SOCIAL AND ENVIRONMENTAL IMPACT ASSESSMENT FOR THE PROPOSED RÖSSING URANIUM DESALINATION PLANT NEAR SWAKOPMUND

Brine Discharge Specialist Study

2014/10/27 Revised: 2014/10/29

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Client

Aurecon South Africa and SLR Namibia, on behalf of Rio Tinto – Rössing Uranium

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List of Acronyms and Abbreviations

g/ℓ	Gram per litre
HAT	Highest astronomical tide
LAT	Lowest astronomical tide
m	Metres
mm	Millimetres
m/s	Metre per second
m^3/s	Cubic metres per second
m^3/d	Cubic metres per day
m^3/yr	Cubic metres per year
mg/ℓ	Milligrams per litre
Mℓ/d	Megalitres per day (1 Megalitre = 1 000 cubic metres)
MLWS	Mean low water spring tide
MHWS	Mean high water spring tide
Mm^3/a	Million cubic metres per annum
MSL	Mean sea level
ppt	Part per thousand
psu	Practical salinity units
µm	Microns

1 Introduction

1.1 General

Rio Tinto Rössing Uranium Limited (Rössing Uranium) is investigating the design, construction and operating of a new seawater reverse osmosis desalination plant in order to supply the water needs of the Rössing Uranium mine. The mine is located near Arandis in the Erongo region of Namibia. The desalination plant will be located within the Swakopmund Saltworks mining licence area, approximately 6km north of Swakopmund (locally known as Mile 4) – see Figure 1.1.

The desalination plant’s peak product water capacity will be 10Mℓ/d. This will require a seawater feed of approximately 25Mℓ/d, with 15Mℓ/d of brine to be discharged back to the sea.

WSP Group Africa was appointed by SLR Namibia and Aurecon South Africa to undertake a specialist study on the nearfield dilution of the brine waste flow for two outfall locations – a preferred location and an alternative location. The study will serve as input to the project Environmental Impact Report. Specifically, this study will allow assessment by a marine ecologist of the potential impacts of the brine discharge on the marine environment.

The study was based on the assumption that the discharge would be in located in the surfzone.

Calculation and modelling of the nearfield brine dilution and dispersion was undertaken using semi-empirical methods and an analytical model. The study scope did not include modelling of the hydrodynamics and far-field dispersion of the discharge.

1.2 Study Approach

Use is made of existing information from the area, particularly data from the NamWater Mile 6 desalination plant studies (CSIR, 2009). Information on the plant flow rates, characteristics and locations was obtained from the engineering team (RHDHV Consulting Engineers).

The characteristics of the discharge, i.e. flow rates, discharge location, and salinity, are described in Section 2.

Section 3 gives an overview of the processes affecting brine dispersion, with particular reference to the surfzone.

The surfzone is characterised by a number of dynamic processes. A major component of the study was therefore to characterise and quantify the parameters that influence the dispersion and dilution of the effluent brine (apart from the jet entrainment) in the surfzone. This was done through an analysis of existing data, supported by numerical modelling of wave transformation and longshore currents in order to quantify the conditions at the point of discharge. This is described in Section 4.

The nearfield[1] dilution of the brine was computed with the computational model VisJet, developed for dense and buoyant jet discharges from diffuser outlets. This modelling is described in Section 5. This type of model typically does not take account of all the processes present in the nearshore and surfzone. The nearfield dilution results were therefore augmented with an intermediate-field numerical model, as discribed in Section 6. The outputs of this modelling give the final dilution results. Conclusions and recommendations are given in Section 7.

A graphical representation of this process is shown in Appendix A.

[1] Nearfield: The spatial extent of the receiving water body in which the initial dilution process takes place.

Figure 1.1: Location map of the project site

2 Discharge Locations and Characteristics

2.1 Discharge Locations and Position

Two outfall locations are investigated in this study and referred to by their geographical locations; the northern site (Outfall 1, also termed the alternative site) and the southern site (Outfall 5, also termed the preferred site). Figure 2.1 shows the locations of the proposed outfalls. The northern site is located along a headland, approximately 3.5 km to the north of the southern site. The latter is located along the straight shoreline at Mile 4, directly opposite the centre of the Swakopmund Saltworks. The southern site is also adjacent to the location where the Saltworks discharge their hypersaline "bitterns" waste onto the beach.

At both locations, the proposed position of the brine discharge point will be in the surfzone, approximately 70m from the high water mark and at a depth of -1.8m below MSL (mean sea level). This depth is 0.8m below the LAT (lowest astronomical tide) water level, meaning that the discharge outlet will always be submerged.

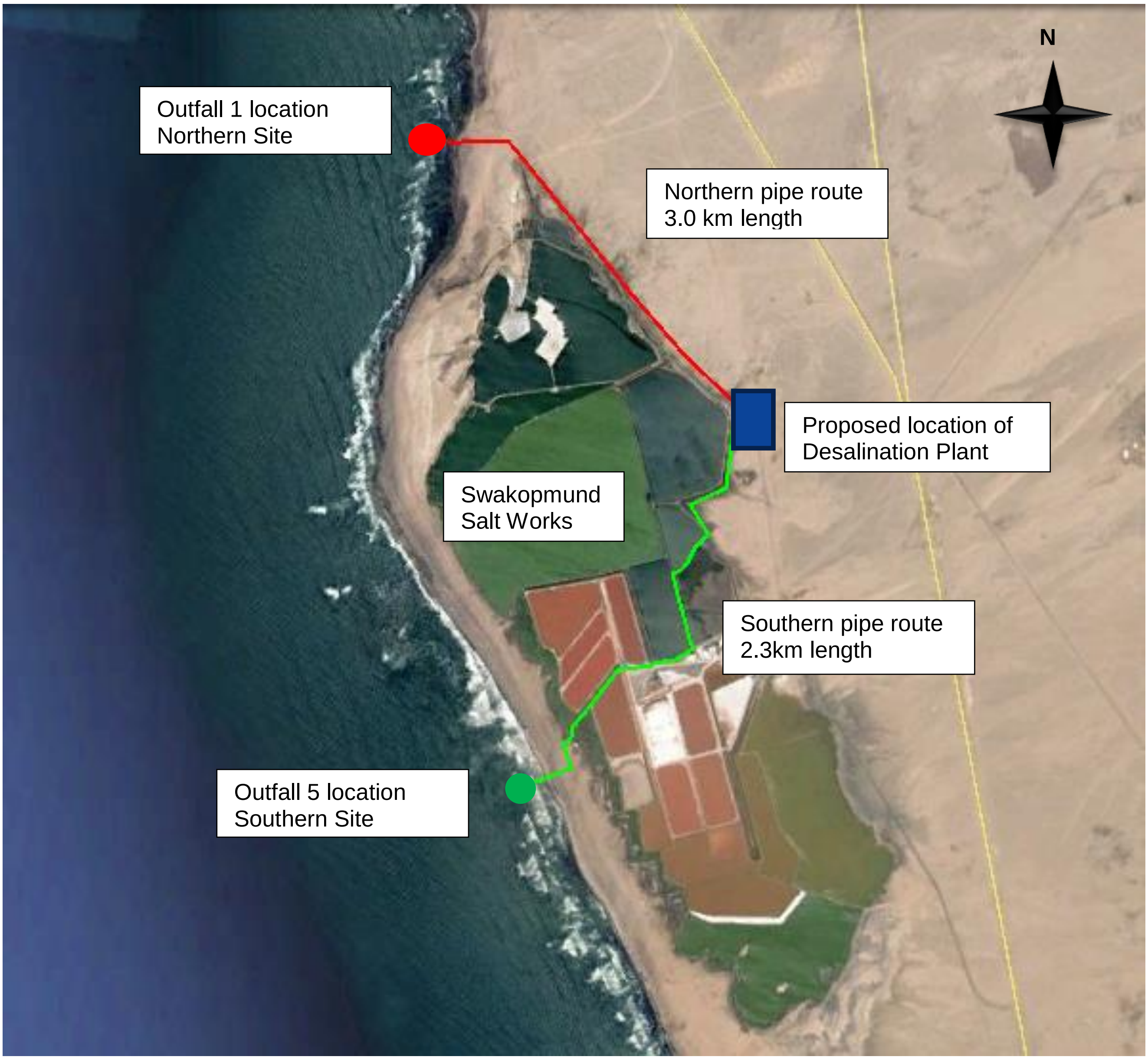


Figure 2.1: Layout of site and location of proposed and two outfall sites considered

2.2 Discharge Rates

The desalination plant's peak product water capacity will be 10Mℓ/d. This will require a seawater feed of approximately 25Mℓ/d, with 15Mℓ/d of brine to be discharged back to the sea. This brine flow translates to 174 ℓ/s.

This flow rate will require an outfall pipe of approximately 400mm diameter. A diffuser with a single port was assumed in this study. The purpose of the diffuser port is to concentrate the flow into a high velocity jet in order to attain good mixing of the effluent brine jet with the ambient receiving waters.

2.3 Brine Concentration and Characteristics

The salinity concentration of the reject brine was assumed to be 66.0 g/l, for an ambient salinity of the intake seawater of 34.2 g/l (communications with RH-DHV via email).

During the desalination process, the intake water would be retained in a series of retention ponds before being processed through the RO plant. This process will raise the temperature of the intake water. As a result, the brine will be discharged at an elevated temperature relative to the receiving waters. The RO process itself generally imparts only a small temperature increase to the water. For this study, a discharge temperature of 17.0ºC is assumed for the brine discharge (communications with RH-DHV via email), based on an ambient seawater temperature of 14ºC.

The density of the brine and ambient water affect the dilution. The density of water is dependent on the temperature of the water and the salinity. Table 1 shows the relevant densities calculated for the ambient seawater and the brine discharge.

Table 1: Salinity values assumed at the site

	Concentration	Density at 14° C	Density at 17° C	Density at 21° C
Median Ambient Salinity (TDS)	34.2 g/l	1025.5 kg/m^3	1024.8 kg/m^3	1023.6 kg/m^3
Brine discharge Salinity	66.0 g/l	-	1049.0 kg/m^3	1047.8 kg/m^3
Recommended concentration (guideline – DWAF 1995)	36.0 g/l	1026.9 kg/m^3	1026.1 kg/m^3	

Information on other constituents of the brine, or co-discharges, such as filter backwashes and cleaning chemicals, was not available. The dilution values calculated in this study for the brine would also be applicable to such co-discharges, provided they do not undergo chemical transformation once discharged.

