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ASSESSMENT OF ENVIRONMENTAL AND PUBLIC HEALTH RISK OF ON-SITE WASTEWATER TREATMENT SYSTEMS

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ABSTRACT

On-site wastewater treatment systems are common throughout Australia, with most systems located in the urban fringe and rural regions. The number of on-site treatment systems is increasing rapidly as these areas undergo more intensive development. Consequently, there is a significant increase in environmental and public health risks associated with these systems. This has lead to the recognition of the need for the articulation of treatment standards and criteria which are flexible and robust to satisfy specific public health and environmental requirements. Currently, these concepts are not being widely applied in on-site treatment of wastewater.

A research project was undertaken to identify and assess the environmental and public health risks associated with on-site wastewater treatment systems in an area within the Gold Coast region, Southeast Queensland, Australia. A detailed surface and groundwater investigation including nutrient and microbiological analysis and modeling studies were undertaken to identify and assess the risk of contamination from nutrients and pathogenic organisms discharged from on-site systems. This also included the assessment of the potential risks in relation to high densities of on-site systems. High levels of nutrients, in particular nitrate, has been found in an unconfined shallow aquifer within the study area, directly below high densities of systems. Similarly, high fecal coliforms have also been observed in various locations throughout the area. Therefore, it crucial that the impact of high densities of on-site systems on shallow groundwater is appropriately assessed in order to minimise the potential risks to the environment.

KEYWORDS. On-site wastewater systems, groundwater, risk assessment

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INTRODUCTION

On-site wastewater treatment systems (OWTS) are common throughout Australia, with approximately 17% of households currently serviced by these systems (O'Keefe 2001). The most common form of OWTS used is the typical septic tank-subsurface soil adsorption system. However, secondary treatment systems, such as aerobic systems, are being more widely used. The use of on-site wastewater treatment systems is increasing rapidly as rural and urban fringe areas continue to be developed. Consequently, there is an increase in potential environmental and public health risks associated with these systems. On-site wastewater treatment systems are capable of providing acceptable treatment of sewage, if they are suitably designed and managed. This includes adequate recognition of the necessary soil and site factors which play an important role in providing proper performance, and appropriate management processes to ensure that the inherent risks to the surrounding environment are reduced (Dawes and Goonetilleke 2003).

The risk of contamination of groundwater and surface water resources due to excess nutrients and pathogens from OWTS is a major concern, particularly if used as a potable source. Numerous cases of contamination of ground and surface water resources as a result of poor OWTS performance have been reported in research literature (Hagedorn et al. 1981; Hoxley and Dudding 1994; McNeillie et al. 1994). High nitrogen levels in potable water supplies can cause *methaemoglobinaemia* in young children and have also been known to cause carcinogenic nitrosamines (Bouwer and Idelovitch 1987). Additionally, high nutrient levels in surface water bodies is a major issue if suitable conditions for the occurrence of eutrophication is created. However, the most concern to water resources is contamination by viable pathogenic organisms. Numerous cases of illness and disease as a result of contaminated water supplies resulting from poor effluent treatment by OWTS have been reported in literature (Cliver 2000). Additionally, an important issue that has not received adequate attention is the impact of high densities or clusters of OWTS. High system densities can significantly increase the potential risk of contamination of the surrounding environment and to public health. Past research has reported on contamination issues in areas that contain high densities of on-site systems (for example Geary and Whitehead 2001, Lipp et al. 2001). However, Geary and Whitehead (2001) noted that although there was evidence that areas with OWTS densities greater than 15/km^2 may present potential groundwater contamination issues, further research was necessary in order to clarify the actual impact clusters had on the receiving environment. Therefore in addition to the general operating performance of OWTS, it is necessary that clusters of on-site systems are also considered in assessing environmental and public health risks.

A project was undertaken on the Gold Coast, in the southeast of Queensland State, Australia, to develop a generic risk assessment framework for assessing the inherent environmental and public health risks associated with the siting and design of OWTS. This paper highlights the outcomes of a groundwater and surface water investigation in a small coastal community in the northern Gold Coast area. This study will be used as a benchmark in order to establish the environmental and public health risks associated with OWTS and in particular clusters of systems.

