Analytic Comparisons of Brine Discharge Strategies Relative to Recommendations of the *SWRCB Brine Panel Report*: In-Plant Dilution vs. High Velocity Diffuser Alternatives at the Carlsbad Desalination Project

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ABSTRACT:

We address implications of the findings and recommendations of California Water Resources Control Board Science Advisory Panel listed in their report entitled, "Management of Brine Discharges to Coastal Waters Recommendations of a Science Advisory Panel", see Jenkins, et al., (2012). Here, diffuser-based discharge strategies are presented as *the preferred discharge technology*, although that section also admits: "*Different discharge strategies can be used, depending on site-specific considerations. There is no single discharge strategy that is optimum for all types of anticipated scenarios*." In addition, a potentially new regulatory standard may follow from this report for discharges from ocean desalination plants. Proposed amendments to the California Ocean Plan based on this report could set a numeric water quality objective limited to 5% over ambient ocean salinity at the limit of a *Regulatory Mixing Zone* measuring 100 m (330 ft) in radius around the discharge point (referred to as *The 5% Rule*). Our concern is that while the diffuser-based discharge strategy may be the best technology at some locations, it may not be the best available technology where certain site specific conditions are present, as is the case for the Carlsbad Desalination Project; which has been fully permitted based on *in-plant dilution* using the once-through sea water circulation system of the Encina Power Station (EPS) in Carlsbad, CA.

Our analysis evaluates present and potential future operating conditions for the Carlsbad Desalination Project, including: 1) existing, fully-permitted, baseline operating conditions where desalination operations occur utilizing heated seawater effluent from power generation by the Encina Power Station (EPS) ; 2) potential future *stand-alone* operating conditions where the desalination plant is withdrawing seawater independent of power generation following retirement of the EPS once-through cooling system . Such future action might occur because the host EPS re-powers and converts to air-cooling systems, or because the EPS generators are decommissioned. In the stand-alone scenario, there is no mortality to entrained organisms by *thermal shock* due to passage through hot condenser tubes. Regardless of present or future operating conditions, our general conclusion is that the high velocity diffuser strategy does not present a compelling advantage over the in-plant dilution strategy at the Carlsbad site when measured in terms of offering further reductions in project mortality to eggs, larvae and juvenile fish. Pump replacement with the in-plant dilution strategy under stand-alone conditions can

potentially provide significant reductions in such mortality; whereas the diffuser strategy risks expanding marine life entrainment impacts to fish species originating from neighboring kelp beds, and inducing formation of bottom turbidity layers with diffuser-induced turbulence that has the potential to significantly degrade those kelp beds.

Analysis Methods: To quantify mortality likelihood for entrained organisms passing through the in-plant dilution pathway of the Carlsbad Desalination Project; or alternatively, through the turbulent mixing zone of an offshore diffuser system, we invoke standard hydraulic calculus, supplemented by computational fluid dynamic (CFD) computer analysis. Thresholds for the various types of entrainment mortality were based on laboratory and field measurements of lethal and sub- lethal pressure gradients, accelerations and turbulent shear stresses, strain rates and turbulence mixing scales; largely derived from the hydro-electric literature for eggs, larvae and juvenile adults of fresh water species. These measurements were applied to in-situ samples of size and abundance of locally relevant marine species. In comparing in-plant vs. diffuser dilution strategies, we assume both are based on 104 mgd of ocean water intake flow (the permitted amount) that unavoidably will cause 100% entrainment mortality on this harvested fraction of source water as a result of the action of the pre-treatment train and RO processes. To provide a common reference point, we first evaluate both in-plant and diffuser-based discharge strategies for a common dilution standard, namely that approved by the Regional Water Quality Control Board, San Diego Region; and then compare those findings to results based on recommendations of California Water Resources Control Board Science Advisory Panel under a dilution standard of *The 5 % Rule.*

In-Plant Dilution Strategy: Under the fully-permitted baseline conditions, this strategy requires 104 mgd of seawater for processing in the desalination facility (as described above) and 200 mgd of dilution water, yielding a total of 304 mgd of seawater intake, derived from Agua Hedionda Lagoon. We quantify the turbulence mortality for these conditions based on the assumption of 100% mortality to organisms entrained in incremental flow required for desalination facility operation when EPS is operating at less than 304 mgd cooling water intake flow rates, (referred to as *short-fall* flow increments).This follows from permit conditions for operating the Encina Power Station (EPS), whence the Carlsbad Desalination Project was granted its permits for the *dual-use* of the heated seawater effluent from the power plant. In the operating history of EPS over the last decade or so, there were 660 days when daily seawater flow rates required by operations of the Encina Power Station (EPS) were less than 304 mgd; 122 of these low-flow days occurred between 1999 and 2006, while 538 low flow days occurred in the more recent 2006-2010 time period. The increase in numbers of low-flow days after 2006 can be correlated with the commissioning of the Palomar cogeneration facility in April 2006; but recent de-commissioning of the San Onofre Nuclear Generating Station seems likely to reverse that trend. In view of these external operating factors, it is sensible to consider two sets of flow rate statistics: the historic record of the last 11 years representative of the long-term average operating environment; and the 2006-2010 subset of that record, representing a potential short-term, worst-case.

Over long term conditions, EPS operated its seawater circulation systems at 92.6% of the baseline operating need for in-plant dilution. During worst-case operating conditions (represented by 2006-2010), EPS operated its seawater circulation systems at 81.3% of flow rate requirements for permitted baseline desalination operations. Applying the well-excepted (and permit-adopted) *flow-proportional principle*, we find that the net impact of in-plant dilution under the permitted baseline is 2.24% entrainment mortality under average long-term EPS operating conditions. This figure represents mortality occurring in additional seawater taken for dilution beyond the amount of dual-use water provided by operations of the Encina Power Station. This net impact is equivalent to an estimated daily loss of 3,323 mature larvae and juvenile adults and 407,680 eggs and immature larvae. Under worst-case EPS operating conditions, in-plant dilution water produces a net impact of 5.66% entrainment mortality. Net impact for this worst-case assessment is equivalent to an estimated daily loss of 8,398 mature larvae and juvenile adults and 1,030,120 eggs and immature larvae.