2.4 Required Initial Dilutions

The brine outfall must be designed to:

1. Prevent recirculation of brine into the seawater intake system of the desalination plant, as this can reduce the efficiency of the desalination plant. A general guideline is that the brine should be diluted to less than 10% above ambient by the time it returns to the intake. This is usually achieved through locating the outfall and intake sufficiently far apart;
2. Achieve the minimum required dilution in order to prevent high salinity levels that could be harmful to the environment – it must satisfy the environmental requirements as per Ground rule 25 – DEA (2014). This minimum required dilution is determined below.

The required initial dilution for the concentration of conservative constituents can be estimated by the conservation of mass as follows (Department of Water Affairs and Forestry, 2004):

Equation 1: $D = \frac{C_e - C_b}{C_g - C_b}$ Where:

D = Required dilution

C_e = Concentration of constituent in wastewater

C_b = Concentration of constituent in receiving marine environment (ambient concentration)

C_g = Recommended concentration (guideline)

From Equation 1, the required initial dilution of the brine effluent was calculated as:

$$D = \frac{66.0 - 34.2}{36.0 - 34.2} = \frac{31.8\,ppt}{1.8ppt} = 17.7$$

This means that for each litre of effluent brine discharged from the RO plant, 17.7 litres of seawater must be mixed with the brine in order to dilute the brine to within 1.8 g/l of the ambient receiving water salinity.

3 Processes Affecting Surfzone Brine Dilution

This section provides an overview of the main processes affecting dilution of brine, particularly in the context of a surfzone outfall. Where relevant, information from recent literature is included.

3.1 Background

Brine concentrates can be discharged in several ways (SCCWRP, 2012):

- Directly into the ocean in deep water with an offshore pipeline and diffuser;
- Directly into the ocean in shallow water via a diffuser in the surfzone;
- As a surface stream at the shoreline;
- Co-mixed (and pre-diluted) with other effluent, such power plant cooling water.

Brine is denser than the ambient receiving waters and will therefore sink to the seabed under gravitational forces, not taking into account any external turbulent mixing mechanisms (e.g. waves and currents). Subsequently, the heavy brine will be transported away from the source by bottom gravity currents due to a sloping bathymetry.

Most large brine outfalls are located in deep water, similarly to sewerage effluent outfalls. International examples of desalination brine discharges in the surf zone are the 320 Mℓ/d plant located in Ashkelon, Israel; 348 Mℓ/d plant located in Hadera, Israel and the 190 Mℓ/d plant in Barcelona, Spain. The latter co-discharges the brine with wastewater effluent.

This study considers a shallow water discharge with a diffuser in the surfzone. It is assumed that the brine will be discharged without any pre-dilution or mixing with other effluent streams apart from the normal co-discharges from the desalination plant.

The surf zone is a high energy area of the coast where multiple processes occur at the same time (e.g. wave breaking, currents, wind, etc.). In the surf zone, waves interact with other waves and currents where turbulence in the breaking wave bores provide rapid mixing in the on/offshore direction while wave induced currents provide an effective advection mechanism.

3.2 Diffusivity: Advection and Diffusion

The movement and mixing mechanisms in the ocean are continually subject to a variety of processes and forces that range between timescales increasing from a few seconds (breaking waves) to a day (tides) to months (seasonal effects).

Mixing of discharges into the ocean is accomplished by the two main processes of advection and diffusion:

- Advection is in essence the transport of a substance over larger distances and time scales (e.g. via currents).
- Diffusion (or dispersion) can be viewed as the ‘blending’ (turbulent motion) of substances over a finite volume of liquid and causes the discharge to spread out independent of any currents.

The brine discharge is diffused in the near field through the entrainment of the ambient surface waters as it is discharged via the diffuser ports. In the surf zone, mixing of the brine discharge includes wave induced mixing by breaking waves and non-breaking waves, longshore currents due to oblique wave breaking, rip currents and tidal forces.

Longshore diffusion and cross shore diffusion has been studied by Inman *et al.* (1971), Harris *et al.* (1963), Feddersen (2009), Johnson & Pattiaratchi (2004), Clarke *et al.* (2007) and Brown *et al.* (2009).

These authors all concluded that advection and dispersion across the surf zone is much faster than alongshore. Inman *et al.* (1971) found that the cross shore diffusivity is between 2 and 20 times the alongshore diffusivity. Harris *et al.* (1963) reports that an acceptable extreme lower bound for the diffusivity parameter observed on the Kwa-Zulu Natal Coast is 0.23m^2/s (150ft^2/min). Pearson *et al.* (2009) showed that the cross shore diffusivity is dependent on the breaker wave height: $\mathrm{D}y \approx f(\lambda, H_b)$ where D_y is the diffusivity which is the process by which a substance is moved (velocity) from one place to another under the action of random fluctuation; γ is the breaker constant as defined by Galvin (1971); and H_b is the breaking wave height.

Koole and Swan (1994) measured the effects of waves in shallow water on a non-buoyant jet, such as brine. The authors found that the additional wave induced mixing has a significant effect on the turbulent fluctuations of the jet. This means that there is a substantial increase in the rate of entrainment of ambient water into the discharged jet resulting in an increase of initial nearfield dilution of the effluent brine.

Concerning rip-channelled beaches, Brown *et al.* (2009) reports that "…the diffusion in the rip current flow patterns is initially dominated by the cross shore, as found by Inman *et al.* (1971), but for large t [time] the diffusion becomes alongshore dominated similar to Johnson & Pattiaratchi (2004)."

Al-Barwani & Purnama (2008) reports that the oscillating flow induced by the tidal current aids greatly in the advection of the brine discharge on a longer timescale (days).

The research cited clearly suggests that the wave conditions and the coastline orientation at the discharge site (affecting longshore currents) influence the diffusivity of the dispersed brine in the cross shore and alongshore directions. Thus, in order to quantify the dispersion of discharged brine into the surfzone, a careful study of the ambient conditions and the quantification of the mixing processes present at the site are necessary.

3.3 Vertical mixing in the surf zone

A literature review on surf zone discharges was undertaken and the following was found in the latest research:

Payo *et al*. (2010) showed through a measuring campaign on a nearshore outfall in Alicante (Spain), that wave action and the duration of the storm aids in reducing near bottom salinity.

Clark *et al*. (2010) investigated the dispersion and advection of dye tracers released in the surf zone. The dye was released 0.5m from the seabed in approximately 1m of water depth in various locations within the surf zone. The authors visually observed that rapid vertical mixing of the tracer took place immediately after release. Further data analysis led to the authors to conclude that "dye tracer is expected to be vertically well mixed at downstream transect [measurement] locations."

Feddersen (2009) studied the cross-shore tracer dispersion and small-scale turbulence mixing in the surf zone; i.e. vertical structure of turbulence in the surf zone. From the experimental measurements it was found that, for water depths less than 3.0m, the assumption that the tracer was vertically well mixed (vertically uniform) throughout the water column was reasonable.

Hally-Rosendahl *et al*. (in press) determined from their analysis of dye release in the surf zone that the dye is vertically well mixed over a water depth of 0m – 3m. In the inner shelf region (water depths greater than 4m) these observations indicate that as dye moves offshore from the well-mixed surf zone, the presence of inner shelf thermal stratification slows vertical dye mixing due to thermal stratification.

Feddersen *et al*. (2007) studied the vertical structure of dissipation in the nearshore and concluded that "…in the nearshore region seaward of the surf zone, white-capping breaking-wave generated turbulence can be significant and may dominate over boundary layer processes."

Svendsen & Putrevu (1994) showed that the cross-shore current, generated by wave activity in the coastal zone is a significant driving force in the mixing (diffusion/advection) of contaminants introduced into this zone.

Beyond the surf zone, Reynolds (1993) states that tidal currents "create a bottom, mechanical, turbulent friction layer." The water column is homogenised from bottom towards the surface. Reynolds found "a bottom mixed layer is evident in all hydrographic sections" in his study. Thus, the vertical structure of the tidal current aids in the vertical and horizontal mixing of the water column through the production of mechanical turbulence over the sea bed. Note, however, that in the surf zone (shallow water), the wave breaking turbulence dominates over an induced vertical tidal current as the primary mixing mechanism, but that in a shallow water environment offshore of the breaker zone, tidal currents enhance the mixing of the effluent over the water column.

From these studies, the following can be deduced:

- In shallow water (depths < 4.0m) the assumption that the discharge is well mixed vertically over the water column is a valid assumption. The maximum depth at the brine discharge point is calculated to be 2.29m during MHWS and 2.57m during HAT;
- Boundary layer processes (e.g. stratification) are most likely not present due to the fact that breaking wave turbulence dominates the water column in this zone;
- Vertical mixing in the surf zone in shallow water has been found to be instantaneous for all practical purposes; and
- Just beyond the surfzone, vertical mixing is enhanced via tidal currents.

3.4 Dilution Models

In order to determine the dilutions achieved from a diffuser, validated numerical models are employed for the nearfield dilution calculation. Typical examples of nearfield numerical dilution include Visual Plumes (US-EPA), VisJet (University of Hong Kong) and CorMix (MixZone). These models can be applied over a various array of discharge and ambient parameters. The models describe the calculated trajectory of a discharge jet as it exits the brine diffuser, and the subsequent dilutions achieved.

Figure 3.1 shows the configuration and notation for an inclined negatively-buoyant jet. This plume shape is applicable to a dense discharge such as brine.

