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Alternative approach for assessment and limitation of environmental impacts from desalination plant water discharges by substitution of the ''mixing zone'' by a ''minimum dilution volume''

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ABSTRACT

Desalination plants are processing huge quantities of sea water for the production of high quality potable and process water. With regard to environmental impact the main concerns are the increased temperature and salinity of the process effluent (brine, cooling water) which has to be rejected to the sea.

Many national and international environmental regulations and guidelines are stipulating discharge limits for temperature and salinity to be complied with by the projected desalination plant in order to obtain the environmental approval for operation. The World Bank guidelines, as well as many national regulations, assume a so called ''Mixing Zone'' around the point of water discharge, within which initial mixing with ambient sea water takes place, and stipulate limits for temperature and salinity increase over ambient conditions at the edge of this mixing zone.

However, the size of this mixing zone is not clearly defined and the procedures by which the temperature and salinity values are to be determined are missing. In consequence compliance with the stipulated discharge limits can hardly be proven in quantitative terms and the results of Environmental Impact Assessment (EIA) reports are usually rather imprecise in this regard.

This presentation describes in a simplified manner an alternative approach for assessment of the environmental impact and corresponding limitation of temperature and salinity increase due to water discharge from desalination and power plants, which is considered more adequate for this purpose. It is proposed to substitute the unclear criterion of a ''Mixing Zone'' size by the water volume available for dilution of the discharged effluent. A basic procedure for the determination of a minimum dilution water volume is outlined, considering the temperature or salinity increase between intake and outfall and the discharged water flow rate.

The described general approach may be considered by both environmental authorities stipulating discharge limits and the responsible project parties to enable a more adequate assessment regarding compliance of a desalination project with applicable environmental regulations on a sound data basis.

Keywords: Seawater; Desalination; Power; Plant; Temperature; Increase; Salinity; Environmental; Regulation; Guideline; Limit; Discharge; Cooling; Water; Brine; Mixing Zone; Assessment; EIA; World Bank; Dilution; Impact; Procedure

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1. Introduction

Desalination plants are processing huge quantities of sea water for the production of high quality distillate water. With reverse osmosis (RO) plants the sea water volume to be circulated through the plant is two to three times the volume of the envisaged production capacity. With thermal desalination plants this ratio is even higher, between 5 and 10, mainly due to cooling requirements.

With regard to environmental impact the main concerns are with regard to the increased salinity and (with thermal processes) the increased temperature of the process effluent (brine, cooling water) which has to be discharged into the sea.

It is an unavoidable consequence of the operation of large scale desalination projects that the salts removed by the desalination process and the thermal energy used for cooling in thermal processes will be returned almost completely back to the sea. Therefore, it may be difficult or even impossible to comply with stipulated discharge limits in a given aquatic environment considering the discharged water volume and its temperature and salinity, water depth at the point of discharge, distance from the shoreline and sea water currents along the coast.

Many national and international environmental regulations and guidelines are stipulating discharge limits for temperature and salinity to be complied with by the projected desalination plant in order to obtain the environmental approval for operation.

However, the conditions under which such environmental compliance has to be proven to the responsible authority are in many cases not clearly defined (except for some countries, e.g. USA, Australia, where more elaborated assessment procedures are available). The author's experience in this regard mainly refers to large desalination and thermal cogeneration plants in the Middle East.

It shall be noted that the suggested approach presented herein for determination of a minimum mixing volume is of a simplified nature and is focussed on the availability of sufficient dilution water and does not account for a number of hydrodynamic factors (i.e., energy of discharged water, wind & tidal movement) which typically should be considered in detailed hydrodynamic modelling. Thus, the suggested formulas are not intended to be used for direct applications but to visualise the general approach. This paper is meant to initiate a related discussion and to point out that there is still a lack of clear assessment procedures for assessment of environmental impacts from desalination and power plants in many environmental guidelines and legislative implementation rules.

2. Existing regulations and guidelines for cooling water and brine discharge

The best known regulation of this kind has been stipulated by the World Bank (WB) [1], which defines a so called mixing zone around the point of water discharge to the sea and limits the temperature increase over ambient conditions (above receiving water) at the edge of this mixing zone to 3 K.

In case the radius is not defined elsewhere it shall be assumed to be 100 m. However, the evaluation procedure and the requirements for the data basis to be used in such assessment are not described in the World Bank guidelines (Fig. 1).