METHODS AND MATERIALS

Research Area

The project area includes the entire Gold Coast City Council jurisdictional area, encompassing approximately 1,500km^2, in which over 15,000 on-site wastewater treatment systems currently exist. Additionally, within this region, several areas have been identified as being highly sensitive to OWTS performance, mostly due to their soil conditions and landscape factors (Dawes and Goonetilleke 2003), as well as having high system densities. One of the most significant of these areas, Jacobs Well, is presented as a case study to highlight the inherent environmental and public health risks associated with clusters of OWTS. The outcomes from this specific case study, as well as those on other identified sensitive areas will be used in developing the overall generic risk assessment process for the Gold Coast region. Jacobs Well (Figure 1) is a small coastal community, situated amongst agricultural land, mostly sugar cane fields, with the eastern edge running along the main channel of the *Jumpinpin-Broadwater* estuary. The Jacobs Well community is solely dependant on on-site wastewater treatment, both septic tank-soil adsorption (ST-SA) systems and secondary treatment systems (typically aerobic wastewater treatment systems or AWTS), as currently no centralised sewage reticulation systems exist in the northern outskirts of the Gold Coast region. The reliance on on-site systems is a major concern, as the average block size in this area is approximately 400m^2, producing a very high density of treatment systems (290/km^2). As such, the potential impact on both the underlying groundwater and adjacent surface water resources can be significant.

