (about 1,300 km from Perth) and Karratha. The Pilbara climate is arid tropical, with a wet summer season (November to April) dominated by infrequent rainfall from cyclones, tropical lows and thunderstorms and intense heat. The dry winter season is progressively more influenced by winter frontal systems towards the south. The north of the region is mostly grasslands with sparse tree overstorey, and the south grades to mixed grasslands and shrublands.

Mining dominates the economic production of the Pilbara, accounting for about 80% of total productivity The major food industry is rangeland beef production. Irrigated agriculture and fisheries are small, but developing, industries.

For irrigated agriculture, a comprehensive study to identify suitable locations for irrigation development has never been done. To address a key question of the PHADI – What land and water resources are available for irrigated agriculture development? – we undertook a desktop assessment between 2014 and 2017 to ascertain water availability and the potential of the land and soil resource (called ‘land potential’ in this report) to support irrigated agriculture.

Through desktop analysis and spatial data modelling, we identified, at a broad scale, areas with land capable of supporting irrigated agriculture. The PHADI created digitally enhanced soil maps based on existing rangeland land inventory information. Information on soil distribution embedded in these inventories was augmented with digital spatial environmental data that reflect aspects of soil formation to determine likely soil type distribution. The process is known as map disaggregation and its purpose is to transform conventional, complex soil-landscape maps into maps with a quantified soil type prediction at every location on the ground.

We conducted a literature review of water resources in the Pilbara to evaluate water supply prospects for irrigated agriculture. All water sources were reviewed, including target aquifers for industry and town water supplies, other non-target aquifers, mine dewater surplus and surface water. Surface water was included because it is a potential source for managed aquifer recharge, which could generate additional water supplies from sources that would otherwise not be used.

2 Land and soil resources

Previous studies to identify which of the Pilbara's soils and landforms are suited to irrigation development used rangeland inventory survey information (MWH 2009; GHD 2015). The surveys were conducted between the 1970s and 2000s and provide an overview of natural resources for pastoral purposes (Payne and Tille 1992; Payne et al. 1988; van Vreeswyk et al. 2004). These surveys, produced at a scale of 1:250,000, map rangeland systems, which represent areas of recurring patterns of landforms, soils and vegetation. Soil distribution is not explicitly mapped in rangeland survey maps. Instead, each map unit is described by percentile distribution of soil types likely to be present, classified by Western Australian Soil Groups (WASGs; Schoknecht and Pathan 2013).

This level of information is adequate for the primary land uses of mining and pastoral grazing of native vegetation in the Pilbara. However, irrigated agriculture is an intensive, location-specific land use that requires substantial capital investment and thus requires the best predictions possible. Existing maps lack the spatial detail required to inform of irrigation potential and only give a very general indication of uncertainty associated with the information (Table 2.1).

Traditional land and soil survey relies on substantial field reconnaissance. This is expensive and time consuming, particularly in remote, challenging environments such as the Pilbara. Rather than undertaking extensive field work to make a higher resolution map using traditional methods, we used a new digital soil mapping technique that attempts to improve the mapped information using existing conventional soil maps as the input soil data. Our aim was to improve the nominal scale of mapped soil-landscape information from 1:250,000, which is suitable for rangeland production, to 1:100,000, which is suitable for identifying areas with development potential. This digital approach to improving the spatial detail of soil maps combines existing land surveys with remotely sensed datasets in a statistical modelling framework to predict where soil types are most likely to occur. The specific method used is called 'Disaggregation and Harmonisation of Soil Maps through Resampled Classification Trees' (DSMART) (Holmes et al. 2014; Odgers et al. 2014; Holmes et al. 2015). The DSMART maps show the probability of soil types – classified according to WASGs (Schoknecht and Pathan 2013) – occurring in every 90 × 90 m grid cell across the region. The PHADI combined these DSMART maps into new maps specifically targeting soils potentially suited to irrigated agriculture.

Table 2.1: Comparison of the resolution, scale and purpose of prior rangelands mapping to the mapping produced during the PHADI, and the ultimate map scale required to develop irrigation areas with confidence

Project development phase (scale produced)	Recommended uses	Scale range (mapped resolution)	Explicitly mapped	Described complexity
DAFWA research trial due diligence	Agricultural research, horticulture	1:5,000 to 1:10,000 (<1 ha)	DAFWA research trial due diligence	Agricultural research, horticulture
Irrigation proponents' due diligence requirements	Irrigation production	1:10,000 to 1:25,000 (1–25 ha)	Irrigation proponents' due diligence requirements	Irrigation production
Government development projects to identify prospective irrigation targets	Irrigation feasibility, dryland production	1:50,000 to 1:100,000 (25–225 ha)	Government development projects to identify prospective irrigation targets	Irrigation feasibility, dryland production
Agricultural feasibility studies and development potential[a]	Strategic planning for dryland agriculture	1:100,000 to 1:250,000 (100–625 ha)	Broad landforms, groups of landforms	Groups of similar landforms and variations + soils/groups of soils and their locations and prevalence within landform
Existing data	Rangelands productivity overview, general planning for pastoral shires	1:250,000 to 1:500,000 (>625 ha)	Groups of landforms	Groups of similar landforms and their variations + much simplified groups of soils

DAFWA = Department of Agriculture and Food, Western Australia (now part of DPIRD)

a This DSMART project.

Source: adapted from Reid (1988); van Gool et al. (2005); Schoknecht et al. (2008)

Digital soil mapping (DSM) as a discipline is growing rapidly in parallel with increases in computing power and improvements in remotely sensed data and products (McBratney et al. 2003; Minasny and McBratney 2015). DSM maps quantify soil-landscape predictions through statistical modelling. The typical output from DSM is grid-based (raster) maps, which are easier to incorporate into subsequent computer models or GIS-based scenarios than conventional soil polygon maps. Standard DSM methods rely on soil information collected from known georeferenced locations that can be directly related to spatial layers for modelling. In the Pilbara, the relatively small number of geolocated historical soil observations and lack of laboratory measured soil properties

available for public use restricts the kinds of modelling that can be applied reliably. DSMART, which requires only conventional soil maps as input for soil data, is an efficient way to extract soil information for modelling but relies on the accuracy of the descriptive soil information embedded in the conventional map products. As the availability and quality of georeferenced soil observations in the Pilbara improves, other DSM methods will yield more reliable soil distributions where they rely on well-calibrated soil observations rather than subjective attribution of traditional soil maps.

Maps and information developed during this PHADI project represent the first step towards identifying prospective areas for irrigation development. Individual irrigation developments require a greater level of field investigation than is feasible from regional assessments of soil distribution. Increasing the density and accuracy of georeferenced soil observations should be a priority activity to advance irrigation development in the Pilbara.

2.1 How we produced the maps

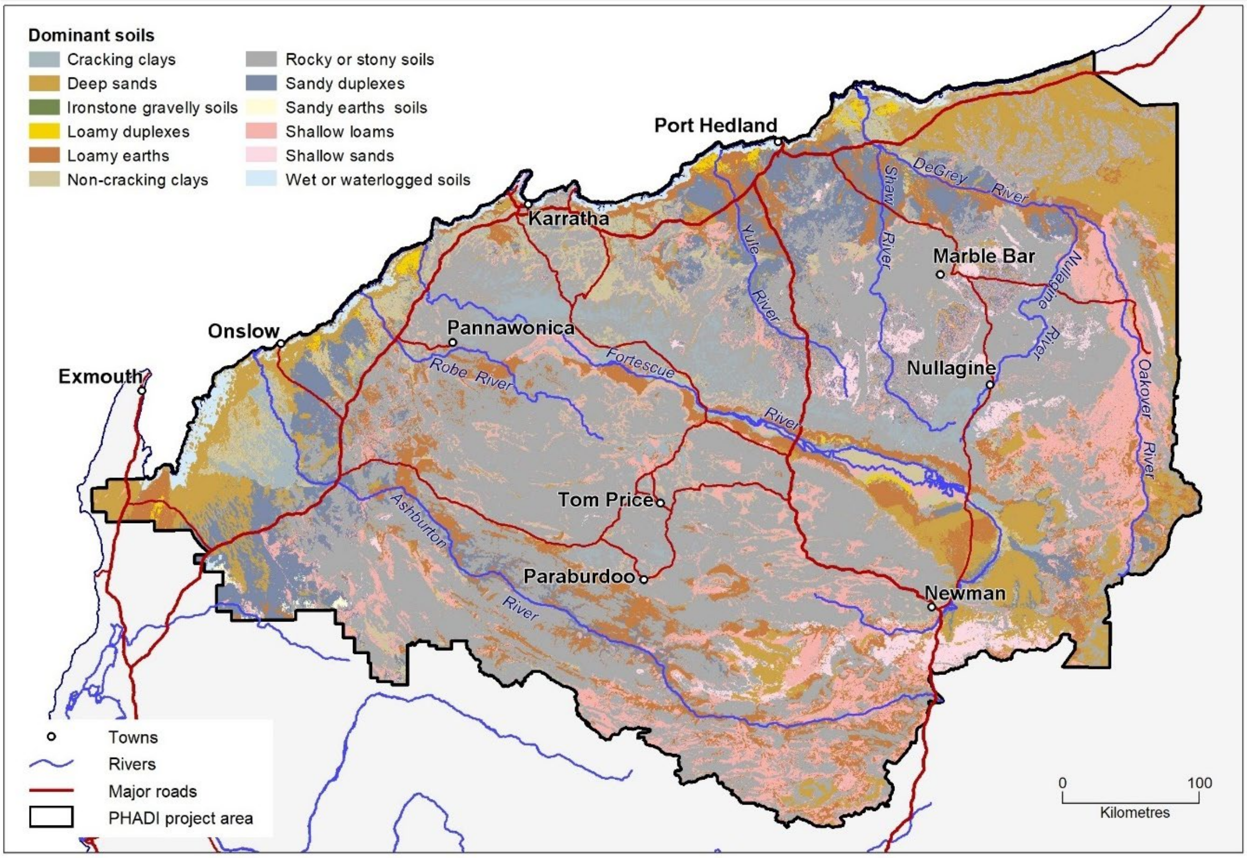
The ‘map disaggregation’ approach transforms conventional, complex soil-landscape maps into more-detailed maps with a soil type assigned to every 90 × 90 m cell location on the ground. It uses information embedded in rangeland survey reports and associated maps that describe soil distribution and combines it with digital spatial data of the environment, such as elevation models and satellite imagery, to better define the likely extent of soil types described, but not mapped, by the original surveyors.

The DSMART approach generates a series of ‘probability layers’, which describe the likelihood of encountering each soil type in each pixel. In this case, soil type is defined by the WASG classification. Each WASG layer can then be combined in different ways to display information about soil distribution for different purposes. Van Gool et al. (2005) contains examples of how the soil distribution information is translated to land evaluation products.

2.2 Overview of soils present

Pilbara ranges comprise erosional landscapes with mostly stony and shallow soils. Deeper, medium- to fine-textured soils are found in areas of transition and accumulation on the flanks and at the bases of the ranges. Deep, fine-textured soils accumulate in river valleys, floodplains and the lower slopes of broad coastal plains in the west. Salinity is often associated with lower soil layers in these clayey soils, because of the generally arid climate. Sandy soil is found as sheets and dunes formed by aeolian (wind-dominated) geomorphic processes associated with desert landforms in the east and north-east; on coastal dunes; and as in situ soil formed from weathered sandstone.

A general soil map of the Pilbara captures these major patterns of soil distribution (Figure 2.1). This map was created by simplifying DSMART probability layers into ‘supergroups’ of WASGs.



Note: Soil types shown are supergroups, the highest level of the WASG classification.

Figure 2.1: Dominant soil types in the PHADI area

2.3 Overview of soil potential for irrigation

WASGs were assessed by an expert panel who reviewed soil types found in WA’s current and proposed irrigation areas. Each WASG was placed into one of 3 irrigation potential classes: high, moderate and no potential. Where the potential of a WASG to support irrigation was uncertain or variable, it was placed in the higher (more suitable) category. Being inclusive with respect of the potential for each WASG to support irrigation maximises the potential area suited to irrigation – the rationale being that more detailed investigations will be conducted in the future. Table 2.2 lists the WASGs classified as having high and moderate potential for irrigated agriculture.

Table 2.2: WASGs with potential to support irrigation

High potential WASGs	Moderate potential WASGs
Red deep sandy duplex	Deep sandy gravel
Brown deep sand	Loamy gravel
Red deep sand	Sandy duplexes supergroup
Yellow deep sand	Red shallow sandy duplex
Brown sandy earth	Loamy duplexes supergroup
Red sandy earth	Red shallow loamy duplex
Red deep loamy duplex	Red shallow loam
Red loamy earth	Red–brown hardpan shallow loam
Yellow loamy earth	Cracking clays supergroup
	Hard cracking clay
	Self-mulching cracking clay
	Red–brown noncracking clay

Note: Some soil groups contribute to the mapping method but are not included in this table because they are not present, or they are present but have no potential for irrigation.

This classification was applied to the DSMART WASG probability layers. The probability layers were combined using the land capability assessment method described by van Gool et al. (2005) to create one map that identifies the regional-scale irrigation potential of soils and landforms.

Since each pixel describes the probability of encountering each WASG, the irrigation potential map retains an element of the spatial complexity implicit in probability mapping of WASGs. Thus, pixels can have an array of endpoints, from near certainty of encountering a single WASG, to a lesser probability of encountering one of numerous possible WASGs, each with their own rating of irrigation potential. We rated the potential of each WASG to support irrigated agriculture by adapting the land capability triangle described by van Gool et al. (2005), replacing the term 'land capability' with 'soil potential for irrigation' (Figure 2.2).