The in-plant dilution strategy for the Carlsbad Desalination Project can be improved by retrofitting the existing cooling water pumps with ultra-low rpm pump options; because pump rpm exerts a strong influence on entrainment mortality. Introducing new technologies that remediate entrainment impacts is contemplated under the various approvals issued for the Carlsbad Desalination Project. Of particular interest in this regard are the large *screw-pumps* that have been used previously in seawater circulation systems for aquariums and mammal tanks at Sea World, San Diego. The screw pump relies on an Archimedes screw to thread through the water mass and push water along the in-plant dilution pathway, rather than spin the water mass to high rpm and eject it at high velocity and acceleration along the dilution pathway in the manner of the existing EPS centrifugal pumps. Mortality during pump passage is dependent on the size of the entrained organisms. With 4 Spaans-Babcock screw pumps diverting 200 mgd directly into the discharge tunnel (by-passing existing EPS conduits and condenser tubes) mortality at the small end of the organism size spectra would be reduced to 0.035% of the entrained organisms, amounting to a daily loss of only 16 mature larvae and juvenile adults and 1,975 eggs and immature larvae. At the high end of the organism size spectra, mortality during passage through a screw-pump would be 0.25% of the entrained species amounting to a daily loss of 114 mature larvae and juvenile adults and 13,934 eggs and immature larvae. Potentially, the screw-pump retrofit to the stand-alone Carlsbad Desalination Project could reduce entrainment mortality (best case) to 206 times less than the100% mortality assumption relied upon in the project approvals; and worst case, reduce entrainment mortality to 74 times less than what was assumed for the project approvals.

High Velocity Diffuser Strategy: There seems to be a general assumption that diffusers avoid all forms of marine life impact. However, there is an emerging body of published evidence that entrainment mortality by a free-jet is a very real phenomenon, whereby physical damage to eggs, larva and juvenile fish can occur in open, free-stream turbulent environments, such as the *turbulent mixing zone* of high pressure diffuser systems. The effect of turbulence on larval mortality was studied in the field by Jessopp (2007), who found that even turbulent *tidal flows* produce significantly increased mortality to thin-shelled veligers of gastropods and bivalves. In fresh water, Neitzel et al., (2000) demonstrated that a turbulent jet in a laboratory tank would cause major and minor injury to 4 different freshwater species of juvenile fish. A significant flow mechanism that causes injury and mortality in diffuser jets is shear sorting of the jet- entrained organisms. Shear induced lift forces concentrate the organisms in the higher velocity region of the shear flow, which is the high velocity core of the jet where both strain rates and accelerations are high and mortality likely.

To evaluate potential marine life impacts due to implementation of the high velocity diffuser strategy at the site of the Carlsbad Desalination Project, we pose a conventional linear diffuser, consisting of five discharge riser/diffusers structures in 10 meters of water depth at the end of a 72 inch diameter brine discharge pipeline, seaward of existing kelp beds. In order to make direct entrainment mortality comparisons to the in-plant dilution strategy, we assume a common hyper-salinity toxicity standard, namely the 40 ppt limit that was adopted for the NPDES permit for the Carlsbad Desalination Project by the Regional Water Quality Control Board, San Diego Region. Therefore, the diffuser would have to entrain receiving water at a rate of 200 mgd in order to achieve a comparable dilution to the in-plant dilution strategy. In the dilution process, the diffuser strategy will apply lethal shear stress to 10.7% of the eggs and larvae entrained by the diffuser jets that live in the receiving water. Using bulk abundance figures from the technical appendices of Tenera (2008) for offshore monitoring stations adjacent Agua Hedionda Lagoon, a conventional diffuser discharge strategy would induce an estimated daily loss of 4,838 mature larvae and juvenile adults and 593,233 eggs and immature larvae. These mortality figures are about 1.5 times worse than the average case estimate for the in-plant dilution strategy using existing Encina pumps, (cf. Section 5). If the in-plant dilution strategy were up-graded with screw pumps, then it would have a compelling 40 to 300 times advantage over conventional diffuser strategies in terms of reducing project mortality to eggs, larvae and juvenile fish at equivalent dilution levels.

If The 5 % Rule is invoked, then estimates of mortality to entrained organisms by diffuser jets are increased by increases in the entrained water mass required in order to achieve higher dilution levels. As a result, additional turbulence mortality will result from an expanded turbulent mixing zone. Under the 5% Rule, conventional diffusers incur a net equivalent entrainment mortality of 16.8%, resulting in an estimated daily loss of 930,563 eggs and larvae. This is 2.3 times more entrainment mortality than the average case assessment of operations of the Carlsbad Desalination Project with in-plant dilution under the presently issued permit; and 67-480 times more than would occur if screw-pumps were retrofitted under those same permit conditions.

Depending on site specific conditions, brine diffuser systems have the potential to introduce artificially high levels of bottom turbulence to offshore areas of seafloor where such high turbulence levels do not occur naturally, and consequently where the seabed sediments may not have adequate grain size to resist onset of motion due to these high turbulence levels. The turbulent brine effluent discharged by the diffuser rises to an apex in its trajectory where the upward flux of turbulent momentum is haulted by the downward force of gravity associated with the negative buoyancy of the brine effluent. This action causes the turbulent brine to fall back onto the seabed at an initial impact point and then spread across the seafloor as a turbulent *spreading layer*. The residual turbulence in this spreading layer resuspends the fine-grained seabed sediments forming a *turbid density current* , that can freely move about the seabed under the influenc of ambient currents or gradients in the bottom slope. The concern at the available offshore diffuser sites for the Carlsbad Desalination Project is that a diffuser-induced turbidity layer might spread into nearby kelp beds and reduce ambient light levels, thereby impacting kelp recruitment. To evaluate this concern, we invoke the Navy's Coastal Water Clarity Model. Based on recent current data and offshore sediment grain size data, we find that bottom turbidity induced by the scour action of a diffuser would reduce the photosynthetically available radiation (light spectrum between 400 and 700 nm referred to as "PAR") in the nearby kelp beds by 90% in worst-case; and on average, cause a 20% to 25% reductions in PAR in these beds. Extrapolating from well documented turbidity impacts observed near the outfall of the San Onofre Nuclear Generating Station (SONGS), it seems quite possible from these percent reductions in PAR that the turbidity impacts induced by diffuser operations could cause similar impairment and recruitment degradation to kelp beds near the available diffuser sites for the Carlsbad Desalination Project .