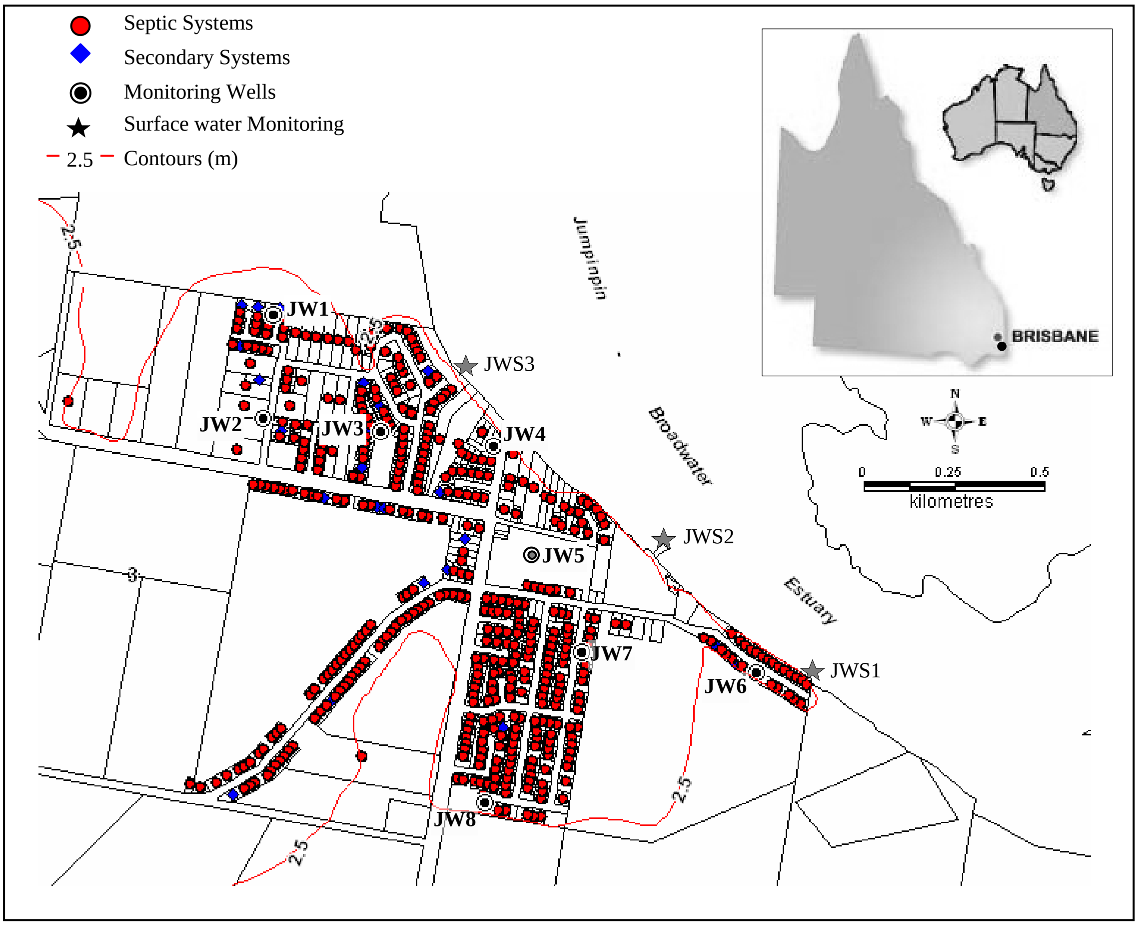

Figure 1. Jacobs Well study area

The Jacobs Well area is currently undergoing extensive new housing developments, which can substantially add to the severity of the consequences. The coastal aquifers at Jacobs Well are used primarily for irrigation, with extraction of water achieved using spear pumps. The estuary is widely used for recreational activities.

According to the Australian Soil Classification (Isbell 1996), the major soil conditions in the area consist of two main soil groups. Salic Hydrosols or permanently saturated soils (equivalent to Ultisols or Inceptisols (NRCS 1999)) account for most of the soil directly within Jacobs Well. This grades into Bleached-Orthic Tenosols (similar to Inceptisols or Entisols (NRCS 1999)) further inland covering the majority of the agricultural land. The area is a flat coastal plan, with an average ground elevation ranging from 2-3m at its highest point. The geology beneath Jacobs Well consists of Cainozoic (Holocene) dune sand underlain by layers of ‘coffee rock’ or sand rock 3-5m below the surface, with a sandy clay horizon from 10-30m. This creates two aquifers with substantially different characteristics. A shallow perched aquifer lies on top of the sand rock layer, providing an average water table depth of only 0.5m below the surface. A semi-confined shallow aquifer is located beneath the sand rock, which in turn is confined at the bottom by the sandy clay horizon. Although retaining a fairly low permeability, the sand rock has numerous cracks and fissures which allow flow from the unconfined aquifer to penetrate into the semi-confined main aquifer. Both aquifers are recharged mostly from rainfall (1200mm annual average rainfall). However, due to the large number of on-site sewage treatment systems, an appreciable recharge of wastewater can be expected to occur.

Groundwater and Surface Water Monitoring

To assess the environmental and public health risks associated with OWTS in Jacobs Well, a combined groundwater-surface water sampling program was undertaken. Groundwater wells were initially located on a regular square grid pattern. Subsequently, additional wells were also located in order to assess the impacts on groundwater quality beneath clusters of primary (septic tank-soil adsorption systems) and secondary (aerobic) treatment systems. Figure 1 shows the locations of the installed groundwater monitoring wells. Wells JW2 and JW3 were installed near clusters of secondary wastewater treatment systems, with the remainder situated amongst the septic systems. Monitoring wells, except for JW5, were installed to a depth of 3m, with the lower 1.5 metres being screened. This allowed sampling from the wells to be taken at an average depth of half a metre below the potentiometric surface of the unconfined aquifer. The monitoring wells were constructed using perforated 50mm PVC pipe, and a suitable filter pack was installed to prevent migration of fine sand particles and silt collection in the wells. The wells were flush mounted and covered with secure concrete caps. Monitoring Well JW5 was a pre-existing well which penetrates the semi-confined aquifer to a depth of approximately 10m below the surface, with the lower three meters screened. Additionally, surface water samples were collected from three identified monitoring locations (JWS1-JWS3) along the main estuary.

Sample Collection and Parameters

Surface and groundwater samples were collected from each site location on a fortnightly basis for three months. This sampling period was selected to, firstly collect samples during the drier winter period, following on into the spring wet season. Each groundwater well was purged using hand bailers to remove at least three well volumes and to allow recharge before sample collection. Samples were collected using clean, sterilised hand bailers and stored in clean PVC sample bottles. Samples for microbiological analysis were collected in sterilised glass bottles. All samples were stored in crushed ice until analysis could be undertaken and were analysed within 24 hours.

