



Water for a Healthy Country

Batch Experiments using Reverse Osmosis Water and Sands from the Swan Coastal Plain

Elise Bekele, Sebastian Sklorz, Grant Douglas and
Henning Prommer

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Citation: Bekele, E. et al., 2007. *Batch Experiments using Reverse Osmosis Water and Sands from the Swan Coastal Plain*. CSIRO: Water for a Healthy Country National Research Flagship

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Acknowledgements

This work was funded jointly by CSIRO Land and Water under the Water for a Healthy Country Flagship Program and the Water Corporation of Western Australia. The study was conducted as part of a student project at CSIRO undertaken by Mr Sebastian Sklorz, a visiting undergraduate student from the Free University in Berlin, during an 8-week period. The authors would like to acknowledge the following individuals at CSIRO, Mr John Adeney and Mr Jon Hanna for their assistance with the chemical laboratory procedures, Dr Richard Silberstein for providing the core material used for the batch experiments and Mr Mark Raven (CSIRO Land and Water Adelaide Laboratory) for mineralogy advice and services. Thank you to Mr Lex Bastian, retired from the Chemistry Centre, WA, for a thoughtful discussion on the mineralogical distinctions of subsystems within the Bassendean Dune system. From the Chemistry Centre, WA, we would like to acknowledge Ms Jenny McGuire for her assistance with water sample preservation methods and Dr David Allen for his advice and soil analytical services. The authors are also grateful for the assistance of Ms Palenque Blair, Mr Jeffery Ibbott and Mr Colin Stewart from the Water Corporation for their explanations of the treatment process at the Kwinana Water Reclamation Plant and their assistance in procuring reverse-osmosis-treated wastewater for the batch experiments.

Executive Summary

Concern over depletion of the Gnangara Groundwater Mound in Perth, WA has opened up possibilities for investigating alternative methods for recharging the superficial aquifer. Managed aquifer recharge using recycled wastewater is one possibility. This study provides an experimental method for conducting batch experiments to investigate hydro- or geochemical interactions between reverse osmosis (RO)-treated wastewater and sands of the Swan Coastal Plain.

The RO water was obtained from the Kwinana Water Reclamation Plant (KWRP). Cored sand from boreholes PJ3 and PJ4 in the superficial aquifer were obtained from two sites on the Gnangara Mound. The cores were characterised in terms of grain size distributions, mineralogical and soil geochemistry, and the stratigraphy was correlated between the two sites. Three layers were selected to use in the batch experiments. These include two cores of white to grey sand from the Bassendean Dune system and one core of yellow sand that is most probably younger Bassendean sand. The three cores are visually distinct in colour and texture, but they are similar mineralogically, being highly weathered, intensively leached sands of the Swan Coastal Plain.

The water chemistry changes from all of the batch experiments after a period of 28 days were minimal compared to experimental controls consisting of reverse osmosis water. Temporal variations in the RO water quality from KWRP produce small variations in the pH, total dissolved solids and electrical conductivity, similar to that observed in the supernatant waters from the batch experiments.

The batch experimental results suggest that managed aquifer recharge with low salt, reverse osmosis water could proceed with sediments of similar characteristics without significant mobilisation of solutes. Natural leaching by rainfall recharge and the geological age of both types of sand are responsible for the null result. However, the sand samples used in the batch experiments were extensively leached and may not be typical of other areas on the Gnangara Mound. The main recommendation from this study is to repeat the geochemical and mineralogical analyses and batch experimental procedure using cored material from

areas that are specifically targeted for managed aquifer recharge. Further testing of material from the underlying confined aquifer should be investigated to fully comprehend the long-term hydrochemistry effects of recharging the Gngangara Mound with RO water.

1. Introduction

One of the significant challenges to developing managed aquifer recharge schemes at new field sites is determining the range of anticipated changes that might alter the groundwater quality. The rationale for conducting batch experiments with sands was to screen for possible constituents that might be leached or mobilised by geochemical reactions by infiltrating low salt (RO) water through aquifer material (Gngangara Mound sands). The objective of the project was to utilise cored material from the superficial aquifer, primarily Bassendean sand, which is relevant to future considerations of aquifer recharge by infiltration on the Swan Coastal Plain.

The aim was to develop an experimental plan for sediment batch experiments utilising cored material from the Gngangara Mound and treated sewage effluent from the Kwinana Water Reclamation Plant (KWRP). As there were cores in storage at CSIRO from a previous investigation on the Gngangara Mound, the student project proceeded with sediments that were readily available. It is anticipated that these procedures could be repeated at a later date using freshly cored material from other field sites for comparison.

The content of this report begins with examples of batch experiments and other methods used in previous studies to interpret hydro- and geochemical changes from managed aquifer recharge. The background section includes a description of the geology and stratigraphy at two cored locations in the unconfined aquifer on the Gngangara Mound. The methods section describes the procedures for analysing the sediment cores and preparing the batch experiments with RO water. Six batch experiments were conducted using sediments from three intervals of Bassendean sand and two different ratios of RO water to sediment. The results include a description of the sediment variability within the cores and an interpretation of the stratigraphy to aid in extending these results to other parts of the Gngangara Mound. The changes in water quality during the experiment and the hydrochemistry after 28 days are reported and discussed for the six batch experiments.

2. Background

2.1. Applications of batch experiments

Batch experiments as referred to in this report are essentially slurries of soil (or sand) and water that are given significant contact time to allow leaching and geochemical reactions to occur. Containers are used to isolate the batch experiments from any changes in environmental conditions. Water temperature should remain constant, while oxygen levels and pH conditions can change within the chambers as chemical reactions proceed. Mechanical shaking of the containers is recommended to ensure adequate mixing and contact between the soil particles and the water. The batches may test different compositions or different proportions of soil and water. Throughout the experiment, changes in soil and/or water composition are tracked to evaluate water-sediment interactions. Batch experiments are relatively inexpensive to conduct and yield valuable information about the compositional changes that can occur due to leaching. Since the batch containers are kept

under closed conditions during the experiment, compositional changes are primarily controlled by mineral solubility and/or ion-exchange reactions.

To predict the compositional changes from leaching in an aquifer where there is rapid infiltration causing fresh source water to impinge on the soil, would require the design of a flow-through column rather than a batch experiment; however batch experiments are a valuable pre-step, particularly where infiltration rates or residence times have not been determined. One limitation of batch tests is that if chemical reactions proceed rapidly, then solutes can accumulate within the batch reactors, leading to supersaturation with secondary mineral products (Cavé *et al.*, 2001). It should be understood that if supersaturation occurs, the results may not resemble those occurring under flow conditions in an operating managed aquifer recharge system.

Batch experiments have been used in feasibility studies to evaluate geochemical changes for planning managed aquifer recharge schemes (e.g. Johnson *et al.*, 1999; Cavé, 2000; Cavé *et al.*, 2001). In these examples, the focus was on the effectiveness of the aquifer material to remove contaminants and identifying readily soluble components in the aquifer. Although batch experiments are commonly used in different types of studies involving leaching, there are relatively few examples involving RO water. The examples listed in Table 1 were the only studies that were identified in a recent survey of the literature. As indicated, a variety of experimental designs have been used to determine the dominant geochemical processes, including batch, column, core plug flow tests and field trials using RO water. Core plug flow tests are better suited for recharge studies involving consolidated or cemented aquifer material as in Mukhopadhyay *et al.* (2004). The initial soil composition and accompanying mineralogy is a critical factor controlling the dominant geochemical processes identified in each of the studies listed (Table 1).

Table 1. Previous investigations of geochemical changes using RO water and different types of aquifer or soil material.

Reference	Recharge/Runoff Study	Water Type	Aquifer Material or Soil Type	Types of Experiments	Dominant Geochemical Processes
Johnson <i>et al.</i> (1999)	Vadose zone injection in Scottsdale, Arizona	RO-, MF-treated wastewater; MF- Colorado River water	Sands and gravel with silts and clay interbeds	Batch test and flow-through columns	Significant leaching of F, Ba and As from the aquifer material
Aase <i>et al.</i> (2001)	Runoff from sprinkler irrigation in Kimberly, Indiana	RO; RO mixed with groundwater	Silt loam with different treatments	Lab sprinkler study	Phosphorus leaching; dissolution of soluble Ca and Mg salts
Mukhopadhyay <i>et al.</i> (2004)	Aquifer injection in Kuwait	RO- treated wastewater	Silty sand and sandstone cemented with carbonate and sulphate cement	Flow tests on core plugs	Dissolution of carbonate minerals
Chua <i>et al.</i> (2005)	Aquifer injection in Singapore	RO-treated wastewater	Sand containing quartz and carbonate minerals, clays	Field monitoring of injection trial	Carbonate dissolution and ion exchange; potential swelling of clays

RO=reverse osmosis; MF=microfiltration

2.2. Study area

The Gnangara Groundwater Mound, a major source of water for the Perth metropolitan area, extends radially outward beneath the Swan Coastal Plain. The top of the Mound where the elevation of the water table exceeds 60 m AHD, lies about 20 km from the coastline (Figure 1). Groundwater levels on the Gnangara Mound have declined significantly during the last two to three decades (Salama *et al.*, 2002). Within a 5 km radius of the area where sediments were cored in the unconfined aquifer, groundwater levels have declined by between 20 to 30 cm/yr since at least the early 1980s (Figure 2).

Concern over depletion of the Gnangara Mound has initiated discussion on using managed aquifer recharge with recycled wastewater to increase the sustainable yields of aquifers (Anonymous, 2005). To this end, investigations are needed to evaluate the potential impacts of managed aquifer recharge on the environment. The next section describes the heterogeneity that exists within two major superficial formations on the Gnangara Mound as their characteristics have a direct bearing on the type of geochemical interactions from leaching experiments.

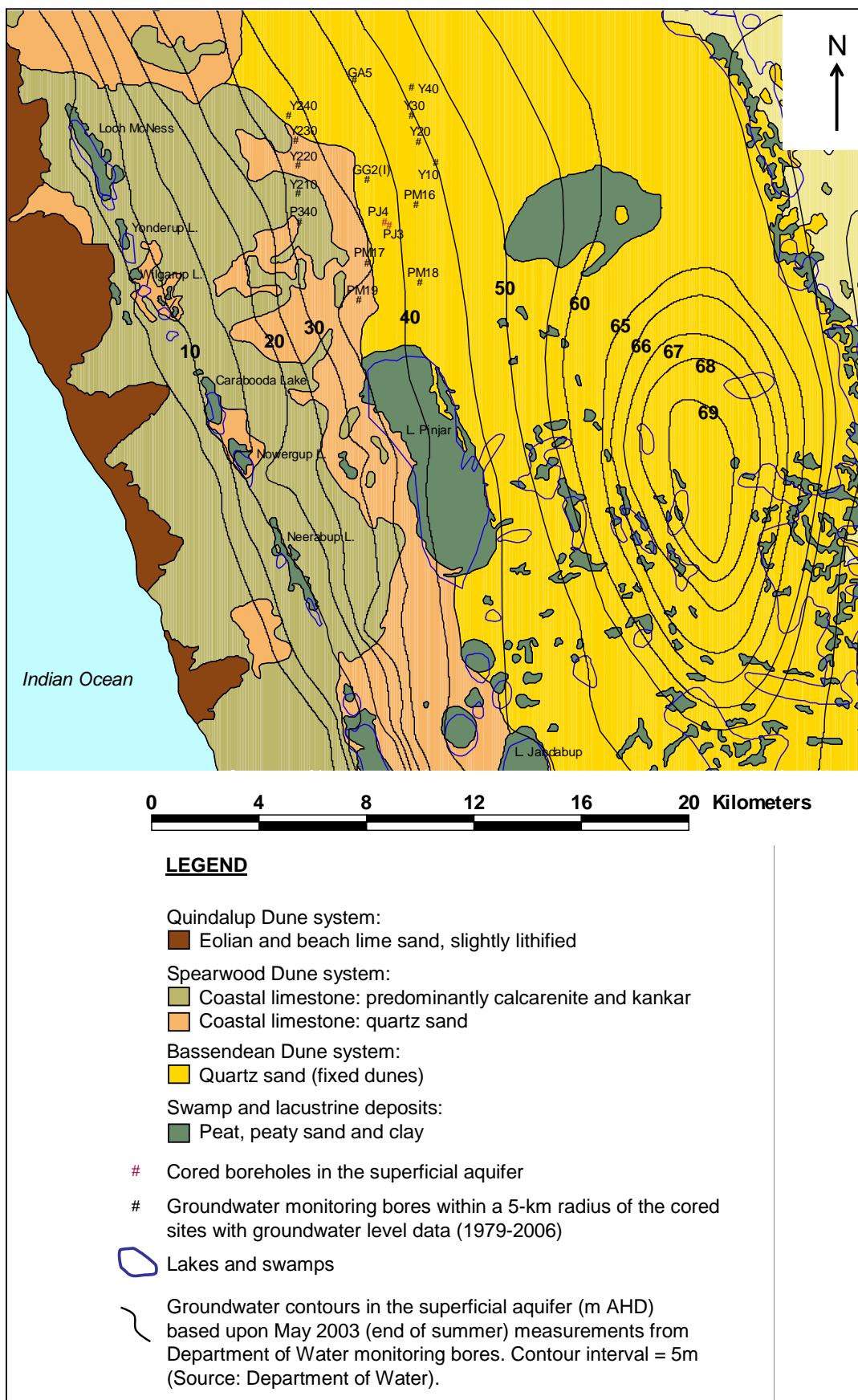


Figure 1. Location map showing the superficial deposits on the Gngalara Mound in relation to contoured groundwater levels (from Department of Water) and the two cored sites. Historical declines in groundwater levels in the surrounding monitored bores are shown in Figure 2.