Efforts to reduce turbulence mortality in diffuser system s are difficult. Turbulence mortality in free-jets is a multi-variant function where it is difficult to simultaneously adjust all the variables in the appropriate direction that limits turbulence mortality. With diffuser jets in the open receiving waters, if one tries to limit turbulence mortality by minimizing the shear stress and strain rates with reduced jet velocities, then two negative feed-back factors result: 1) the dilution rates in the brine plume decline, and hyper-salinity toxicity in the inner regions of the turbulent mixing zone become an issue; and 2) the Komogorov turbulence scales (the turbulence scales where most dissipation occurs) tend to increase (because the dissipation rate tends to decrease with decreases in maximum jet velocities); and turbulence mortality will likely still occur through the action of turbulent eddies that are either comparable to, or larger than, the entrained organism. Efforts to reduce bottom turbidity impacts of diffusers are equally difficult, particularly when offshore sediment deposits contain significant amounts of silts and clays. The negative buoyancy of a diffuser brine plume invariably brings the turbulence in that plume into direct contact with the seabed; and efforts to reduce the sediment transport capacity of that turbulence by reducing jet velocities sets up the same negative feed-back processes mentioned above.

The primary issue that has been addressed in the present study is whether conventional high velocity diffuser systems are actually a "preferred technology" at the site of the Carlsbad Desalination Project, as some might otherwise infer from The Brine Panel Report and the language of the proposed 5% rule; or alternatively, is the in-plant dilution strategy better suited to this particular site in terms of being more protective of resident marine life. This question hinges on which discharge strategy has lesser potential impacts on marine life associated with turbulence mortality and bottom turbidity, since both are capable of producing dilution below acute and chronic hyper-salinity toxicity levels. Table 1 below summarizes the quantitative and process-based comparisons of environmental impacts between in-plant dilution and high velocity diffuser strategies. From these comparisons, it appears that there are greater quantifiable impacts and greater uncertainties associated with diffusers at this specific location; and consequently that discharge strategy cannot be considered the best available technology for the site specific conditions at the Carlsbad Desalination Project.

Table 1: Comparison of Environmental Impacts of Brine Discharge Alternatives

	Carlsbad Desalination Project Permitted Operating Conditions (co-located with Encina Power Plant)	Carlsbad Desalination Potential Operating Conditions (following retirement of Encina Power Plant)	Staff's Proposed Ocean Plan Amendments
Brine discharge salinity (ppt)	40.0	40.0	65.0
Receiving water salinity (ppt)	33.5	33.5	33.5
Salinity reduction requirement and discharge technology	Reduce salinity from 65 ppt to sublethal level of 40 ppt prior to discharge through in-plant dilution. Remainder of dilution achieved through natural mixing via low velocity (1 to 3 feet per second) discharge into high energy surf zone seaward of the point of discharge. Zone of initial dilution (the "ZID") extends 1,000 feet from end of the discharge channel.	Similar to permitted operating conditions *See*	Mechanical mixing achieved through pressurized diffuser used to reduce full strength brine salinity to from 65 ppt to 35.5 ppt through high velocity (5 m/s) turbulent mixing in receiving water. ZID extends 100 meters from the point of discharge.
Initial dilution	5:1 prior to discharge and 15:1 in the ZID.	5:1 prior to discharge and 15:1 in the ZID.	20:1 in the ZID
Habitat present in the vicinity of the discharge	Sandy bottom	Sandy bottom	Silty seabed at diffuser site with rock with kelp forest immediately south (down-drift from the diffuser).
Volume of seawater exposed to entrainment impacts to achieve required salinity level	200 MGD of seawater is pumped through the Encina Power Station once-through cooling water system for in-plant dilution to achieve 5:1 dilution.	200 MGD of seawater is transferred from the Encina Power Plant intake to the discharge channel using low impact, low-rpm screw- pumps to achieve 5:1 dilution. These pumps minimize turbulence and impeller blade-strike impact mortality.	Up to 950 MGD of seawater is entrained by 5 high velocity jets turbulent/high-velocity jets to achieve 20:1 dilution. Shear sorting in the diffuser discharge plume causes entrained organisms concentrate in the high velocity jet core where shear stresses and strain rates are significantly above lethal limits.

Entrainment mortality	Estimated net impact of 2.24% entrainment mortality, occurring in additional seawater taken for dilution beyond the amount of dual-use water provided by average operating conditions of the Encina Power Station (407,680 eggs and larvae).	Mortality estimated to be 0.035% of the entrained organisms for best case scenario. The absolute worst case mortality estimate is 0.25 % of the entrained organisms (1,975 eggs and larvae to 13,934 eggs and larvae).	Mortality estimated to be 16.8% of organisms entrained by 5 diffuser jets; or 2.3 times greater than average mortality estimates for permitted project; 67 to 480 times greater than mortality estimates for in-plant dilution with screw pumps (930,563 eggs and larvae).
Organisms in entrained water	Due to the intake location in Agua Hedionda Lagoon, ninety-five percent of the larval organisms entrained are lagoon based species that have saturated Agua Hedionda Lagoon (e.g., gobies and blennies makeup over 80% of the entrained fish larvae). Less than 0.5% of the entrained organisms are recreationally or commercially important species; no threatened or endangered species were identified.	Same as permitted operating conditions.	Due to the diffuser location off shore and its proximity to the Carlsbad kelp bed, the diffuser would entrain significantly greater numbers of commercially and recreationally important fish and invertebrates than the lagoon based intake. Additionally, the higher level of dilution (20:1 vs. 5:1) would result nearly a five-fold increase in entrainment.
Marine organisms exposed to lethal level of brine concentration?	The marine organisms entrained in the dilution water are briefly exposed to lethal levels of salinity up to 65 ppt. The brine is rapidly reduced to sub-lethal levels (40 ppt) in discharge tunnel and pond system prior to discharge.	The marine organisms entrained in the dilution water are briefly exposed to lethal levels of salinity up to 65 ppt. The brine is rapidly reduced to sub-lethal levels (40 ppt) in discharge tunnel and pond system prior to discharge.	The marine organisms entrained in the high velocity diffuser jets are briefly exposed to lethal levels of salinity up to 65 ppt. The brine is rapidly reduced to sub-lethal levels in the receiving water.