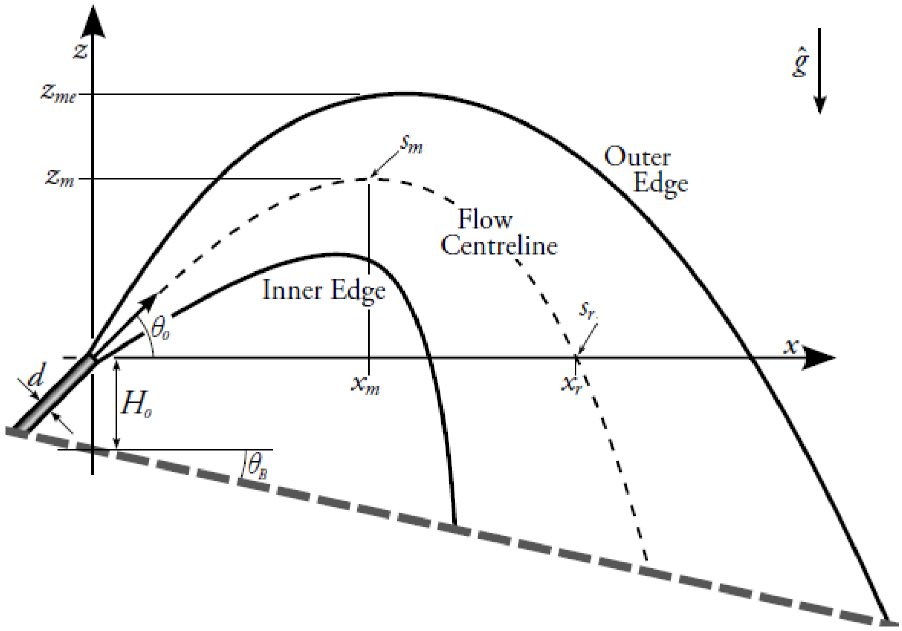


Figure 3.1: Configuration and notation for an inclined negatively-buoyant jet (Oliver, 2012)

For discharges with an exit a discharge angle (θ_0) less than 20º, the dilution (*D*) for the nearfield is calculated at the maximum return distance (s_r) = (x_r , *0*) due to the fact that the discharge is still in the jet region of flow and has sufficient momentum to entrain ambient water (Kikkert, 2006).

The influence of waves on a discharge jet has been investigated in the laboratory and with numerical modelling techniques (e.g Mori and Chang (2003), Ryu *et al.* (2005), Chang *et al.* (2009), and Hsiao *et al.* (2011)).

Hsiao *et al.* (2011) concluded that the turbulence intensity of the jet increases significantly when the jet is under (non-breaking) waves. Also, the width and the turbulence of the jet increase with an increase in wave height. This means that surface waves increase turbulent mixing of the ambient waters with the discharge jet and as a direct result, aid in the dilution of the effluent brine.

At present, the interaction of jet discharges with surface waves is not taken into account within the nearfield dilution models normally employed in engineering practise. Thus, it can be concluded that the dilution predictions from the nearfield models are conservative when discharging brine in the surfzone at a relatively shallow depth.

4 Surfzone Climate Quantification

4.1 General

In order to quantify the impact of the brine effluent discharge on the environment, a holistic approach has been followed for the discharge of land-based effluent to the coastal environment as per Ground rule 24 – DEA (2014). In this section, the ambient receiving surf zone climate is quantified and described in terms of available information (offshore wave climate) and recognised engineering methods that translates the offshore wave conditions to the nearshore and surf zone.

This section details the physical processes present at the site and the influence these processes have on the mixing of the brine discharge with the ambient waters.

4.2 Wave/Beach Orientation

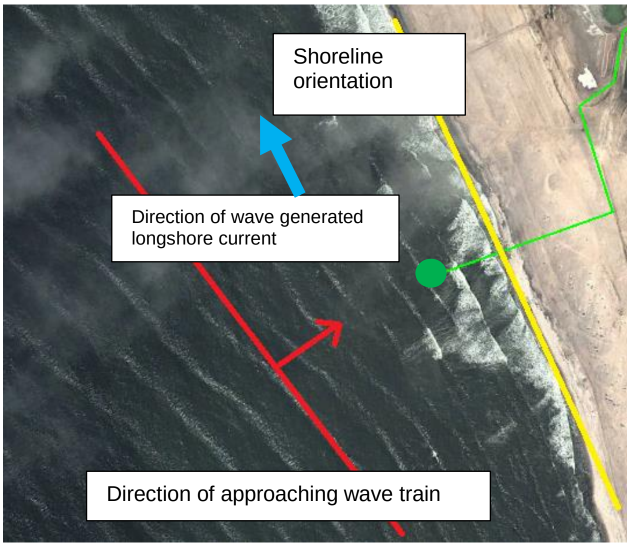
The two proposed outfall locations are situated on beaches that differ significantly in orientation relative to the dominating incoming offshore wave directions.

The shoreline at the southern site is orientated in a north west to south east direction and, as a result is facing the incoming waves without any major loss of wave energy; refraction and shoaling play a role in the nearshore transformation of the incoming waves. The waves approach the shoreline mostly perpendicular with small angular deviations (Figure 4.1).

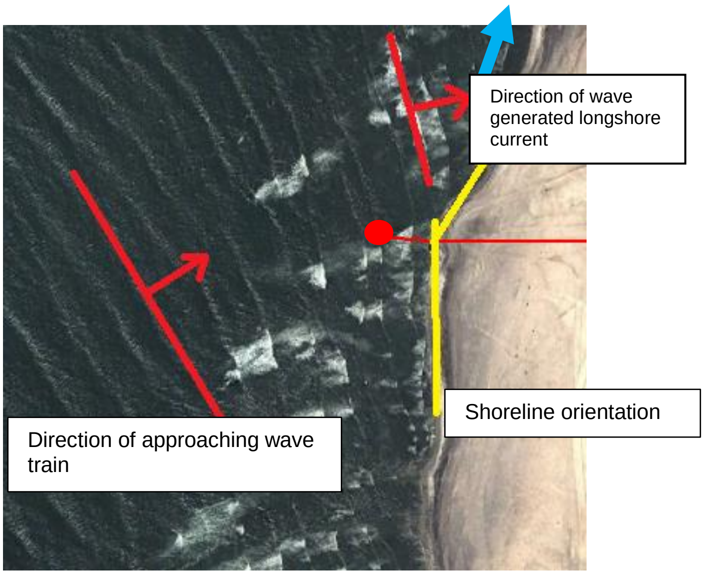
The shoreline at the northern site is orientated in a south-south-west to north-north-east direction. Due to this orientation relative to the incoming wave directions, more refraction of the waves takes place than at the southern site. A slight decrease in wave energy is expected due to the additional refraction at the site along with a relatively shallower bathymetry approaching the shoreline from the dominant wave directions. In reality, a slight reduction of wave energy at the northern site outfall discharge point will not significantly affect the total wave energy at this location: i.e. this section of coast is considered highly energetic and no significant sheltering occurs due to the beach orientation. Thus, for this study, it is assumed that the wave energy present at the northern and southern sites is effectively the same. The veracity of this assumption can be tested through 2D wave modelling or in-situ measurements; however, this is beyond the scope of this study.

The incoming high energy breaking waves will drive longshore currents in the surfzone at both the sites due to the oblique approach angle of the waves relative to the shoreline orientation. It is expected that these longshore currents will be relatively low at the southern site due to the small approach angle of the waves, while it is expected that the longshore currents at the northern site will be higher because of the larger approach angle of the waves relative to the shoreline.

Figure 4.1 illustrates the orientations of the incoming waves, the shoreline and the resultant direction of the wave generated longshore current in the surfzone.



Wave train approaching the proposed southern discharge site. Note the approaching wave train is approximately parallel to the shoreline orientation.



Wave train approaching the proposed northern discharge site. Note the approaching wave train is oblique to the shoreline orientation.

Figure 4.1: Examples of the orientation of the shoreline at the proposed outfall relative to approaching wave train

4.3 Wave Conditions

4.3.1 Offshore waves

Fourteen years of offshore deep water wave data were obtained from the Fugro OCEANOR hindcast data set (hereafter referred to as Fugro data) to investigate the offshore wave conditions. The data are derived from the European Centre for Medium-range Weather Forecasts' (ECMWF) operational and hindcast models and are calibrated by Fugro OCEANOR against satellite data, and where available in-situ buoy data to ensure that the data are as high quality as possible (Oceanor, 2014). The wave data was extracted at the point 13.5°E, 22.5°S, approximately 100km due west of Swakopmund, in a water depth of 160m. The wave height and direction occurrence rose is given in Figure 4.2. Table 2 provides a summary of the percentage wave height occurrence versus the wave direction.

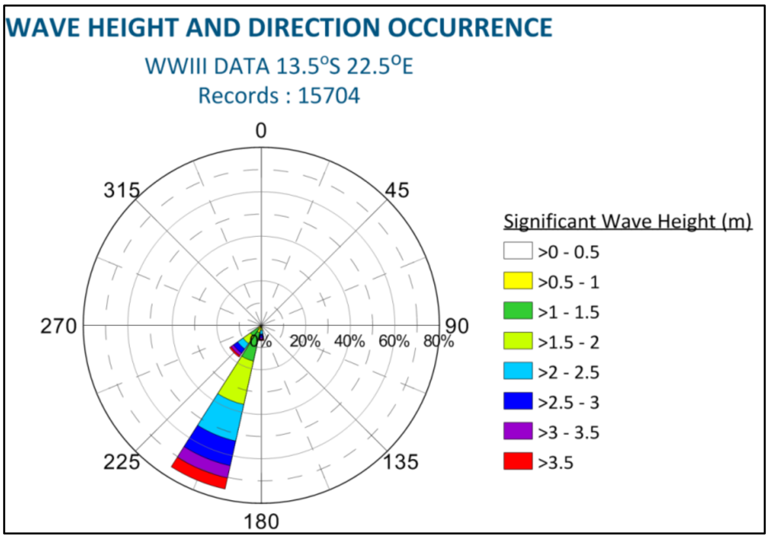


Figure 4.2: Wave rose of the ten year data set indicating wave direction and percentage occurrence of wave heights

Table 2: Offshore wave statistics indicating percentage of time a given wave height (Hs) is exceeded given (a) the approaching wave direction or (b) the peak wave period.

(a)

Hs (m)	Wave Direction (Degrees TN)			
	S	SSW	SW	All
0.0	100%	100%	100%	100%
1.0	7%	72%	16%	95%
2.0	5%	39%	8%	52%
3.0	1%	10%	2%	13%
4.0	0%	2%	1%	3%
5.0	0%	0%	0%	0

(b)

Hs (m)	Peak Period (s)			
	6-8	8-10	10-12	12-14
0.0	100%	100%	100%	100%
1.0	15%	45%	28%	6%
2.0	5%	23%	18%	5%
3.0	0%	5%	6%	2%
4.0		1%	1%	1%
5.0		0%	0%	0%

From Table 2 (a) and (b) it is clear that the majority of waves (97% of the year) fall within the following parameters:

- Offshore wave heights: 0.0m < Hs < 3.0m

- Wave direction: South to South West with the majority originating from South South West
- Peak period: 6s < Tp < 14s

The remaining 2% - 3% of the year fall outside these limits.