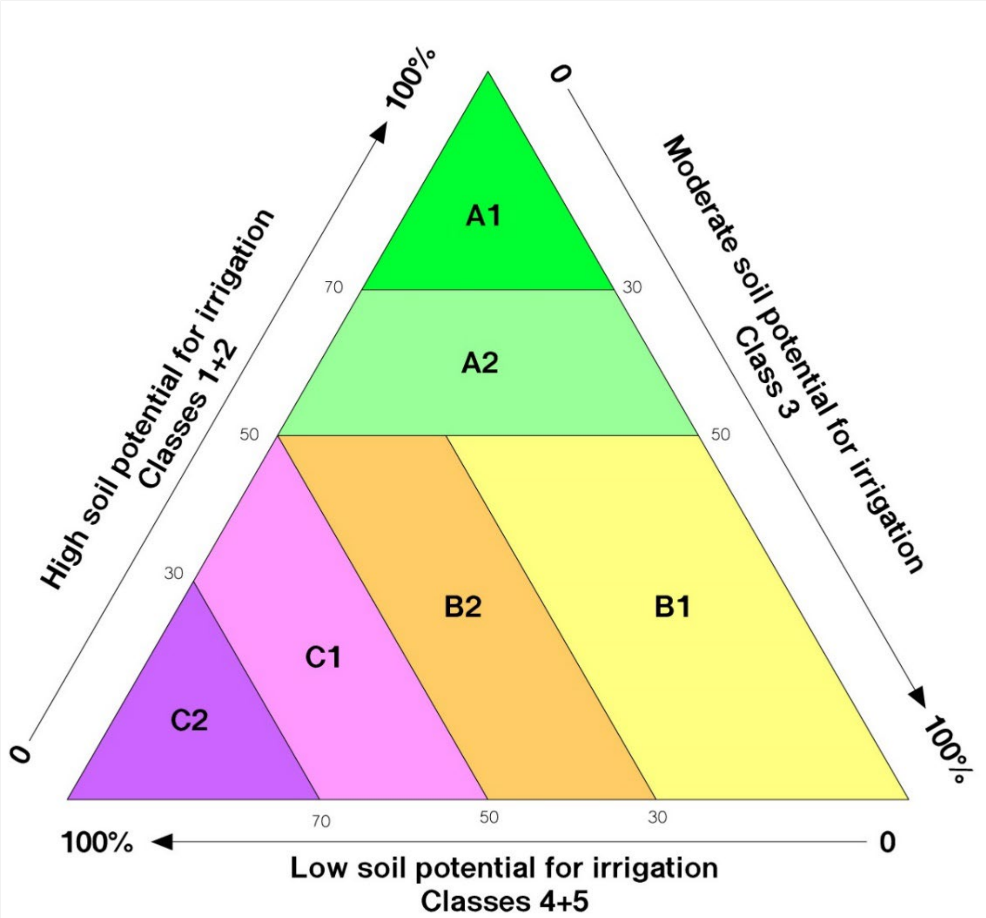


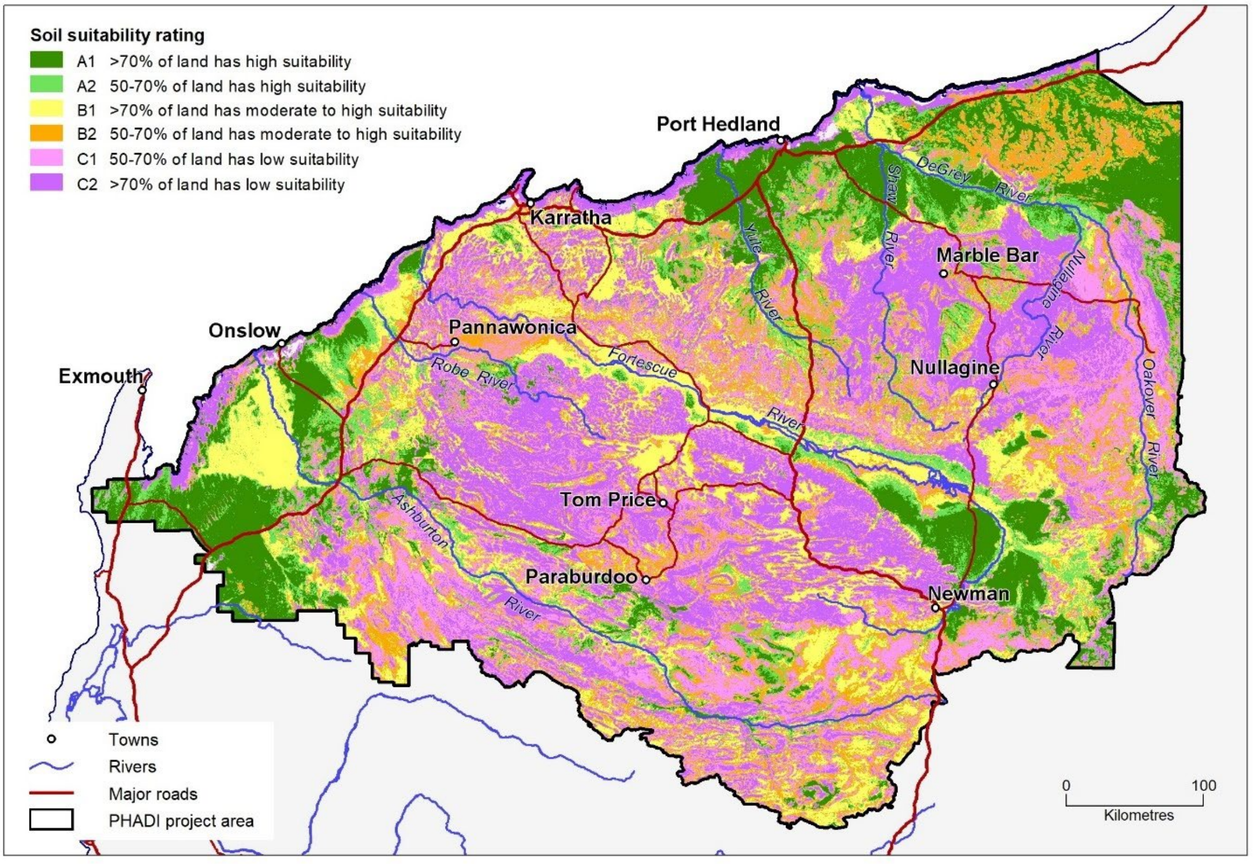
Figure 2.2: Rating DSMART WASG map for the soils' potential to support irrigated agriculture, using a modified land capability triangle from van Gool et al. (2005)

Importantly, this classification amalgamates soil types with the same irrigation potential even though they may have very different characteristics and management requirements – this is a necessary compromise for assessing irrigation potential at a regional scale. This means that the current irrigation potential mapping cannot resolve detail for different types of management, such as whether the soil is suited to flood or sprinkler irrigation, or whether the soil is best suited to annual horticulture or pasture production.

This work was done to guide future field investigations. More detailed mapping will be required to define soil characteristics important to specific management systems so as to determine land capability and soil suitability at an irrigation production level. The resulting irrigation potential map (Figure 2.3) shows the distribution of high potential land is:

- concentrated at the headwaters and along the slopes adjacent to the river valleys of the Fortescue River
- on slopes and plains adjacent to the mid and lower reaches of the Ashburton River
- at the coastal margin of the western and northern lower slopes of ranges

- surrounding the alluvial floodplains of the major river systems, such as the De Grey and Shaw rivers between Port Hedland and Marble Bar, and the Robe and Ashburton rivers between Onslow and North West Coastal Highway
- on the sandplain areas of the Great Sandy Desert in the north-east
- on the south-western plains near the Yannerie River.



Note: Areas prone to significant hazards unrelated to soil type have not been removed.

Figure 2.3: Soil suitability of land with potential for irrigated agriculture in the PHADI area

2.4 Mapping significant regional hazards

Key regional-scale degradation hazards and production risks (hereafter termed hazards) impacting land development and irrigation infrastructure in the Pilbara are water erosion, flooding and ocean surges (caused by cyclones and tsunamis). Three additional datasets representing these hazards supplement the general land potential assessment for irrigated agriculture. These hazard datasets constrain the area capable of supporting irrigation by defining the land unsuited to intensive development because of these external hazards. The hazard datasets provide a regional, broadscale overview of indicative environmental hazards.

2.4.1 Water erosion hazard based on slope class mapping

The arid subtropical climate of the Pilbara has extended periods of negligible rainfall irregularly interspersed with intense, highly erosive rainfall events resulting from summer thunderstorms and cyclones (Sudmeyer 2016). Water erosion on shedding landscapes is a primary concern for soil stability and sustainable irrigation practices.

We conducted a literature review of irrigation development in northern Australia and identified slope threshold values beyond which the risk of land degradation increases unacceptably. A digital elevation model (DEM) at 30 m resolution was used to classify slopes and exclude areas with excessive slopes (Gallant and Austin 2015). The assessment of irrigation potential in this study was limited to the soil and landscapes most capable of assimilating rainfall and water flows without eroding. Landscapes comprising slopes above 2% were excluded from assessment – in the north-west of WA, land exceeding this slope is regarded as generally incapable of supporting irrigation because of the increased cost of managing the hazard (Smolinski et al. 2015). There may be situations where slopes more than 2% could be irrigated, but this would require a detailed survey and management plan and would generally only be feasible if high-value crops are planted to offset the much higher establishment and ongoing management costs.

Landscapes with less than 2% gradient are regarded as suitable for development. These areas were divided into 2 hazard categories:

- slopes with gradients of 0–0.5% are regarded as a low hazard for water erosion potential (Easey et al. 2016; Smolinski et al. 2015)
- slopes with gradients of 0.5–2% are regarded as moderately risky and may require management intervention to prevent water erosion but are otherwise capable of supporting irrigated agriculture (Smolinski et al. 2015; Easey et al. 2016).

This general hazard assessment does not consider the numerous additional factors (including slope length, soil characteristics and management interventions) that contribute to the complex process of water erosion and its avoidance. These can only be accounted for during detailed site assessments.

2.4.2 Flood hazard mapping

Water from intense rainfall can cause flooding, which is detrimental to irrigation productivity and profitability, and can cause significant damage to infrastructure. The PHADI acquired proprietary flood hazard information from Landgate WA, who developed a flood model for the whole of Australia. The model maps flood hazard on a 5-tier rating (negligible, low, moderate, high, extreme) at a 90 m^2 cell resolution, using 2 data sources:

- inundated pixels derived from time-series, multispectral remotely sensed images from satellites
- DEMs and stream density.

Appendix A contains Landgate’s detailed explanation and metadata statement.

The extreme and high categories of flood hazard (representing regular flooding) were used to constrain the land potential mapping.

2.4.3 Storm surge hazard mapping

The Pilbara coastline is Australia's most cyclone-prone region (BOM n.d.), has the highest storm surge hazard and potentially lies in the path of significant tsunamis generated by earthquakes and volcanic eruptions along the tectonically active Indonesian archipelago. The extreme and unpredictable nature of cyclones and tsunamis, combined with the lengthy and varied Pilbara coastline, required a general regional hazard assessment.

We reviewed information relevant to Pilbara coastal surges from Burbidge and Cummins (2007), Burbidge et al. (2008), Dominey-Howes (2007), Goff and Chaque-Goff (2014) and Scheffers et al. (2008). These authors identified indicators of past coastal surges generated by storms and tsunamis in historical, geological and geomorphological records. From this review, we generated a list of estimated or measured surge height above mean sea level of the Australian Height Datum (AHD). We applied these results to a DEM and produced a storm surge hazard data layer representing land less than 10 m above AHD and abutting the coast. This layer was compared to detailed, modelled storm surge assessments conducted for coastal townsites in the Pilbara (Cardno 2011; JDA 2012a; JDA 2012b). Our general model closely matched the detailed studies that modelled storm surges, so was accepted as a reasonable estimation applicable across the Pilbara coast.

Importantly, this assessment does not negate the risk of developments close to the coast being affected by extreme examples of such hazards. Dominey-Howes (2007) studied geological and archival records dating back to 1788 and found that about 40 tsunamis hit Australia during this time. The tsunami generated by the earthquake offshore from Java in 2006 resulted in the greatest impact to coastal landforms ever recorded in WA. This tsunami hit north-western Australia at Steep Point during low tide, with a tsunami flow depth estimated at 1.5–2 m. Maximum recorded run-up was about 10 m above mean sea level, flooding 200 m inland (Prendergast and Brown 2011). Examples such as this confirm that a general model cannot account for confounding factors that contribute to actual risk, including magnitude, location and direction of source; state of tide and wind; shape and constitution of coastline; and seabed bathymetry.

2.5 Identifying areas most capable of supporting irrigated agriculture

The 3 hazard maps were overlain on the land potential map to identify areas of high potential without significant regional constraints. Class A1 land has the most potential for irrigation development – this is land with soil and landforms rated as highly suited to irrigation making up more than 70% of its area. The area of class A1 land remaining after constrained areas were removed was 2.1 million ha (8% of the PHADI area; Table 2.3, Figure 2.4). This indicates that the area of land available and potentially capable of supporting irrigated agriculture in the Pilbara is not a limitation to development.