Potential for increased turbidity and sediment flux down coast from the discharge to create a long-term negative effect on kelp reproduction in the nearby kelp beds	No. Low velocity discharge over sandy beach and surfzone sediments that contain no silts or clays to cause turbidity.	No. Low velocity discharge over sandy beach and surfzone sediments that contain no silts or clays to cause turbidity	Yes. High velocity discharge coupled with silty offshore seabed sediments will cause bottom turbidity layers that reduce ambient light intensities in nearby kelp beds. Photosynthetically available radiation (PAR) in the nearby kelp beds reduced by 90 % in worst-case; and on average, reduced by 20 % to 25 % . Similar experience with diffuser technology at the San Onofre Nuclear Generating Station that had a long-term negative effect on kelp reproduction in the nearby San Onofre kelp bed, with significant losses of kelp plants, the failure of adult recruitment of new kelp plants, and a dramatic decline in the fish and shellfish that had depended on the now damaged or destroyed kelp forest for habitat, cover and food.
Other environmental impacts	None	None	Impacts associated with construction of a new ocean outfall and diffuser extending one mile offshore. Increased energy consumption.

1.0) Introduction:

In Section 10.2 (Conclusions and Recommendations-Discharge Strategies) of the SWRCB *Brine Panel Report*, (Jenkins, et al, 2012), diffuser-based discharge strategies are presented as a preferred discharge technology, although that section also admits: "Different discharge strategies can be used, depending on site-specific considerations. There is no single discharge strategy that is optimum for all types of anticipated scenarios." As an example of a *different* or alternative discharge strategy, the Carlsbad Desalination Project has been fully permitted based on the use of *in-plant dilution* with reverse osmosis (R.O.) facilities that are co-located with the once-through sea water circulation system of the Encina Power Plant. Nothing in EPA regulations, EPA guidance, or the California Ocean Plan prohibits the use of in-plant dilution or blending for purposes of reducing salinity concentrations at the point of discharge (Welch, 2011). However, the primary concern with this alternative disposal strategy is mortality to micro-organisms (eggs and larvae) arising from the velocity shear and turbulence occurring in pumps and pipelines of once-through sea water circulation systems, (Bamber and Seaby, 2004). This is generally referred to as *Entrainment Mortality*, but should probably be further distinguished as *Confined Entrainment Mortality*. This qualifier should be applied because there exists published evidence that this same sort of physical damage (due to turbulence and velocity shear pulling apart eggs and larva) can also occur in open, free-stream turbulent environments, similar to what would occur when these organisms are entrained into the *turbulent mixing zone* of high velocity diffuser systems. Herein we will refer to this as *Free-jet Entrainment Mortality*, indicating such mortality can also occur in the unconfined spaces of the interior water column of the receiving water body.

In this technical note, we evaluate present and potential future operating conditions for the Carlsbad Desalination Project, including: 1) existing, fully-permitted, baseline operating conditions where desalination operations occur utilizing heated seawater effluent from power generation by the Encina Power Station (EPS) ; 2) potential future *stand-alone* operating conditions where the desalination plant is withdrawing seawater independent of power generation following retirement of the EPS once-through cooling system . Such future action might occur because the host EPS re-powers and converts to air-cooling systems, or because the

EPS generators are decommissioned. In the stand-alone scenario, there is no mortality to entrained organisms by *thermal shock* due to passage through hot condenser tubes.

The desalination project has been fully permitted for production of 50 mgd of product water derived by RO treatment of 104 mgd of ocean water intake flow. Here, we confine our analysis to a comparison of marine life impacts for two distinct intake/discharge strategies, namely *in-plant dilution* and *high velocity diffusers*. In comparing these strategies, we assume both are based on 104 mgd of ocean water intake flow that unavoidably will initially cause confined entrainment mortality to 100% of the 104 mgd of source water taken through an open ocean intake as a result of the action of the pre-treatment train and RO processes. We will also assume that both discharge strategies dilute the brine discharge below the same level of chronic toxicity. Thus the analytic comparison becomes:

1) Marine life impacts from turbulence mortality are evaluated for an additional 200 mgd of ambient ocean water by-passed around the RO system to affect *in-plant dilution* to salinity levels below chronic toxicity upon discharge to the ocean.

2) Marine life impacts in the receiving water from turbulence mortality are evaluated for 50 mgd of brine discharged through a *high velocity diffuser system* to dilute brine in the receiving water from double ambient ocean salinity to levels below chronic toxicity.

There is an emerging body of published evidence that free-jet entrainment mortality is a very real phenomenon, whereby physical damage to eggs, larva and juvenile fish can also occur in open, free-stream turbulent environments, such as the *turbulent mixing zone* of high pressure diffuser systems. The effect of turbulence on larval mortality was studied in the field by Jessopp (2007), who found that even turbulent *tidal flows* produce significantly increased mortality to thin-shelled veligers of gastropods and bivalves. In fresh water, Neitzel et al., (2000) demonstrated that a turbulent jet in a laboratory tank would cause major and minor injury to 4 different freshwater species of juvenile fish. Increased mortality of zebra mussel veligers (Rehmann et al, 2003) and yolk-sac larvae of paddlefish (Killgore et al, 1987) due turbulent shear has also been demonstrated under laboratory conditions.

Discharge jet velocities from brine diffusers typically range from 3 m/s to 5 m/s, higher than naturally occurring tidal flows; and the turbulence from these high velocity jets effect large volumes of receiving water on the order of tens to hundreds of cubic meters (the turbulent mixing zone). In the turbulent mixing zone of a diffuser in certain environments, entrained eggs and larvae suffer additional physical stress from contact with very high salinity, because the diffuser does not produce its full initial dilution until the outer edges of the mixing zone. The literature cited herein suggests that diffuser discharge technology merely displaces turbulence-induced mortality from in-plant flow processes to the water column of the receiving water body. This displacement might actually be more impactful than the in-the-pipe impacts associated with in-plant dilution, when the offshore location of discharge diffusers directly impinges (in situ) on high value, sensitive and/or keystone offshore marine communities.