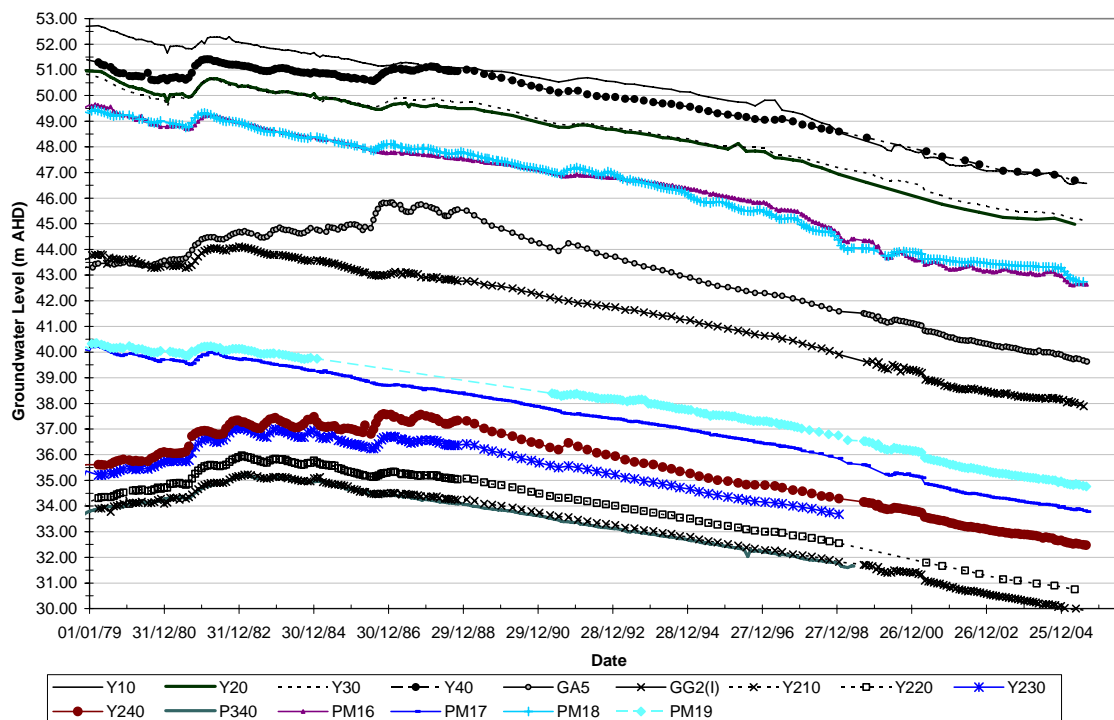


Figure 2. Historical groundwater levels in monitoring bores surrounding the cored sites. Data acquired from the Department of Water.

2.2.1. Distribution and variability within the Bassendean and Spearwood sands

The Bassendean Dune system (early to middle, or possibly late Pleistocene) and Spearwood Dune system (late Pleistocene) are superficial formations on the Swan Coastal Plain deposited sub-parallel to the present coastline and separated from each other by a chain of lakes and swamps in many areas (Playford *et al.* 1976; Figure 1). As both formations are in close proximity to the cored sites, this section provides background on the distribution and variability within them.

Both formations are coastal dune and shoreline deposits that were originally composed mainly of lime sand with a smaller proportion of quartz sand, but extensive leaching has altered the chemistry and the topographic relief of the coastal dunes (Playford *et al.*, 1976). The Spearwood sands extend about 10 to 15 km from the coastline, whereas the Bassendean sands are further east and extend 15 to 40 km from the coastline. In general, the thickness of these coastal sands is less than 70 m. The sands of Bassendean Dune system typically have higher percentages of coarse- and medium-grained sands, whereas the Spearwood has higher percentages of fine-grained sand (Salama *et al.*, 2005); however Gozzard (1987) analysed Spearwood sand, referred to as Tamala sand from more than thirty-one sites and Bassendean sand from forty-seven sites on the coastal plain and noted the dominance of medium grain sizes between 0.30 and 0.425 mm for both formations, which suggests that the two formations have similar grain-size distributions.

The Spearwood sands are generally brown or yellow-brown sands overlying a core of aeolianite (Bettenay *et al.*, 1960). The yellow sand colour is derived from hydrated iron oxide, which colours the kaolinitic clay (Bastian, 1996). The Spearwood sands have evolved from *in situ* weathering of the underlying Tamala Limestone (Tapsell *et al.*, 2003). The Bassendean Dune system consists of older, siliceous sands which have been heavily

leached by rainfall recharge. Bassendean sand near the ground surface is typically clean and white, but at depth it can be yellow to brown from higher iron content (Abeysinghe, 2003). The origin of the Bassendean sands is believed to be related to the underlying Ascot Formation (Kendrick *et al.*, 1991; Tapsell *et al.*, 2003). The carbonate deposited originally in the Bassendean sands was completely removed by leaching within the last 100,000 to 200,000 years (McArthur and Bettenay, 1974).

The surface geology map for the Swan Coastal Plain indicates that the cored holes PJ3 and PJ4 are located 2 km east of the transition from Spearwood to Bassendean sands (Davidson, 1995). Although the cores are predominantly white or grey sand that is typical of the Bassendean Dune system, the upper portions of both cores contain yellow sand. The yellow sand is most probably the youngest dunes of the Bassendean Dune system, referred to as the Gnangara Dunes as identified in Bastian (1996) in the cored region (Lex Bastian, personal communication).

The soils in the Bassendean are podsoles that have been subdivided based on the depth to the groundwater and the drainage status, which impact the extent of soil profile development (McArthur, 1991). The soils of the Bassendean include the Jandakot sand, the Gavin sand and the Joel sandy loam. The distribution of these soils varies with well-drained, iron-humus podsoles typical of the Jandakot series toward the west, humus podsoles typical of the Gavin series in areas where the water table is fairly shallow further east and in older parts of the Bassendean Dunes, and humus podsoles with a cemented organic horizon of the Joel series in seasonally flooded areas (McArthur and Bettenay, 1974; McArthur, 1991). The Joel series is typically found in depressions in the Bassendean Dune system and has been almost completely leached of iron (McArthur and Bettenay, 1974). The PJ cores used in this study most likely contain the Jandakot sandy soils.

The Spearwood and Bassendean Dune systems have also been subdivided in conjunction with the geomorphic features based on the degree of weathering of the heavy-mineral assemblages (Bastian, 1996). In the sequence of mineral weathering for the coastal sands, calcium carbonate is the first to be leached out, followed by the weathering of feldspars (plagioclase and then microcline) to clay minerals such as kaolinite; the weathering sequence continues with residual/heavy minerals (e.g. garnet), amphiboles and epidote, followed by the alteration of ilmenite to leucoxene, which remains with almost pure quartz sand (Bastian, 1996). From west to east across the dune systems, there is a systematic shift in the ratio of easily weathered minerals to heavy minerals, namely ilmenite and its weathering product leucoxene (Bastian, 1996). A semi-quantitative index of maturity was developed by Bastian (1996) to subdivide the dune systems, which reveals an aging trend from west to east. The percentage of garnet, amphibole and epidote in the residual/heavy-mineral fraction tend to be higher in the Spearwood Dune system than in the Bassendean Dune System (Bastian, 1996; Tapsell *et al.*, 2003). The proportion of feldspar minerals in the whole sample are not as diagnostic, but are lower in the Bassendean sands than in the Spearwood sands (Bastian, 1996).

It is important to determine the characteristics of the cored material used in the batch experiments as there is variability recognised within the Bassendean Dune system. It is also important to recognise the limits of extrapolating the results from these experiments to sands in other parts of the Swan Coastal Plain as there may be differences in the duration of leaching, soil profile development and chemistry.

3. Methods

As described in the background section, the mineralogy and chemical characteristics of the soil play a critical role in determining the range of geochemical reactions that may occur during leaching experiments involving RO water. The focus of this section is to provide a description of the methods used to characterise the cores and the methods for preparing the batch experiments.

3.1. Selection and analysis of sediment cores

Two boreholes (PJ3 and PJ4) were cored in the superficial aquifer to depths of 19.5 and 32.25 m in early November 2004. The boreholes are located in the Pinjarra region of the Gnamptara Mound and were cored as part of a separate investigation by a CSIRO Land and Water colleague (R. Silberstein, personal communication). The boreholes are located north of Kestral Rd in a pine plantation at the following coordinates: PJ3 (-31.5537S 115.7901E); PJ4 (-31.5527S 115.7884E) as indicated in Figure 1. The topographic elevations of the cored sites are 59.649 AHD for PJ3 and 70.559 AHD for PJ4. The cored sites are separated by a distance of approximately 197 m.

The wireline coring method with a hollow stem auger was used to obtain the sediments, which were transferred into air-tight plastic tubes in the field. Each core tube contained sediments that were extracted from the 75 cm-long, 50 mm-diameter core barrel within each auger. The process of coring through very loose sand was difficult due to collapse, thus some storage tubes contain shorter sections of cored material. The sediment cores remained stored and undisturbed in the plastic tubes under laboratory conditions (ca. 22°C). In July 2006, a student project was initiated to conduct batch experiments with RO water and permission was obtained from R. Silberstein to use the cores in storage for these experiments.

A detailed examination of the cores had not been conducted previously, thus one of the first activities was to describe the gross characteristics of the sediments (e.g. colour; texture; presence of organic matter) before conducting more detailed analyses (Figure 3 and Results section).

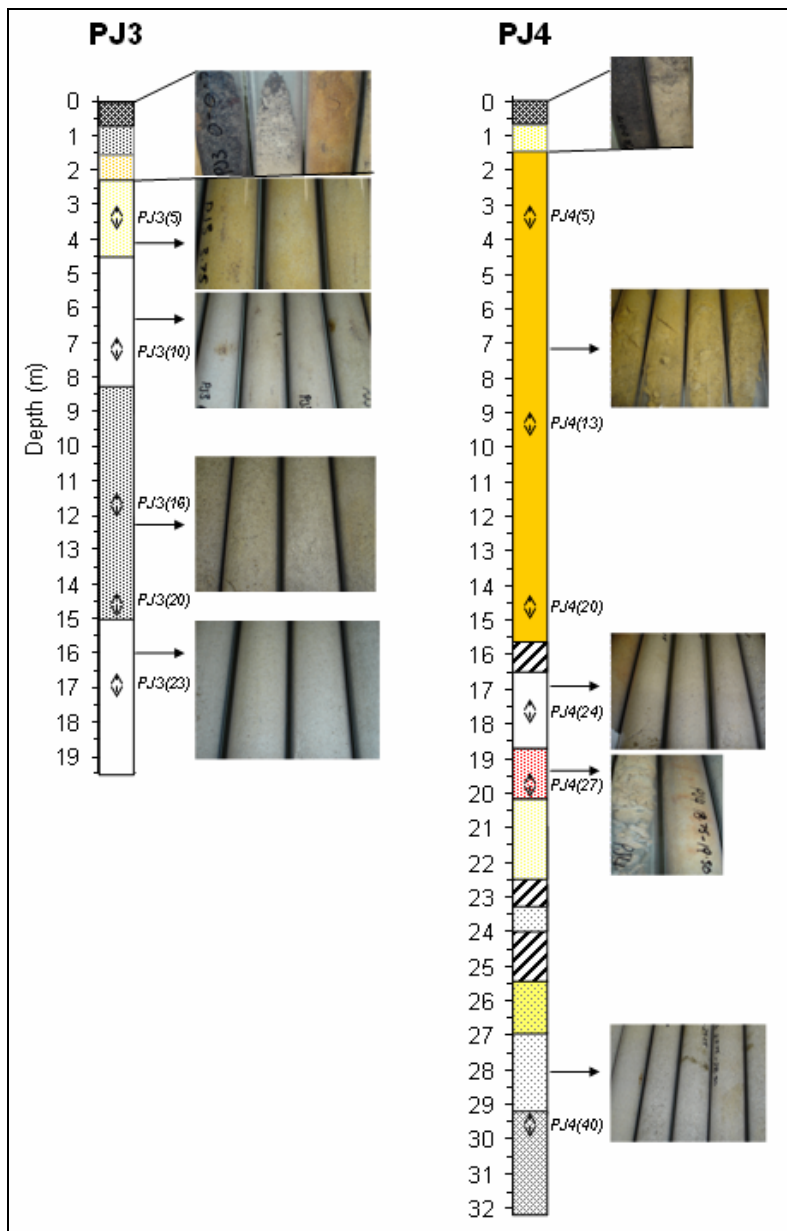


Figure 3. PJ3 and PJ4 cores and identification of analysed sections described in Table 2. Batch experiments were conducted using sediment from PJ3(16) , PJ3(23) and PJ4(5) Missing or damaged cores sections indicated with a slash pattern (/). Photos by Sebastian Sklorz.