Table 2.3: Areas of land remaining in each land potential class after applying regional hazard data to excise land unsuited to development

Land potential class	Description	Area (ha)	Percentage of total area (%)
A1	>70% of land has high potential	2,100,000	8
A2	50–70% of land has high potential	1,800,000	7
B1	>70% of land has moderate and high potential	3,000,000	11
B2	50–70% of land has moderate and high potential	3,350,000	13
C1	50–70% of land has low potential	2,300,000	9
C2	>70% of land has low potential	700,000	3

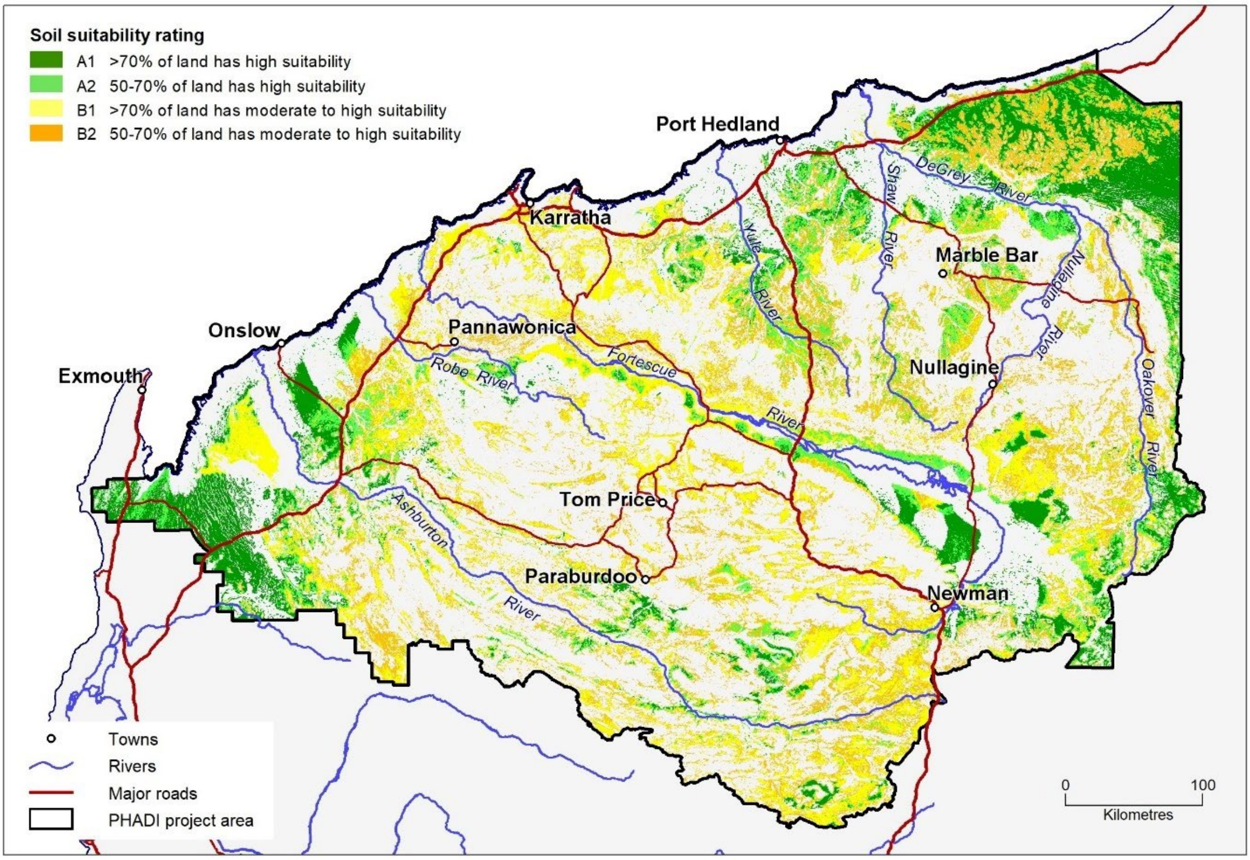


Figure 2.4: Soil suitability of land with potential for irrigated agriculture after excising the land prone to hazards that would render irrigation unfeasible

2.6 Testing the DSMART maps

Maps are frequently assumed to be correct, but they only estimate reality and traditionally rely on expert opinion for their generation. Validating maps and providing an assessment of their accuracy and precision has become more commonplace over recent years and is necessary to ensure that new maps are more accurate than old ones (Congalton 2001). However, validating soil and landscape maps is fraught

because much variation of soil properties occurs over small (<10 m) scales (Beckett and Webster 1971) and thus deciding on a 'point of truth' validation is complex (Bishop et al. 2015). Key considerations include:

- identifying the appropriate map scale to address management requirements and avoid unnecessary complexity
- applying the appropriate map attribution to balance the trade-off between apparent uniformity within map units (or pixels) and precision of description to suit likely uses of the map (Shao et al. 2019)
- determining appropriate validation data and their scale of applicability – typically, point observations that are precisely defined are used, but are not necessarily most appropriate; a range of spatial supports from point-scale to 1 km blocks should be used to test map validity at a range of scales (Bishop et al. 2015)

We tested the quality of mapped information developed during this project by comparing the spatial accuracy and precision of the PHADI maps to the regional rangelands survey mapping. First, we compared how well each map could correctly predict soil type and land capability using 968 soil observations, which were classified to WASG by previous surveyors and assigned land capability ratings according to section 2.3. These geolocated classifications were overlain on each map type to compare the overall accuracy of DSMART to rangelands maps. It is important to understand that this method provides a fair comparison of map types but cannot provide independent assessment of map reliability, since the observations may not precisely define soil types or be representative of the entire region. This is addressed by using an independent dataset later in this section.

Considering the WASG classifications, the 'area averaged' DSMART mapping correctly predicted the dominant WASG 33% of the time, whereas the rangelands mapping only correctly predicted the dominant WASG 26% of the time (Figure 2.5). The area averaged test grouped the 9 pixels of the PHADI mapping around the soil observation point (the pixel that the point apparently resides in and the 8 surrounding pixels). This test accounted for geolocation inaccuracies in the point observation data and ascertained a reliable 'local area dominant WASG', averaged from 9 pixels rather than rely on false precision of a single pixel value. The test also provided a compromise between assessing at-point prediction and broader spatial support, as discussed by Bishop et al. (2015).

Similar testing of maps versus point observations classified by land capability returned a similar improvement in overall accuracy of DSMART over rangelands: DSMART correctly predicted land capability rating 65% of the time, whereas rangeland mapping correctly predicted land capability rating 55% of the time (Figure 2.5).

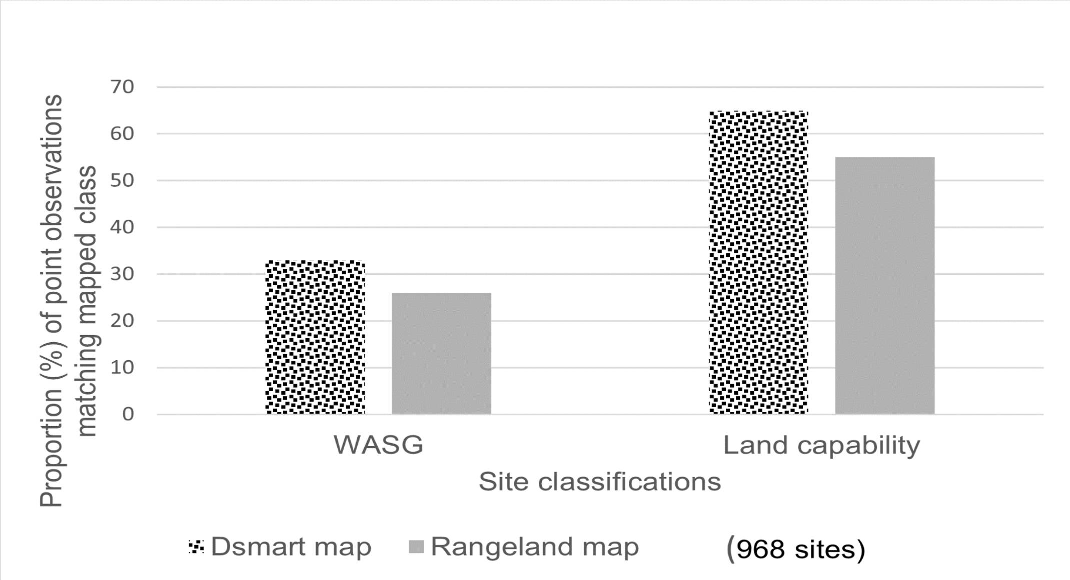


Figure 2.5: Comparison of the reliability of traditional mapping to the DSMART mapping

This initial comparison of mapping cannot avoid issues of autocorrelation generated by using original site data collected during the rangelands mapping, which also influences the DSMART mapping. To overcome this issue and to improve data for future mapping efforts, new observations were collected between July and October 2017 as independent test data. The new data has more reliable geolocation, improves the overall observation density and removes bias towards rangeland production locations. The DSMART maps and rangelands map were evaluated using a similar method to the initial assessment but with the new independent sites to avoid autocorrelation.

We used Latin hypercube sampling (McKay et al. 1979; Helton and Davis 2003) to select 360 new sites within 200 m of accessible roads and tracks that spanned the variability of the PHADI area. Latin hypercube sampling collates all relevant environmental data (such as topographic variability, geology, climate and vegetation communities) and identifies a statistically valid sample set that encompasses the combined variability. Not all potential sites could be accessed, so some additional sites were opportunistically added during field work, resulting in 383 new sites classified by WASGs. The sampling method identified sites that represent the various combinations of environmental raster datasets that cover the area. The rationale was that these datasets broadly represent surrogates for processes of soil formation and distribution, so the point locations should represent the suite of soils present in the area at a representative density. This is the current best practice sampling strategy for techniques to model soil distribution using these environmental rasters, so the additional sites constitute a valuable dataset.

The DSMART maps overall are of similar reliability to the rangelands mapping in terms of the WASGs identified but DSMART maps distinguish more detailed spatial patterns. Visual assessment identifies realistic patterns, such as breaks in slope, drainage courses and parent material differences, although they are not always easy to interpret. The DSMART maps provide a specific WASG, soil class or irrigation class, at a particular site, which at an ‘area averaged’ scale over 9 pixels is equivalent to about

7.3 ha in area. In contrast, the traditional mapping only provides a proportional estimation of WASG, soil class or land suitability over a larger area – each map unit contains a number of soil types whose area in the map unit is denoted by percentage. For example, the recommended minimum polygon area for a traditional map produced at 1:100,000 scale is 20 ha. Most rangelands polygons are much larger than 20 ha. This subjective comparison of improved scale from a traditional 1:100,000 map to DSMART indicates a nominal doubling of accuracy (20 ha to 7.3 ha) and greater spatial complexity.

The final column in Table 2.4 highlights the improvement in spatial complexity. The difference in 'percentage consistent' between rangelands mapping and DSMART at the WASG level represents the spatial similarity between the products – 100 means 'identical' and 0 means 'infinitely more detailed'. A value of 58 indicates that DSMART has almost twice the spatial detail as the rangelands mapping at the WASG level. The difference is less noticeable at the irrigation suitability level – a value of 72 – which is expected because fewer classes of map units mean the map will inevitably be more similar.

Our subjective and objective assessments indicate that DSMART mapping significantly improves overall precision provides no information about the reliability of the maps in correctly assigning WASG and irrigation suitability. To assess this, we compared the maps to the new observations at their specific location (labelled 'precise' in Table 2.4) and in the surrounding neighbourhood (labelled 'buffer' in Table 2.4 – 180 m radius or about 10 ha in area) to see if fine and coarse patterns in the map products corresponded with the site observations. Table 2.4 summarises these results.

Table 2.4: Percentage of sites correctly predicted by various map types

	Map type				Spatial similarity index of rangelands map to DSMART map
Classes of sites	DSMART precise	DSMART 180 m buffer	Rangelands map precise	Rangelands map 180 m buffer	
WASGs (40+ classes)	25%	39%	24%	26%	58
Suitability for irrigation (3 classes)	59%	74%	59%	63%	72

Note: Number of sites used in analysis = 393.

In this assessment, DSMART at the precise scale and rangeland mapping at both precise and buffer scale are equivalent and were equally poor at predicting WASG (all clustering at 24–26% correct), as none match the historical or newly collected site data well. We attribute this to misclassification of WASGs in rangeland map unit attribution and at legacy sites, which also affects the DSMART attribution, and the factors that Bishop et al (2015) discussed about local variability and validating at different spatial supports. It is unreasonable to expect DSMART to significantly improve predictions since it uses attribute information embedded in the original polygon mapping for prediction. Identifying this problem has been a significant benefit of this work. As a result, quality control measures have been designed and conducted across all the site

data. The upgraded data will be available for all future projects. The DSMART and rangelands' maps were also equally precise in their ability to correctly predict irrigation suitability, ranging in a cluster from 59% to 63% correct.

In contrast, a second comparison between the site value and all pixel values in a 180 m radius on the DSMART maps and the dominant soil class assigned to each rangelands survey map unit identified a marked increase in accuracy of DSMART over rangelands mapping (see Table 2.4 – DSMART buffer). In this comparison, DSMART improved the correct identification of WASGs from 24−26% up to 39% of the time, and it improved the ability to correctly predict irrigation suitability from 59−63% up to 74% of the time. This meaningfully improves the utility of the new DSMART mapping over the older rangelands mapping to identify areas worthy of further assessment for irrigation development.

2.7 Concluding comments on upscaling mapping

In hindsight, the best method to compare the reliability and accuracy of DSMART to traditional mapping products would be to target areas of difference between the 2 mapped products and identify the actual soil during field investigations. Doing so would compare a realistic subset of the soil population to both models and thus determine where these models vary and which one more closely matched reality more often.

A significant outcome of this work is a thorough assessment of soil information quality in the Pilbara and the initiation of a quality control process to support future analyses and inference of soil-landscape information. DSMART products illustrate the potential for incorporating remote sensing datasets into an automated or semi-automated soil mapping system. The reliability of the DSMART maps largely depends on the veracity of the original polygon attribution. In this case, DSMART is reliable in that it reflects the attribution of the polygons it derives from. However, the final maps are not very accurate when measured against the newly collected soil observations because these observations did not match the soil types described by the surveyors as present in map polygons. Data quality issues that affect the accuracy of these products and that require attention include the map unit attribution, consistency in applying WASG classifications, map unit edge matching and data entry error checking. Since completing the DSMART data products in 2015, new approaches for modelling have been developed and a wider range of better resolution environmental rasters have become available. Once quality control of the input soil data is complete, it would be prudent to conduct new modelling to improve the reliability of the irrigation potential mapping.