2.0) Turbulence Related Discharge Issues

Hyper-salinity toxicity: This is the primary regulatory driver for how much dilution water is required either through in-the-pipe dilution in the form of intake by-pass water around the RO treatment train, or by turbulent mixing and entrainment by diffuser jets in the receiving water. *By either discharge-dilution technology, the exact same quantity of dilution water is required to satisfy any given hyper-salinity toxicity standard.* There are two regulatory discharge compliance questions related to brine dilution: 1) Will the discharge strategy (in-plant dilution vs diffusers) satisfy the 0.3 TUa objective of Requirement III.C.4(b) of the present version of the *California Ocean Plan* as it would apply to a *Zone of Initial Dilution* (ZID); and, 2) Will the discharge strategy satisfy suggested amendments to the California Ocean Plan based on a recently released study by the California Water Resources Control Board Science Advisory Panel. Suggested amendments to the California Ocean Plan based on this report could set a numeric water quality objective limited to 5% over ambient ocean salinity at the limit of a *Regulatory Mixing Zone* measuring 100 m (330 ft) in radius around the discharge (referred to as *the 5% rule*).

The present NPDES permit issued by the Regional Water Quality Control Board, San Diego for the Carlsbad Desalination Project finds that the use of in-plant satisfies the present 0.3 TUa discharge water quality objective of Requirement III.C.4(b) of the California Ocean Plan.

However the project design based on existing infrastructure and the use of an open channel discharge into the neighboring surf zone will not satisfy the potentially more restrictive 5% rule with its 100 m Regulatory Mixing Zone in certain rare environmental cases, when extreme small ocean waves occur in combination with extreme low tides. During these rare events, the ocean waterline is seaward of the discharge jetties, and much of the proposed 100 m Regulatory Mixing Zone (as measured from the point of discharge) is dry beach where dilution is not possible, and the remainder is only shallow swash zone and inner surf zone (Jenkins and Wasyl, 2005; 2007). The primary issue addressed in the present study is whether conventional high velocity diffuser systems are actually a "preferred technology" at the site of the Carlsbad Desalination Project, as some might otherwise infer from The Brine Panel Report and the language of the proposed 5% rule; or alternatively, is the in-plant dilution strategy better suited to this particular site in terms of being more protective of resident marine life. This question hinges on which discharge strategy has lesser potential impacts on marine life associated with turbulence mortality and bottom turbidity, since both are capable of producing dilution below acute and chronic *hyper-salinity toxicity.*

Turbulence mortality: Physical damage (due to turbulence and velocity shear) may occur when planktonic organisms are entrained into the turbulent mixing zone of high velocity diffuser systems. Discharge jet velocities from the brine diffusers typically range from 3 m/s to 5 m/s, generally higher than naturally occurring ocean currents. In the turbulent mixing zone of a diffuser, entrained eggs and larvae may suffer *impact mortality* from direct contact with the high velocity core of a diffuser jet; and *turbulent shear mortality* in the entrainment and outflow regions of the turbulent mixing zone (Ulanowicz, 1976).

Bottom turbidity: The turbulent mixing zone of high velocity diffuser systems may cause re-suspension of bottom sediments and the formation of a bottom turbidity layer. This turbidity layer has the potential to cause impairment of the recruitment and growth of kelp beds on neighboring hard bottom substrate. Based on the high percentage of fine-grained sediments in the offshore regions around Encina Power Plant, significant diffuser induced bottom turbidity appears likely causing reductions of ambient light levels in local kelp beds (cf. Section 6.2).

3.0) Mechanics of Turbulence Mortality:

Our assessment of the issue of mechanical damage to entrained ichthyoplankton in turbulent flows begins with a review of the physical forces which could stress the organisms. The three major forces often associated with high velocities and turbulent flow are 1) pressure gradient forces, 2) inertia forces associated with acceleration, and 3) shear stresses and friction forces arising from velocity shear.

3.1) Impact Mortality: Pressure gradient forces and inertia forces associated with acceleration act together to cause impact mortality to ichthyoplankton in *confined entrainment* within a pump and pipe system or in *free-jet entrainment* by a high velocity diffuser. When a pressure gradient produces a substantial change in pressure over a distance comparable to the size of an egg or larvae, that pressure change can cause external or internal cellular damage by compressing or stretching those organisms (Tsvetkov, et al, 1972; Morgan, et. al, 1974, Marcy, et al, 1978). The pressure gradient will also cause the organism and surrounding fluid to accelerate. The acceleration induces a body force on the entrained organism that can be many times the acceleration of gravity.

We can speak in terms of at least three ranges of acceleration. At the lower end of the scale are the accelerations due to change in the bulk speed of the fluid flow. Typically these accelerations would be encountered near the intake of a power plant seawater circulation system (eg, Encina), or in the entrainment region of a high velocity diffuser (see Figure 1). These forces usually range from very slight to the order of magnitude of the gravitational force. In all likelihood they are not very damaging (Tsvetkov, et al, 1972; Ulanowicz, 1976, Marcy, et al, 1978).

In the intermediate range are the accelerative inertial forces associated with the turbulent eddies characteristic of most discharge flows from power plant seawater circulation systems, or the outer portions of the turbulent mixing zone of a high velocity diffuser (see Figure 1). If one follows the tortuous path of an entrained organism in such flows, abrupt changes in speed and direction will be induced upon that organism. Such accelerations give rise to body forces several times that of gravity and could possibly be damaging to ichthyoplankton, either immediately or in later development, (Tsvetkov, et al, 1972; Marcy, et al, 1978; Cada and Glenn, 2001 and Cada et al, 2006).

Potentially the most destructive accelerative forces would be short duration, high magnitude impulses from the impact of the organism with a solid surface or with the core of a high velocity jet. Such forces could be many times the acceleration of gravity and are typically fatal (Tsvetkov, et al, 1972; Ulanowicz, 1976; Cada and Glenn, 2001; and Cada et al, 2006). High magnitude impulses arising from large pressure gradients and large accelerations or decelerations are commonly associated with the legacy term *impact mortality*, (Ulanowicz, 1976; Marcy, et al, 1978), although smaller acceleration in turbulent eddy fields may also be deleterious to ichthyoplankton , especially at the smaller end of the size spectrum.