Collected water samples were tested for several physical and chemical parameters including pH, EC, NO_3^--N and PO_4^{3-}. These parameters were selected specifically for assessment of environmental risks. Samples were also analysed for several bacterial indicators including Total Coliforms (TC), Total fecal coliforms and E coli which were enumerated by membrane filtration (47mmΦ 0.45um cellulose filters), using M-Endo broth (Millipore Corporation, Bedford, Massachusetts) with appropriate dilutions aiming to achieve 20-80 colonies per filter. Dark colonies formed were taken to be coliforms whilst shiny colonies were considered as fecal coliforms. Identified E coli colonies were subsequently tested for confirmation of E Coli Type I (predominately human origin), using the standard Indole method and Eijkmann tests (APHA 1999). Positive samples in both tests indicated that the E coli colonies were predominately of human origin.

RESULTS

Groundwater and Surface Water Results

Results from the groundwater investigations show substantial variations in most parameters, mostly due to the hydrogeologic conditions as well as the spatial distribution of the on-site treatment systems. The results from the field investigations have however, highlighted several important contaminant issues, as shown in Table 1. In relation to nutrient levels, most monitoring wells reported NO_3^--N levels far in excess of the 10mg/L water quality standard in relation to drinking water (ANZECC, 2000). It was apparent from the results that levels further inland and away from the estuary retained higher NO_3^--N levels, with levels reducing towards the estuary interface. Obviously, a dilution effect occurs within this groundwater/surface water zone. Although no exact limits apply to phosphate levels in water, the sample results have shown significant phosphate concentrations in the groundwater samples, with an occasional a high peak being observed. The highest phosphate levels have been recorded at wells JW1, JW2, JW7 and JW8. This is most likely due to the general groundwater flow direction and climatic changes.

Table 1. Averaged Results of Groundwater and Surface Water Investigations

Well	Mean pH	Mean EC μS/cm	Mean NO_3^--N (range)	Mean PO_4^{3-} (range)	Mean Total Coliforms CFU/100mL	Mean Fecal Coliforms CFU/100mL	Mean E coli CFU/100mL
Groundwater							
JW1	6.01	235.16	44.58	6.35	3983	128	40
JW2	5.95	178.87	42.73	6.81	1221	68	37
JW3	5.96	822.74	112.15	3.39	4520	153	70
JW4	5.55	378.22	38.33	4.78	760	113	10
JW5	5.41	207.43	14.36	4.33	2325	65	40
JW6	6.74	422.28	15.04	3.90	9729	180	180
JW7	3.90	143.61	46.99	8.92	2735	35	43
JW8	5.08	235.80	35.70	6.92	1524	123	20
Surface Water							
JWS1	7.54	44262.34	8.35	2.82	94	10	7
JWS2	7.68	44039.60	7.06	3.24	205	54	30
JWS3	7.71	43100.92	10.46	2.49	313	52	48

The impact of agricultural practices, namely the application of fertiliser on local cane and turf farms, on the background concentrations of the aquifers does impose some questions in relation to the source of the high nitrate and phosphate levels. Although farms surround the Jacobs Well area, the closest cane farm to Jacobs Well is approximately 500m south from monitoring well JW8, and over a kilometre north west from JW1 and JW2. Therefore, although it is observed that high levels in these wells may suggest outside sources of contaminants, a significant increase in nitrates does occur in some wells in the centre of the community. This increase in concentration levels directly below Jacobs Well, is therefore, predicted to result from the OWTS.

Results from the microbiological tests indicate significant fecal coliform contamination in the immediate shallow groundwater. However, as the water is used mostly for irrigation, only two sites, JW3 and JW6 do not comply with the 150 fecal coliforms/100mL limit for recreational water quality (ANZECC 2000). Several other sites do have fecal contamination just below this limit. Well JW5, which penetrates to the semi-confined aquifer, also shows significant fecal and E coli contamination within the groundwater, indicating that effluent is able to percolate through the ‘coffee rock’ and into the semi-confined aquifer. The highest level of fecal and E coli contamination was observed at JW6, which lies close to the estuary. This is significant as this area is currently undergoing residential development activities, which will lead to further increase in the number of OWTS in the direct vicinity. A significant difference was noted between the quality of groundwater samples from wells located near septic systems and those located near secondary treatment systems. The nitrate concentrations were significantly higher in JW2 and JW3 than all the other wells. This indicates that higher nitrate concentrations are being emitted from secondary systems in this particular case. In contrast, monitoring wells located in clusters of septic systems were observed to have higher phosphate plumes.