New DSM techniques use all available site data rather than the surveyors' post-survey estimation of soil types attributed to the polygon data. An early demonstration of these DSM techniques in the Fitzroy catchment indicates a more reliable prediction of the WASG and horticulture potential. The Fitzroy catchment DSM was validated independently, using unbiased data collected after the main survey was complete, to show that soil generic groups were correctly predicted 48% of the time (Thomas et al. 2018). These results appear more reliable than the predictions achieved with DSMART, although it is impossible to provide definitive statements because the Fitzroy catchment is not directly comparable to the whole Pilbara region.

3 Water resources

Previous studies reviewed the existing data and information to assess Pilbara water resources at a regional scale (Skidmore 1996; Johnson and Wright 2001; Haig 2009; McFarlane 2015). The PHADI conducted the first audit of potential water resources in the Pilbara to specifically identify those that could support irrigated agriculture.

Available water resource information focuses on areas that have undergone specific investigations, mostly for public water supplies or mine dewatering, and very little detailed information is available for the broader region.

Most Pilbara watercourses are ephemeral and remain dry for long periods each year. Streamflow in the Pilbara results from large, highly seasonal and variable rainfall events, which mostly result from tropical thunderstorms and cyclones that occur during summer and autumn (December to May).

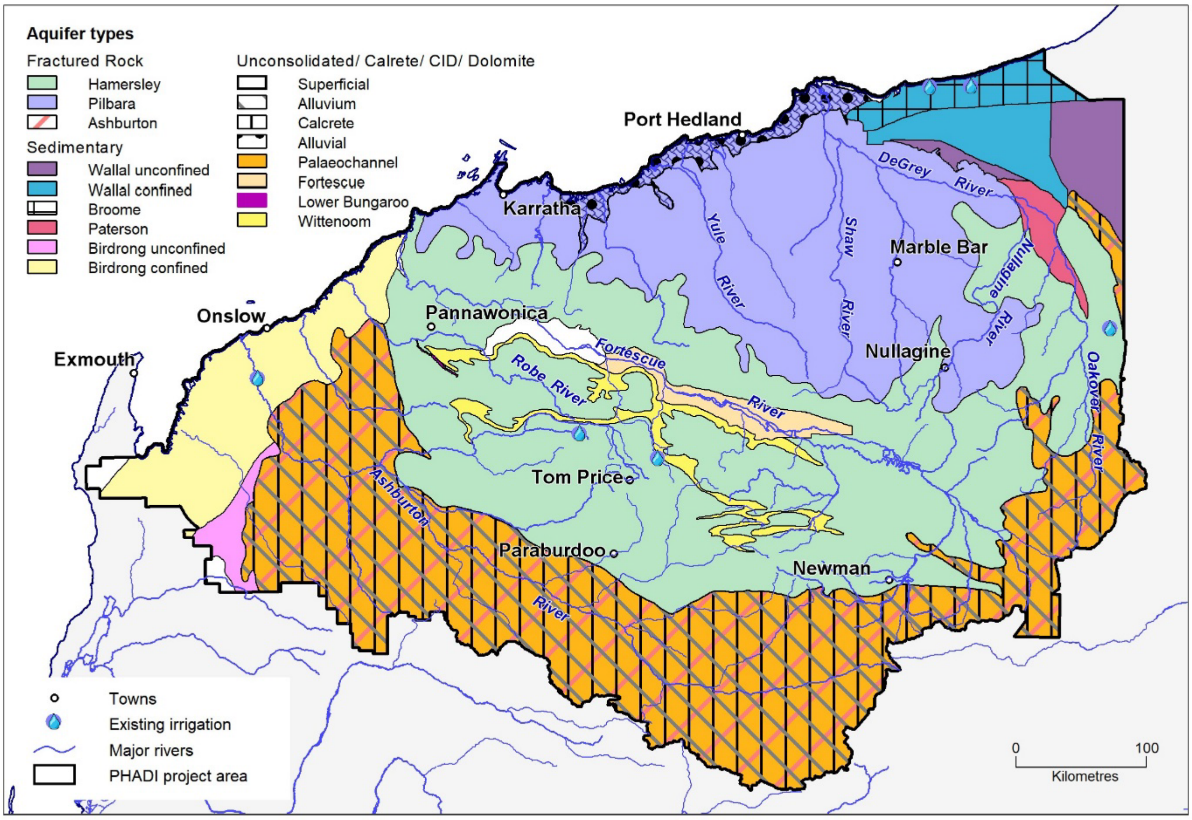
The main water source in the Pilbara is groundwater, which is used for domestic, industrial and agricultural purposes. Most aquifers are recharged by water infiltrating through streambeds, except in the riverless Great Sandy Desert where recharge occurs as water infiltrates through the permeable sandy soils. Groundwater recharge varies annually and depends on the frequency, duration and volume of surface flows, aquifer permeability and available storage.

The Pilbara is a proclaimed area under the *Rights in Water and Irrigation Act 1914* (WA) (DoW 2013). The PHADI area encompasses all the Pilbara, the West Canning subarea in the western portion of the Canning–Kimberley and the north-eastern portion of the East Murchison groundwater allocation areas. Water resources are allocated, licensed and managed by the Department of Water and Environmental Regulation (DWER). In 2016, 80 GL of water was licensed to be used annually for irrigated agriculture on 3,400 ha of land at 6 locations. About half (40 GL) of this water is directly licensed for extraction and use for irrigated agriculture, with an additional estimated 40 GL of mine dewater surplus (MDS) also being licensed to be used for irrigated agriculture.

3.1 Groundwater

Groundwater occurs throughout the Pilbara in alluvial sedimentary basin and basement rock aquifers (Figure 3.1). The regional watertable mostly reflects the topography. Although the watertable is generally continuous, it is absent in elevated areas with shallow basement rocks (Johnson and Wright 2001). The prospective aquifers are grouped into several types based on their materials (Johnson and Wright 2001; Haig 2009; McFarlane 2015). These aquifer types are:

- unconsolidated sediments and chemically deposited aquifers
  - coastal alluvial
  - river alluvial and valley fill
  - calcrete
  - channel iron deposit (CID)
- sedimentary rock aquifers – West Canning and Carnarvon basins
- karstic dolomite rock aquifers – Wittenoom Formation and Carawine Dolomite
- fractured rock aquifers.

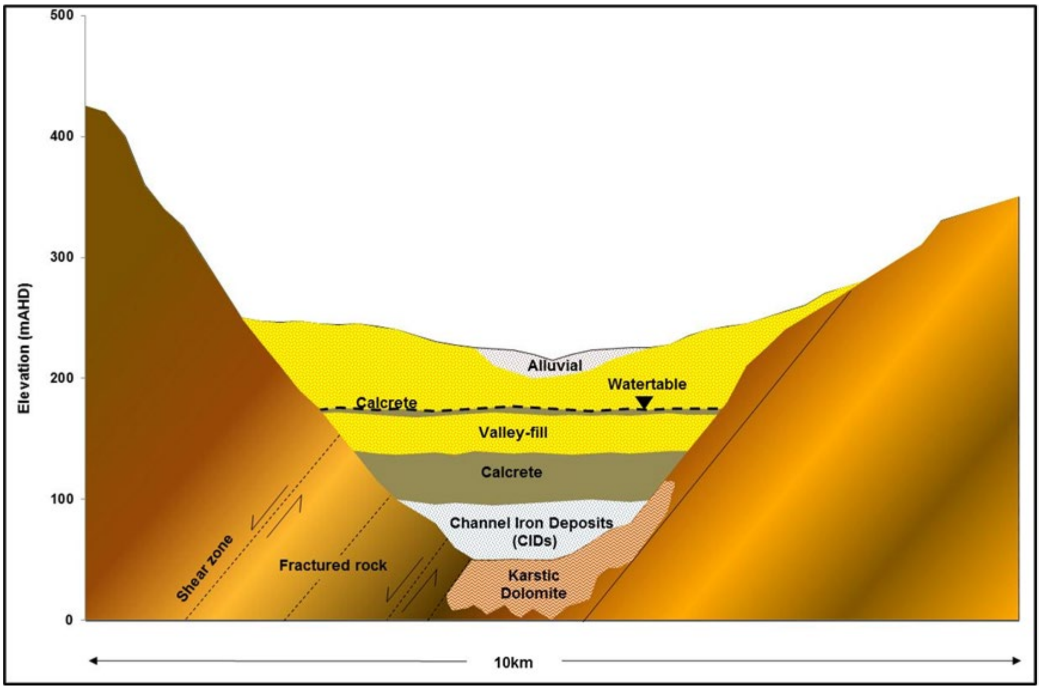


CID = channel iron deposit

Source: adapted from DoW (2013)

Figure 3.1: Spatial distribution of aquifer types and existing irrigation sites

Most aquifer types, except for coastal alluvial and sedimentary rock aquifers, are found in the Hamersley Range – which is mostly south of the Fortescue Valley – and are conceptually illustrated in Figure 3.2.



Source: adapted from McFarlane (2015)

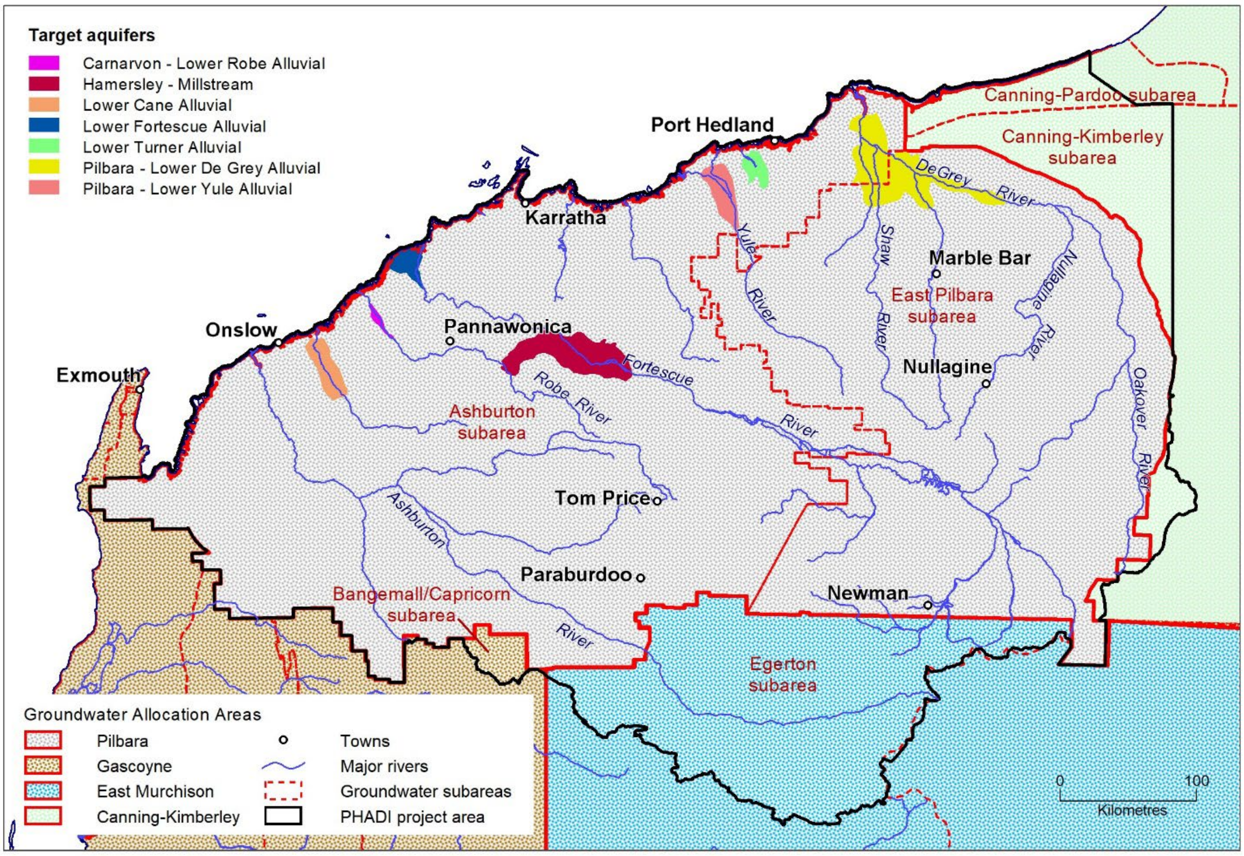
Figure 3.2: Schematic diagram of aquifer types in the Hamersley Range

3.1.1 Target aquifers

DWER has 9 targets aquifers in the Pilbara for existing or potential water supplies (Figure 3.3) for ports and coastal towns (DoW 2013). These aquifers have detailed management plans that define objectives, allocation limits, local policy and performance indicators. Most target aquifers are fully licensed, except for the Lower Robe alluvial aquifer on the coastal plain between Onslow and Karratha and the Broome Sandstone aquifer in the West Canning Basin (WCB) north-east of Port Hedland.

The Lower Robe alluvial aquifer, which is north-east of Onslow on the west side of North West Coastal Highway along the Robe River, has an annual water allocation of up to 5 GL (Figure 3.3). This aquifer is undeveloped because of the distance to existing ports and towns and the economics of transmitting the water, but it has sufficient volume and quality of water to support local agriculture (Haig 2009). The river alluvial aquifer has an estimated storage of 70 GL of groundwater within 10 m of the surface and possible bore yields of 1,000–1,300 kL/d (Commander 1994). Groundwater salinity ranges from 450 mg/L (fresh) near the river to 1,280 mg/L (brackish) on the margins of the alluvial aquifer (Commander 1994).