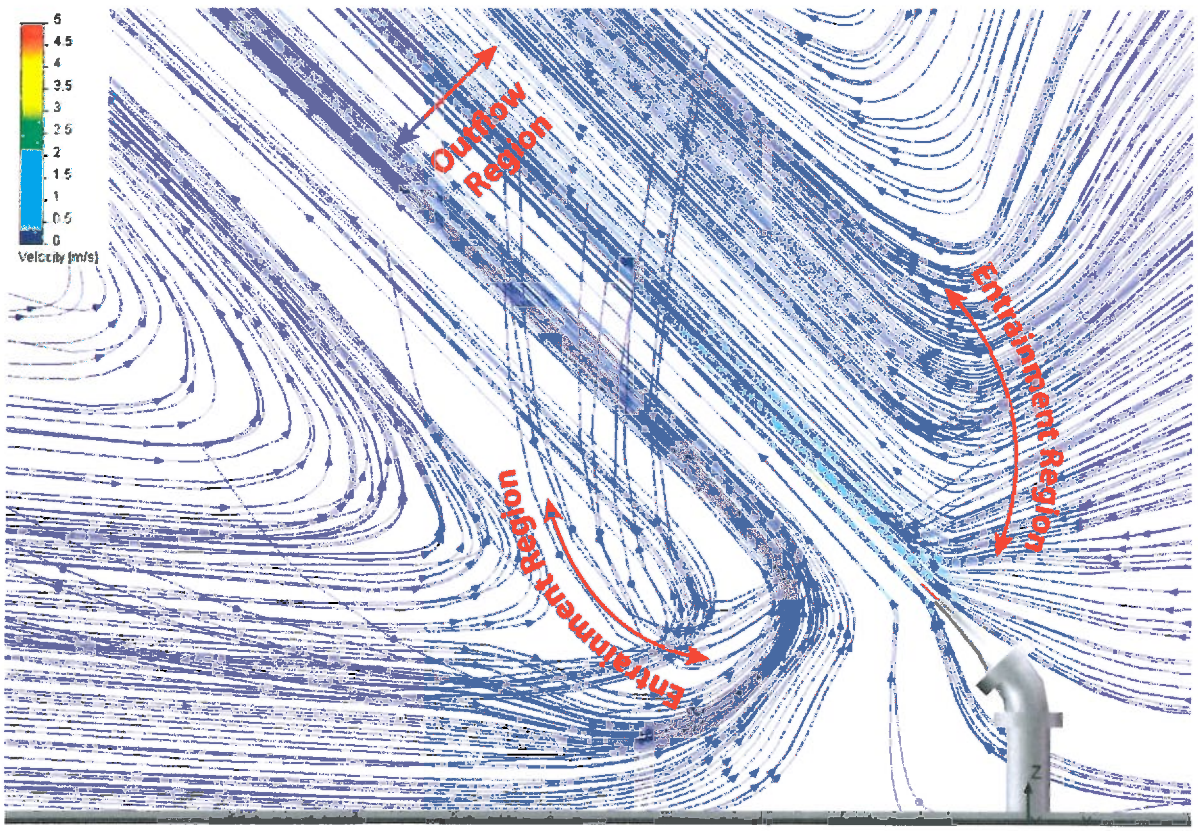

Figure 1: Hydrodynamic simulation of outflow and entrainment regions in the nearfield of a diffuser riser. Total discharge =10 mgd total brine discharge at 65 ppt end-of-pipe.

3.2) Turbulent Shear Mortality

Shear stresses and friction forces arise from the action of viscosity when the velocity field exhibits *velocity shear*. Velocity shear is simply a change in velocity over some cross-stream distance as shown in Figure 2. This is most commonly noticed when fluid moves with respect to a solid surface and exerts a friction force on the surface (Figure 3), but also occurs in a free-jet (Figure 4).The frictional shear stresses arising from the velocity shear are present throughout the fluid, however, and its potential effect on an egg or larvae in the flow field as illustrated in Figure 5. An egg or larvae within the velocity shear would be subject to a fluid velocity on its upper side (V') greater than that on its lower side (V"). The resultant forces on the egg can be resolved into a rotational and a deformational component. The rotational effect would be to disturb the internal order of the egg or larvae, while the deformation would stress both the membrane and the interior (Ulanowicz, 1976; Marcy, et al, 1978). The special case of damage incurred when the surface of the organism contacts the solid boundary is sometimes termed abrasion- shear mortality and deserves special study, since the resulting damage is a function of the two contacting surfaces.

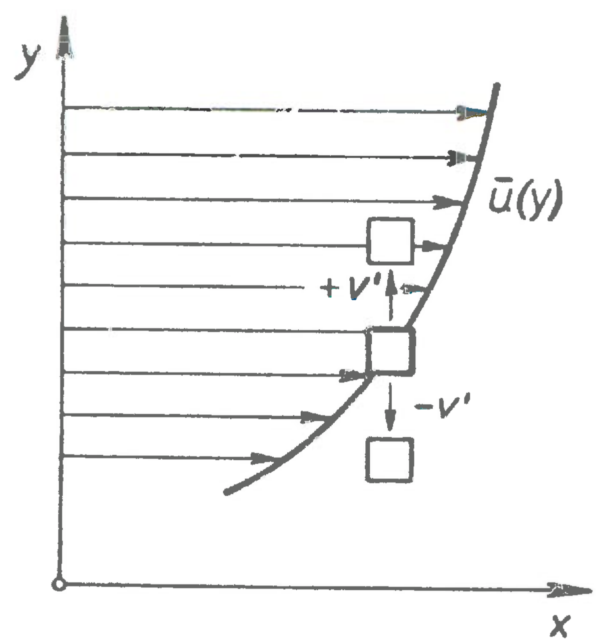

Figure 2: Schematic of velocity shear. Mean flow velocity, $\overline{u}\,(y)$, changes over cross-stream distance y.