3.1.1. Grain size analysis by sieving

Grain size analyses were conducted by sieving ten samples (four from PJ3; six from PJ4) as listed in Table 2. The results from the grain size analysis and the gross descriptions made it possible to correlate the stratigraphy between the two boreholes and to relate different cores to regional studies of the coastal sands. Aided with this information, three sections of relatively uniform sand were selected to use for the batch experiments.

The determination of the grain size distributions of core samples was made by sieving the sediments using ten different sieve sizes between 0.063 and 2 mm. The sediment samples were first dried at 105°C for 48 hours and approximately 100 g of each sample were prepared for sieving. The weights of samples and the empty sieves were measured

separately. The samples were sieved for approximately 15 minutes; afterwards, the sieves were re-weighed. To determine the amount of sediment in a particular class of grain sizes involved taking the difference between the weights of the full and empty sieves. For example, to determine the amount of sediment with grain sizes between 0.063 mm and 0.09 mm required re-weighing the 0.063 mm-size sieve. The difference between the total amount of sediment used and the sum of the sediment residuum in each sieve equals the sediment loss, which was calculated for each sample. The grain size distributions were produced by plotting percentage of residual sediment against the different classes of grain sizes.

3.1.2. Preparation of sediments for batch experiments and selection for analyses

Several steps were needed before the sediment-water slurries for the batch experiments were prepared. These steps involved homogenisation of the three separate batch sediments and the estimation of pore water in these sediments. Sub-samples from the homogenised mixtures were submitted to two laboratories for further testing, namely the CSIRO laboratory in Adelaide for mineralogical analyses and the Chemistry Centre of Western Australia for soil chemistry analyses (Table 2). The samples submitted to both laboratories included 50 g each of the three soils for the batch experiments. Two additional samples from different sections of the core were submitted for soil chemistry and XRF analyses to investigate the geochemical variability within the Bassendean sands (PJ3(20) and PJ4(40)). To have sufficient quantities of core material for all of the analyses and the batch experiments, approximately 1200 g was obtained from each of the selected intervals. The core material from each selected interval was homogenized in a rotating cylinder for 12 hours.

The soil chemistry analyses performed by the Chemistry Centre WA laboratory included the determination of soil pH, electrical conductivity, Cl, exchangeable cations (Ca, Mg, Na, K), and organic carbon. The methods for analysing for pH and EC are from Rayment and Higginson (1992). Soil water extracts to determine pH and EC were prepared by shaking 1 part soil and 5 parts deionized water for 1 hour, end-over-end at 10 rpm. Soil chloride was determined using in-house method developed by the Chemistry Centre based on Adriano and Doner (1982), which involved titration of chloride extracted from soil by dilute nitric acid. Cation extractions for Ca, Mg, Na and K were prepared by shaking 1 part soil and 20 parts ammonium chloride overnight, end-over-end at 10 rpm (David Allen, CCWA, personal communication). The organic carbon content was determined by wet oxidation using the Walkley-Black method as detailed in Rayment and Higginson (1992).

The mineralogical samples were analysed for qualitative (phase identification) by X-Ray Diffraction (XRD). The coarse sand samples were sieved to <100 µm to remove coarse quartz then ground in an agate mortar and pestle and pressed into aluminium holders for X-ray diffraction analysis (Mark Raven, personal communication). A separate XRD analysis was conducted on the magnetic fractions of several samples using the 100-150 µm sieved fraction to isolate heavy minerals for analysis. XRD patterns were recorded with a Philips PW1710 microprocessor-controlled diffractometer (Mark Raven, personal communication).

The major and trace element geochemistry of the sediment samples was analysed using X-Ray Fluorescence (XRF) spectroscopy. XRF was conducted using fusion and pressed powder methods, which require whole oven-dried sample (Mark Raven, CLW, personal communication). The fusion samples were analysed on a Philips PW1480 wavelength dispersive XRF system, whereas the pressed powder samples were analysed with a Spectro X-Lab 2000 energy dispersive XRF system (Mark Raven, personal communication).

Table 2. Analyses performed on cores from PJ3 and PJ4. The core IDs refer to Figure 3. Batch experiments and pore water (%) calculations were conducted using sub-samples from cores indicated (grey shaded rows).

Core ID	Core depth (m)	Grain size analysis	Soil chemistry	Mineralogy from XRF	Mineralogy from XRD
PJ3(5)	3.0-3.75	√	--	--	--
PJ3(10)	6.75-7.5	√	--	--	--
PJ3(16)	11.25-12.0	√	√	√	√
PJ3(20)	14.25-15.0	--	√	√	--
PJ3(23)	16.5-17.25	√	√	√	√
PJ4(5)	3.0-3.75	√	√	√	√
PJ4(13)	9.0-9.75	√	--	--	--
PJ4(20)	14.25-15.0	√	--	--	--
PJ4(24)	17.25-18.0	√	--	--	--
PJ4(27)	19.5-20.25	√	--	--	--
PJ4(40)	29.25-30.0	√	√	√	--

It was necessary to estimate the amount of pore water present in the cores as this could affect the accuracy of the ratio of sediment to water used in the batch experiments. The quantity of pore water within each core varies due to its original depth relative to the natural wetting front of rainfall recharge and due to moisture losses during storage. Although the sediment cores were enclosed in air-tight, plastic tubes in the field and stored in a cool laboratory, there may have been moisture losses, particularly where only a small portion of the cored interval could be extracted into the 75-cm long tube. Different quantities of pore water may exist in the cores. The following procedure was used to estimate pore water on sub-samples. These sub-samples were not re-used for the batch experiments as drying may have potentially altered the sample hydrochemistry.

- Sediments were removed from the plastic tubes and weighed to obtain an initial mass (m_i).
- The samples were then oven-dried for a minimum of 48 hours at 105°C.
- The samples were re-weighed after drying (m_f) and the difference in mass equals the pore water volume, assuming the density of water is 1 g/cm³.

As an example, this procedure was applied to the sediments within one whole core tube: $m_i=1132.2$ g; $m_f=1113.7$ g, therefore the pore water was 18.5 cm³ or 18.5 mL

This procedure was repeated using 200 to 230 g of sediment from the three selected intervals.

3.2. Sediment batch experiments

The sediment batch experiments involve combining known quantities of sediment and water and monitoring changes in several water quality parameters at regular time intervals. The experimental plan developed for this study included six separate batch experiments, using three sediment-types and two different ratios of sediment to water (Table 3). Different ratios were used to determine if the results were sensitive to the proportion of water in contact with the sediment. The ratios tested were 10 g of soil to 1 litre of RO water and 100 g of soil to 1 litre of RO water.

The water used in the batch experiments was RO-treated effluent from the Kwinana Water Reclamation Plant, which was collected on the 23-August 2006. The RO water was collected from a sample tap located on the pipe after the storage tank. The water passed through initial screens, microfilter and RO membranes, a degasser and storage tank.

The batch experiments were conducted over a period of 28 days, starting on Day 0 (28-August 2006) with water quality measurements and samples collected for chemical analysis on Days 1, 3, 8, 15 and 28. In addition to preparing separate bottles or batch compositions as described in Table 3, separate bottles were prepared for sampling on different days, thus avoiding the difficulty of trying to eliminate the creation of an atmospheric headspace while re-sampling from the same batch. Any contact between the batch samples and air was avoided during the experiment. To gain an understanding of experimental reproducibility, triplicate batches were prepared for selected sample days from each experiment as identified in Table 3.

As the reaction/exchange kinetics of the 28-day experiment were not known, water samples were collected on sample days 1, 3, 8 and 14 and stored for subsequent chemical analysis according to the procedure outlined in Section 3.2.2.

Table 3. Summary of batch experiments conducted with sediment cores from the Pinjar boreholes and reverse osmosis (RO) water. Samples and water quality measurements were obtained on days 1, 3, 8, 14 and 28.

Experiment #	Approximate mass of soil used (g)*	Core ID	Sample day selected for doing triplicate batches
1	10	PJ4(5)	Day 14
2	100	PJ4(5)	Day 14
3	10	PJ3(16)	Day 8
4	100	PJ3(16)	Day 8
5	10	PJ3(23)	Day 3
6	100	PJ3(23)	Day 3

* Soil mass listed is approximate as they include a porewater fraction. Refer to Table A1 (Appendix 1) for the precise amounts of soil and water used in the experiments.

3.2.1. Preparation of batch experiment bottles

Plastic (Nalgene) bottles were used for the majority of the batch experiments. Dissolved organic carbon may be affected by the plastic, thus glass and plastic bottles were prepared for the batch experiments sampled on Day 28. The glass bottle batch experiments were only sampled for DOC to compare with the batches conducted in plastic. One litre bottles were used. The number of bottles required for the batch experiments was: 42 plastic and 6 glass bottles. Additional bottles of RO water were obtained from the Kwinana Water Reclamation Plant to use as controls and for chemical analysis.

The batch bottles and caps were first soaked in 10% hydrochloric acid for two hours, rinsed six times with distilled water, and then air-dried for two days. The following procedure was used to prepare the batch bottles on the days before the start of the experiment:

1. The dry bottles and caps were weighed and assigned a numerical label.
2. The bottles were transported to the Kwinana Water Reclamation Plant and filled without headspace at the sample tap with RO water. Some small air bubbles may have been present in the water, but every attempt was made to minimise their presence.
3. In the geochemistry laboratory at CSIRO Land and Water, the appropriate amount of sediment for each batch experiment was carefully weighed using a watch glass and acid-washed Teflon spatula.
4. A small volume of RO water was removed from each bottle to make space for the sediment, and then the sediment was transferred directly from the watch glass to each batch bottle. The headspace in each bottle was filled with RO water and then the bottles were capped tightly and weighed.

Table A1 (Appendix 1) contains the data derived from this procedure. In total, there were 48 batch bottles prepared, each containing about 1 litre of RO water and either approximately 10 g or 100 g of sediment, using one of the three sediment-types and labelled for sampling once on either Day 1, 3, 8, 14 or 28. Included among these prepared bottles were 12 batches representing replicates and 6 batches in glass bottles for testing the concentration of dissolved organic carbon on Day 28 for each soil-type and soil ratio.

Upon completion of this procedure for preparing the soil-water slurries (Day 0), the batch bottles were placed into orbital shaking machines that were set to a temperature of 25 °C with between 55 and 100 revolutions per minute. Two additional, one litre bottles containing RO water were also prepared and given the same treatment to provide experimental controls. Water quality measurements were taken on the control RO water samples on Days 8 and 28.

3.2.2. Water sampling procedure

The following procedure was used to prepare samples of the supernatants from the batch experiments for chemical analysis by the Chemistry Centre of Western Australia. The procedure was designed to meet the requirements for storage of the water samples for up to one month before chemical analysis. The water samples from Day 28 were initially submitted for analysis to quantify the extent of the sediment-water interaction. As the Day 28 results did not indicate substantial differences in the water chemistry between the control RO and sediment water samples, irrespective of the sediment to water ratio, there was no justification for analysis of water samples collected on intervening sample days (Days 1, 3, 8

and 14). Hence, the procedures are described here in detail as a reference for future batch experiments.

On the designated days for sampling, the appropriate batch bottles corresponding to that sample day were removed from the orbital shakers. The following information was recorded: pH, Eh, temperature, total dissolved solids (TDS) and electrical conductivity (EC) compensated for temperature, which were measured when the batch containers were opened to pour off the supernatant. The water quality measurements were made using WTW (Wissenschaftlich-Technische Werkstätten) metering instruments that were calibrated against standard solutions. The probes were inserted directly into the bottles to minimise the influence of air on the water. A syringe was then used to extract the supernatant.

For each batch bottle, the supernatant was sub-sampled into four separate bottles, requiring different methods of storage to analyse for different constituents in the water. Table 4 summarises the intended chemical analyses for the four sub-samples of supernatant from each batch experiment. The first samples that were prepared were those for alkalinity (bottles labelled “A”), which should avoid excessive contact with the air. The supernatant delivered into bottles labelled “C”, “D” and “E” was passed through a 0.45 µm filter. All sample bottles were filled without headspace to minimise gas exchange with the air. The water samples in the “B” bottles were acidified by adding 0.5 ml of concentrated nitric acid to 50 ml of supernatant (1% acidification). Samples labelled “C” were frozen to prevent the loss of ammonia and to preserve the DOC (Jenny McGuire, CCWA, personal communication).

Table 4. Sample bottles prepared for storage of the supernatant from the batch experiments. All samples were refrigerated, except those labelled “C”.