The WCB is the western part of the second largest sedimentary basin in Australia. It contains multilayer aquifers, with the main aquifer units being the Broome and Wallal sandstones (Haig 2009). The Broome Sandstone aquifer is unconfined and unconformably overlies the predominantly confined Wallal Sandstone aquifer.



Source: DoW (2013)

Figure 3.3: Allocation subareas and target aquifers

The Wallal Sandstone aquifer in the West Canning subarea of the Canning–Kimberley groundwater area is the largest groundwater resource in the Pilbara (Figure 3.1, Figure 3.3). It has an annual allocation of 51 GL, which is fully licensed with a proportion reserved for public water supply (DWER 2018). Pardoo and Wallal Downs pastoral stations have licences for irrigated agriculture, which total 29.5 GL (DWER 2020). Both stations currently irrigate fodder for cattle production.

The Wallal Sandstone aquifer has large artesian flows, with positive piezometric heads more than 30 m above ground level in the northern part of the WCB near the coast (Haig 2009) and records of heads as high as 50 m above ground level in the eastern half (DoW 2012). Wallal Sandstone aquifer is unconfined in its southernmost part where the Broome Sandstone directly overlies Wallal Sandstone without the intervening aquitard of the Jarlemai Siltstone, which is present where the aquifer is confined (Haig 2009). Groundwater salinities in the Wallal Sandstone aquifer are less than 500 mg/L (fresh) in the east but more than 1,000 mg/L (brackish) in the west (DoW 2012).

DoW (now DWER) investigated the future potential of the Wallal Sandstone aquifer to determine if the system could sustainably provide more groundwater (DoW 2016a; DWER 2018). They now better understand the hydrogeology of the WCB and the impacts of abstracting small volumes from the aquifers. However, because of the size of the groundwater resources and the uncertainties of using limited information to predict aquifer responses, the impact of withdrawing larger volumes of groundwater on the aquifer and the values it supports was unable to be adequately predicted (DWER 2018).

The impacts on the aquifers will be further tested by current use (groundwater extraction), enabling DWER to assess how taking the current water allocation limits is affecting the resource and its dependent systems (DWER 2018). This will provide vital information to support the future review of allocation limits for both the Wallal and Broome Sandstone aquifers; this review is planned to be undertaken by DWER as demand increases.

The Broome Sandstone aquifer in the West Canning – Pardoo subarea, which overlies the West Canning subarea, in the Canning–Kimberley groundwater area has an annual water allocation of 10 GL (DWER 2018), with water still available for general licensing (DWER 2020). The Broome Sandstone aquifer is within 5 m of the surface and ranges in thickness from 10 m in the south to 130 m in the north-east (Haig 2009). Depth to groundwater in the south is about 40 m and less than 3 m in the north along the coastal strip. Groundwater salinities in the eastern part of the Broome Sandstone aquifer are less than 1,000 mg/L (marginal) but increase to more than 5,000 mg/L (saline) in the west along the coast (Haig 2009).

3.1.2 Non-target aquifers

Other aquifers in the Pilbara were considered by DoW as non-target. Some have allocation limits and others are allocated limits on a case-by-case basis (DoW 2013). Whether the non-target aquifer has an allocation limit or not, it still may require further investigation to confirm water availability (DoW 2013). A brief outline of the various non-target aquifer types found in the Pilbara, with examples of water supply prospects for irrigated agriculture, is provided below.

River alluvial, valley fill, channel iron deposit and calcrete

River alluvial and deeper palaeovalley aquifers – including valley fill, calcrete and CIDs – are significant localised aquifers (McFarlane 2015). Valley-fill aquifers are present across the Pilbara, typically containing alluvium and colluvium that is potentially hydraulically connected to the underlying calcrete, CIDs and, in places, dolomite or fractured rock aquifers (Johnson and Wright 2001; Haig 2009; McFarlane 2015). The thickness of the valley-fill sediments is highly variable: generally, it is deeper in the valleys of the Hamersley Ranges and thinner north of the Fortescue River Valley in granite greenstone terrain.

In the north-west Hamersley Range, palaeovalley aquifers that contain CIDs were investigated as potential future groundwater sources. CID aquifers generally contain fresh water, have large storages and bores can yield more than 1,500 kL/d (DoW 2016c). The CID and calcrete aquifers underlying valley-fill materials in the Upper Bungaroo, Weelumurra West and Caliwingina Creek systems were considered the most prospective water resources.

Shallow alluvial and valley-fill aquifers associated with a buried palaeovalley adjacent to the De Grey River were investigated as a possible water supply for the proposed Spinifex Ridge mining project. Bore yields of 300–1,000 kL/d and water salinities ranging from 1,000 (brackish) to 3,000 mg/L (saline) were reported (Moly Metals Australia 2007).

Karstic dolomite

The karstic dolomite has high-yielding aquifers that occur in cavernous zones that are well fractured or below the valley-fill sediments. Aquifers are generally absent where the dolomites outcrop at the surface or occur near the valley sides, where the dolomite rock is mostly massive, hard, unfractured and lacks karst development (Skidmore 1996). The karstic dolomite occurs within the Wittenoom Formation in the Hamersley Range and the Carawine Dolomite in the Oakover River Valley and forms important regional aquifers with potential for large water supplies. Bore yields are highly variable and dependent on the cavern and fracture densities, with ranges in the Wittenoom Dolomite of 50–2,000 kL/d and up to 5,500 kL/d in the Carawine Dolomite. There is an annual water allocation of 20 GL from the Wittenoom Formation in the Ashburton subarea with water available for licensing, but only limited water is available for licensing from the 50 GL allocation from the Wittenoom Formation in the East Pilbara subarea (DoW 2013). No allocations are set for the Carawine Dolomite (referred to as the Hamersley fractured rock aquifer in the Pilbara groundwater allocation plan); allocations from this aquifer are set on a case-by-case basis (DoW 2013).

Coastal alluvials

Alluvial aquifers occur across the coastal plain. The size of the aquifer relates to the size of the river and flow regimes. Groundwater salinity of the alluvial aquifers depends on the mean salinity of the river flows (McFarlane 2015). Most of the larger aquifers are targeted for port and town water supplies – the Cane River aquifer supplies Onslow, the Yule River and De Grey River aquifers supply Port Hedland. However, some of the smaller alluvial aquifers of the coastal plain are undeveloped or no longer used and may have water available for abstraction.

Small (1–2 GL/y) potential groundwater resources have been identified along the mid-George, Sherlock and Maitland rivers in the coastal area between Onslow and Port Hedland (Haig 2009). An alluvial aquifer adjacent to the Harding River in Roebourne had a 1 GL allocation in the 1980s for the town water supply before it was replaced by water sourced from the Harding Dam. There is an annual water allocation of 7 GL from the coastal alluvial aquifers in the Ashburton subarea of the Pilbara groundwater area (DoW 2013), most of which is available for general licensing.

Fractured rock

Fractured rock aquifers exist within various basement rock formations across the Pilbara. These aquifers are locally prospective in areas where secondary porosity has developed through intense fracturing, mostly around intrusive quartz veins, major fault zones, bedding planes and joints in the basement rock, or where the weathered profile is thick (Skidmore 1996; DoW 2016c). The basement rocks contain very little groundwater outside the zones where secondary porosity has not developed (Haig 2009).

Exploration drilling on the Sholl Shear Zone near Roebourne identified fracturing in the uppermost 30 m of the shear zone, with groundwater salinity ranging from 650 (marginal) to 1200 mg/L (brackish) and estimated production bore yields ranging from 500 to 1200 kL/d. It was estimated that 3 GL/y of fresh groundwater might be available along the full length (>50 km) of the shear zone (Haig 2009).

Carnarvon Basin

The Carnarvon Basin sediments are generally not prospective for fresh groundwater, as the main aquifer – the Birdrong Sandstone – is only fresh in small areas along the inland basin margin in the east, with groundwater salinity exceeding 10,000 mg/L (highly saline) along the coast in the west (McFarlane 2015).

3.1.3 Mine dewater surplus

Mine dewater surplus (MDS) is the portion of mine dewater not used for mine operations or mitigation of environmental impacts. MDS accounts for more than half the water abstracted for mining, and across the WA resources sector one-quarter of the MDS is discharged off-site (CMEWA 2018). In 2013, more than 120 GL of MDS was reported to have been discharged in the Pilbara (GHD 2015).

In the Pilbara, mining below the watertable, water abstraction and discharge of MDS to the environment have all increased since 2013 and are predicted to increase further (CMEWA 2018). The resources sector in the Pilbara was reported to have the highest volume of water abstraction in the State, with 450 GL being abstracted in 2016; this is predicted to increase to 580 GL by 2024 (CMEWA 2018).

However, because of the variability and duration of supply, previous studies (MWH 2009; McFarlane 2015; GHD 2015) concluded that MDS should not be considered as a sustainable long-term reliable water supply, but an opportunistic source of water that could be used in conjunction with other water resources. To date, irrigated agriculture ventures using MDS have been successfully developed only where the company conducting the dewatering also controls the irrigation development.

MDS is currently used to irrigate Rio Tinto’s Hamersley and Nammuldi agricultural projects near Tom Price (Figure 3.1). MDS from Rio Tinto’s Hamersley Iron Marandoo operation supplies the Hamersley Agricultural Project, which was developed in 2012. It contains 16 centre pivots for cropping that each cover an area of 40–50 ha, and a small 7 ha pivot for native seed production, with a total irrigation area of 850 ha. MDS from Rio Tinto’s Nammuldi Mine supplies the Nammuldi Agricultural Project developed in 2014, which contains 19 centre pivots irrigating 900 ha.

MDS was also used for the PHADI Woodie Woodie pilot site, a 38 ha demonstration and evaluation of irrigated cropping options using surplus dewater from the Consolidated Minerals Woodie Woodie manganese mine, east of Nullagine (Figure 3.1). The trial was seriously compromised when the manganese price dropped and the Woodie Woodie mine went into care and maintenance and dewater pumping ceased, until the Department of Agriculture and Food, Western Australia (DAFWA; now DPIRD) negotiated with the mine's owner to pay for the diesel to keep the pumps running (Wood 2016).

DoW commissioned a desktop study (GHD 2015) to assess the availability and potential use of MDS in the Pilbara for irrigated agriculture. Ten potential irrigation areas were evaluated to establish a shortlist of 4 areas where other groundwater resources in their vicinity were assessed for the potential to augment MDS. Three of the 4 areas – Weeli Wolli – Marillana creeks catchment, Newman and Woodie Woodie – were considered potentially viable and were recommended for further investigation (GHD 2015). In 2017, only the Weeli Wolli – Marillana and Newman areas were discharging or proposed to discharge substantial (>10 GL/y) volumes of MDS.

The Weeli Wolli – Marillana creeks catchment is about 80 km north-west of Newman in the central Pilbara. Mining operations that currently or propose to discharge MDS to these creeks are:

- BHP’s Yandi
- Rio Tinto’s Yandicoogina and Hope Downs 1
- BCI Minerals Limited Iron Valley Project
- Fortescue Metals Group’s proposed Nyidinghu Project.

The reported volumes of MDS discharged to the creeks are cumulative. Each mine site reports the volume of MDS they pump and discharge to the environment. After MDS is discharged, a significant, but unknown, proportion infiltrates and returns to the same aquifer. A proportion of this water is pumped and released to the environment repeatedly by downstream mining operations. Reporting separate volumes of the same water, pumped repeatedly, artificially inflates the water accounting and confounds the estimation of MDS available for other uses.

The current average cumulative MDS discharge to the Weeli Wolli – Marillana creek system is about 45 GL/y, with peaks of up to 70 GL/y as occurred in 2013. Mining below the watertable is expanding in this area, with new mines proposed downstream of current mining areas. Future discharge is estimated to average 100 GL/y with peaks of up to 140 GL/y.

Recent research indicates that, downstream of the confluence with Marillana Creek, groundwater recharge from infiltration through the base of Weeli Wolli Creek accounts

for 65% (130 GL) of the total water discharged (about 220 GL) between 2007 and 2013 (Dogramaci et al. 2015).

The aquifer storage capacity beneath the junction of the Weeli Wolli Creek and Fortescue River Valley is suggested to be many times larger than 600 GL (Dogramaci et al. 2015) and it may be possible that this aquifer system could yield sufficient water to augment the supply to a potential irrigated agriculture area (GHD 2015).

The potential irrigated agriculture area assessed north of Newman encompassed BHP's Mt Newman and Jimblebar Hub mining operations and Rio Tinto and Hancock Prospecting joint venture Hope Downs 4 Iron Ore Project. Water balance modelling indicated the collective water balance for BHP's eastern Pilbara operations (Jimblebar, Eastern Ridge and Whaleback) will potentially have between 3 and 18 GL/y of MDS to manage over the next 15 years (BHP Billiton 2015). Options assessed to manage this MDS included transferring water to meet operational demands, discharging to Ophthalmia Dam and short-term contingency discharge to local water courses. The latter option includes releasing up to 80 ML/d (7.5 GL/y) of water from the Ophthalmia Dam to the Fortescue River over the 3 months following the wet season (February to May). The intent is to maximise storage capacity for dewatering surplus in the year following (BHP Billiton 2015).

Additionally, north-west of Newman, Hope Downs 4 iron ore mine discharges MDS to Kalgan Creek and may require dewatering at a maximum rate of 20 GL/y, with up to 17.5 GL/y discharged to the creek. This discharge may provide an opportunity to supplement water discharged from Ophthalmia Dam and be used for irrigated agriculture.