The surface water samples are indicated that nitrate and fecal coliform levels are significantly high, with site JWS3 recording the highest nitrate and fecal coliform levels. However, levels of nitrate are significantly lower than groundwater samples near the estuary. In relation to the fecal coliforms levels, higher counts may be due to animal and bird droppings as well as from runoff after rainfall events. Therefore, further quantification of the source of the high levels of fecal coliforms in surface water samples should be investigated to assess the level of public health risk associated with utilizing these waters.

Modeling

The results of the groundwater sampling were used to calibrate a contaminant transport model using MODFLOW-2000 to establish the general groundwater flow paths and the extent of nitrate and phosphate contaminant plumes emitted from both the ST-SA systems and AWTS. Due to the similar soil conditions throughout the Jacobs Well area, the aquifers were modelled as being homogenous, although variation in the permeability values between soil layers were significant. Values for permeability were established though in-situ pump tests or via falling head permeability tests conducted on soil cores taken from the study area. Core samples taken from the Jacobs Well also indicated that the indurated sand layer or ‘coffee rock’ had numerous cracks and fissures throughout its structure, which provides a much higher permeability than would be typical of a cemented or hardpan soil layer. Therefore, the ‘coffee rock’ layer was considered to be an aquitard rather than an aquiclude or confining layer.

The recharge areas for the model were taken as the entire Jacobs Well area in terms of rainfall. Rainfall was determined to recharge approximately 135mm/year (rainfall minus evaporation) based on the average annual value for the area and pan evaporation values. A nearby lake to the west, resultant from sand-mining operations, was estimated to provide an additional 10% (of rainfall) recharge to the semi-confined aquifer. Additionally, the effluent discharged from the ST-SA systems and AWTS in Jacobs Well would also provide a substantial amount of recharge to the aquifers. The general direction of groundwater flow at Jacobs Well runs northwest, except for the more southern reaches, where it flows southwards or towards the estuary as depicted in the model output in Figure 2 defining the current contaminate plume locations. This highlights that agriculture may not have as much of a direct impact as previously thought, particularly from the south. The model also shows that the current sand mine operations to the west has had a significant effect on the ground flow. The modelled NO_3^--N contaminant plumes all highlight higher concentrations surrounding the secondary treatment systems, as indicated by the darker patches in Figure 2. This is typical of secondary treatment systems in that they essentially transform most of the nitrogen into the nitrate species. However what is of great concern is the distance that the nitrate has travelled. The model indicated that one particular plume covers approximately 200m in the unconfined aquifer from the original discharge point. The main reason for this is most likely due to the high permeability of the sand material, and the lower permeability of the underlying ‘coffee’ rock which would essentially force the plume to move laterally before gradually seeping through the cracks and fissures in the ‘coffee rock’ and into the semi-confined aquifer. However, in contrast to this, the phosphate plumes tend to show higher levels of phosphorus being emitted from the septic systems as highlighted in Figure 3, which shows the modeled phosphate plume below Jacobs Well.

In relation to the density of OWTS, it was evident from the modelling that high densities of systems do significantly increase the potential for groundwater contamination. As highlighted in both Figures 2 and 3, plumes (both NO_3^--N and PO_4^{3-}) from systems on larger residential blocks were relatively smaller with concentrations reducing substantially within the first 50 to 100m. Systems on the smaller lot sizes seemed to contribute to a generalised plume, which is shown to be approximately 900m in length. This is due to the cumulative effect of high numbers of point sources (or systems) contributing to the plumes rather than one specific system. The model output also highlighted a pocket of contamination to the south, away from the main plume. The wastewater discharged from this cluster of systems essentially flows directly into the adjacent estuary, were dilution occurs. However, this pocket also provides the highest fecal coilform and E coil counts. Although this indicates that contamination from this specific pocket is quite localised, it does signify that the quality of groundwater is a major concern and its subsequent use, even for recreational purposes may need to be restricted.