ID	Preparation and preservation of water for subsequent analysis	Analytes requiring preparation by the methods indicated
A	Unfiltered	Alkalinity
B	Filtered and acidified	Metals
C	Filtered, then frozen at -4 °C	DOC, nutrients
D	Filtered	Chloride, SO ₄ , SiO ₂

4. Results

4.1. Analyses of the Bassendean sand samples

4.1.1. Core descriptions

PJ3

Cores from PJ3 extend from the ground surface to a depth of 19.5 m (Figure 3). Within the first 4.5 m the lithology changes from black, sandy soil with organic material present to less organic-rich sand layers that change in colour from grey to red-orange to yellow. Organic matter is not present at depths below 9 m. There is a top section of yellow sand between depths of 2.25 and 4.5 m, which is most likely a subsection of the Bassendean Dune system referred to as Gngangara sand (Bastian, 1996; Lex Bastian, personal communication). Below 4.5 m, PJ3 contains white sands that are typical of the Bassendean sands with sections of white and grey sand with sparse black mineral particles between 9 and 15 m.

PJ4

Core from PJ4 extend from the ground surface to a depth of 32.25 m (Figure 3). Below a top section of 1.5 m of black soil is a relatively uniform section of yellow sand to a depth of 15.75 m. There are 1 to 3 m sections of white or grey sand interspersed with light yellow, orange and red sands to a depth of 29.25 m, but the stratigraphy for PJ4 is incomplete due to damaged or missing cores between 15.75 and 24.75m. The lowermost 5.25 m of PJ4 contains white and light grey sand with sparse black mineral particles. There are more densely packed or cemented zones from 16.5 to 20.25 m and from 29.25 to 32.25 m.

4.1.2. Grain size analyses

The grain size results are given for four PJ3 cores and six PJ4 cores (Table 5). These are mainly medium-grained sands with the majority of grain sizes between 0.18 and 0.5 mm, according to the sediment classifications used by Salama *et al.* (2005) for Gngangara soils. With increasing depth, the dominant grain size increases from between 0.25 and <0.355 mm to between 0.5 and <1 mm (coarse sand). This change in grain size distribution occurs at different depths, i.e. below 7.7m for PJ3 and below 20.25 m for PJ4..

Table 5. Summary of grain size results for all 10 samples referred to by their Core IDs. Refer to Appendix 2 for detailed measurements. Batch experiments were conducted using sub-samples from cores indicated (grey shaded columns).

Sieve size (mm)	Percentage in each sieve class for each Core ID:									
	PJ3 (5)	PJ3 (10)	PJ3 (16)	PJ3 (23)	PJ4 (5)	PJ4 (13)	PJ4 (20)	PF4 (24)	PJ4 (27)	P4 (40)
2.000	0.01	0.00	0.04	0.00	0.01	0.00	0.00	0.00	0.00	0.00
1.000	0.84	0.68	1.51	0.87	0.85	0.53	1.52	2.77	0.34	1.53
0.500	21.60	21.54	42.78	33.77	21.62	20.46	21.42	22.62	19.51	44.62
0.355	23.18	23.03	23.44	23.27	23.19	22.93	15.49	18.66	26.35	20.48
0.250	31.21	33.14	19.40	20.65	31.21	26.62	25.17	28.83	32.76	16.74
0.180	13.65	14.02	6.17	9.81	13.63	13.84	18.07	16.41	12.43	8.87
0.125	5.45	4.29	2.97	4.51	5.44	9.72	12.90	6.58	4.20	4.32
0.090	1.25	0.86	1.04	1.71	1.24	2.58	2.56	1.65	1.40	1.18
0.063	0.91	0.73	0.81	1.42	0.92	1.34	1.41	1.09	1.11	0.79
<0.063	1.89	1.72	1.84	4.00	1.89	1.97	1.46	1.39	1.90	1.47

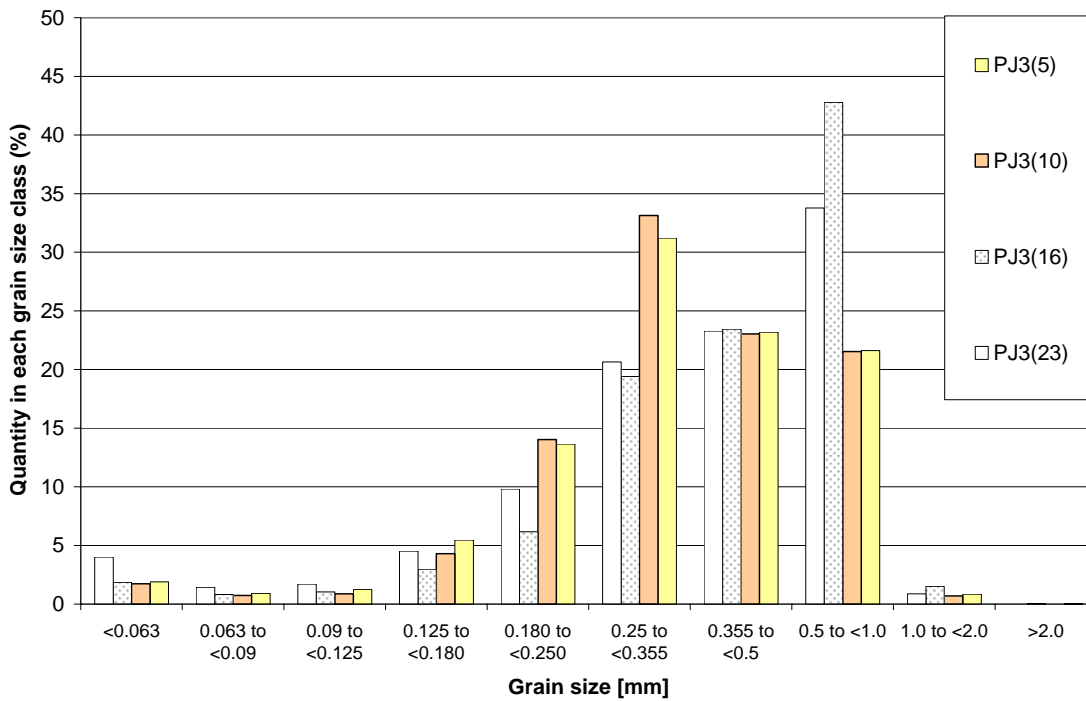


Figure 4. Grain size analysis results for PJ3. The dominant grain size increases to between 0.5 and <1 mm below 7.5 m depth as revealed by PJ3(16) and PJ3(23).

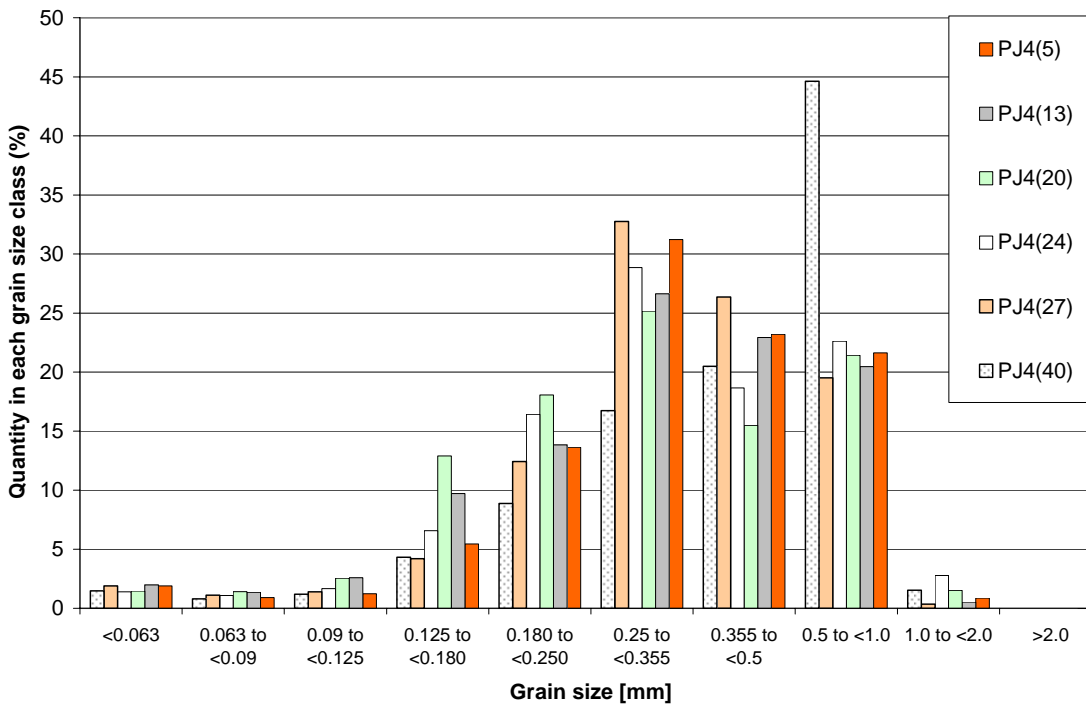


Figure 5. Grain size analysis results for PJ4. The dominant grain size increases to between 0.5 and <1 mm below 20.25 m depth as revealed by PJ4(40).

4.1.3. Pore water analyses

The results from the pore water measurements reveal that on average, the sediment used in the batch experiments contained 35% water (Table 6). This volume of pore water was used to correct the mass of soil used in the batch experiments (Table 7).

Table 6. Results from pore water measurements.

Core ID	Sediment dry (g)	Sediment wet (g)	Pore water (g)	Pore water (%)
PJ4(5)	234.43	177.29	57.14	32
PJ3(16)	207.18	150.43	56.74	38
PJ3(23)	219.67	163.03	56.64	35

Table 7. Corrections to account for the pore water in the sediments used in the batches for Day 28 experiments. The corrected ratios include pore water and RO water.

Experiment #	Core ID	Volume of pore water (ml)	Corrected mass of sediment (g)	Corrected ratio of water:sediment
1	PJ4(5)	3.22	6.85	150.49
1*	PJ4(5)	3.21	6.81	164.96
2	PJ4(5)	32.01	68.02	15.08
2*	PJ4(5)	32.03	68.06	16.75
3	PJ3(16)	3.81	6.22	165.62
3*	PJ3(16)	3.83	6.25	181.50
4	PJ3(16)	38.03	62.04	15.70
4*	PJ3(16)	38.01	62.02	18.16
5	PJ3(23)	3.51	6.51	152.62
5*	PJ3(23)	3.50	6.51	170.12
6	PJ3(23)	35.02	65.05	15.78
6*	PJ3(23)	35.03	65.06	17.29

*Batch experiments conducted in glass bottles for DOC analysis.

4.1.4. Mineralogy

The XRD results on the sieved <100 µm fractions for each sample were dominantly quartz (Table 8). Microcline (a potassium feldspar, KAlSi_3O_8) was identified in minor or sub-dominant quantities in the samples. Mineral coatings were not analysed. Clay-sized particles (i.e. grain sizes < 2 µm) were included in the XRD samples, but they were not isolated and analysed separately. The XRD results yield some insight into the composition of the clay-sized particles as the dominant clay mineral is kaolin (as kaolinite or halloysite).

Table 8. Results from XRD analyses performed by the CSIRO Land and Water Mineralogy laboratory in Adelaide on the < 100 µm magnetic fractions for each sample.

Core ID	Mineralogical composition from XRD
PJ4(5)	Dominant quartz, minor microcline (K-feldspar), trace kaolin
PJ3(16)	Dominant quartz, sub-dominant microcline, minor kaolin
PJ3(23)	Dominant quartz, minor microcline and kaolin

*Dominant (>60%), co-dominant (sum of phases >60%), sub-dominant (20-60%), minor (5-20%), trace (<5%)

A separate XRD analysis was conducted on the magnetic fractions of the samples to isolate heavy minerals that might be used to distinguish different sand types. Preliminary magnetic separation was done on the 100-400 µm and the photographs reveal two distinct types of magnetic particles: the darker and mostly finer material is likely titanium oxides (i.e. rutile or ilmenite) and light quartz grains coated with likely clay minerals and very fine iron oxides (Figure 6; Mark Raven, CLW, personal communication). The 100-150 µm sieved fractions

were analysed by XRD (Table 9). The XRD results confirm quantities of titanium oxides, either as ilmenite (FeTiO_3), pseudorutile ($\text{Fe}_2\text{O}_3\cdot 3\text{TiO}_2$) or rutile (TiO_2). The oxidation and leaching of ilmenite produces the alternation products pseudorutile and rutile. The heavy mineral analyses on the PJ3 and PJ4 cores did not detect garnet, epidote or amphibole, associated with heavy mineral fractions often found in Spearwood sands rather than in Bassendean sands (Bastian 1996; Tapsell *et al.*, 2003).

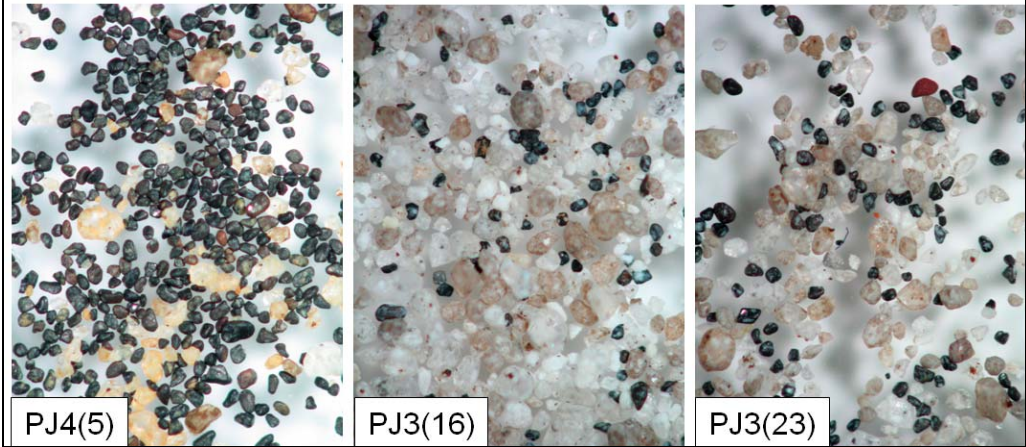


Figure 6. Photographs showing two distinct types of magnetic particles obtained by separation of the 100-400 μm fractions of the samples. Field of vision is 4.5 mm (Photos by Mark Raven).