Similar statements can also be found in other national environmental regulations [2,3], some of which are more stringent than those of the World Bank. In the UAE, for example [3], the temperature increase at the edge of the mixing zone is limited to 1 K, and the salinity increase to 2% of the background level (weekly average). But most of the national environmental regulations do not include the size of the mixing zone to be considered and the procedure of how to determine the temperature and salinity at the edge of the mixing zone, which have to be compared with the applicable limits.

Formally this is usually defined by the project Environmental Impact Assessment (EIA) on the basis of the existing environmental conditions at the point of discharge. This is considered basically correct since the conditions of the discharged water stream itself, the specific ambient conditions, and the existing environment at the point of discharge have to be taken into consideration for this kind of assessment. However the lack of a clear evaluation procedure leads to a variety of different approaches in EIA studies, the results of which are not comparable.

Correspondingly, EIA reports of desalination or power projects are usually unclear in this regard and often a lack of sound input data is compensated by qualitative discussions with improvable results.

In consequence the stipulated discharge limits could easily be circumvented and potential exceeding of applicable limits can hardly be proven in quantitative terms.

3. Alternative approaches

In the following different assessment procedures will be described which will enable a clearer comparison of the expected thermal and salinity impacts on the receiving waters with the stipulated discharge limits and will allow for comparison of the calculated impacts

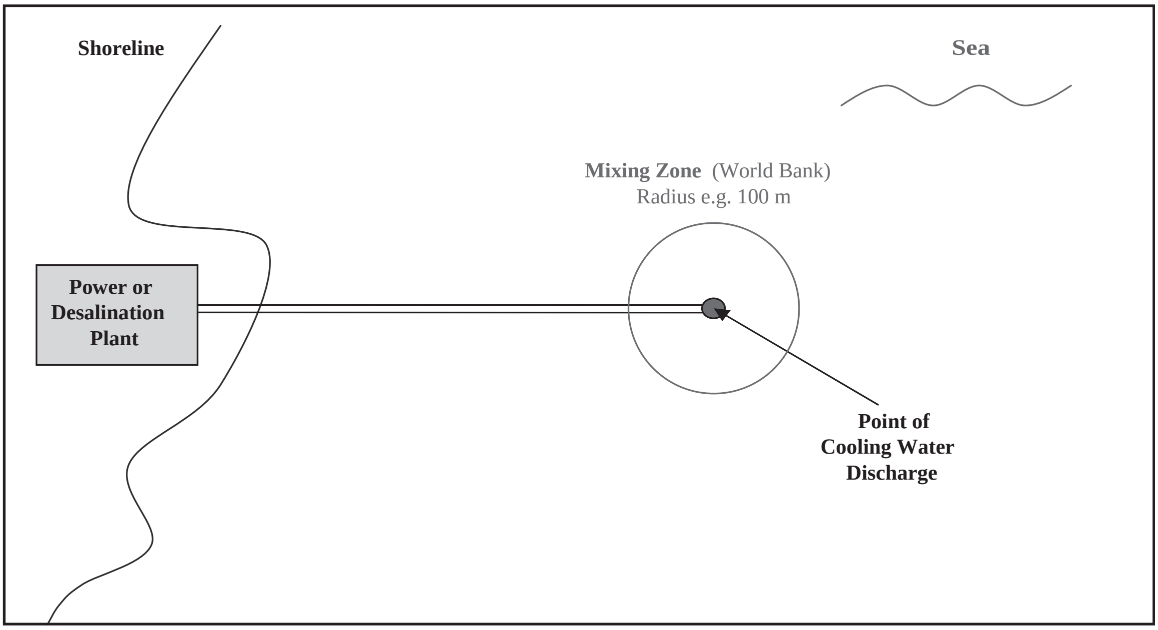

Fig. 1. Mixing zone as defined by the World Bank.

of different plants at different locations based on the same evaluation procedure.

If we consider this simple figure as a model for water discharge to the sea, than it can immediately be understood that the efficiency of mixing of the discharged brine with the ambient sea water is strongly dependent on the actual water depth and the velocity distribution of the sea water currents at this point. Although various other parameters have to be considered, the two parameters mentioned above determine the volume of ambient sea water available for dilution of the discharged water and thus to reduce the initially elevated average sea water temperature and salinity in this area by mixing.