Given the extensive area of potentially suitable soils for irrigated agriculture north of Newman, proximity to Newman and existing infrastructure, and the reported large MDS from multiple mine sites, the Newman area was considered as potentially viable for irrigated agriculture development and recommended for further investigation (GHD 2015).

The main challenge of using MDS to support irrigated agriculture is to minimise the variability of supply by determining and using effective methods to capture, transmit and store the water.

3.2 Surface water

The surface water resources in the Pilbara and their development potential, including preliminary evaluations of potential dam sites have been assessed by Sadler et al. (1974), Wark (1996), WRC (1996), Petheram et al. (2014) and McFarlane (2015).

The Pilbara encompasses 5 main Australian Water Resource Council river basins: Ashburton River, Onslow Coast, Fortescue River, Port Hedland Coast, De Grey River and parts of the Great Sandy Desert where the WCB is located (Figure 3.4).

The main rivers generally have well-defined courses and are ephemeral. They are dry for long periods each year, with streamflow generated from large, highly seasonal and variable rainfall events. Annual streamflow is highly variable (Figure 3.5), with most streamflow occurring between January and March when tropical cyclones or thunderstorms wet catchments. Mean annual flows are not representative because they

are skewed by irregular large flow events; median annual flow is more representative of the annual flow of Pilbara rivers (Ruprecht and Ivanescu 2000).

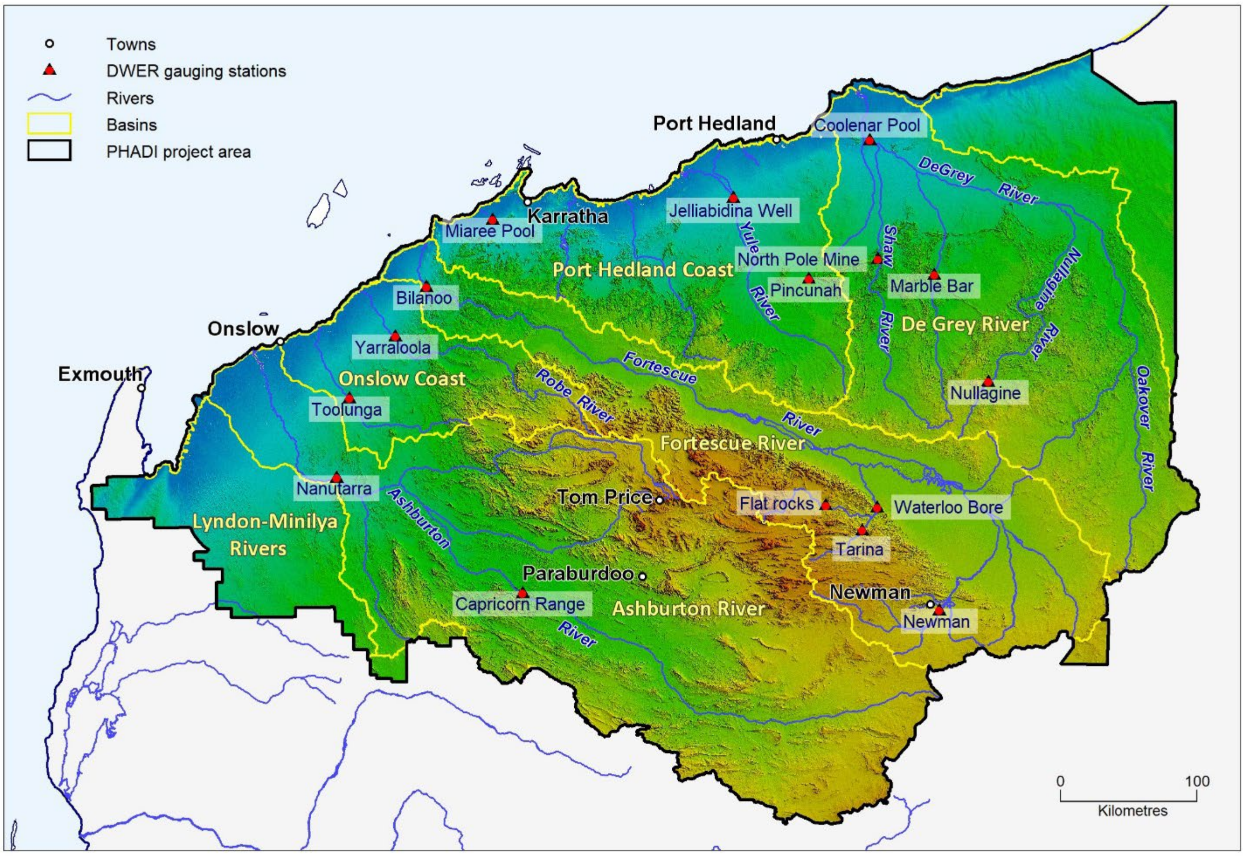
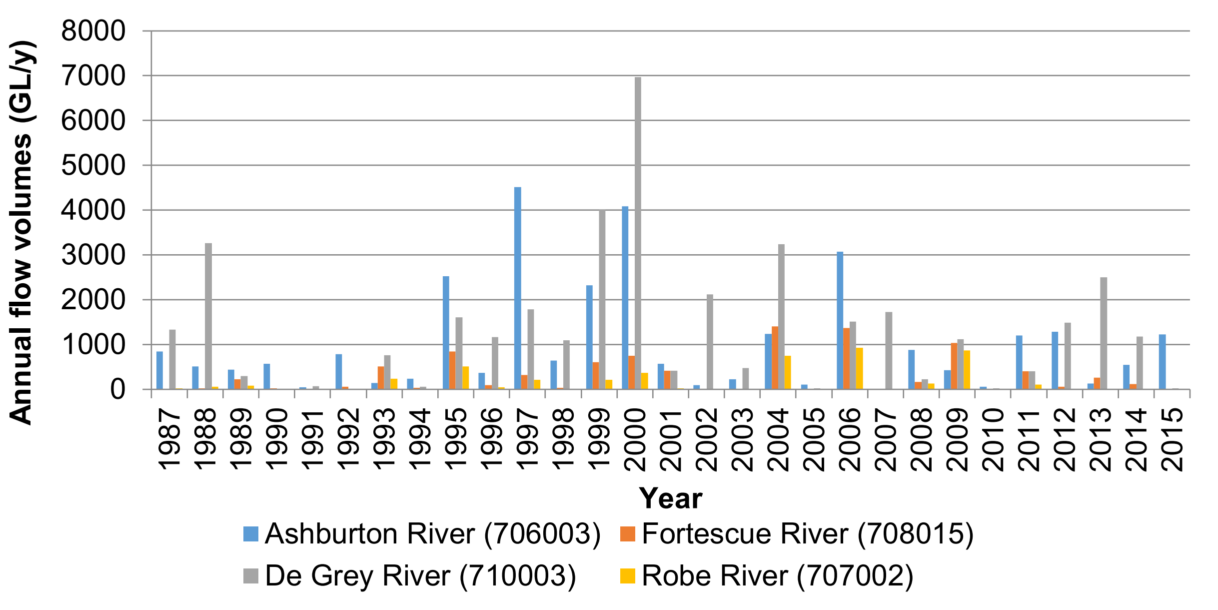


Figure 3.4: River basins and operational gauging stations



Note: Annual flow was derived from select gauges listed in Table 3.1.

Source: DoW (2016b)

Figure 3.5: Annual flows from selected stream gauges, 1987–2015

De Grey River has the highest annual streamflow volume in the Pilbara (Table 3.1). The divertible yield estimated for the De Grey River Basin was at least 4 times higher than any other river basin in the region (WRC 1996; NHT and NLWRA 2001). The estimated divertible yield of 120 GL/y equates to 15% of the median annual flow and would allow more than 80% for environmental flows. However, analysis of daily streamflow data is needed to understand flow characteristics and determine appropriate extraction limits.

Table 3.1: Mean and median annual flows at operational stream gauges

River or creek	Stream gauge and site number	Catchment area (ha)	Annual flow (GL/y)	
			Mean	Median
Ashburton River	Nanutarra (706003)	7,138,700	790	440
	Capricorn Range (706209)	4,309,800	400	270
Robe River	Yarraloola (707002)	710,400	120	15
Cane River	Toolunga (707005)	232,600	75	60
Marillana Creek	Flat Rocks (708001)	137,000	10	5
Fortescue River	Bilanoo (708015)	1,840,100	300	90
	Newman (708011)	282,200	50	30
Weeli Wolli Creek	Waterloo Bore (708013)	399,100	30	5
	Tarina (708014)	151,200	25	10
Sherlock River	Coonanarrina Pool (709003)	458,100	150	15
Maitland River	Miaree Pool (709004)	194,800	60	15
Yule River	Jelliabidina Well (7009005)	842,700	300	135
Turner River	Pincunah (709010)	88,500	30	10
De Grey River	Coolenar Pool (710003)	5,000,700	1,150	770
Nullagine River	Nullagine (710004)	87,500	30	15
Coongan River	Marble Bar (710204)	373,600	100	65
Shaw River	North Pole Mine (710229)	650,100	210	105

Currently there are 3 surface water impoundments in the Pilbara–Harding Dam and Ophthalmia Dam constructed in the 1980s, and an ‘upside down or leaky weir’ on the Ashburton River constructed in 2010. Harding Dam was built to supplement water supply from the Millstream aquifer and Ophthalmia Dam was built to augment recharge to the alluvial aquifer that supplies Newman and its surrounding mining operations. The ‘upside down or leaky weir’ on the Ashburton River was built to augment recharge to an alluvial aquifer adjacent to the river and was established to trial managed aquifer recharge (MAR) as a source of water to irrigate livestock fodder crops.

The WRC (1996) desktop study to determine potential dam sites in the Pilbara evaluated 22 sites to determine wall heights, storage capacity, water surface area and potential annual yields (Table 3.2).

Table 3.2: Potential dam sites evaluated by WRC (1996)

River	Potential dam site (DS)	Annual average stream flow (GL)	Dam wall height (m)	Storage capacity (GL)	Surface area (ha)	Potential annual yield (GL/y)
Ashburton	Ashburton River (DS340)	320	32	1120	19,250	37
Robe	Robe River (DS124)	27	20	108	18,300	4
Robe	Robe River (DS154)	18	31	72	5,300	9
Robe	Kumina Creek (DS20)	2.5	27	13	100	<1
Cane	Cane River (DS74)	62	10	110	4,500	6
Cane	Cane River (DS114)	18	24	90	2,300	3
Fortescue	Bullinnarwa (DS48)	200	39	672	6,190	54
Fortescue	Booyeemala (DS123)	147	35	210	1,840	42
Yule	Kangan Pool (DS95)	184	18	644	9,620	8
Sherlock	Kangan Pool (DS48)	172	20	602	12,640	8
Sherlock	Nunyerry Creek (DS9)	10	76	820	3,300	5
Maitland	Munni Munni Creek (DS15)	20	27	80	1,510	1.5
Shaw	Shaw North Pole (DS88)	180	40	522	5,400	80
Coongan	Doolena Gap (DS54)	130	30	240	3,000	15
Coongan	Marble Bar (DS85)	110	50	440	4,400	26
De Grey	Yarrie Station (DS158)	600	32	2400	25,000	120–200
Oakover	Oakover (DS102)	260	30	950	11,000	20–50
Oakover	Oakover (DS145)	120	30	590	7,500	5–25
Nullagine	Nullagine (DS40)	125	30	200	3,500	0–20
Nullagine	Nullagine (DS56)	115	23	460	4,930	25–40
Nullagine	Nullagine (DS108)	90	36	360	3,570	20–35
Nullagine	Nullagine (DS142)	80	30	410	3,500	15–30

In 2014, the Office of Northern Australia commissioned the CSIRO to conduct a rapid appraisal, using the DamSite model, to identify catchments with potential surface water storage sites near large contiguous areas of soils suitable for irrigated agriculture. The study identified several low yielding (50–150 GL/y) potential dam sites, with yields being limited by low and highly variable inflows to potential reservoirs and high net evaporation rates (Petheram et al. 2014). One site on the Shaw River had previously been considered as one of the most prospective sites in the Pilbara and was investigated by the Public Works Department in 1970s and the Water Authority in 1990s.

Potential dam sites identified in the Pilbara are unlikely to be developed because of concerns about the reliability of surface water storage and the environmental and cultural heritage impacts (Haig 2009). Surface storage in the Pilbara has limited effectiveness because of poor reliability of streamflows, high evaporation rates and turbidity caused by diurnal temperature changes (DoW 2014).

3.2.1 Managed aquifer recharge

Previous surface water investigations in the Pilbara conclude that surface water resources should only be developed in conjunction with a groundwater supply (Haig 2009). MAR is the purposeful recharge of an aquifer under controlled conditions to store water for later abstraction. It is an alternative option for capturing and storing surface water flows.

DWER supports MAR activities that have environmental, social, or economic benefits and that maximise the use of the state's water resources (DWER 2021a; DWER 2021b). DWER will approve MAR schemes if the recharge and recovery operations will not adversely affect the groundwater system, the environment, existing groundwater users (for example, through changes in water quality or quantity), or aquifer integrity (DWER 2021a).

A rudimentary estimate of potential extractable or divertible yields for MAR, based on 10% of the median annual streamflow and assuming half could be recovered and used, indicates that the Ashburton, De Grey, Shaw and Yule rivers could each yield more than 5 GL/y.

The Minderoo Pastoral Station (MPS), south-west of Onslow, trialled a MAR system in an alluvial aquifer associated with the Ashburton River (Figure 3.1). MPS is licensed to abstract 13.2 GL/y of water for irrigated agriculture (DWER 2020). It is currently investigating the potential presence of other low-salinity groundwater resources further upriver. The upper Ashburton River, upstream of the Capricorn Range stream gauge (706209), was not considered suitable for MAR because the alluvial aquifers are not very thick or conductive and generally hold little prospect for large supplies (McFarlane 2015).