Table 9. Results from XRD analyses performed by the CSIRO laboratory in Adelaide on the 100-150 μm magnetic fractions for each sample.

Core ID	Mineralogical composition from XRD
PJ4(5)	Co-dominant quartz and pseudorutile, minor ilmenite, trace rutile
PJ3(16)	Dominant quartz, sub-dominant pseudorutile, minor microcline, trace ilmenite and possible calcite
PJ3(23)	Dominant quartz, sub-dominant pseudorutile, minor microcline, trace kaolin and possible calcite

The XRF fusion results, which are based on whole samples, confirm the presence of quartz (SiO_2), feldspar (K_2O , Al_2O_3 , SiO_2) and kaolin (SiO_2 , Al_2O_3) as indicated in Table 10. All of the samples have been heavily leached of calcium carbonate as indicated by quantities of CaO below the detection level. Although mineral coatings were not removed and analysed specifically, there is an indication that a very light coating of iron oxides (Fe_2O_3) is present at least on PJ4(5), this being the only sample of yellow sand submitted for mineralogical analysis. If there are iron oxides or S as sulphides present on the other samples, they are at or below the detection limits of XRF and likely only present as very light coatings (Mark Raven, CLW, personal communication).

Table 10. Major element compositions (weight %) from the XRF fusion method.

Major elements (%)	Detection limit (%)	PJ3(16)	PJ3(20)	PJ3(23)	PJ4(5)	PJ4(40)
SiO ₂	0.35	96.52	98.93	98.18	98.13	97.90
Al ₂ O ₃	0.20	2.08	0.77	1.17	0.84	1.01
K ₂ O	0.05	0.76	0.27	0.37	0.07	0.42
Fe ₂ O ₃	0.05	0.05	<0.05	<0.05	0.20	<0.05
TiO ₂	0.03	0.03	<0.03	0.03	0.07	0.05
CaO	0.10	<0.10	<0.10	<0.10	<0.10	<0.10
MgO	0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Na ₂ O	0.08	<0.08	<0.08	<0.08	<0.08	<0.08
P ₂ O ₅	0.03	<0.03	<0.03	<0.03	<0.03	<0.03
SO ₃	0.02	<0.02	<0.02	<0.02	<0.02	<0.02
MnO	0.01	<0.01	<0.01	<0.01	<0.01	<0.01

The minor elements identified by the XRF fusion method are less than 0.06% of the total oxides, but several minor elements are noteworthy (Table 11). In most of the samples, BaO, Cr₂O₃, CoO and Cl are the minor element oxides in greatest abundance and above 50 ppm, except the yellow sand sample PJ4(5), which contains BaO at the detection limit. The XRF pressed power results provide the trace metal composition of the samples (Table 12). The results for tungsten (not shown) were all elevated due to contamination by the grinding process using a tungsten grinding piece.

Table 11. Partial list of the minor elements compositions (in ppm) measured using the XRF fusion method. In all of the samples, the elements La₂O₃, NiO, PbO, SnO₂, SrO, ThO₂, U₃O₈, Y₂O₃, ZnO (not shown) are below detection limits.

Minor elements (ppm)	Detection limit (ppm)	PJ3(16)	PJ3(20)	PJ3(23)	PJ4(5)	PJ4(40)
BaO	35	203	108	137	35	166
Cr ₂ O ₃	17	129	117	125	121	114
CoO	12	78	80	87	76	82
Cl	40	56	55	62	81	48
CeO ₂	20	44	36	43	38	32
ZrO ₂	30	32	37	<30	47	30
Rb ₂ O	14	24	<14	<14	<14	16
V ₂ O ₅	17	22	18	<17	24	<17
As ₂ O ₅	8	14	16	14	18	18
CuO	12	14	<12	<12	<12	21
Ga ₂ O ₃	7	11	10	9	7	10

Table 12. A partial list of the trace metal compositions (ppm) measured using the XRF pressed powder method. In all of the samples, the elements As, Bi, Br, Cs, Hg, I, In, Pr, Sb, Se, Sm, Ta, Te (not shown) are below detection limits.

Trace metal (ppm)	PJ3(16)	PJ3(20)	PJ3(23)	PJ4(5)	PJ4(40)
Ba	156	97.1	110.3	38.4	101.2
Co	72	78	17	31	90
Zn	50.3	45	43.6	28.5	59.5
Ge	38.6	39.4	29.9	23.7	48.3
Zr	37.2	37.8	54.7	119.5	62.1
Sr	20.4	14.9	20.4	9.8	13.8
Rb	18.3	13.1	13.6	8.4	11.8
Yb	15.5	< 2.0	< 2.0	7.2	< 2.0
Th	15.3	14.9	16	12.5	11.1
Pb	14.9	9.6	9.7	9	11.2
Mo	13.4	15.5	12.9	14.5	13.8
U	13.4	< 0.9	< 0.9	< 0.9	< 0.9
Tl	9.5	11.2	9.3	9.4	14
Ce	9.1	< 2.5	13.4	< 2.5	4.2
Y	8.2	8.7	8.1	8.8	9.8
Nb	8	8.5	9.2	14.8	10.2
Cu	5.4	< 0.6	1.1	< 0.6	< 0.6
Ga	3.3	1.5	1.4	< 0.5	2
Cd	0.9	0.8	0.7	0.5	0.7
Hf	0	4.5	0	3.6	3.6
Nd	< 3.0	< 3.0	43.6	20	< 3.0
La	< 2.0	< 2.0	15.3	< 2.0	< 2.0
Sn	< 0.5	< 0.5	< 0.5	< 0.5	3.9
Ag	< 0.5	< 0.5	< 0.5	< 0.5	1.2
Ni	< 0.8	< 0.8	< 0.8	< 0.8	1.1

4.1.5. Soil chemistry

The chemistry results reveal soils that have been extensively leached of major ions (Table 13). The amount of organic carbon (Wt%) in the sample from PJ4(5) is nearly double that found in the other samples, most likely because it is the shallowest sample (3-3.75 m depth), whereas the other analysed samples are deeper (>11.25 m). PJ4(5) is presumably younger due to its stratigraphic position and has had a shorter duration of leaching compared with the other samples. The exchangeable Ca is also highest in PJ4(5), but the other exchangeable cations are not uniquely higher in PJ4(5). For example, exchangeable Na is highest in

PJ3(16) and exchangeable Mg is highest in both PJ4(5) and PJ3(16), the latter representing the cored interval from 11.25-12m depth.

Table 13. Soil chemistry results. Analyses conducted by the Chemistry Centre of Western Australia. The exchangeable cations are in milliequivalents per 100 g of soil.

Analyses	PJ3(16)	PJ3(20)	PJ3(23)	PJ4(5)	PJ4(40)
Electrical conductivity (mS/m)	1	1	1	1	1
pH	6.5	6.8	6.3	6.5	6
Cl (%)	<0.001	<0.001	<0.001	<0.001	<0.001
Organic carbon (%)	0.05	0.04	0.04	0.09	0.03
Exchangeable Ca	0.03	0.03	0.03	0.11	0.02
Exchangeable Mg	0.13	0.06	0.06	0.13	0.04
Exchangeable Na	0.08	0.04	0.03	0.03	0.02
Exchangeable K	0.03	0.03	0.02	0.02	0.02

4.2. Stratigraphic interpretation

An attempt was made to correlate the stratigraphy between PJ3 and PJ4, which were cored at sites separated by a distance of 197 m on the Gnangara Mound. The interpretation of the stratigraphy aided in selecting the most relevant depths in the cores to sample for the batch experiments. The justification was to select samples of different types of Bassendean sand to gain a sense of the variability. At the time of sample selection, the mineralogy and soil chemistry results were not available, thus a decision was made on the basis of grain size distributions and mineralogical differences from visual inspection of the cores. The batch experiments were conducted with yellow sand from PJ4(5) and white and grey sand from PJ3(16) and PJ3(23) (Figure 7).

The grain size data reveal similarities between PJ3(5) and PJ4(5), PJ3(10) and PJ4(24), and PJ3(16) and PJ4(40). Both PJ3(5) and PJ4(5) have very similar grain size distributions (Figure 7). It is not possible to accurately correlate individual layers; some layers may not have been deposited or were removed by erosion or redistributed by aeolian processes.

Geochemical data (using XRF fusion and pressed powder methods) were obtained for a subset of cores. A ternary plot of the molar proportions of Al_2O_3 , $CaO+Na_2O$ and K_2O (diagram modified after Nesbitt and Young, 1984) has been used to differentiate the major element geochemistry of the Bassendean sands (Figure 8). An “average” granitoid composition similar to that of the parent Yilgarn Craton granitoids and a theoretical weathering line are also shown. While this represents a primary granitoid composition it is

likely that a number of intervening weathering cycles and grain size fractionation have resulted in substantial deviation of sediment compositions from this theoretical line.

Sample PJ4(5) is clearly differentiated from samples PJ3(16), PJ4(40), PJ3(20) and PJ3(23) using major element geochemistry on the basis of its lower relative K_2O concentration, falling to the left of the “average” granitoid weathering line. This result is in agreement with the results of semi-quantitative mineralogical analysis which indicates that there is only minor microcline (K-feldspar, 5-20%) in sample PJ4(5) (Table 8). While sample PJ3(23) also has only minor microcline, this sample has the lowest theoretical K-feldspar (based on molar proportions) of this group of four sediment samples and thus plots farthest away from the K-feldspar composition and closest to sample PJ4(5).

The relative deficit of K_2O in sample PJ4(5) may, in addition to an increased plagioclase feldspar content, indicate incorporation of a different sediment source or net loss of K_2O via factors such as particle size differentiation or more intense weathering leading to a net loss of K-feldspar. The latter seems less likely given that the yellow sands of PJ4(5) were identified in this region as the youngest dunes of the Bassendean Dune system, referred to as the Gnangara Dunes (Bastian, 1996; Lex Bastian, personal communication) and hence should be less weathered relative to the other samples. The relative difference in grain size of samples PJ3(16), PJ4(40), PJ3(20) and PJ3(23) compared to the PJ4(5) sample may also be the cause of compositional differentiation.

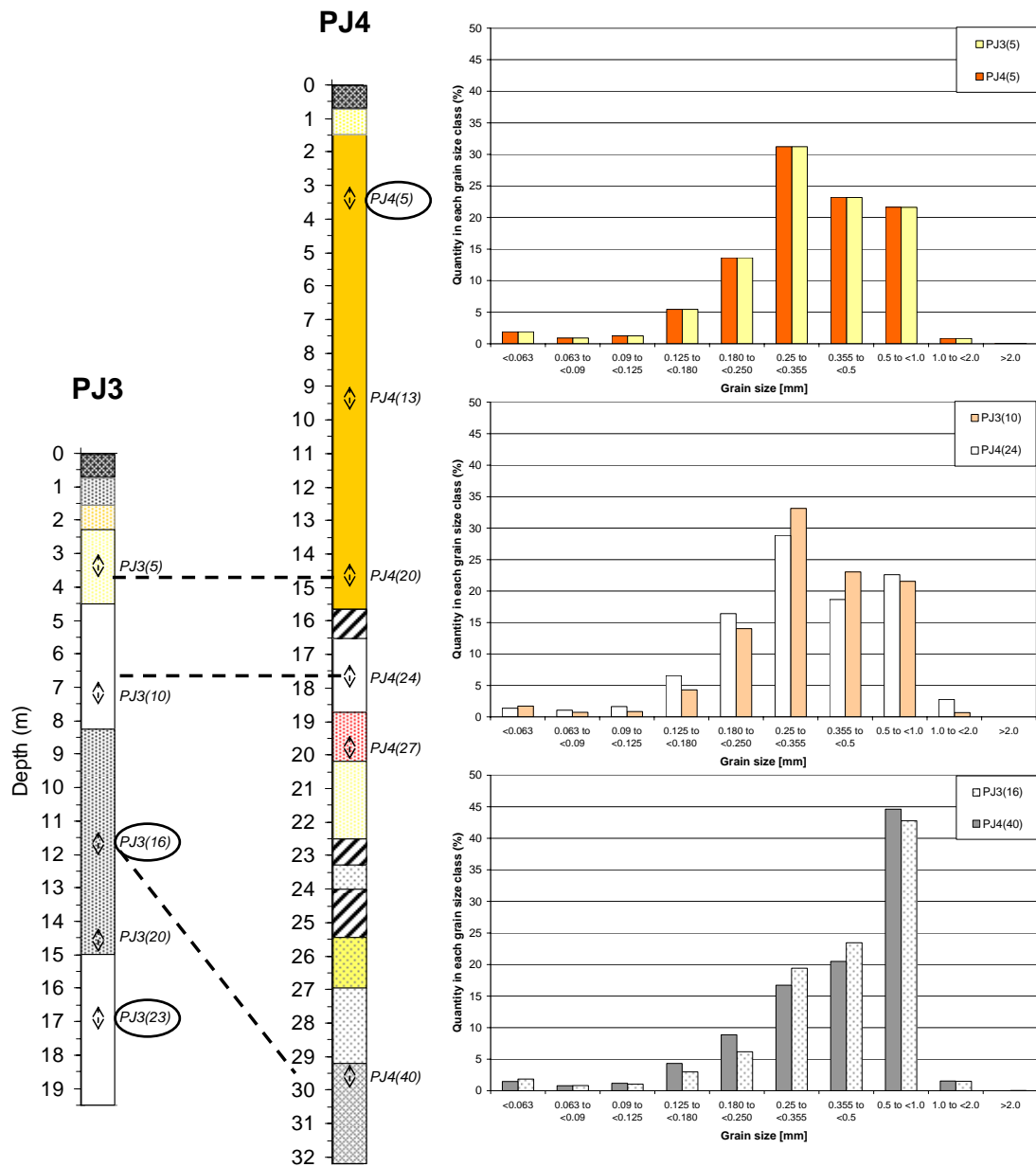


Figure 7. Stratigraphic correlation and selection of cores for the batch experiments (circled Core IDs). The elevation difference between the two sites is 11 m.