However such mixing normally does not take place only within the area around the discharge. The zones of increased salinity and temperature are moving with the sea water current forming a characteristic dispersion pattern in both horizontal and vertical directions.

Different scenarios have to be considered to reflect the typical daily and seasonal distributions of seawater currents in the discharge area. The worst case scenario has to be identified and the temperature and salinity values calculated for this scenario have to be compared to the applicable discharge limits.

The data and information required for such an assessment could be derived from a dedicated sea water recirculation study, which is required in any case for large scale desalination projects, in order to avoid efficiency losses due to recirculation between intake and outfall.

Usually recirculation studies mainly focus on the situation of temperature and salinity increase at the plant water intake. For the purpose of environmental impact assessment, however, particularly the situation around the point of brine and cooling water discharge is of interest.

Therefore, it is recommended to the responsible project party to specify this aspect in detail into the scope of work for the recirculation study, the results of which are later to be used by the EIA-Consultant.

Several different approaches can be used to assess the compliance with a discharge limit for temperature or salinity increase after mixing with ambient seawater within a defined mixing zone, different.

One approach is simply to assume a mixing zone with a radius of 100 m according to WB guideline and apply it to the graphic dispersion isoline plot of a recirculation study is not sufficient to assess the compliance with a discharge limit at the edge of the mixing zone.

The temperature and salinity at the edge of the mixing zone are considerably different upstream and downstream of the water flow direction. It is unclear whether the temperature in current flow direction downstream of the discharge (maximum) or an average along the mixing zone circle has to be considered. The same question arises considering the distribution over the water depth.

Therefore, a clear procedure for calculation of an average over the 3-dimensional distribution of temperature and salinity is required before any meaningful comparison with applicable limits can be performed (Fig. 2).