4.3.2 Surf zone wave climate

These offshore wave conditions were transferred to the southern proposed brine discharge site using the numerical model SWAN 1D (Simulating WAves Nearshore) as distributed by Delft Hydraulics. The model takes account of the process of refraction, shoaling, and breaking. The model was used to compute the nearshore wave height at each of the brine discharge locations. The resulting nearshore waves were then analysed for wave breaking at the depth of the brine discharge port (-1.8m to MSL).

Varying tidal water levels, along with the calculated wave setup, were taken into account in the analysis of the wave time series. Predicted tidal data from the same time period as the wave data was used. The wave data was then analysed to determine for what period of time the waves are expected to break at the site. The results are summarised in the next section. The breaking criteria of Battjes and Janssen (1978) are used in the SWAN 1D model to compute depth induced breaking.

Table 3 shows the percentage of breaking waves at the southern brine outfall discharge point relative to the wave direction and wave periods. Waves are breaking for a majority of the time per year, i.e. 97% or 355 days of the year (Table 3(a) and Table 3(b)).

Table 3: Percentage of time that wave breaking in the surf zone occurs at the proposed southern brine discharge location.

(a)

Hs (m)	Wave Direction (Degrees TN)			
	S	SSW	SW	Total
Breaking	8%	70%	18%	**96%**
Not Breaking	0%	2%	2%	**4%**
Total	**8%**	**72%**	**20%**	

(b)

Hs (m)	Peak Period (s)						
	6-8	8-10	10-12	12-14	14 - 16	16 - 18	Total
Breaking	4%	14%	23%	40%	12%	4%	**97%**
Not Breaking	0%	1%	2%	1%	0%	0%	**3%**
Total	**4%**	**15%**	**25%**	**41%**	**12%**	**4%**	

Note that the days that waves are not breaking at the surf zone outfall location are not necessarily consecutive days. Analysing the time series for consecutive days that waves are not breaking reveals that there are 21 events during the 14 year data set that waves do not break for 1 day or longer. The longest consecutive time that waves did break was 2.5 days during 1 event (28 Oct 2001 to 31 Oct 2001). Thus, for isolated amounts of time (i.e. a few hours, one day or a maximum 3.5 consecutive days) waves do not break at the surf zone outfall discharge point.

Thus it is reasonable to assume that waves are almost always breaking at the surf zone outfall site.

As stated earlier, it is expected that the wave energy at the northern site will be slightly less when compared to the southern site due to the northern site's beach orientation. However, the wave climate at the northern site is still considered to be highly energetic and it is assumed that wave breaking will occur at this location for a significantly high percentage of the time.

4.4 Water Levels

The water level at any coastal site at a given time comprises of components of astronomical tide, storm surges (induced by wind and barometric pressure variances) and wave setup. At the point of wave breaking the tide and storm surge components are dominant. At the shoreline, the wave setup also plays a role.

The sea water intake and brine discharge site is located approximately 6.5km north of Swakopmund, Namibia. The tidal levels applicable to the site are given in Table 4.

Extreme high water levels (barometric pressure effects, wave setup and wind setup) will normally occur during storm events and will therefore be associated with periods of increased turbulent mixing of the brine.

Table 4: Tidal levels at Walvis Bay (Sanho, 2014)

Description		Level in m
		Relative to Mean Sea Level
Highest Astronomical Tide	HAT	+1.004
Mean High Water of Spring Tide	MHWS	+0.724
Mean High Water of Neap Tide	MHWN	+0.324
Mean Level	ML	+0.014
Mean Sea Level	MSL	0.00
Mean Low Water of Neap Tide	MLWN	-0.296
Mean Low Water of Spring Tide	MLWS	-0.696
Lowest Astronomical Tide	LAT	-0.966
Chart Datum	CD	-0.966

4.5 Surf zone currents

Currents near the shore are dominated by wind-driven currents and local wave-generated currents. The offshore Benguela Current has little impact on nearshore circulation. Similarly, tidal currents are weak and have negligible influence on nearshore currents.

Longshore currents are generated by waves approaching the shore at an angle and are strongest in the surfzone. The longshore transport model Unibest (Deltares) was used to compute wave driven currents in the surfzone. Table 5 and Table 6 list the currents, as simulated with this model, for representative calm and energetic wave conditions at the southern and northern sites respectively.

Table 5: Longshore currents generated by the incoming waves at the outfall discharge point for the southern site.

Hs	Tp	Dir	Diff Dir	Longshore Current (m/s)
(m)	(s)	Deg	Deg	Unibest
0.78	13.5	27	10.80	0.15
0.70	11.2	0.7	0.30	0.01
2.50	8.0	38.6	16.40	0.50
2.50	13.5	38.6	15.50	0.57

Table 6: Longshore currents generated by the incoming waves at the outfall discharge point for the northern site

Hs (m)	Tp (s)	Dir Deg	Diff Dir Deg	Longshore Current (m/s) Unibest
0.78	13.5	45	16.90	0.15
0.70	11.2	45	17.20	0.09
2.50	8.0	45	23.40	0.76
2.50	13.5	45	19.80	0.75

From Table 5 and Table 6 it is clear that the current velocities increase for an increase in incoming wave angle relative to the coastline orientation. Typically the currents are fairly weak for low wave height (calm) conditions: between 0.08m/s and 0.15m/s, increasing with an increase of wave period. The current velocity increases with an increase in wave height, to between 0.5m/s up to 0.8m/s. However, the most significant factor affecting the longshore current velocity is the relative incoming wave angle, whith an increase in the relative wave angle resulting in higher current velocities.

For this study it was assumed that the calculated longshore current is constant over the water column at the outfall discharge point. Current speeds of 0.25m/s were used to represent typical energetic sea conditions – this is a conservative assumption given the energetic surf zone at the discharge point, and 0.08m/s for calm, non-breaking wave conditions.

Wave breaking also causes localised rip currents. These are a seaward directed return flow of water and can readily attain velocities of up 1 m/s. Rip currents can extend beyond the surfzone.

It is likely that rip currents occur at the site, particularly during periods of high waves and near features that cause gradients in wave height, such as reefs or ridges on the seabed. Their occurrence can be inconsistent and their velocities are difficult to quantify. They would generally be considered more representative of far-field mixing and advection processes. Their influence on the dilution of the discharged brine was therefore not considered in this study.

4.6 Wind

Wind analysis was not carried out at the site due to the fact that wind mainly drives surface currents while the discharged brine is more influenced by bottom currents / processes. Wind has little effect on the near bottom currents, particularly in the surfzone (Payo *et al*., (2010)).

4.7 Salinity

The salinity of seawater can be measured by the total dissolved solids (TDS) concentration, usually given in units of gram per litre (g/l). Salinity levels are also described in practical salinity units (psu), or as a concentration in parts per thousand (ppt). These three units of measurement are equivalent for practical purposes.

The median ambient salinity of the seawater at the site was assumed to be 34.2 g/l, based on data from the NamWater Mile 6 studies (CSIR, 2009). The brine salinity is 66 g/l. Thus, the difference in concentration between the brine discharge and the ambient salinity is 31.8 g/l.

Table 7 gives an overview of selected water quality standards implemented worldwide for the discharge of brine into ambient waters.

Table 7: Regulations and salinity limits for selected desalination brine discharges

Country / Region	Criteria	Compliance point relative to discharge
South Africa (DWAF)	**Between 33.0 g/l and 36.0 g/l**	**To be kept to a minimum**
United States (EPA)	**Increment ≤ 4 ppt above ambient**	**Not given**
Western Australia	**Increment < 5% above ambient**	**Not given**
Oman	**Increment ≤ 2 ppt above ambient**	**300 m**

The Southern California Coastal Waters Research Project (SCCWRP, 2012) investigated the best practises for brine disposal and concluded that "Based on existing information, a salinity increase of no more than 2ppt to 3ppt in the receiving waters around the discharge appears to be protective of marine biota."

In Namibia, application for a domestic and industrial wastewater and effluent disposal exemption permit requires that the disposal of brine is to comply with South African Marine Quality Water Guidelines (communication with SLR Consulting). This study is therefore conducted in line with the guidelines and statutes set out in DWAF (1995), DWAF (2004) and DEA (2014), in particular, the applicable Ground Rules set out in DEA (2014).

According to the South African Marine Water Quality Guidelines (Department of Water Affairs and Forestry, 1995), the target value for salinity should range between 33.0g/l and 36.0 g/l. For this study the value of 36g/l is assumed. Thus, the difference in concentration between the published guidelines (36 g/l) and the ambient salinity (34.2 g/l) is 1.8 g/l. As such, it is assumed that a dilution of the effluent brine in the near field to a level of 1.8 g/l above ambient is acceptable. This is comparatively strict when compared to the international examples, as in Table 7.

4.8 Water Temperature and Density

The ambient water temperature at the site varies between 13.9ºC and 23.5ºC with an average of 17.2ºC. The water temperature has pronounced seasonal variability with the lowest temperatures occurring during the winter season (CSIR, 2009).

4.9 Stratification

Stratified conditions (layering in the water column) occur due to a density gradient between the surface and the bottom, subsequently inhibiting an effluent plume to rise with subsequent reduced initial dilutions, resulting in a submerged waste field below the surface. In shallow water, stratification is less significant, due to the influence of wave motions. This is particularly the case in the surfzone, where rapid and continual interaction occurs between surface and bottom water as a result of wave breaking. The possible stratification of the water column is therefore of little significance for a surfzone brine outfall.

5 Modelling of Nearfield Dilution

5.1 General

The dilutions achieved in the nearfield as a result of the brine jet exiting the diffuser are determined in this section. They are checked against the required dilutions.

It is assumed that the diffuser is installed in shallow water (below LAT) and the effluent jet is discharged horizontally (0 degrees to the horizontal). When the jet is discharged horizontally, the momentum of the jet along its trajectory is stopped by the sea floor. The calculations in this section neglect the effect of mass flux due to incoming waves on the effluent jet discharge, but take into account the ambient longshore current. However, surf zone turbulence (wave action) and alongshore currents results in significant mixing in the surf zone (Koole & Swan, 1994). Thus, the calculations in this section can be considered conservative with regards to dispersion, entrainment and mixing of the effluent jet with the ambient waters.

5.2 Model inputs

The industry benchmarked model VisJet, developed and maintained by the University of Hong Kong, is used to determine the initial nearfield dilutions.