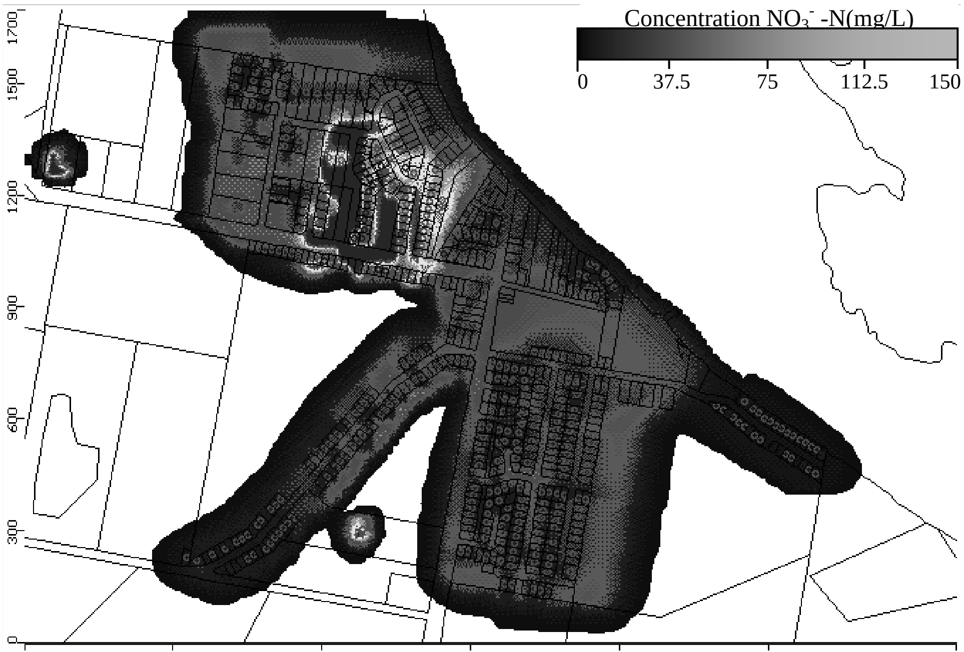

Figure 2. Present NO_3^--N contaminate plumes in unconfined aquifer below Jacobs Well

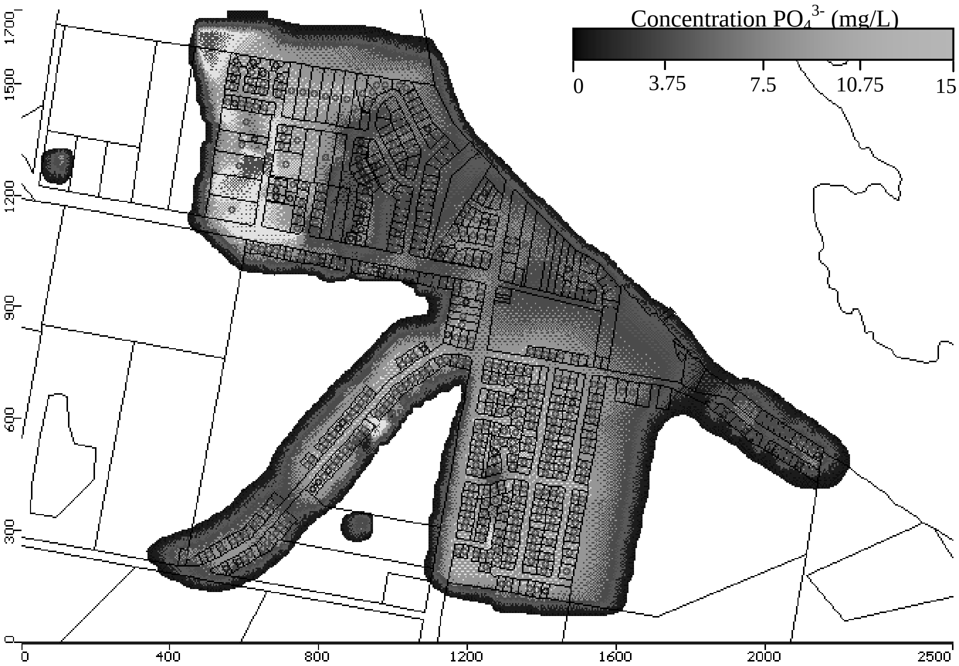

Figure 3. Present PO_4^{3-} plumes in shallow unconfined aquifer below Jacobs Well