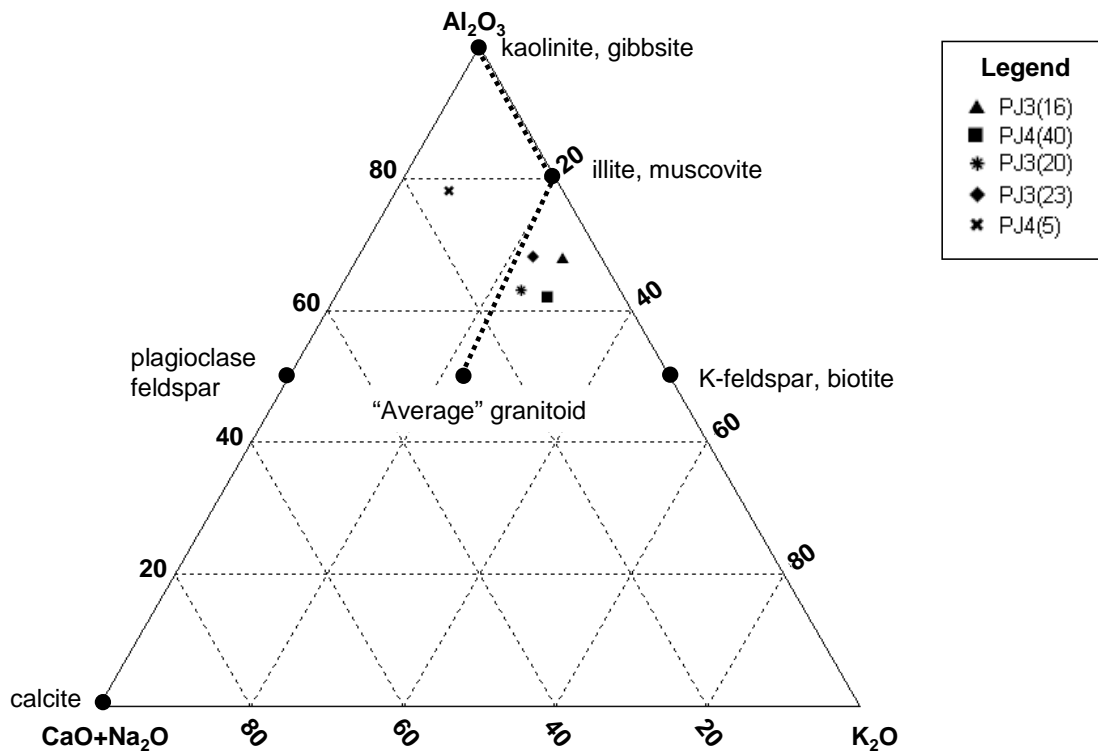


Figure 8. Ternary Al_2O_3 - $\text{CaO}+\text{Na}_2\text{O}$ - K_2O plot for core materials after Nesbitt and Young (1984). Mineral phases (expressed in molar proportions) relevant to the Bassendean sands including feldspars (plagioclase, and K-feldspar), clay minerals (illite and kaolinite), micas (biotite and muscovite) and calcite and gibbsite are depicted. An “average” granitoid composition similar to that of the parent Yilgarn Craton granitoids and a theoretical weathering line are also shown.

4.3. Experimental results

4.3.1. Batch experiments and RO water quality measurements

In evaluating the water quality results from the batch experiments, an important consideration is the range of variability in the hydrochemistry of RO water from the Kwinana Water Reclamation Plant (KWRP). Temporal variations in the RO water quality from KWRP may produce variations in the pH, TDS and EC. For example, pH is typically circumneutral; 7.0 ± 0.5 . The EC of the RO water is low and typically 2 - 4 mS/m as shown in Figure 9. The TDS of the RO water is usually between 12 and 24 mg/l. These data were from samples collected after the tap used to obtain RO water for the batch experiments (Palenque Blair; Water Corporation, personal communication). The water quality of the RO water used in the 48 batch bottles was not measured on Day 0, except one sample of RO water was submitted to the Chemistry Centre for analysis on the date of sampling and the EC was 2 mS/m.

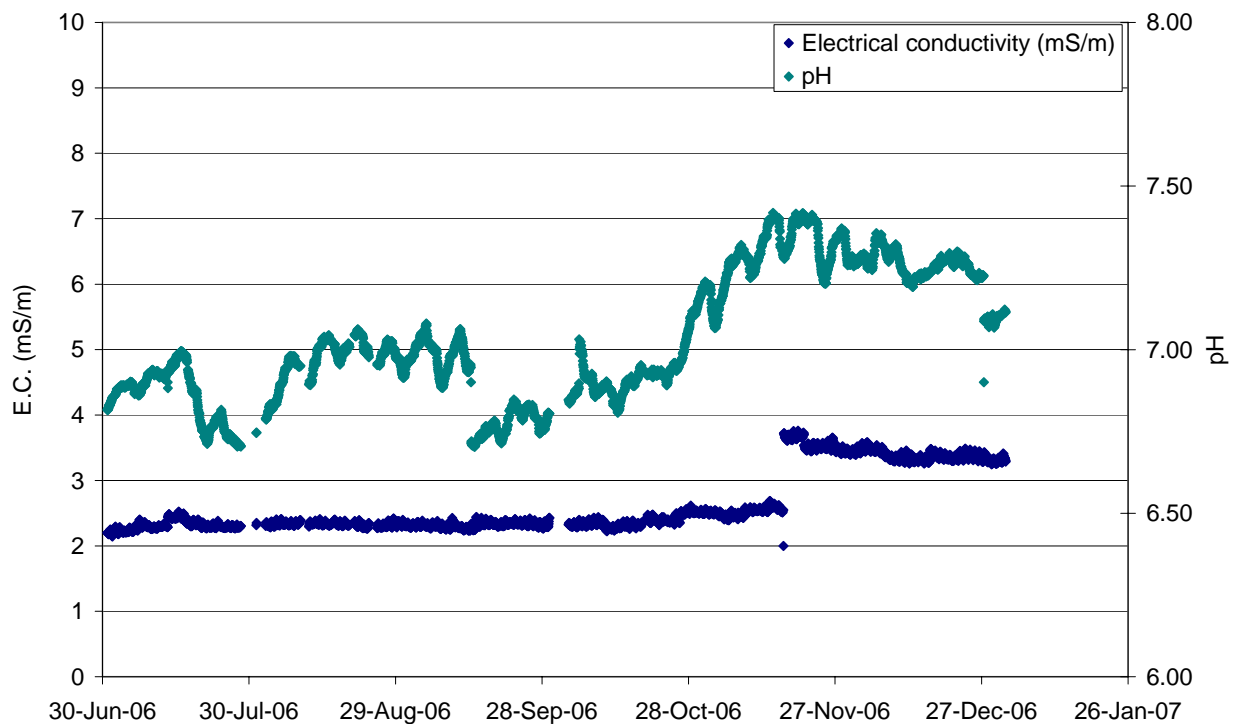


Figure 9. Water quality of RO product water sampled hourly at the Kwinana Water Reclamation Plant (Palenque Blair; Jeff Ibbott, Water Corporation, personal communication).

The results of the supernatant water quality from the batch experiments on Days 1, 3, 8, 14, and 28 are shown in Figure 10. In general, there is little evidence to suggest that substantial dissolution or mobilisation of solutes occurred as a result of mixing the different types of sand with RO water. The concentration of total dissolved solids and the electrical conductivity remained similar, between 19 and 22 mg/l with the exception of Experiment 6. The TDS of the supernatant in Experiment 6 increased to 30 mg/l on Day 8 and then returned to 21 mg/l on Days 14 and 28. It was likely this is due to a measurement error. Replicate experiments were not performed on Day 8 for Experiment 6.

During the 28-day experimental period, there were two RO water controls that were sampled on Days 8 and 28. The TDS of the controls remained at 19 mg/l and EC remained near 1.93 mS/m, but the Eh, pH and temperature of the RO water varied over time.

The temperature of the supernatants from the batch experiments and the RO water (controls) varied between 28 and 21 °C and decreased over time. Although the orbital shakers containing these bottles were set to 25 °C, it appears that either the temperature was not uniformly maintained in the machines or the temperature of the supernatants was affected by lab conditions during sampling.

Most of the batch experiments showed the same pattern of variation in pH for the supernatant, except Experiment 1, which showed a delay in rising to a maximum pH of 6.7 (average of triplicate samples). As the sediments equilibrated with the RO water within the first few days, the pH of the supernatants in most of the experiments went from an average of 6.3 to near neutral. The variation in pH on Day 1 is most likely related to variations in the pH of the RO water.

The variations in Eh were quite similar for all of the batches except Experiments 1 and 2. On Day 1, most of the supernatants from the batches had a similar Eh around 535 mV, except Experiment 2, which had an Eh value of 433 mV. The large decrease in Eh that occurred between Days 1 and 14 in Experiments 1 and 2 of 232 and 153 mV, respectively, could possibly be related to the higher organic carbon content of the PJ4(5) sediments (0.09%) compared with the sediments used in the other experiments. The lower carbon (~0.05%) in the PJ3(16) and PJ3(23) samples corresponds with the smaller decrease in Eh of the supernatants relative to the experiments conducted with PJ4(5) sediments. The oxidation of the organic carbon can cause reducing conditions. The organic carbon in the PJ3(16) and PJ3(23) sediments used in the other experiments may have also oxidized and caused the Eh decrease observed in the experiments conducted with these sediments, but it remains unclear without further soil testing.

In general, the water quality results for the batch experiments on Day 28 are constrained over a fairly limited range. By the end of the trial, the supernatant pH values for all of the batches were between 5.96 and 6.26; the pH of the RO water was 6.2. The supernatant Eh values were between 335 and 457 mV; the Eh of the RO water was 434 mV.