The following assumptions were made with respect to model inputs:

- Jet exit velocity: of 6.14m/s
- Horizontal discharge of the jet below the LAT water line in water depths ranging between 0.870m (at MLWS) and 2.29m (at MHWS).
- The wave induced longshore current of 0.25m/s (energetic condition) and 0.08m/s (calm condition) perpendicular to the jet discharge direction.
- The influence of waves on the discharged jet is not taken into account

Figure 5.1 shows an idealised visual rendering of an outfall jet. Note that the pipe size is exaggerated in the rendering.

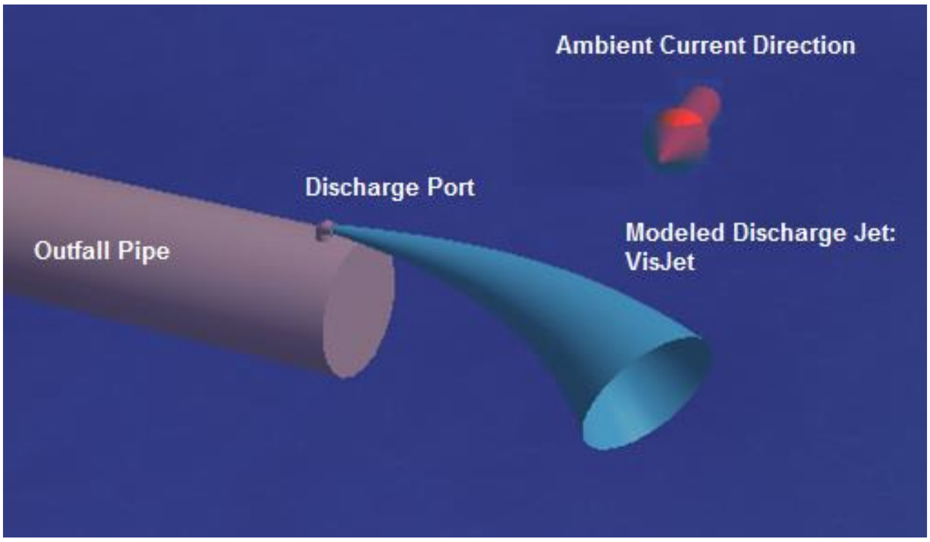


Figure 5.1: VisJet model rendering of an outfall jet. The blue cone simulates the evolution of the discharge jet over distance. The red arrow indicates the current direction. Note that the pipe size rendering is exaggerated.

The input parameters used to determine the dilutions achieved by discharging into the surf zone is given in Table 8.

Table 8: Input parameters used for the surf zone near field dilution models

Parameter		Input Value
Brine flow		0.174 m^3/s
Port diameter		0.19m
Port exit velocity		6.14m/s
Discharge angle		0 deg
Ambient density		1025.5 kg/m^3
Effluent density		1049.0 kg/m^3
Ambient current		0.25m/s and 0.08m/s
Water depth at diffuser port	**At MHWS**	2.29m
	At MLWS	0.87m

5.3 Initial nearfield dilution results

The numerical model was run for the input conditions in Table 8. The dilution results are given below in Table 9.

Table 9: Numerical near field dilution results from VisJet

Model Parameter	Typical current condition	Calm current condition
Ambient current	0.25m/s	0.08m/s
Distance to jet centre line impact point on the bottom (x_r)	4.5m	4.6m
Dilution at centre line bottom impact point (S_r)	12.7:1	9:1

From Table 9 it is clear that the surf zone diffuser does not achieve the required initial dilution of D =17.7:1 (as calculated in Section 2) at the impact point of the jet trajectory for typical current nor calm current conditions. Further dilutions are necessary.

The worst case is the calm current condition, where a nearfield dilution of only 9:1 is achieved from the diffuser jet. At this stage the brine has been diluted to a concentration of 37.7 psu which is still 37.7 g/l – 34.2 g/l = 3.5 g/l above ambient. As a result, a further dilution of $D = \frac{3.5\ ppt}{1.8\ ppt} = 1.9$ is needed to achieve a concentration of 1.8g/l above ambient to adhere to the water quality guidelines as per DWAF (1995).

For the typical current condition, a near field dilution of 12.7 is achieved from the jet discharge. A further dilution of 1.4 is required. The required dilution for the calm current conditions is greater (more strict) and is therefore set as the condition that must be met.

The dilutions achieved in the region beyond the diffuser jet are termed the intermediate field dilutions. The intermediate field investigates advection and diffusion of the initially diffused jet (D = 9:1) within a relatively short geographical range spanning between 50m cross shore and 100m alongshore from the discharge point. Within this zone the further dilution of the excess salinity (3.5g/l) under the influence of tidal currents, longshore currents and wave action can be determined. The intermediate field dilutions are determined in the next section.

6 Intermediate Field Dilution

6.1 General

In this section, the two dimensional advection-diffusion equations are solved in order to determine the dilution and dispersion (transport and fate) of the remaining required dilutions under oscillating tidal currents and due to the local surf zone processes. The salinity build-up process due to a continuous brine discharge is investigated. In particular, the focus is aimed at the salinity fluctuations in the presence of an oscillatory tidal current.

A representative time series is extracted from the 14 year Fugro database. This time series spans at least a spring and neap tidal cycle along with wave heights that represent the typical conditions at the site. The dispersion of the brine in this intermediate field is analysed over this time series and can be seen as a measure of the transport and fate of the excess salinity for the typical wave conditions at the site.

From Section 3, it has been determined that vigorous mixing through wave action occurs in the surf zone. Therefore the brine at the centreline maximum height is effectively vertically well mixed over the water column at the maximum rise height by the wave bore.

In order to analyse the spread of the vertically mixed partially diluted brine at the two sites, an analytical solution of the two dimensional advection-diffusion equations, incorporating an oscillating tidal current (Al-Barwani & Purnama, 2008) are employed.

6.2 Model Inputs

The following assumptions are made:

- A straight solid boundary at the shore is assumed (rocky shoreline);
- A time varying water level across the study area;
- A relatively small area under investigation 100m alongshore and 50m cross shore;
- The brine is discharged continuously;
- The dominant diffusive processes are represented by D_x (cross shore diffusivity) and D_y (alongshore diffusivity). D_x is calculated in accordance with Pearson (2009);
- Depth limited wave breaking: Hs=0.78 x depth (Galvin, 1971);
- Initial dilutions achieved from the outfall diffuser ($D=9:1$) is evenly distributed vertically over the water column.

Table 10 gives the input parameters used in order to determine the intermediate field dilutions:

Table 10: Input parameters used for the surf zone intermediate-field dilution models

Parameter	Input Value
Brine flow	0.174 m^3/s
Port exit velocity	6.14m/s
Ambient salinity	34.2 g/l @ 14ºC
Undiluted effluent salinity	66.0 g/l @ 17 ºC
Diffuser diluted salinity	37.7 g/l @ 17 ºC
Ambient current	0.08m/s (calm conditions)
Diffusivity (m^2/s)	Varying with breaker height as per Pearson (2009)
Water levels at surf zone diffuser (m)	Neap to spring tidal cycle

The intermediate dilution equations (Al-Barwani & Purnama, 2008) were applied in order to assess further dilutions achieved due to advection / diffusion processes along and across the coast taking into account an oscillating tidal flow.

Time varying water levels were assessed to determine the conservative but realistic case for a normal tidal water level time series varying from a neap tidal cycle to a spring cycle. A representative time series was chosen from the 14 year Fugro data set: 2003/05/08 to 2003/05/19 (as shown in Figure 6.1). This time series contains offshore wave heights between 1.0m and 2.0m with peak periods ranging between 8s and 12s and water levels ranging between MLWS and MHWS. This time series represents the waves that occur for 60% of the time from south-south-west (the dominant direction - (Table 2 (a) and (b)). Waves are smaller than this 1.0m to 2.0m band for only 5% of the time.

The water level time series were modelled based on the assumptions given in Table 10 using the intermediate dilution model and does not take into account any water level variations due to storm surge, wave or wind setup.

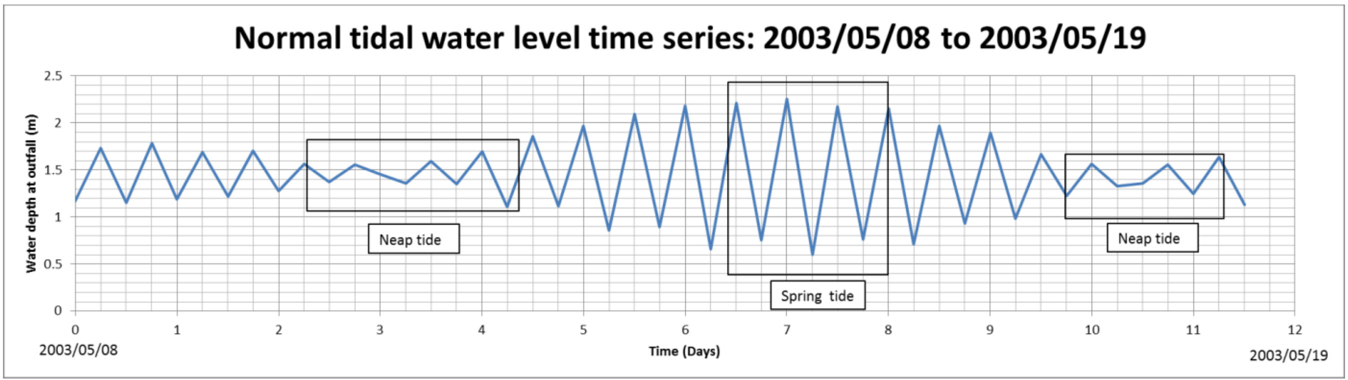


Figure 6.1: Normal tidal water level time series: 2003/05/08 to 2003/05/19 representing the average wave conditions occurring at the site.

6.3 Dilution Results

Graphical outputs (contour plots of parts per thousand above ambient salinity) of the intermediate dilutions are given in Appendix A: Drawing RP001 for the southern site and Appendix A: Drawing RP002 for the northern site. The plots show steady state contour lines for the 174 l/s outfall flow indicating the 1.8g/l above ambient salinity boundary for the time series modelled.

With reference to the results for the southern site – Drawing RP001:

i) A general influence area of approximately 25m to 30m from the brine outfall diffuser in the cross shore direction; and

ii) A general influence area of approximately 35m to 45m in the alongshore direction of the coastline can be seen for the brine discharge.

With reference to the results for the northern site – Drawing RP002:

i) A general influence area of approximately 30m to 40m from the brine outfall diffuser in the cross shore direction; and

ii) A general influence area of approximately 35m to 50m in the alongshore direction of the coastline can be seen for the brine discharge.