The lower De Grey and Yule rivers alluvial aquifers are already targeted and used for the Port Hedland regional water supply scheme. The Yule River was not considered further because the current allocation of 10.5 GL/y is nearly 10% of the median annual flow. The current allocation of 10 GL/y for the De Grey River alluvial aquifer is less than 2% of the median annual flow, hence the river reach upstream of the water supply aquifer was considered a potential target for further MAR investigations.

The Shaw River, upstream of the Marble Bar Road is also considered a potential target for further MAR investigations because it is not currently targeted for public water supplies and the medium annual flow at the North Pole Mine gauging station (710229) in the upper reaches has one of the 5 highest streamflows in the Pilbara, with a median annual flow of 105 GL/y (Table 3.1).

Further investigation of MAR opportunities is required and will need to consider the feasibility of harnessing surface water flows and discharged MDS, and the effect of recharging an aquifer on hydrology, hydrogeology and ecology.

4 Prospective target areas for further investigation

Our preliminary land and water resource assessment identified 10 locations in the Pilbara worthy of further investigation to determine the feasibility of developing medium- to large-scale irrigated agriculture areas. Potential water resources could deliver a further 100–120 GL/y over 10 sites, equating to about 5,000–12,000 ha of irrigated land, if those water and land resources can be validated (Figure 4.1, Table 4.1).

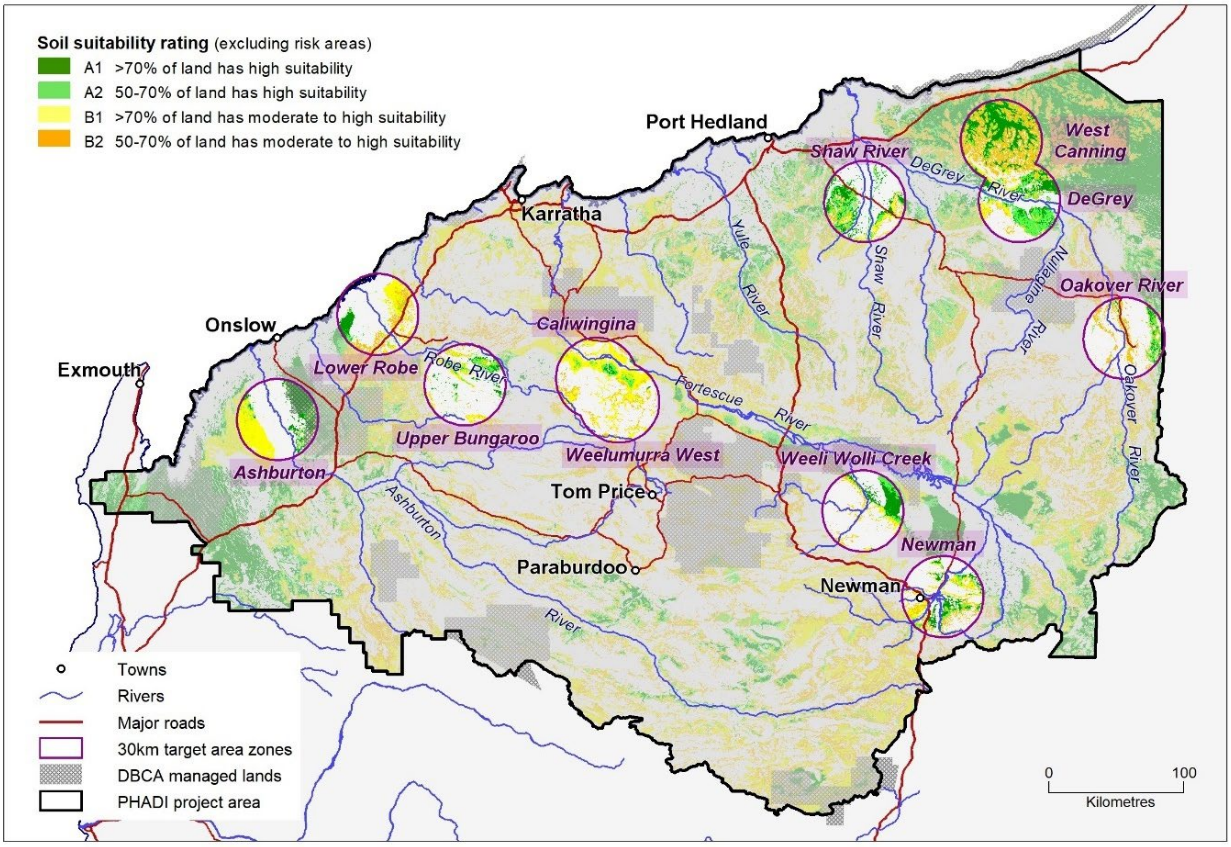


Figure 4.1: Target areas for further investigation

The area assessment for sites with water sources described as ‘aquifer’ or ‘MDS’ assumes that water is extracted from a point source. The area assessment for water sources from MAR was conducted along the river reach where MAR is considered potentially feasible. All ‘land potential’ areas were calculated using these constraints:

- A 30 km buffer around the point source or river reach – the maximum distance water can feasibly be transported (GHD 2015).
- Only areas level with and downslope of the ground-level abstraction point (that is, highest possible water source) were considered feasible for development. The high cost of pumping water renders it unlikely that proponents will pump upslope after pumping from depth to access groundwater.
- Only areas contiguous with the ground-level abstraction point are considered – proponents are unlikely to pump over catchment divides to irrigate remote land that is otherwise capable of development.
- Assessment areas were limited to the highest land potential class (A1).

- The total areas of class A1 land were multiplied by 0.7 to recognise that mapping high potential land at this scale includes some land that may not meet this definition (see Section 2.3).

The easiest sites to develop will be those where the area of land with high irrigation potential is more extensive than the volume of water supply needed to irrigate it – that is, an excess of good land over water supply (Table 4.1). This excess facilitates irrigation development on the best land at the lowest cost, with the least environmental and production constraints, and will result in production that requires less management intervention to prevent degradation. We introduce the concept of ‘land excess factor’ to identify these areas (Table 4.1). We assume that 1 GL of water can irrigate 100 ha per year, a value that depends on crop type, irrigation method, water quality, and other factors that should be identified during more detailed irrigation suitability assessments. This value lies at the most efficient end of the water use spectrum, which ranges from 10 to 20 ML/ha/y. It is therefore the most conservative value when considering how much good land is required to use the water potentially available for irrigation. We multiply the potential water supply (in GL/y) by 100 to calculate the maximum irrigation development area. We then divide the total area of high potential land within 30 km of the water resource by this value to generate the land excess factor.

Oakover River Valley has an estimated water supply that just meets the irrigation requirement for the entire area of high potential land and Caliwingina/Weelumurra only has a land excess factor of 2 – that is, their potential water supply is close to matching the likely area of high potential. For these 2 areas, we include the area of class A2 land suited to irrigation because although this land is more variable, it contains soil suited to irrigation. Further reconnaissance of these areas is needed, given the uncertain nature of land potential mapping identified when testing the reliability of the maps.

Other opportunities, which are not included in this assessment, exist for smaller developments that are based on water supplies of less than 5 GL/y. For example, the 1 GL/y water resource in the Harding River alluvial aquifer near Roebourne could be used for irrigated agriculture, along with numerous opportunities for using the different aquifer types found across the Pilbara, particularly in conjunction with MAR.

The WASGs identified in Table 4.1 are described in more detail in Table 4.2 and in Schoknecht and Pathan (2013) to provide a general assessment of their potential for agriculture.

Table 4.1: Prospective target areas for further investigation and detailed capability assessment

Site name	Water supply source	Potential annual water supply (GL)	High potential land within 30 km of water source (ha)	Land excess factor for water available	WASGs present on high potential land
Ashburton River	MAR	20 [a]	75,000	37	Red deep sandy duplex; Red deep sand; Minor Red loamy earth
Caliwingina / Weelumurra	CID aquifers	5–10 [b]	2,000 (+ 8,500 ha class A2 land not included in calculations)	2	Red loamy earth (may be patchy)
De Grey River	MAR	30 [a]	36,000	12	Red deep sandy duplex; Red loamy earth; Minor Red deep sand
Lower Robe River	Coastal river alluvial 'target' aquifer	5	10,000	20	Red deep sandy duplex; Minor Red deep sand
Newman	MDS discharges to Ophthalmia Dam and Kalgan Creek	5–10 [b]	19,000	19	Red deep sand; Red loamy earth
Oakover River Valley	Carawine Dolomite fractured rock aquifer	5+ [b]	500 (+ 1,500 ha class A2 land not included in calculations)	1	Red deep sand; Minor Red loamy earth
Shaw River	MAR	5 [a]	15,000	30	Red deep sandy duplex; Red loamy earth
Upper Bungaroo	CID aquifer	10	7,000	7	Red loamy earth
Weeli Wolli Creek	MDS discharge to Weeli Wolli Creek	5–15 [b]	20,000	13	Red loamy earth; Red deep sand
West Canning[c]	Broome Sandstone 'target' aquifer	10	not assessed	not assessed	Red deep sand

CID = channel iron deposit; MAR = managed aquifer recharge; MDS = mine dewater surplus

a MAR water supply estimate is based on about 5% of median annual streamflows.

b Water supply estimate is a range to account for variability of supply.

c The West Canning Basin is mostly outside the PHADI area, but the aquifer intrudes the project area.

Table 4.2: Key characteristics of WASGs that are potentially capable of supporting irrigated agriculture

Characteristic	WASG				
	Red deep sand	Red sandy earth	Red loamy earth	Red deep sandy duplex	Red deep loamy duplex
Surface texture (0–30 cm)	Sand	Sand	Loam	Sand	Loam
Subsurface texture (30–80 cm)	Sand	Sand–loam	Loam	Clay (by 80 cm)	Clay (by 80 cm)
Subsoil texture >80 cm	Sand–loam	Loam	Loam–clay	Clay	Clay
Indicative plant-available water in top metre	63 mm	77 mm	85 mm	80 mm	88 mm
Relative nutrient-holding capacity (top 30 cm)	Low	Moderate	High	Moderate	High
Indicative soil depth – annual species	Deep	Deep	Deep	Moderate	Moderate
Indicative soil depth – perennial species	Deep	Deep	Deep	Moderate	Deep

5 Other considerations for detailed assessments

5.1 Social, environmental and economic considerations

To date, land and water assessments have been limited to biophysical assessments of resources from the point of view of agricultural intensification and development. Due diligence requires government and proponents to consider a suite of additional factors that may alter the feasibility of development. This task is difficult to achieve at such a broad, regional level, but at the least, consideration must be given to key information available in the public domain.

The key considerations:

Social

- location of towns to provide supporting infrastructure and labour access
- location of known Aboriginal cultural heritage sites of significance
- location of historic heritage places
- land reserved for infrastructure, such as railways, roads, power lines, pipelines
- location of public drinking water supply protection areas
- native title claim boundaries

Economic

- land tenure and use
- mining tenements and mineral deposits that could be mined in the future
- transport and energy infrastructure

Environmental

- national parks and conservation reserves
- environmentally sensitive areas and management zones
- declared rare, threatened, or priority species and ecological communities
- groundwater dependent ecosystems

5.2 Further investigation requirements

All prospective sites will require land surveys at scales suitable to validate, verify and map the occurrence of suitable soils and to determine land suitability to support specific irrigated agriculture developments.

Various environmental impact, cultural assessments, pastoral diversification permits and native title claim determinations may be required for development proposals at any of the target sites.

Each site will also need to confirm the information required for:

- a ‘5C licence water entitlement’ to determine the level (H1–H3) of hydrogeological investigations (DWER n.d.)
- the Commissioner of Soil and Land Conservation to assess the risk of land degradation.

The specific hydrological investigations required at target sites are variable and depend on the system complexity and breadth of previous studies (Table 5.1). Extensive field-based hydrogeological and geophysical investigations have occurred on all the target aquifers to determine allocation limits and operating strategies. They have also been conducted on all mine sites that require dewatering as part of the current approval process for water and environmental licensing to abstract and discharge water. The MDS sites will also require analysis of the long-term water balances to determine the variability of supply during mining life and the sustainable abstraction yields after mining ceases.

Only desktop assessments were conducted on most other aquifers; substantial hydrogeological investigations will be required to further assess appropriate abstraction limits and determine potential impacts.

River reaches with potential for multiple MAR systems require investigations that align with DWER's MAR operational policy (DWER 2021a). Proponents of MAR schemes will need to identify and quantify the impacts of recharge and recovery operations on the groundwater system, the environment and existing groundwater users.

Table 5.1: Level of hydrological investigation at target sites

Site name	Water supply source	Level of investigation
Ashburton River	MAR	desktop
Caliwingina and Weelumurra	CID aquifers	desktop
De Grey River	MAR	desktop
Lower Robe River	coastal river alluvial 'target' aquifer	detailed
Newman	MDS discharges to Ophthalmia Dam and Kalgan Creek	basic
Oakover River Valley	Carawine Dolomite fractured rock aquifer	desktop
Shaw River	MAR	desktop
Upper Bungaroo	CID aquifer	desktop
Weeli Wolli Creek	MDS discharge to Weeli Wolli Creek	detailed
West Canning	Broome Sandstone 'target' aquifer	detailed

CID = channel iron deposit; MAR = managed aquifer recharge; MDS = mine dewater surplus

6 Conclusion

This study is the first to investigate the potential for irrigated agriculture across the entire Pilbara region. We enhanced traditional rangeland inventory maps to better define the spatial extent of WASGs and land suited to irrigation. This resulted in soil distribution maps about twice as detailed as were previously available. We conducted a comprehensive desktop analysis of water resources present and possibly available for irrigation. We created and sourced hazard maps to excise land unsuited to irrigation because of these 3 main hazards: water erosion, inland flooding and coastal inundation.