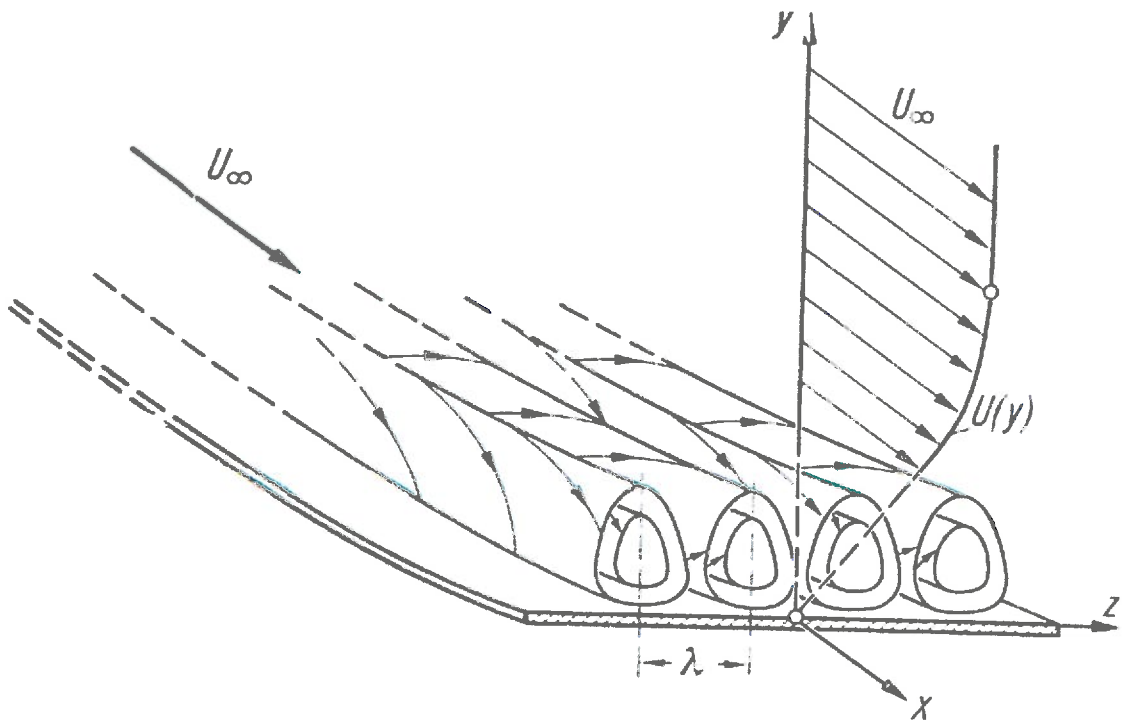

Figure 3: Three-dimensional velocity shear near a curved wall, (from Schlichting and Gersten 1999)

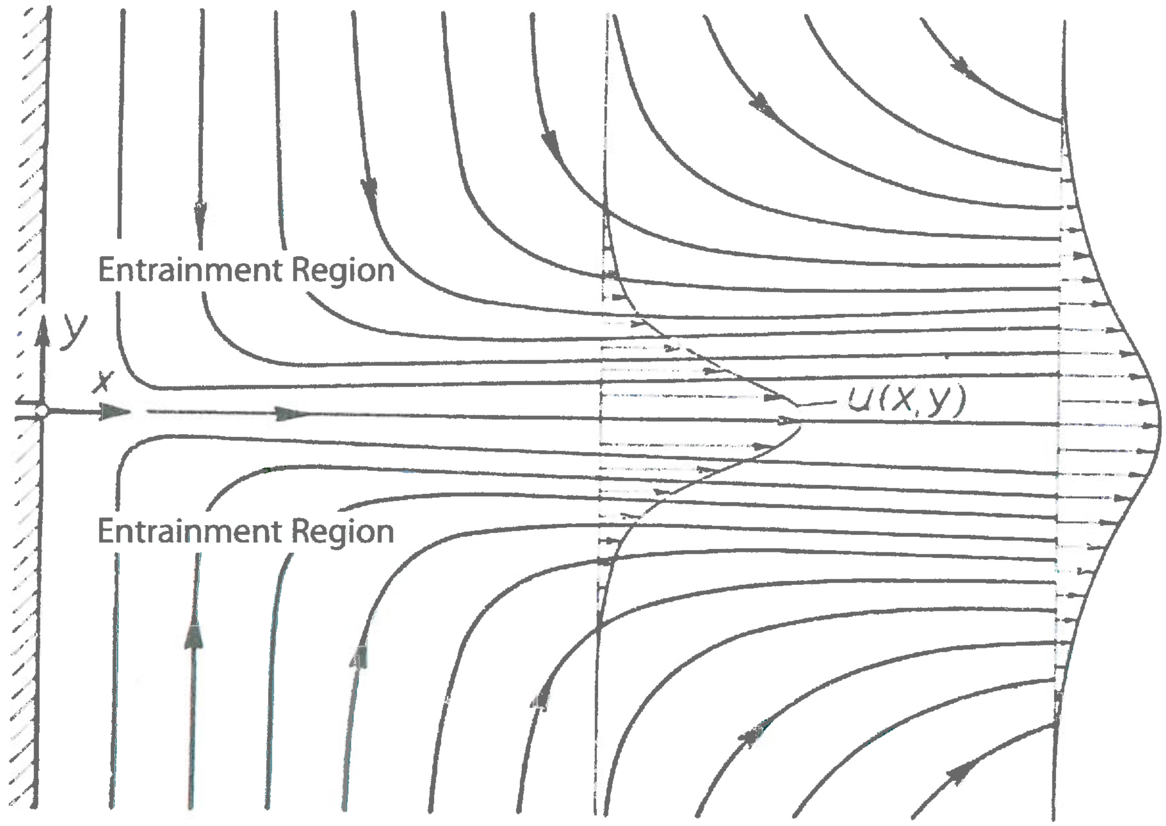

Figure 4: Velocity shear due to a free-jet emerging from a wall, surrounded by the entrainment region of the interior of the receiving water (cf. Figure 1). Strain rate decreases with increasing distance away from the jet orifice, (from Schlichting and Gersten 1999)

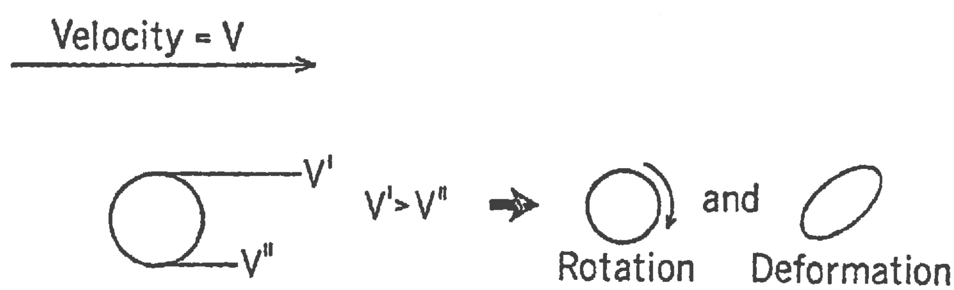

Figure 5: Schematic of physical effects on an egg or larvae drifting in a velocity field with shear. (after Ulanowicz, 1976).