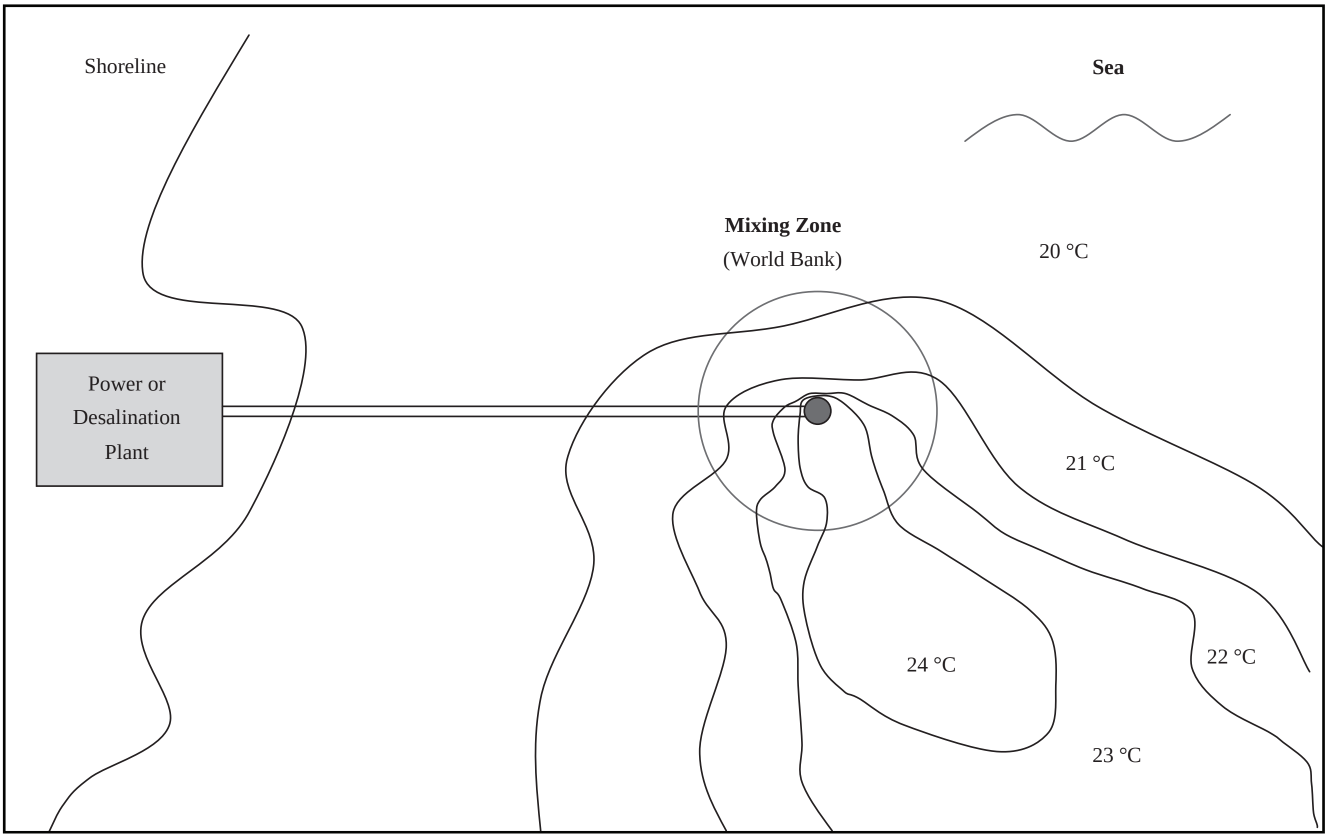

Fig. 2. Temperature distribution iso-lines around the point of discharge.

One approach close to the intention of the World Bank would be to calculate the average temperature and salinity at the edge of a circular mixing zone, e.g. by graphical evaluation of the recirculation study plots. In order to achieve representative results this should be carried out for different water depths and an average should be calculated from the results at different depths (Fig. 3).

However, when using this approach the required radius of the mixing zone is still not defined. For a given project discharge flow the radius of the mixing zone would obviously have to be larger in shallow water compared to deeper water.

The World Bank recommends a radius of 100 m in case the mixing zone is not defined elsewhere. However, criteria for the definition of the radius are missing in the World Bank Guideline. In view of very different bathymetric conditions and sea water currents at different project sites it appears more suitable to refer to a minimum water volume which is available for dilution and cooling of the discharged water stream.

The actual volume flow available for dilution can be roughly determined by multiplication of the average sea water (SW) current along the point of discharge, the diameter of the mixing zone (MZ) in an angle of 90 degrees to the direction of the SW current and the SW depth at the point of discharge:

$$V_{Dil} = AC_{SW} * Di_{MZ} * De_{SW}$$

V_{Dil} = Volume flow available for dilution [m^3/h]
AC_{SW} = Average SW current flow [m/h]
Di_{MZ} = Mixing zone diameter [m]
De_{SW} = SW depth [m]

In order to enable direct comparison between different projects the calculation should be done using the same mixing zone diameter. In case the natural SW current is very low, than minimum virtual sea water current could be assumed, reflecting the dilution potential by mere diffusion and convection within the water volume (Fig. 4).

In order to achieve sufficient dilution a minimum dilution volume could be defined by multiplication of the water volume flow to be discharged into the sea, the temperature increase above ambient conditions ($T_{outfall} - T_{Intake}$) and a (minimum) dilution factor to be stipulated by the environmental guideline