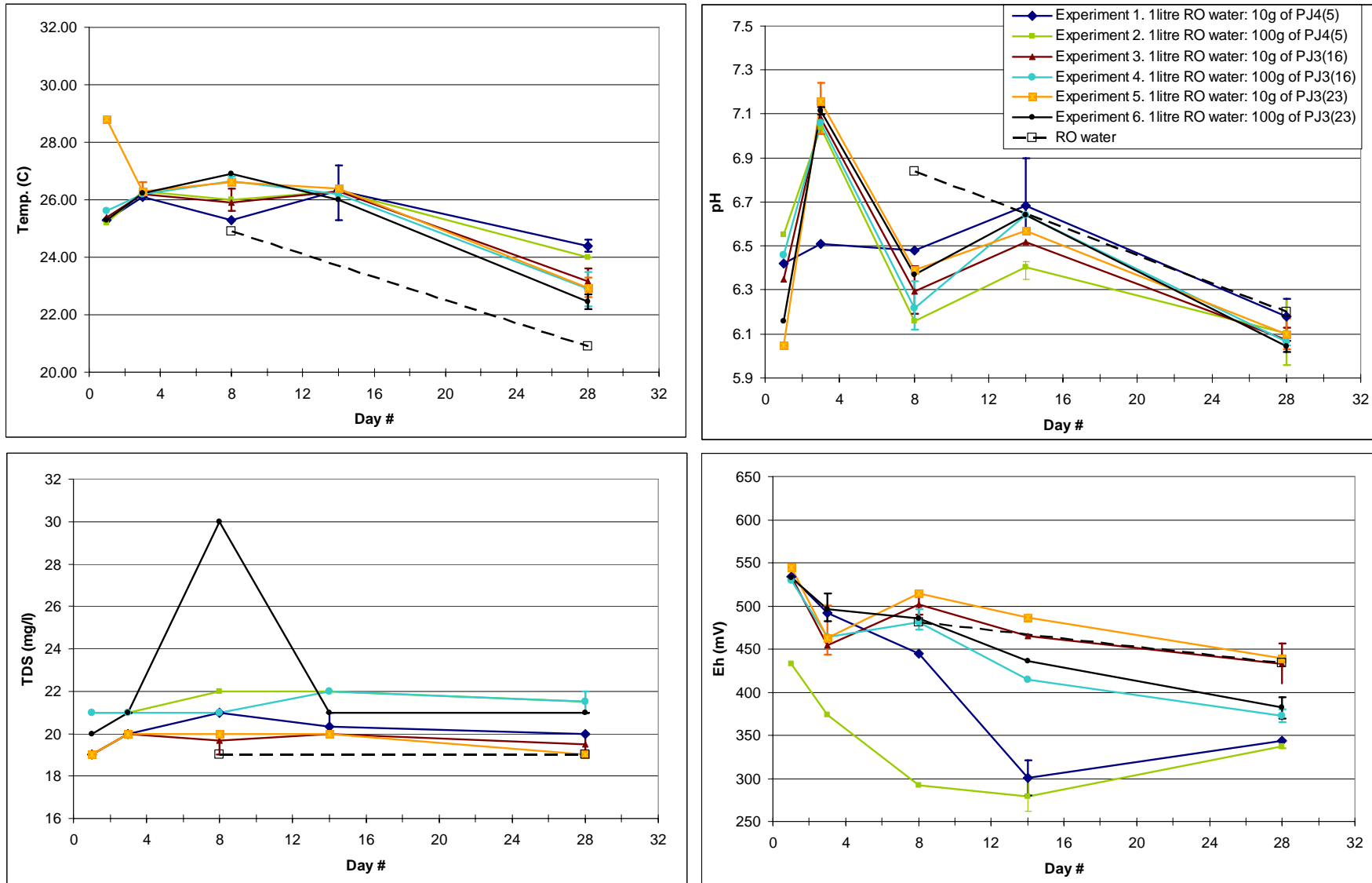


Figure 10. Trends in temperature, TDS, pH and EH for the supernatants from the batch experiments and RO water (control). Refer to Appendix 3 for experimental data.

4.3.2. Hydrochemistry results for the supernatants on Day 28 and RO water

The results for the Day 28 supernatants from the batch experiments are given in Table 14. Although water samples from Days 1, 3, 8 and 14 were preserved, the Day 28 samples were submitted first to evaluate the gross differences between samples. The results from Day 28 indicate that minimal leaching or mineral dissolution occurred using the RO water, thus it was unnecessary to investigate the minor changes in water chemistry that occurred incrementally on intervening days. The concentrations of the following analytes were all less than the detection limits indicated: U <0.0001 mg/l; As, Mn, Mo and Se <0.001 mg/l; Ba < 0.002 mg/l; Co and V < 0.005 mg/l.

The two RO water controls that were used for sampling on Days 0 and 28 have similar compositions. Although both RO water samples were collected at the same time from the KWRP Plant just prior to the batch experiments, there was a slight difference in EC for the sample that was placed in an orbit shaker for 28 days compared with the initial sample.

The small differences in the quantities of leached solutes between the experiments conducted with the yellow sands of PJ4(5) and white and grey sands from PJ3(16) and PJ3(23) likely reflect the differences in sediment geochemistry and mineralogy. The concentrations of Al and Fe in Experiments 1 and 2 are slightly higher due to the presence of iron oxide coatings. Most of the calcium carbonate has been leached from these sands, but there is slightly higher Ca in the supernatant from Experiment 2.

The ratio of RO water to sediments did affect the quantities of leached solutes in some cases, for example, Al, Fe, SO₄ and SiO₂. The most significant differences were the SiO₂ results where the supernatant concentrations in the experiments conducted with 100 g of sediment were as much as 10 times higher in the batches prepared with 10 g of sediments. Thus dissolved SiO₂ appears to be the solute most critically affected by the solid-solution ratio. This has implications for the dissolution and transport of silica in the superficial aquifer in the presence of RO water. Nevertheless, there were negligible differences in electrical conductivity of the supernatants in these experiments.

Although duplicate batches in glass and plastic bottles were prepared for Day 28 samples for all six experiments for DOC analysis, the results were all <1 mg/l. The DOC results from the batch experiments conducted in plastic bottles were similarly low.

Table 14. Hydrochemistry of the supernatants from the batch experiments on Day 28 and two RO water samples on Days 0 and 28. Analyses conducted by the Chemistry Centre of Western Australia. The ratio of RO water: sediment was corrected for the volume of pore water in the sediments.

	Expt 1	Expt 2	Expt 3	Expt 4	Expt 5	Expt 6	RO Water Day 0	RO Water Day 28
Ratio RO water: sediment	150	15	166	16	153	16	--	--
Al (mg/l)	0.270	0.720	0.009	0.018	0.011	0.015	<0.005	<0.005
Alkalinity, total expressed as CaCO ₃ (mg/l)	10	5	10	10	10	10	10	15
B (mg/l)	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.07
CO ₃ (mg/l)	<2	<2	<2	<2	<2	<2	<2	<2
Ca (mg/l)	<0.1	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Cd (mg/l)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0002	<0.0001	<0.0001
Cl (mg/l)	1.1	1.2	1.1	1.3	1.0	1.4	1.0	0.9
Cr (mg/l)	0.0012	0.002	<0.0005	<0.0005	0.0006	<0.0005	<0.0005	<0.002
Cu (mg/l)	<0.001	<0.001	<0.001	<0.001	0.001	0.001	<0.001	<0.005
DOC (mg/l)	<1	3	<1	<1	<1	<1	<1	<1
ECond (mS/m)	2.2	2.4	2.2	2.3	2.2	2.6	2.6	2
Fe (mg/l)	0.038	0.061	<0.005	0.009	<0.005	<0.005	<0.005	<0.005
HCO ₃ (mg/l)	12	6	12	12	12	12	12	18
K (mg/l)	0.5	0.5	0.5	0.4	0.5	0.5	0.5	0.5
La (mg/l)	--	--	--	--	--	--	--	<0.005

Mg (mg/l)	<0.1	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
N_NH3 (mg/l)	0.14	0.12	0.14	0.06	0.13	0.1	0.14	0.12
N_NO3 (mg/l)	0.11	0.13	0.1	0.1	0.1	0.1	0.1	0.09
Na (mg/l)	3.5	3.7	3.5	4.1	3.5	3.8	3.5	3.7
Ni (mg/l)	--	--	--	--	--	--	<0.001	<0.001
P_SR (mg/l)	<0.01	0.01	<0.01	<0.01	0.01	<0.01	<0.01	0.01
Pb (mg/l)	0.0004	0.0011	<0.0001	0.0001	0.0004	0.0003	<0.0001	0.0002
SO4_S (mg/l)	0.2	0.8	0.3	0.8	0.2	0.7	0.2	0.2
SiO2_Si (mg/l)	1.1	11.0	0.5	2.7	0.4	2.5	<0.1	0.1
Sr (mg/l)	--	--	--	--	--	--	--	<0.002
Zn (mg/l)	0.020	0.005	0.006	0.012	0.013	0.019	<0.005	<0.005

5. Discussion

The results from the analyses and batch experiments reveal only a subtle distinction between the different types of Bassendean sand selected from the PJ cores. The XRD analyses conducted on the magnetic fractions of the sand samples indicated that all of the samples contain ilmenite and its weathering products pseudorutile and rutile. The yellow sand sample PJ4(5) however, appears to be distinct from the other sands selected for the batch experiments with a lower molar proportion of K_2O (Figure 8) and a greater proportion of medium grain size sands.

It is evident that the PJ samples represent highly weathered, intensively leached sands. If further sites for managed aquifer recharge with RO water are situated in these types of sands, one can anticipate very little mobilisation of solutes. However, it is important to realise that there can be differences in the level of maturity within Dune systems (Bastian, 1996), which make it difficult to extend the batch results to new sites without adequate knowledge of the mineralogy and sediment characteristics.

With regard to the procedure developed for the batch experiments, the results showed that apart from dissolution of SiO_2 , the ratio of sand to RO water did not have a major impact. However, if the sediments were less mature and more solutes were mobilised, then the ratio would play a larger role in the interpretation of results and would need to be considered in modeling or extrapolating the results to a field setting. In the present case, the batch results revealed only minor changes in the water quality of the supernatant, but these results cannot be extrapolated to the case of less mature sands because the changes were smaller than the range of temporal variations in the quality of the RO water sourced from KWRP.

6. Conclusions

This study was intended to develop a procedure for conducting batch experiments for determining possible hydro- or geochemical interactions between RO water and sands of the Swan Coastal Plain and the range of solute concentrations that would likely result. The procedure is an effective, low-cost method for preliminary assessment of the possible compositional changes. Although supersaturation of the supernatant with secondary mineral products did not occur in this study, it would be a concern if using highly reactive sediments in a closed system, and where chemical reactions proceed rapidly. A longer term study focusing on Si dissolution from aquifer sediments may be warranted to assess its degree of mobility in RO water. Other methods for predicting the compositional changes in an aquifer such as flow-through columns packed with sediment or core plugs are better suited if supersaturation is a concern. In the present case, the procedure developed for this study was suitable for obtaining screening level information and the results will serve as a reference for future work.

The water chemistry changes from all of the batch experiments were minimal, which suggests that managed aquifer recharge with low salt, reverse osmosis water could proceed with sediments of similar characteristics without significant mobilisation of solutes. The procedure described in this study should be repeated using freshly cored material from other sites to develop a regional synthesis and over a longer period to address the question of Si dissolution. Given existing information about the systematic east-west changes in the maturity or weathering of sediments on the Swan Coastal Plain from heavy-mineral studies by Bastian (1996), one may be able to correlate the maturity index for specific dune

subsystems to the results from corresponding batch tests with RO water and use this information to predict the hydrochemistry at intermediate locations.

The main recommendation from this study is to replicate the geochemical and mineralogical analyses and batch experimental procedure using cored material from other areas that are specifically targeted for managed aquifer recharge on the Swan Coastal Plain. Further testing of material from the underlying confined aquifer should be investigated to fully comprehend the long-term hydrochemistry effects of recharging the Gnangara Mound with RO water.

Appendix 1

Table A1. Description of the batch experiment bottles intended for sampling on either Days 1, 3, 8, 14 or 28 and the quantities of sediment and RO water in each batch. The volume of water was calculated from mass, assuming the density of water is 1 g/cm³. The glass bottles (*) are indicated.

Experiment #	Sample day #	Bottle #	Core ID	Mass of sediment (g)	Volume of RO water (ml)
1	1	1	PJ4(5)	10.024	1,027.23
	3	2	PJ4(5)	10.019	1,025.42
	8	3	PJ4(5)	10.034	1,026.69
	14	4	PJ4(5)	10.060	1,027.81
	14	5	PJ4(5)	10.059	1,025.46
	14	6	PJ4(5)	10.025	1,029.22
	28	7	PJ4(5)	10.069	1,027.18
	28	45*	PJ4(5)	10.022	1,121.02
2	1	8	PJ4(5)	100.070	993.23
	3	9	PJ4(5)	100.017	992.19
	8	10	PJ4(5)	100.023	993.62
	14	11	PJ4(5)	100.031	992.23
	14	12	PJ4(5)	100.088	992.15
	14	13	PJ4(5)	100.089	991.82
	28	14	PJ4(5)	100.026	993.71
	28	46*	PJ4(5)	100.087	1,108.30
3	1	15	PJ3(16)	10.010	1,027.72
	3	16	PJ3(16)	10.044	1,029.21
	8	17	PJ3(16)	10.045	1,026.79
	8	18	PJ3(16)	10.013	1,026.20
	8	19	PJ3(16)	10.060	1,027.10
	14	20	PJ3(16)	10.031	1,025.96
	28	21	PJ3(16)	10.030	1,026.13
	28	47*	PJ3(16)	10.074	1,129.77
4	1	22	PJ3(16)	100.064	992.64
	3	23	PJ3(16)	100.030	990.00
	8	24	PJ3(16)	100.015	989.45
	8	25	PJ3(16)	100.033	991.32
	8	26	PJ3(16)	100.064	990.98

Experiment #	Sample day #	Bottle #	Core ID	Mass of sediment (g)	Volume of RO water (ml)
	14	27	PJ3(16)	100.034	989.35
	28	28	PJ3(16)	100.071	936.12
	28	48*	PJ3(16)	100.033	1,088.04
5	1	29	PJ3(23)	10.030	1,026.44
	3	30	PJ3(23)	10.026	1,028.10
	3	31	PJ3(23)	10.078	1,028.12
	3	32	PJ3(23)	10.070	1,026.50
	8	33	PJ3(23)	10.053	1,028.13
	14	34	PJ3(23)	10.081	1,025.54
	28	35	PJ3(23)	10.020	990.48
	28	49*	PJ3(23)	10.008	1,103.17
6	1	36	PJ3(23)	100.046	993.29
	3	37	PJ3(23)	100.048	993.05
	3	38	PJ3(23)	100.031	993.52
	3	39	PJ3(23)	100.032	993.98
	8	40	PJ3(23)	100.032	992.78
	14	41	PJ3(23)	100.083	992.14
	28	42	PJ3(23)	100.070	991.48
	28	50*	PJ3(23)	100.098	1,089.87

Appendix 2

Table A2. Grain size analysis results for PJ3(5). The total amount of PJ3(5) sample used for sieving was 99.41 g. The sum of the sediment residuum was 99.47 g, thus there was a measurement error of 0.06 g.