The following graphical results are extracted from specific points located fixed distances away from the outfall discharge point. Drawing RPPT001 illustrates the locations of these output points relative to the outfall discharge point for the southern site. The same relative positions are applicable for both the southern and northern sites. These fixed points are 5m, 10m, 15m, 20m and 22m away from the point of initial dilution (x_r as given in Table 9) for the 2003 time series and labelled A (closest to the diffuser outfall) through to E (furthest away from diffuser).

Figure 8.1 to Figure 8.5 show time series plots for these fixed outfall points (“A” to “E”). The green line indicates the additional required dilution of D = 1.9:1 which adheres to DWAF (1995) while the blue line shows the dilutions achieved at any point in time.

- Figure 8.1: The required dilution at point “A” (5m from the discharge point) is only achieved in the midst of the neap and spring cycles. Most of the time the required dilutions are not achieved. However, this is expected for a continuous brine discharge measures very close to the outlet.
- Figure 8.2: The required dilution at point “B” (10m from the discharge point) is only achieved in the midst of the neap and spring cycles. Most of the time the required dilutions are not achieved.
- Figure 8.3: The required dilution at point “C” (15m from the discharge point) is achieved most of the time. During isolated periods of the time (for a maximum of 0.5 day) dilutions are below the required D=1.9:1.
- Figure 8.4: The required dilution at point “D” (20m from the discharge point) is achieved almost all of the time. Only during spring low (day 6 to day 8) dilutions are below the required D=1.9:1 for a short period of time; less than 6hours of the day.
- From Figure 8.5 it can be seen that the required dilutions are achieved for typical conditions all of the time at a distance of 22m from the discharge point at point “E”.

7 Conclusions and Recommendations

This assessment has been completed in order to quantify the dilutions achieved for a brine effluent surfzone discharge, detailing the attributes of the surf zone brine discharge options for two proposed locations.

The surf zone brine diffuser was conceptually designed to conform to the ground rules set out by DWAF (2014) with the aim to achieve the required dilutions in the nearfield. The conceptual design of the surf zone diffuser is shown in Appendix A: Drawing SRP003.

The coastal climates at the northern and southern sites were evaluated in terms of the waves, currents, wind, tides, geographical orientation, temperature and salinity. It was found that wave breaking and longshore wave currents are the dominant processes that will aid in the diffusion and advection of the effluent brine discharge. It is also assumed that the northern and southern sites are similar in terms of nearshore wave energy despite their different geographical orientations.

Longshore currents due to wave breaking was quantified and it was found that the currents will be larger at the northern site than at the southern site due to the more oblique angle of the beach orientation relative to the dominant incoming wave direction.

The median ambient salinity of the seawater at the site was assumed to be 34.2 g/l (CSIR, 2009). The salinity concentration of the reject brine was assumed to be 66.0 g/l for an ambient salinity of 34.2 g/l (communications with RH-DHV via email). For this study the given ambient salinity guideline value of 36g/l is assumed. Thus, the difference in concentration between the published guidelines and the ambient salinity is 1.8 g/l. As such, it is assumed that a dilution of the effluent brine in the near field to a level of 1.8 ppt above ambient is acceptable.

The nearfield diffusion of the effluent brine was investigated through a benchmarked numerical model (VisJet). Partial dilution in the nearfield is achieved, D=9:1, which is equivalent to a salinity of 37.7 g/l. Note that this is the dilution achieved by the diffuser port only, and does not take the effects of the environmental processes (waves, currents, etc.) into account. A further dilution (D = 1.9:1) of the effluent brine is needed in order to reach a diluted salinity of 36.0 g/l (or 1.8g/l above ambient) as recommended by DWAF (1995).

In order to assess the further dilution in the intermediate-field for the surf zone outfall, the two dimensional advection-dispersion equations were solved over the intermediate-field domain (Al-Barwani & Purnama (2008). The equations take into account the alongshore and cross shore diffusivity, tidal oscillations and longshore drift currents. Under these assumptions, a contour indicating the 1.8g/l salinity level above ambient salinity was plotted to assess the impact zone of the diluting brine stream as it is discharged into the energetic surf zone (Appendix A: Drawings RP001 and RP002).

The results of the intermediate mixing indicate a general influence area of approximately 30m to 40m from the effluent discharge point under varying water levels and coastal processes.

For the reasons mentioned above, the surf zone discharge is considered to be a viable option for brine effluent disposal within the parameters detailed in this study.

Both the northern and southern sites were studied in terms of their potential to aid in the dispersion and advection of the effluent brine. It was found that both these sites are equally suited for this purpose. For the reasons mentioned above, both sites can be considered as potential outfall locations from a coastal processes and coastal engineering perspective.

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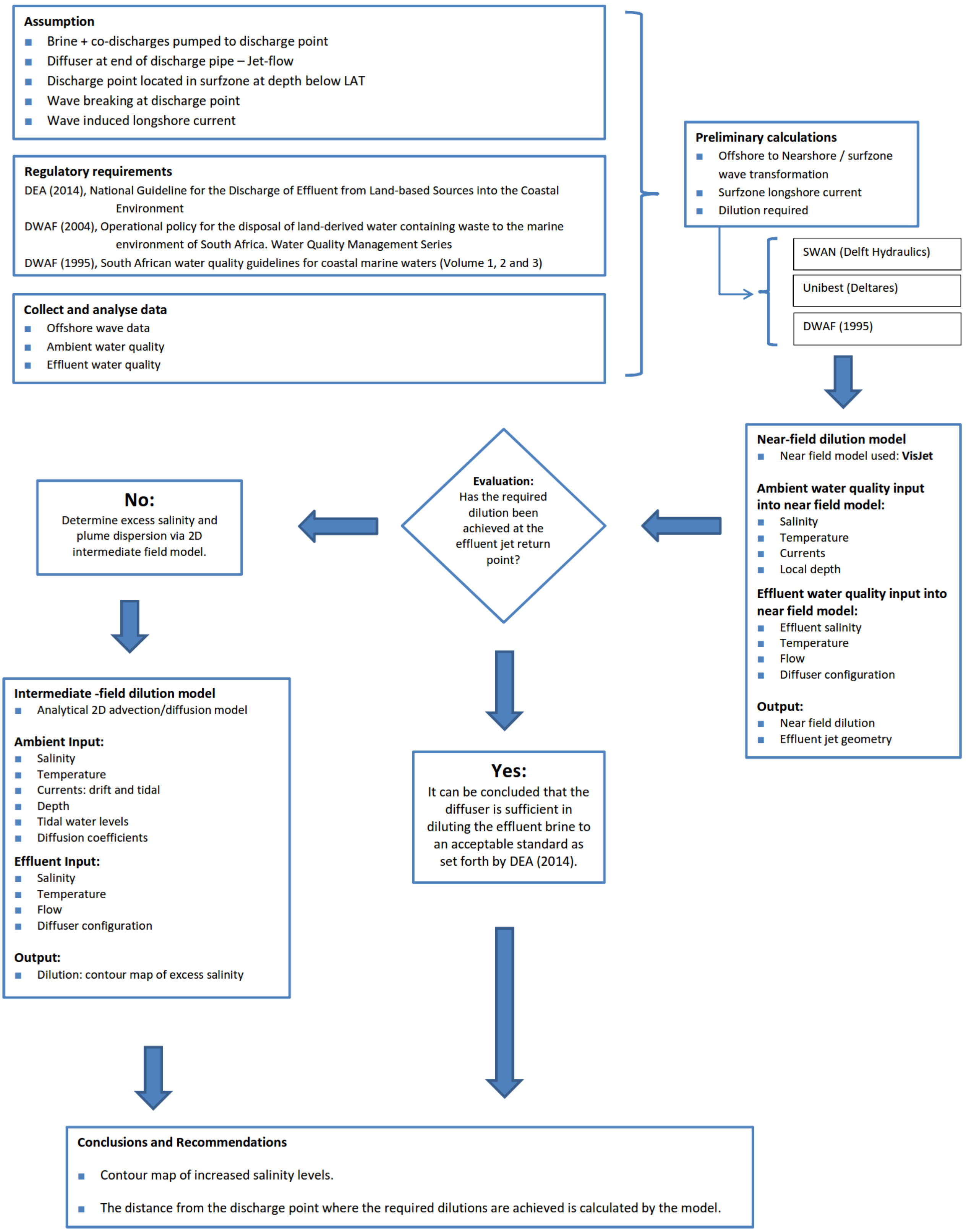
8 Appendix A: Drawings and Figures

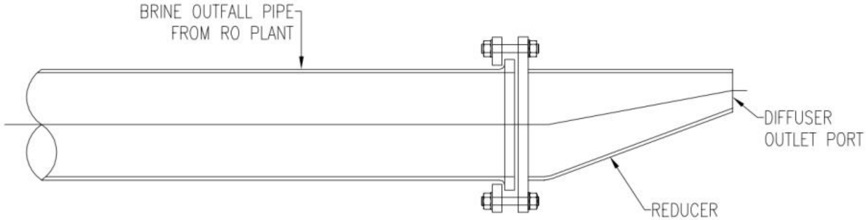
Brine Dilution Analysis Process Flow Chart



The process of study and methodology flowchart

HORIZONTAL DIFFUSER PORT DISCHARGE
HOLLYWOOD OUTFALL, CALIFORNIA, U.S.A.
EFFLUENT COLOURED FOR VISIBILITY

DIFFUSER PORT DISCHARGE
EFFLUENT COLOURED FOR VISIBILITY



DIFFUSER SECTION: SURFZONE DIFFUSER

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TITLE:
TYPICAL DIFFUSER SKETCH AND EXAMPLES OF INSTALLED DIFFUSERS

FIGURE No:
SRP003

P:\118203.R - Gecko Saltworks Desal\2 - Design\2.10 - BFS design\2.10.3 - Discharge\Infiltration ponds\SKS007 Rev A_FvE_2.dwg 25 Sep, 2014 - 3:39pm

Drawing RP001: Contour plot of the diluted intermediate field brine influence area (given in parts per thousand above ambient salinity) for the southern site.

C:\Users\ZAFV02693\Documents\Projects\Gecko\Infiltration ponds\SKS007 Rev A_FvE_3.dwg 13 Oct, 2014 - 10:37am

Drawing RP002: Contour plot of the diluted intermediate field brine influence area (given in parts per thousand above ambient salinity) for the northern site.