We compiled these data and identified a total potential water supply of about 100–120 GL/y, sufficient to irrigate about 5,000–12,000 ha, depending on crop type and management. Ten sites had sufficient water and significant areas of land with high potential for irrigation. We recommend that these sites become the focus of further investigations. For each site, we identified the area of land with high potential for irrigation within 30 km of the foci. Because of extensive previous investigations, there is a high or very high level of knowledge of the water supply for 4 of these 10 sites. Each of these 4 sites has sufficient water to develop irrigation precincts. They also have areas of suitable land more extensive than the water supplies available to irrigate them. This excess facilitates irrigation development on the best land at the lowest cost and with the least environmental and production constraints and will result in production that requires less management intervention to prevent degradation.

The 4 most prospective areas are:

- Lower Robe River – estimated 5 GL/y of water available and 10,000 ha potentially suited to irrigation
- Newman – estimated 5–10 GL/y of water available and 19,000 ha potentially suited to irrigation
- Weeli Wolli Creek – estimated 5–15 GL/y of water available and 20,000 ha potentially suited to irrigation
- West Canning – an estimated 10 GL/y of water available, although the area potentially suited to irrigation was not determined because most of it is outside the PHADI area and other studies assess the West Canning subarea. Refer to Taylor et al. (2021) for water supply study and Galloway et al. (2018) for soil and land investigations.

We compiled key social, environmental and economic considerations for development, but we did not include these considerations in our regional assessment. However, they will apply to irrigation precinct and property development level investigations.

The information we developed will benefit proponents considering smaller-scale developments. We advise proponents to consider our information in their preparatory stages and be aware of the regulatory processes they must comply with.

Appendix A Landgate description of flood hazard mapping method

METADATA

LANDGATE FLOOD HAZARD CLASSIFICATION

Western Australian Land Information Authority (Landgate)

1. Background to the model

The Landgate Flood Risk Model (FRM) can be considered a "semi-static" model based on a statistical-morphological approach which determines inundation probability. It is derived by using GIS and Image processing techniques making use of two different sources of data:

- Inundated pixels derived from multi-temporal and multispectral remotely sensed images;
- Topographic Data: Digital Elevation Models and stream density.

The probability p_i has been derived by using fuzzy-function fitting for each of the following topographic-morphometric features:

- Distance of each inundated pixel from the water bodies (p_1);
- Difference in elevation between each inundated pixel and the closest water surface (p_2);
- Slope of inundated pixels (p_3);
- Profile convexity of inundated pixels (p_4);

All four probabilities have been used to assign to each pixel the total probability as a value of Flood Risk Index (FHI):

$$FHI = p_1 . p_2 . p_3 . p_4$$

which is subsequently adjusted by a ridges and channels classification.

According to this index, any nominated area can be divided into a semi-qualitative threshold of probability classes, each with a different level of flood risk category, namely: “Extreme”, “High”, “Medium”, “Low” and “Negligible” in Figure 1.

The user can define different thresholds of FHI to determine their own classification categories of hazard.

2. The Landgate Flood Hazard Model - Validation

Most current flood models use estimated Australian Rainfall and Runoff figures derived from the Bureau of Meteorology. This database was last updated in 1987 and due to climate change and incomplete records it is found to be wanting in many respects. Landgate uses the actual flood inundation from its archived inundation data to model flood risk i.e. evidenced based flood modelling as opposed to statistical information.

The following three figures (Figures 1,2 and 3) are provided as a visual demonstration of the strength of the correlation between the model and a substantial flood event.

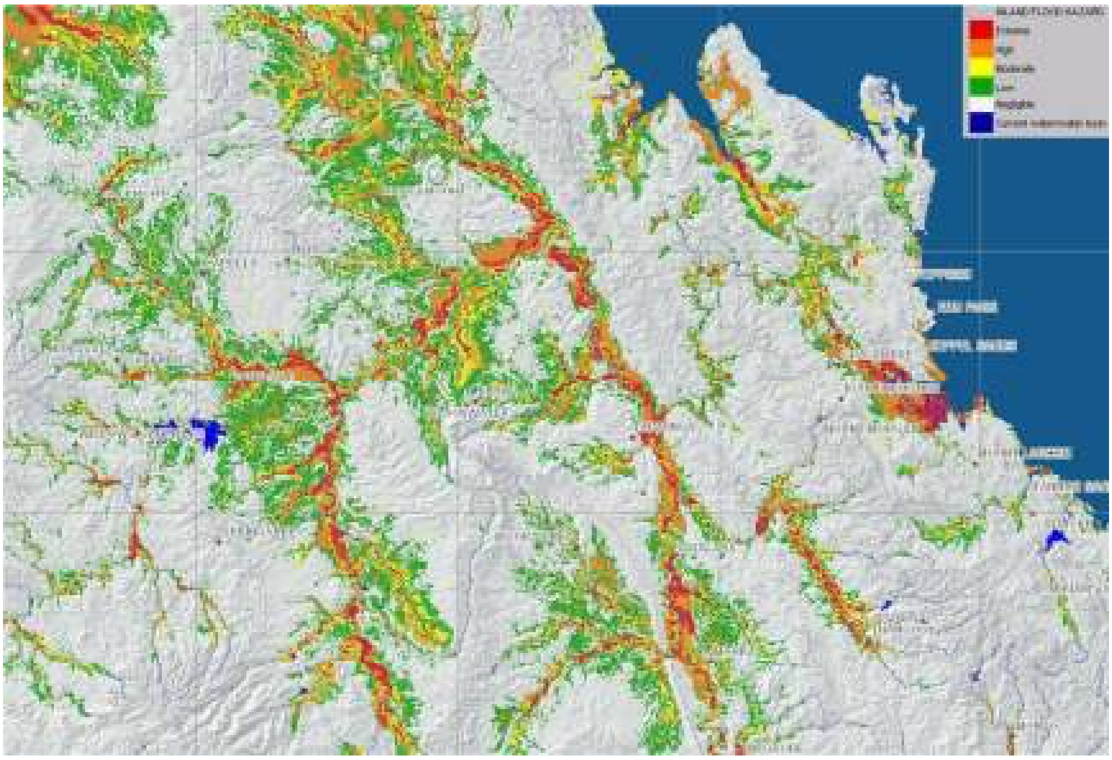


Figure1.

Landgate Flood Hazard Model in the region of Rockhampton, QLD.

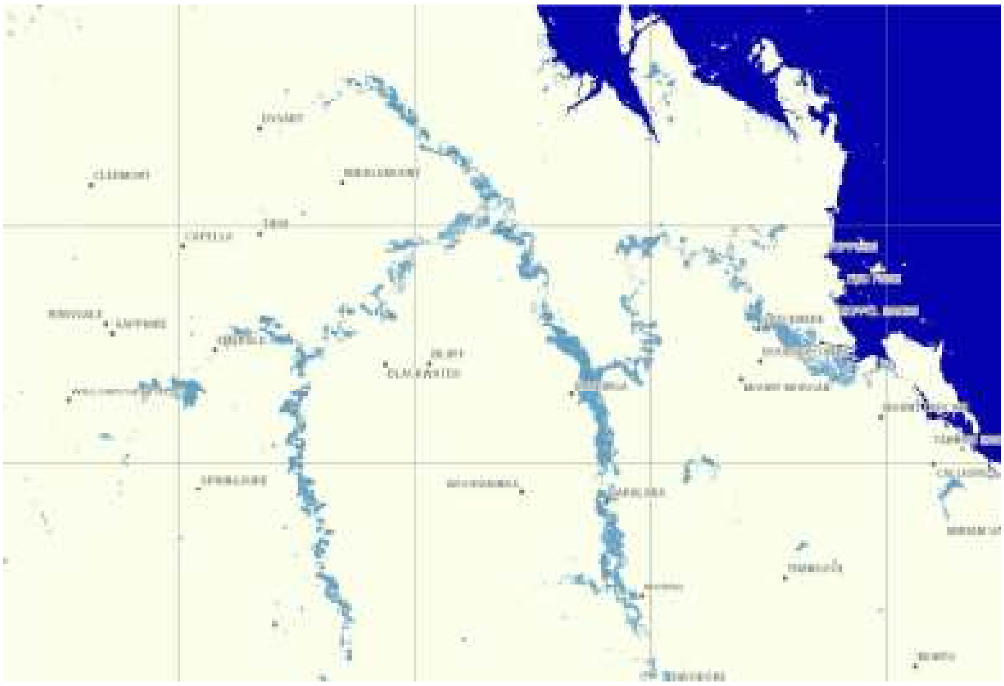


Figure2.

Landgate daily surface water captured from satellite for the Rockhampton Flood events of 2010/2011

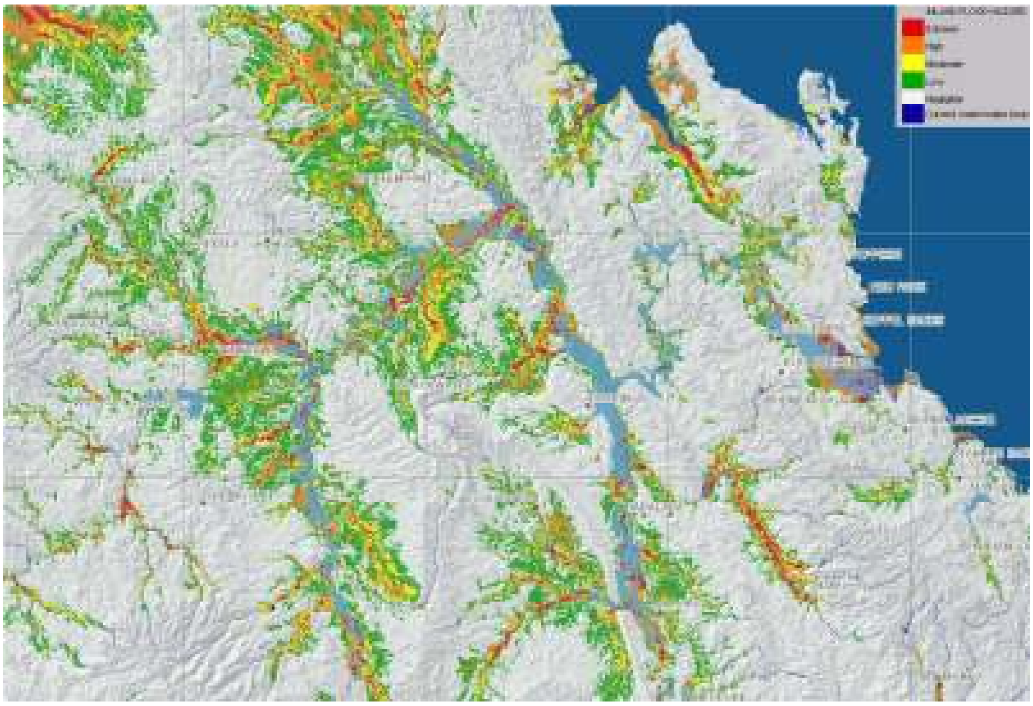


Figure3.

Calibrating and validating the Flood Hazard Model with the satellite captured flood event.

3. The file data

Region of Interest

File name: FHI_CLASSIFIED.TIFF

File type: GEO-TIFF

File data: BYTE

File dims: 9589 (samples) x 6206 (lines) x 3 (band)

File size: 59,560,903 bytes

File datum: WGS-84

Projection: Geographic (Lat/Long co-ordinates)

Top Left: 113°45’59.92”E and 19°38’27.00”S

Pixel size: .000833 degrees x .000833 degrees (approximately 90m x 90m)

Date Values: The Flood Hazard Index has been split into five risk categories - Negligible, Low, Moderate, High and Extreme with the following colour scheme:

The five risk categories and their associated colours are generated according to the following classification scheme in the table below.

Risk Category	**Colour**	**FHI – lower limit**	**FHI- upper limit**	**LUT- Red**	**LUT - Green**	**LUT- Blue**
Negligible	white	0	2000	245	247	245
Low	green	2000	4000	0	164	0
Moderate	yellow	4000	6000	255	255	4
High	orange	6000	8000	242	127	0
Extreme	red	8000	10000	230	0	0
Water body	dark blue	20 000	20 000	0	0	255
Ocean	light blue	30 000	30 000	0	92	139

Supplied: Landgate SRSS - October 2015

Western Australian Land Information Authority (Landgate)
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PO Box 471, WEMBLEY WA 6913
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Shortened forms

Short form	Long form
<	less/fewer than
>	more/greater than
AHD	Australian Height Datum
CID	channel iron deposit
cm	centimetre
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DAFWA	Department of Agriculture and Food, Western Australia (amalgamated into DPIRD, 1 July 2017)
DEM	digital elevation model
DoW	Department of Water (amalgamated into DWER, 1 July 2017)
DPIRD	Department of Primary Industries and Regional Development (from 1 July 2017)
DSM	digital soil mapping
DSMART	Disaggregation and Harmonisation of Soil Maps through Resampled Classification Trees (digital modelling method)
DWER	Department of Water and Environmental Regulation (from 1 July 2017)
GIS	geographic information system
GL; GL/y	gigalitre; gigalitres per year
ha	hectare
kL	kilolitre
km	kilometre
L	litre
m; mm	metre; millimetre
MAR	managed aquifer recharge
MDS	mine dewater surplus
mg/L	milligrams per litre
ML/d	megalitres per day
PHADI	Pilbara Hinterland Agricultural Development Initiative
WA	Western Australia
WASG	Western Australian Soil Group
WCB	West Canning Basin
y	year

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