Sieve size (mm)	Mass of full sieve (g)	Mass of empty sieve (g)	Mass of sediment in each sieve after sieving (g)	Percentage in each sieve class
2.000	410.81	410.80	0.01	0.01
1.000	385.00	384.16	0.84	0.84
0.500	360.98	339.49	21.49	21.60
0.355	345.26	322.20	23.06	23.18
0.250	350.21	319.17	31.04	31.21
0.180	321.10	307.52	13.58	13.65
0.125	305.56	300.14	5.42	5.45
0.090	296.54	295.30	1.24	1.25
0.063	292.22	291.31	0.91	0.91
<0.063	274.79	272.91	1.88	1.89
Sum:			99.47	100.00

Table A3. Grain size analysis results for PJ3(10). The total amount of sample used for sieving was 101.33 g. The sum of the sediment residuum was 101.31 g, thus the sediment loss was 0.02 g.

Sieve size (mm)	Mass of full sieve (g)	Mass of empty sieve (g)	Mass of sediment in each sieve after sieving (g)	Percentage in each sieve class
2.000	410.82	410.82	0.00	0.00
1.000	384.87	384.18	0.69	0.68
0.500	361.34	339.52	21.82	21.54
0.355	345.53	322.20	23.33	23.03
0.250	352.77	319.20	33.57	33.14
0.180	321.76	307.56	14.20	14.02
0.125	304.52	300.17	4.35	4.29
0.090	296.20	295.33	0.87	0.86
0.063	292.05	291.31	0.74	0.73
<0.063	274.69	272.95	1.74	1.72
Sum:			101.31	100.00

Table A4. Grain size analysis results for PJ3(16). The total amount of sample used for sieving was 107.48 g. The sum of the sediment residuum was 105.3 g, thus the sediment loss was 2.18 g.

Sieve size (mm)	Mass of full sieve (g)	Mass of empty sieve (g)	Mass of sediment in each sieve after sieving (g)	Percentage in each sieve class
2.000	410.86	410.82	0.04	0.04
1.000	385.81	384.22	1.59	1.51
0.500	384.54	339.49	45.05	42.78
0.355	346.88	322.20	24.68	23.44
0.250	337.48	317.05	20.43	19.40
0.180	314.06	307.56	6.50	6.17
0.125	303.32	300.19	3.13	2.97
0.090	296.41	295.32	1.09	1.04
0.063	292.19	291.34	0.85	0.81
<0.063	274.88	272.94	1.94	1.84
Sum:			105.30	100.00

Table A5. Grain size analysis results for PJ3(23). The total amount of sample used for sieving was 101.39 g. The sum of the sediment residuum was 101.46 g, thus there was a measurement error of 0.07 g.

Sieve size (mm)	Mass of full sieve (g)	Mass of empty sieve (g)	Mass of sediment in each sieve after sieving (g)	Percentage in each sieve class
2.000	410.83	410.83	0.00	0.00
1.000	385.11	384.23	0.88	0.87
0.500	373.75	339.49	34.26	33.77
0.355	345.82	322.21	23.61	23.27
0.250	340.15	319.20	20.95	20.65
0.180	317.51	307.56	9.95	9.81
0.125	304.76	300.18	4.58	4.51
0.090	297.06	295.33	1.73	1.71
0.063	292.78	291.34	1.44	1.42
<0.063	277.00	272.94	4.06	4.00
Sum:			101.46	100.00

Table A6. Grain size analysis results for PJ4(5). The total amount of sample used for sieving was 99.57 g. The sum of the sediment residuum was 99.44 g, thus the sediment loss was 0.13 g.

Sieve size (mm)	Mass of full sieve (g)	Mass of empty sieve (g)	Mass of sediment in each sieve after sieving (g)	Percentage in each sieve class
2.000	410.81	410.80	0.01	0.01
1.000	385.00	384.15	0.85	0.85
0.500	360.98	339.48	21.50	21.62
0.355	345.26	322.20	23.06	23.19
0.250	350.21	319.17	31.04	31.21
0.180	321.10	307.55	13.55	13.63
0.125	305.56	300.15	5.41	5.44
0.090	296.54	295.31	1.23	1.24
0.063	292.22	291.31	0.91	0.92
<0.063	274.79	272.91	1.88	1.89
Sum:			99.44	100.00

Table A7. Grain size analysis results for PJ4(13). The total amount of sample used for sieving was 99.43 g. The sum of the sediment residuum was 99.08 g, thus the sediment loss was 0.35 g.

Sieve size (mm)	Mass of full sieve (g)	Mass of empty sieve (g)	Mass of sediment in each sieve after sieving (g)	Percentage in each sieve class
2.000	410.85	410.85	0.00	0.00
1.000	384.70	384.17	0.53	0.53
0.500	359.78	339.51	20.27	20.46
0.355	344.91	322.19	22.72	22.93
0.250	345.56	319.18	26.38	26.62
0.180	321.28	307.57	13.71	13.84
0.125	309.80	300.17	9.63	9.72
0.090	297.89	295.33	2.56	2.58
0.063	292.66	291.33	1.33	1.34
<0.063	274.88	272.93	1.95	1.97
Sum:			99.08	100.00

Table A8. Grain size analysis results for PJ4(20). The total amount of sample used for sieving was 98.49 g. The sum of the sediment residuum was 100.52 g, thus there was a measurement error of 2.03 g.

Sieve size (mm)	Mass of full sieve (g)	Mass of empty sieve (g)	Mass of sediment in each sieve after sieving (g)	Percentage in each sieve class
2.000	410.80	410.80	0.00	0.00
1.000	385.71	384.18	1.53	1.52
0.500	361.01	339.48	21.53	21.42
0.355	337.77	322.20	15.57	15.49
0.250	344.49	319.19	25.30	25.17
0.180	325.73	307.57	18.16	18.07
0.125	313.13	300.16	12.97	12.90
0.090	297.90	295.33	2.57	2.56
0.063	292.74	291.32	1.42	1.41
<0.063	274.40	272.93	1.47	1.46
Sum:			100.52	100.00

Table A9. Grain size analysis results for PJ4(24). The total amount of sample used for sieving was 96.66 g. The sum of the sediment residuum was 96.69 g, thus there was a measurement error of 0.03 g.

Sieve size (mm)	Mass of full sieve (g)	Mass of empty sieve (g)	Mass of sediment in each sieve after sieving (g)	Percentage in each sieve class
2.000	410.81	410.81	0.00	0.00
1.000	386.85	384.17	2.68	2.77
0.500	361.38	339.51	21.87	22.62
0.355	340.25	322.21	18.04	18.66
0.250	347.08	319.20	27.88	28.83
0.180	323.42	307.55	15.87	16.41
0.125	306.56	300.20	6.36	6.58
0.090	296.93	295.33	1.60	1.65
0.063	292.38	291.33	1.05	1.09
<0.063	274.29	272.95	1.34	1.39
Sum:			96.69	100.00

Table A10. Grain size analysis results for PJ4(27). The total amount of sample used for sieving was 100.15 g. The sum of the sediment residuum was 100.06 g, thus the sediment loss was 0.09 g.

Sieve size (mm)	Mass of full sieve (g)	Mass of empty sieve (g)	Mass of sediment in each sieve after sieving (g)	Percentage in each sieve class
2.000	410.80	410.80	0.00	0.00
1.000	384.49	384.15	0.34	0.34
0.500	358.99	339.47	19.52	19.51
0.355	348.54	322.17	26.37	26.35
0.250	351.94	319.16	32.78	32.76
0.180	319.95	307.51	12.44	12.43
0.125	304.36	300.16	4.20	4.20
0.090	296.70	295.30	1.40	1.40
0.063	292.41	291.30	1.11	1.11
<0.063	274.82	272.92	1.90	1.90
Sum:			100.06	100.00

Table A11. Grain size analysis results for PJ4(40). The total amount of sample used for sieving was 99.4 g. The sum of the sediment residuum was 99.61 g, thus there was a measurement error of 0.21 g.

Sieve size (mm)	Mass of full sieve (g)	Mass of empty sieve (g)	Mass of sediment in each sieve after sieving (g)	Percentage in each sieve class
2.000	410.85	410.85	0.00	0.00
1.000	385.79	384.27	1.52	1.53
0.500	384.01	339.56	44.45	44.62
0.355	342.62	322.22	20.40	20.48
0.250	335.91	319.24	16.67	16.74
0.180	316.41	307.57	8.84	8.87
0.125	304.51	300.21	4.30	4.32
0.090	296.53	295.35	1.18	1.18
0.063	292.13	291.34	0.79	0.79
<0.063	274.43	272.97	1.46	1.47
Sum:			99.61	100.00

Appendix 3

Table A12. Water quality measurements for the supernatant of the batch experiments and two samples of RO water, recorded on the sample days indicated.

Experiment	Sample day #	Bottle #	Core ID	Temp. (°C)	pH	E.C. (mS/m)	TDS (mg/l)	Eh (mV)
1	1	1	PJ4(5)	25.3	6.42	NA	19	533.8
	3	2	PJ4(5)	26.1	6.51	NA	20	491.7
	8	3	PJ4(5)	25.3	6.48	2.04	21	445.0
	14	4	PJ4(5)	26.5	6.9	2.01	20	280.1
	14	5	PJ4(5)	27.2	6.57	2.09	21	301.1
	14	6	PJ4(5)	25.3	6.58	1.99	20	321.3
	28	7	PJ4(5)	24.2	6.26	1.99	20	344.0
	28	45*	PJ4(5)	24.6	6.1	1.98	20	344.0
2	1	8	PJ4(5)	25.2	6.55	NA	21	433.1
	3	9	PJ4(5)	26.3	7.04	NA	21	373.4
	8	10	PJ4(5)	26.0	6.16	2.19	22	292.0
	14	11	PJ4(5)	26.1	6.43	2.2	22	300.3
	14	12	PJ4(5)	26.3	6.35	2.18	22	276.4
	14	13	PJ4(5)	26.5	6.43	2.18	22	262.0
	28	14	PJ4(5)	24.0	6.25	2.17	22	335.3
	28	46*	PJ4(5)	24.0	5.96	2.15	21	338.4
3	1	15	PJ3(16)	25.4	6.35	NA	19	533.4
	3	16	PJ3(16)	26.2	7.08	NA	20	453.9
	8	17	PJ3(16)	25.7	6.28	1.96	20	489.3
	8	18	PJ3(16)	25.6	6.19	1.94	20	512.3
	8	19	PJ3(16)	26.4	6.41	1.95	19	503.6
	14	20	PJ3(16)	26.3	6.52	1.98	20	465.0
	28	21	PJ3(16)	23.6	6.02	1.96	20	409.7
	28	47*	PJ3(16)	22.7	6.13	1.93	19	456.7
4	1	22	PJ3(16)	25.6	6.46	NA	21	529.9
	3	23	PJ3(16)	26.2	7.06	NA	21	464.0
	8	24	PJ3(16)	26.5	6.34	2.15	21	473.5
	8	25	PJ3(16)	26.6	6.19	2.14	21	473.1
	8	26	PJ3(16)	26.8	6.12	2.13	21	496.2
	14	27	PJ3(16)	26.2	6.64	2.18	22	414.5
	28	28	PJ3(16)	23.5	6.05	2.15	21	364.9
	28	48*	PJ3(16)	22.3	6.08	2.16	22	380.5

Experiment	Sample day #	Bottle #	Core ID	Temp. (°C)	pH	E.C. (mS/m)	TDS (mg/l)	Eh (mV)
5	1	29	PJ3(23)	28.8	6.05	NA	19	544.4
	3	30	PJ3(23)	26.2	7.24	NA	20	446.0
	3	31	PJ3(23)	26.6	7.01	NA	20	443.2
	3	32	PJ3(23)	26.1	7.22	NA	20	500.1
	8	33	PJ3(23)	26.6	6.39	1.95	20	514.4
	14	34	PJ3(23)	26.4	6.57	1.96	20	486.7
	28	35	PJ3(23)	23.3	6.03	1.94	19	440.1
	28	49*	PJ3(23)	22.6	6.17	1.91	19	438.5
6	1	36	PJ3(23)	25.3	6.16	NA	20	532.8
	3	37	PJ3(23)	26.3	7.1	NA	21	482.1
	3	38	PJ3(23)	26.3	7.11	NA	21	514.1
	3	39	PJ3(23)	26.1	7.13	NA	21	492.1
	8	40	PJ3(23)	26.9	6.37	2.94	30	485.4
	14	41	PJ3(23)	26.0	6.64	2.12	21	436.5
	28	42	PJ3(23)	22.7	6.02	2.13	21	394.5
	28	50*	PJ3(23)	22.2	6.07	2.15	21	369.0
RO water	8	52	water	24.9	6.84	1.93	19	481.2
RO water	28	44	water	20.9	6.2	1.92	19	434.3

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