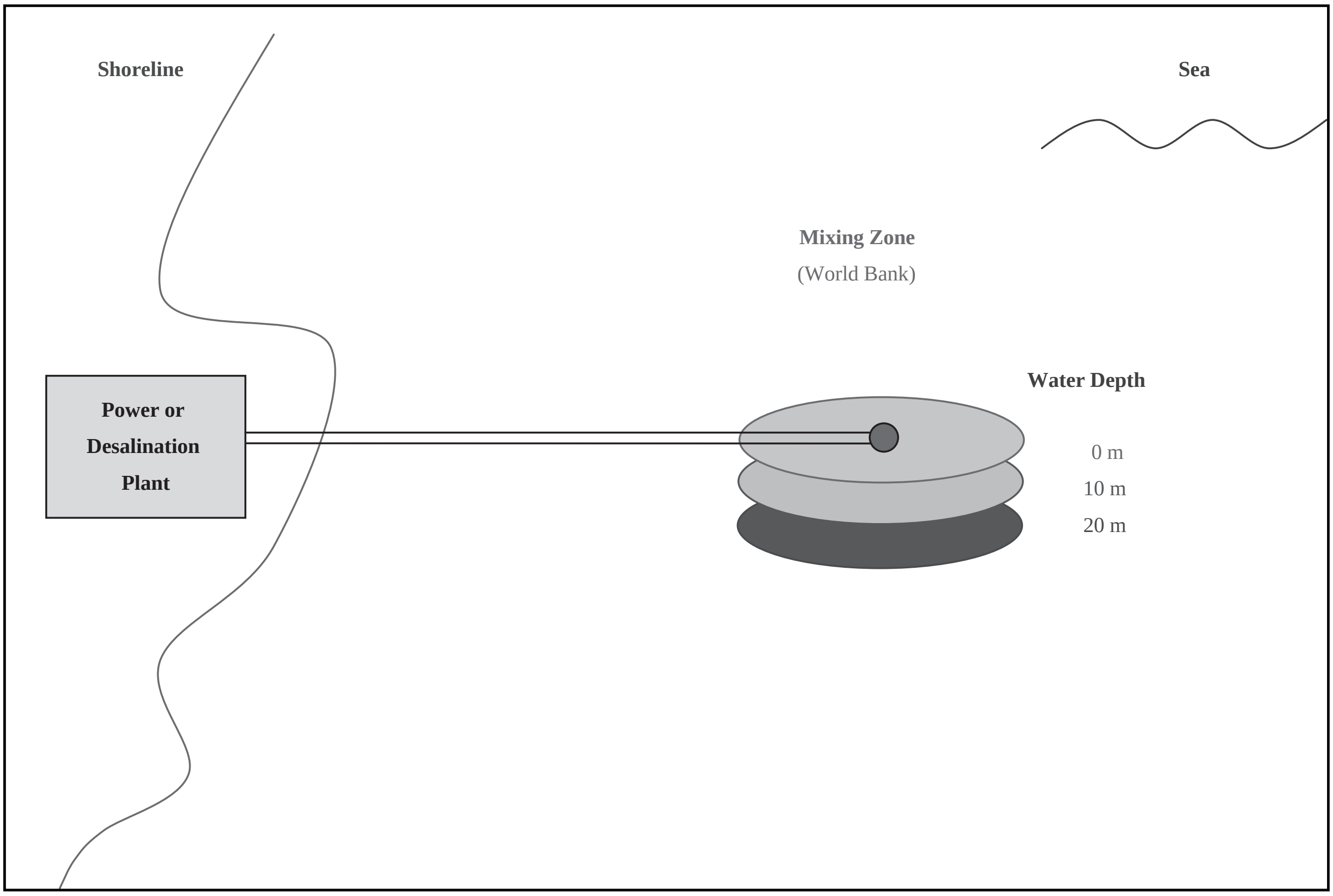

Fig. 3. World Bank mixing zone at different water depths.

representing the minimum required dilution volume per Kelvin of temperature increase (in a second step the factor may be adjusted depending on the sensitivity of the receiving water environment).

$$MV_{Dil} = V_{Dis} * DT * FT_{Dil}$$

MV_{Dil} = Minimum dilution volume flow [m^3/h]
V_{Dis} = Discharge volume flow [m^3/h]
$\triangle T$ = Temperature increase above ambient [K]
FT_{Dil} = Dilution factor for temperature [1/K]

The same would be applicable for the salinity increase:

$$MV_{Dil} = V_{Dis} * DS * FS_{Dil}$$

MV_{Dil} = Minimum dilution volume flow [m^3/h]
V_{Dis} = Discharge Volume Flow [m^3/h]
$\triangle S$ = Salinity Increase above Ambient [ppt]
FS_{Dil} = Dilution Factor for Salinity [1/ppt]

Note: ppt – parts per thousand.

4. Conclusions

With the general approach presented here the only limit to be stipulated by an environmental guideline would be the (minimum) dilution factor per Kelvin ensuring that the same kind of assessment is possible for all potential plant sites. Due to the fact that the SW currents are also considered in this approach, possible future obstructions to the SW currents, e.g. by construction works, could be considered in the environmental assessment, based on corresponding results of a recirculation study.

Although being very simplistic, this general approach provides for comparable basic assessment of all projects and enables a clear comparison with a stipulated limit for increase of ambient temperature or salinity.

Of course, the dispersion flow patters still have to be investigated in the EIA by means of detailed hydrodynamic modelling to ensure that no sensitive aquatic environment is adversely affected by the discharge.