Drawing RPRT001: Locations of output points analysed for the 2003 time series. The points are spaced 5m apart with point E being 22m from the point of initial dilution.

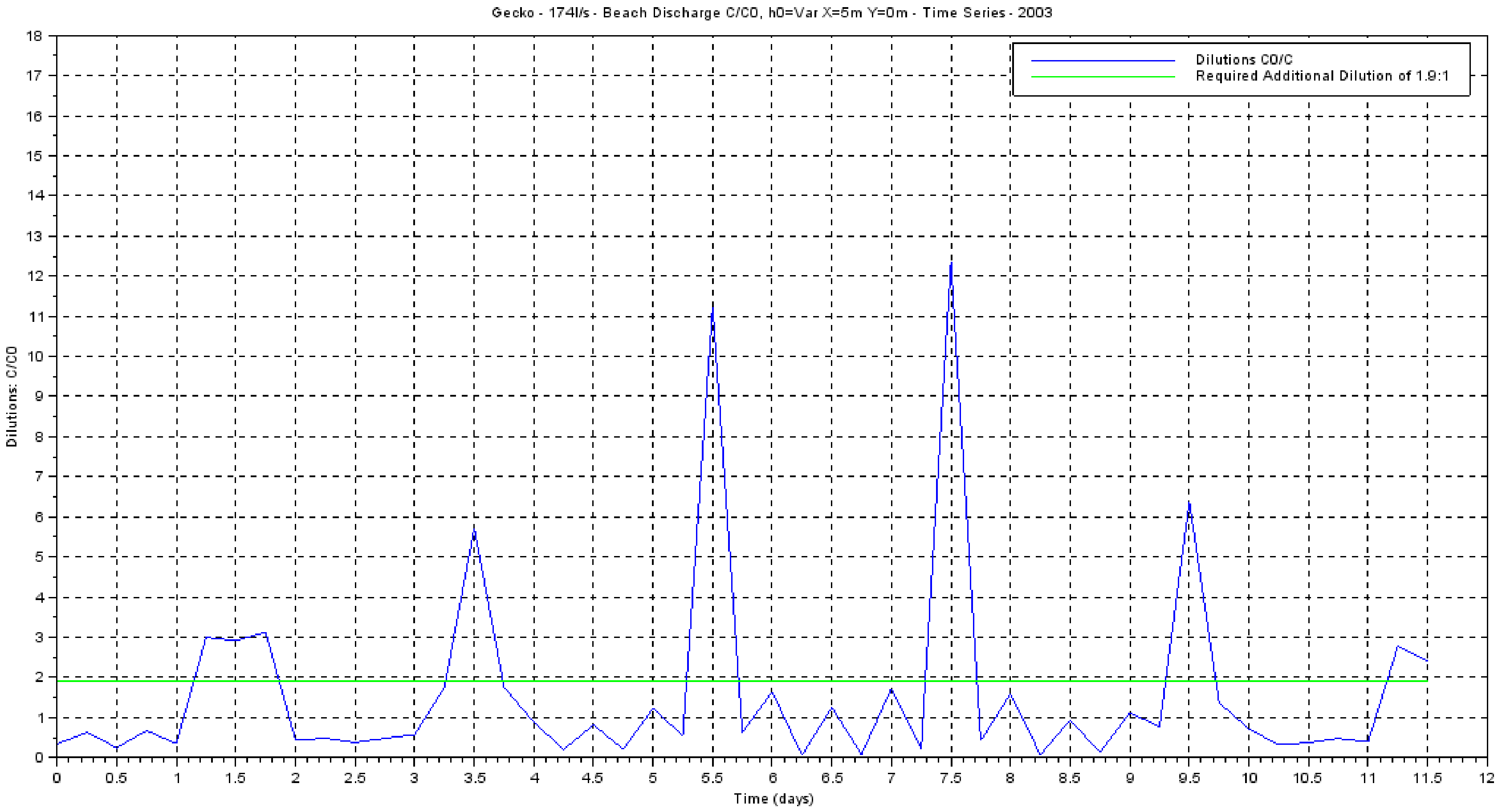

Figure 8.1: Plot of dilutions achieved for the 2003 time series calculated at a fixed point "A" (5m from the point of initial dilution) for the brine effluent discharge. The green line indicates the required dilution of D=1.9:1. The blue peaks below the line indicate dilutions below the required D=1.9:1.

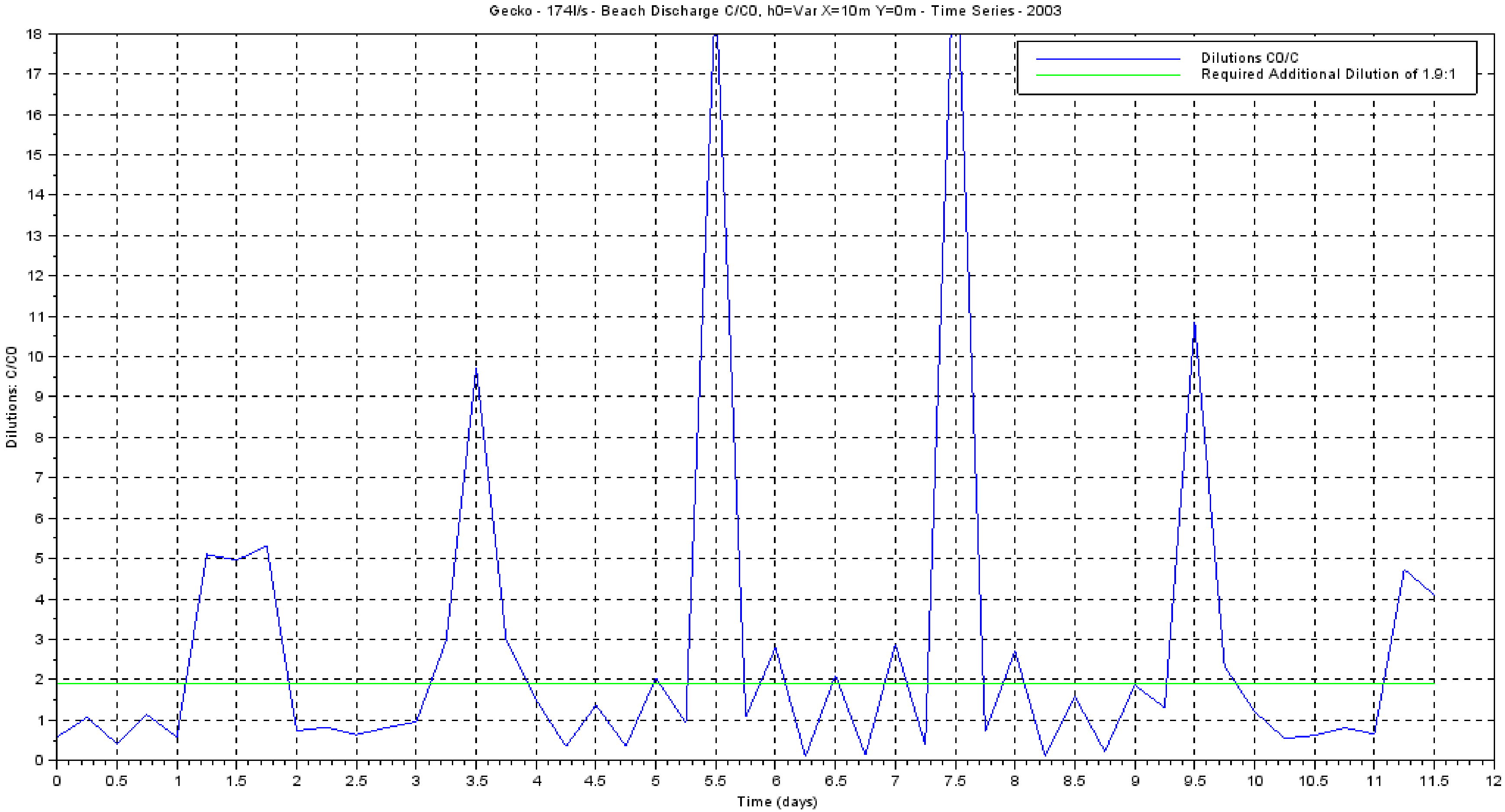

Figure 8.2: Plot of dilutions achieved for the 2003 time series calculated at a fixed point "B" (10m from the point of initial dilution) for the brine effluent discharge. The green line indicates the required dilution of D=1.9:1. The blue peaks below the line indicate dilutions below the required D=1.9:1.