As can be observed from Figures 2 and 3 for the current predictions of the contaminant plumes, high densities of systems can impact substantially on the underlaying groundwater, particularly in unconfined aquifer settings. After calibrating the model based on current contaminant concentrations, the model was used to predict the plume movement and concentrations over a 10 year period. Figure 4 highlights the predicted plumes and the respective concentrations for nitrate. As can be seen, if the continual discharge of wastewater is continued, the groundwater under the entire Jacobs Well area will be impacted to some degree. However, most of the contaminant plume coverage shown retain relatively small concentration levels, below the 10mg/L NO_3^- -N limit. Similar impacts were found for phosphorus levels within the aquifer, although the spatial extent of the phosphate plumes is not as widespread due to the adsorption and mineralization processes reactive phosphate ions readily undergo. The higher contaminant levels remain in a similar proximity to the actual systems as highlighted in initial model predictions, although the levels were shown to increase slightly. The plumes emitted from the secondary systems also increase their travel distance as expected.

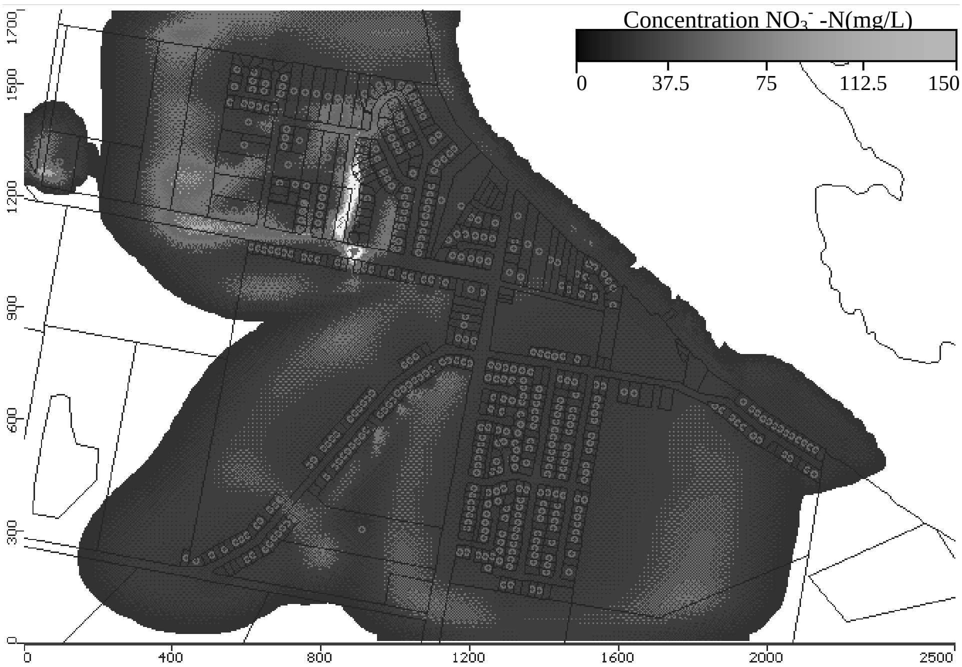

Figure 4. NO_3^--N contamination – 10 year prediction

CONCLUSION

The conclusions derived for the Jacobs Well area indicate appreciable groundwater contamination, particularly nitrate and coliform contamination occurring as a result of high on-site wastewater treatment system density. The modelling of the two main aquifers beneath Jacobs Well also indicates that contaminants have infiltrated from the upper unconfined aquifer and into the semi-confined aquifer. This raises significant concerns, particular as the area currently being further developed for residential purposes, thereby increasing the number of on-site systems in the future.

Quantification of the public health risk is difficult primarily due to the groundwater not being used as a potable water source. The level of fecal coliforms and E Coli at certain locations is however cause for concern, even for general recreational activities. However, in regards to environmental risk, the level of contaminants in the groundwater particularly nitrates and along with the general direction of the groundwater flow towards the estuary, the risk of contamination of the estuary is quite high. Although, at present it appears a significant amount of dilution of contaminants occur within the estuary boundary, further development, and thereby the increase in the number and density of on-site systems throughout the region will inevitably increase the risk of environmental impacts such as nutrient enrichment. The high levels of risk such as evident from the Jacobs Well case study highlights the need for incorporating risk based approaches in adopted standards and codes.

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