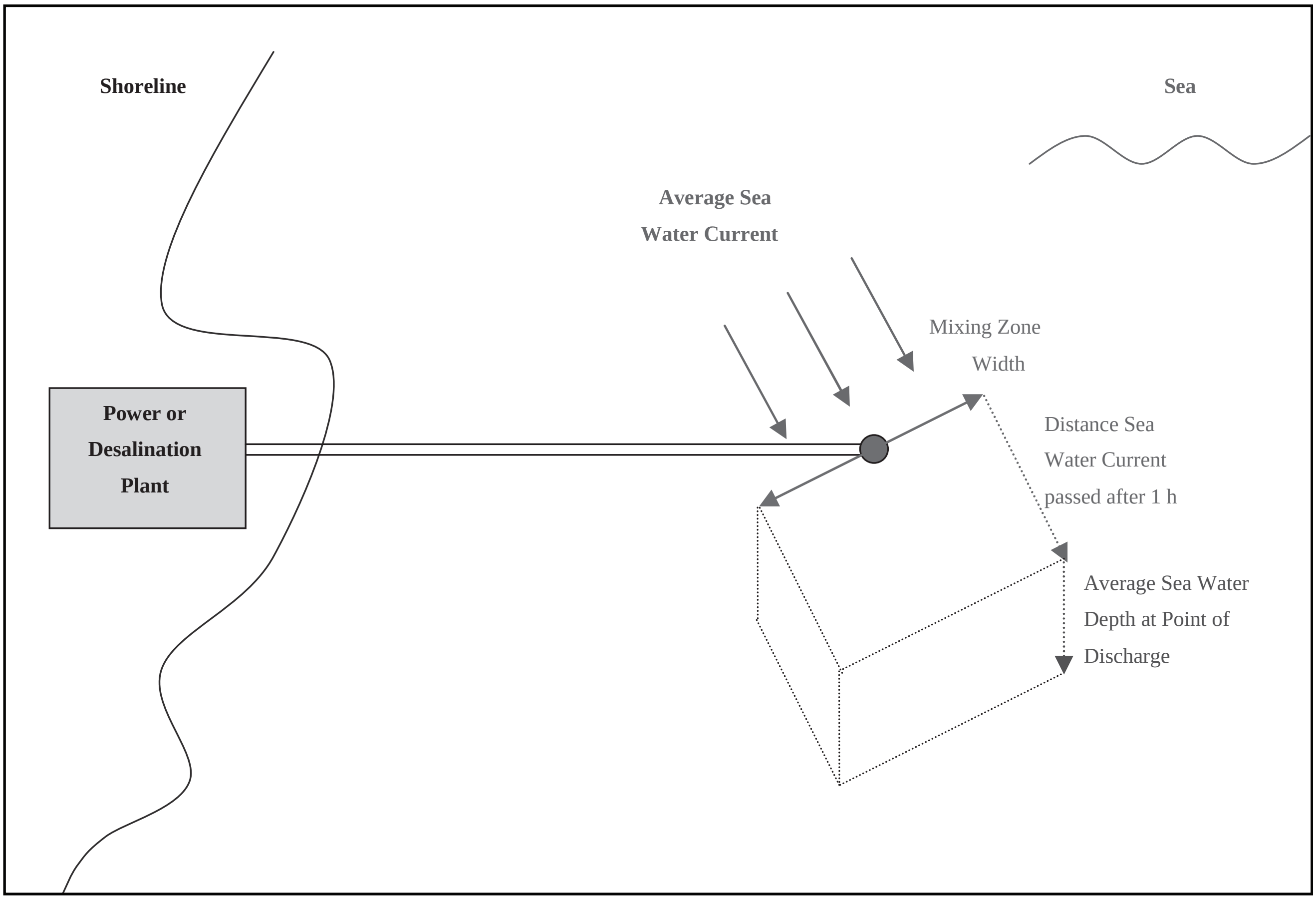

Fig. 4. Definition of dilution volume.

It is recommended to national and international environmental authorities to revise their regulations with regard to effluent discharge limits for desalination and power plants and to include a clear procedure, such as the one just described above on how to assess the compliance with the stipulated discharge limits. This is required to achieve comparable results for plants located in different environmental conditions and for a sound assessment of their environmental impacts with regard to stipulated water discharge limits.

References

[1] World Bank Pollution Prevention and Abatement Handbook 1998, World Bank Group 1999, pp. 419, Table 1: Effluents from Thermal Power Plants.
[2] Environmental Protection Standards, 2001, Presidency of Meteorology and Environment (PME), Kingdom of Saudi Arabia, Page 12, Table B1 Physico-chemical Pollutants (Guidelines at edge of mixing zone).
[3] Local Order 61, Dubai Municipality, Environmental Protection Section, 1999, p. 9.