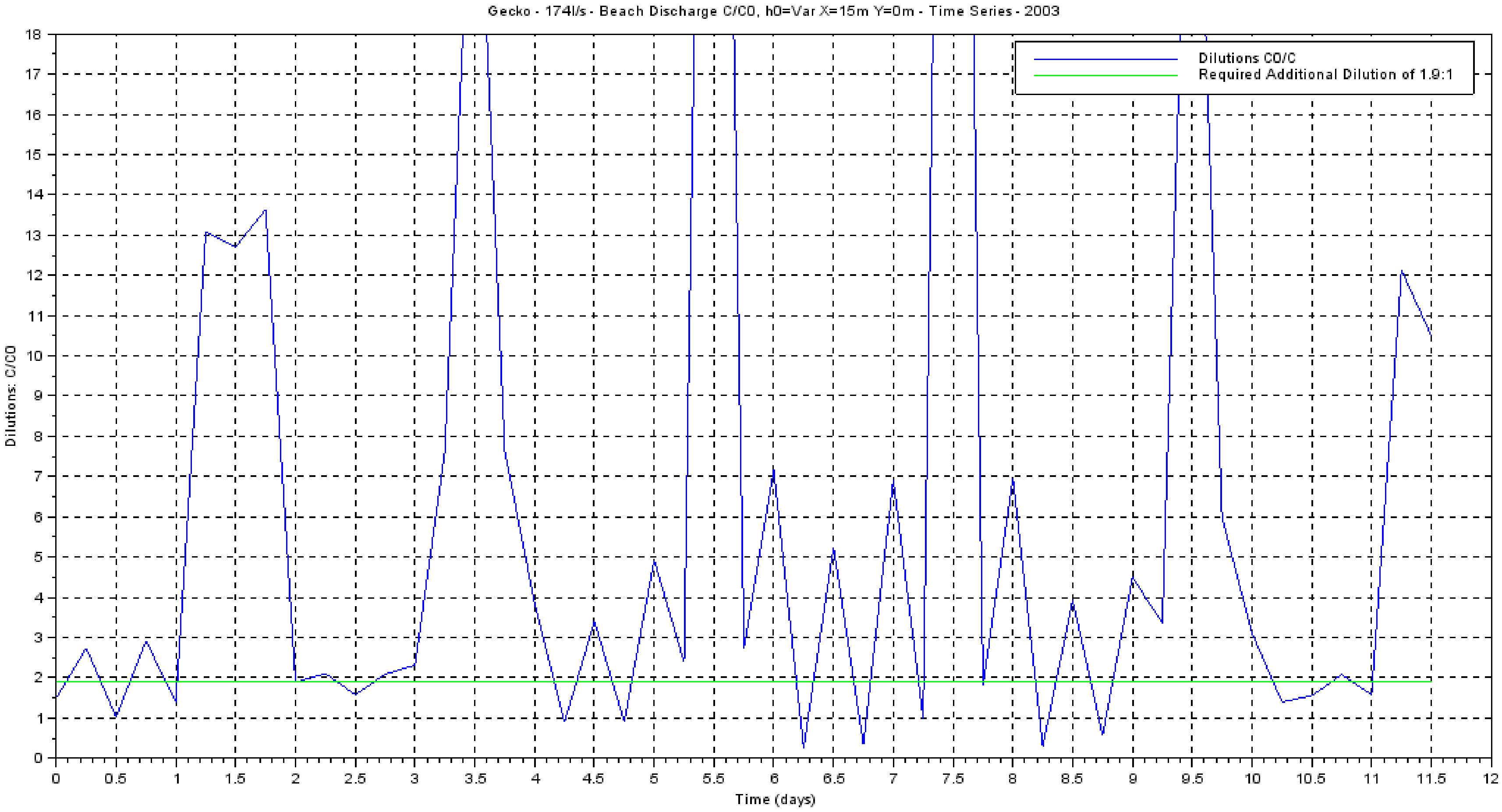

Figure 8.3: Plot of dilutions achieved for the 2003 time series calculated at a fixed point "C" (15m from the point of initial dilution) for the brine effluent discharge. The green line indicates the required dilution of D=1.9:1. The blue peaks below the line indicate dilutions below the required D=1.9:1.

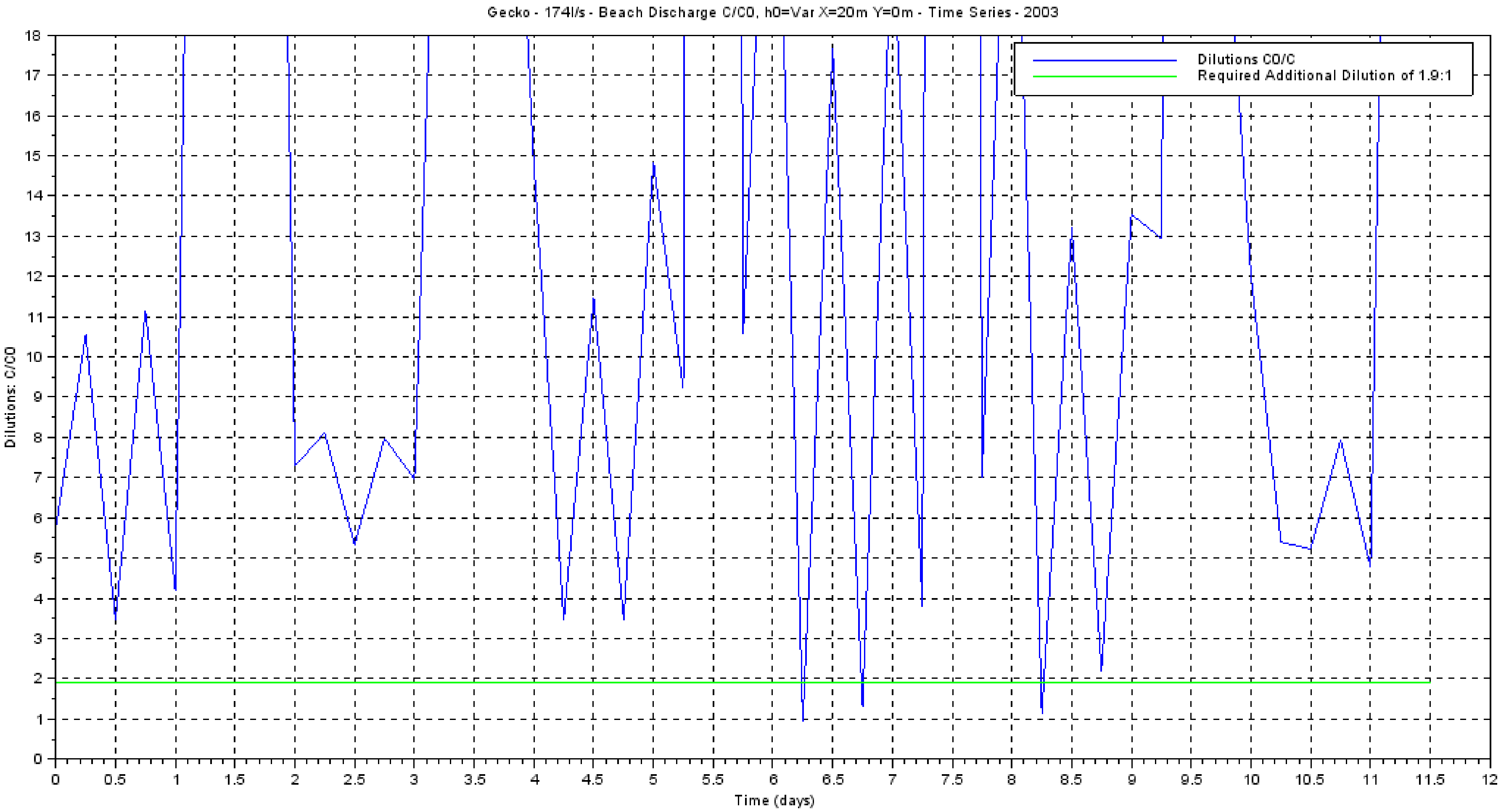

Figure 8.4: Plot of dilutions achieved for the 2003 time series calculated at a fixed point "D" (20m from the point of initial dilution) for the brine effluent discharge. The green line indicates the required dilution of D=1.9:1. The blue peaks below the line indicate dilutions below the required D=1.9:1.

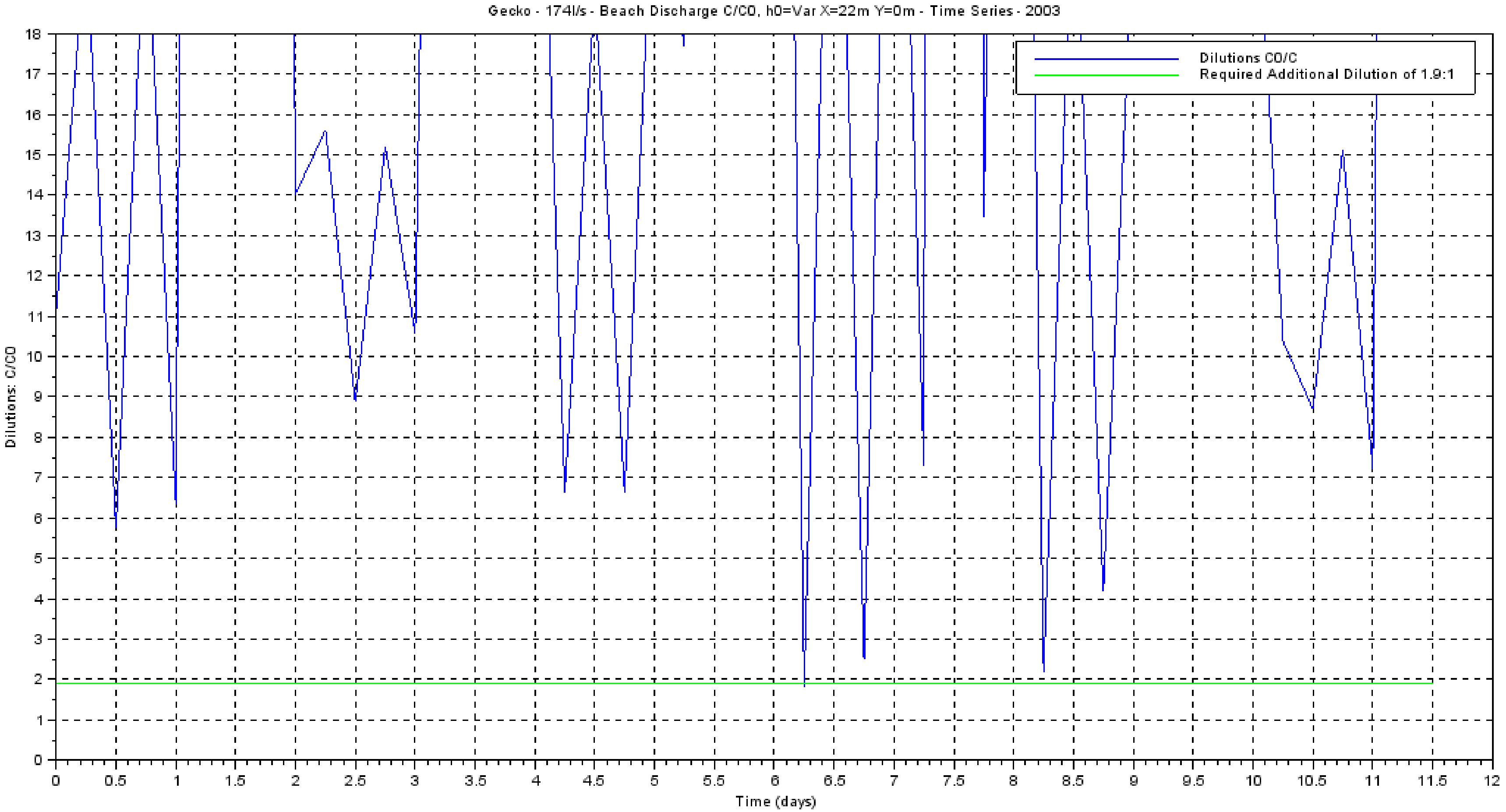

Figure 8.5: Plot of dilutions achieved for the 2003 time series calculated at a fixed point "E" (22m from the point of initial dilution) for the brine effluent discharge. The green line indicates the required dilution of D=1.9:1. The blue peaks below the line indicate dilutions below the required D=1.9:1.

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