Shear stress (like pressure) has units of force per unit area ($dynes/cm^2$). The rate of shear (strain rate) has units of rotation, (sec^{-1}), and is often used in biological applications. For a Newtonian fluid, such as water, the two are directly proportional, the constant or proportionality being the coefficient of viscosity or eddy viscosity in a turbulent flow. Within a flow field, the greatest shear stresses will be encountered in the near neighborhood of solid surfaces, (e.g., conduit walls, pump impellers, screens, vanes in the case of power plant cooling systems); or near the high speed core of a diffuser jet (Figure 1) . In flows of high turbulent intensity one could also expect high strain rates to exist at the interfaces between eddies of a turbulent diffuser jet (Figure 6).

A decisive question surrounding the ability of turbulent eddies to cause shear mortality to ichthyoplankton is the size of the eddy relative to the organism. This question hinges on the size of the Komogorov turbulent mixing lengths, η, defined as:

$$\eta = \left(\frac{\nu^3}{E_D} \right)^{1/4} \qquad \text{and} \qquad E_D = \rho C_D u^3 \qquad (1)$$

Here ν is the kinematic viscosity, ρ is the fluid density, and E_D is the energy dissipation rate proportional to the velocity cubed, with a size and shape dependent proportionality factor C_D referred to as the dissipation or drag coefficient. The Komogorov turbulent mixing lengths are the length scales of those particular turbulent eddy velocity fluctuations at which the preponderance of turbulent kinetic energy is dissipated. Figure 6 gives a visualization of Komogorov turbulent mixing lengths by means of shadow-graphic techniques applied to a densely stratified turbulent jet, similar to a brine plume. Figure 7 shows schematically the hyper-distortion and shearing that occurs to organisms whose sizes are comparable to Komogorov turbulent mixing lengths. Because most of the turbulent flow energy is concentrated on the organism's body at these mixing lengths, turbulent shear mortality results. If the organism is large in comparison to the Komogorov turbulent mixing lengths (as shown schematically in Figure 7a) then turbulent mixing causes a *scrubbing* action that varies along the length of the organism's body, but does not result in full-body distortion and probable mortality as is the case in Figure 7b. Therefore, turbulent shear mortality generally does not occur if the organism

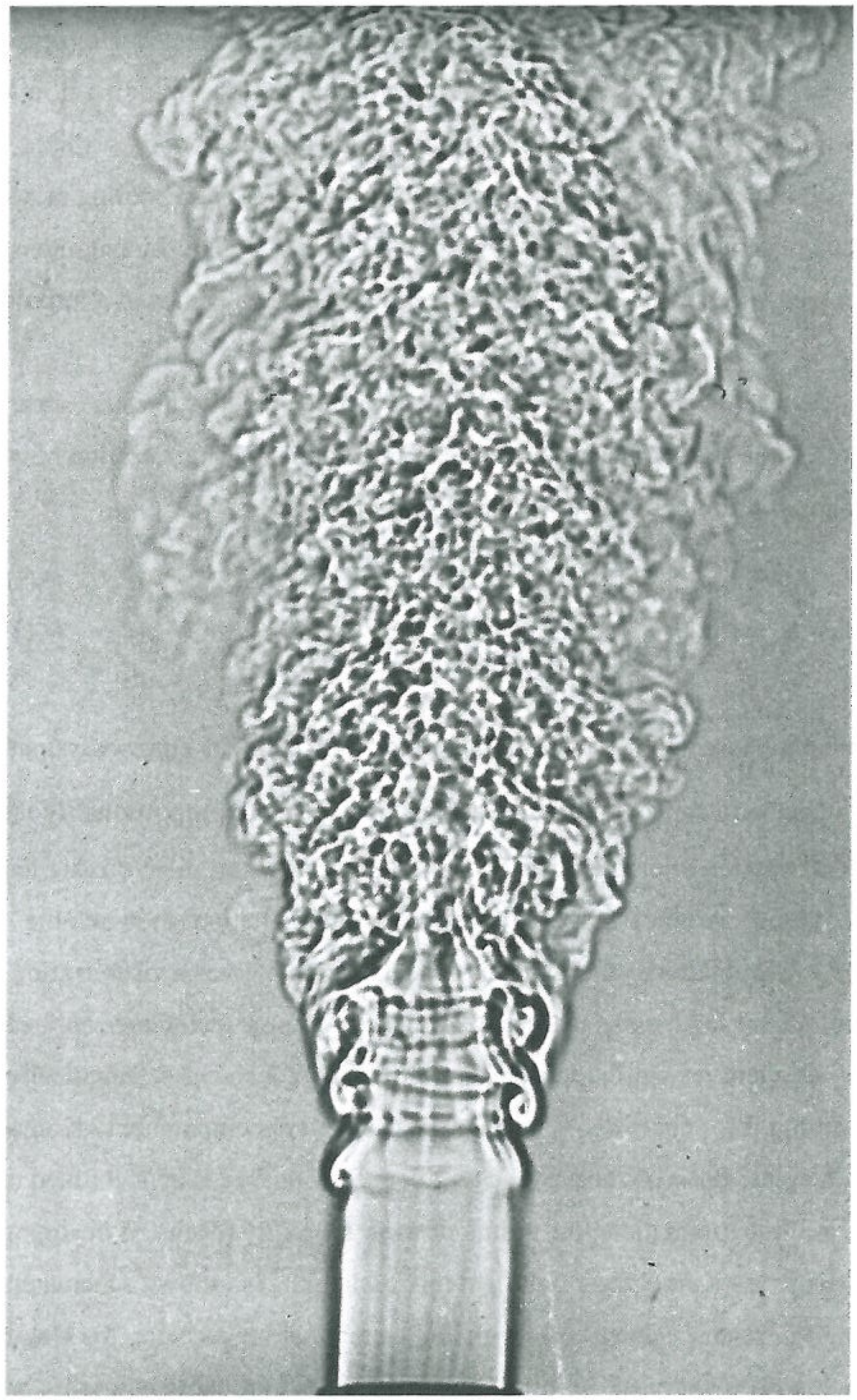

Figure 6: Shadowgraph of turbulent velocity fluctuations (eddies) in a dense (stratified) turbulent jet, revealing size of Komogorov turbulent mixing lengths; (from Schlichting and Gersten, 1999).

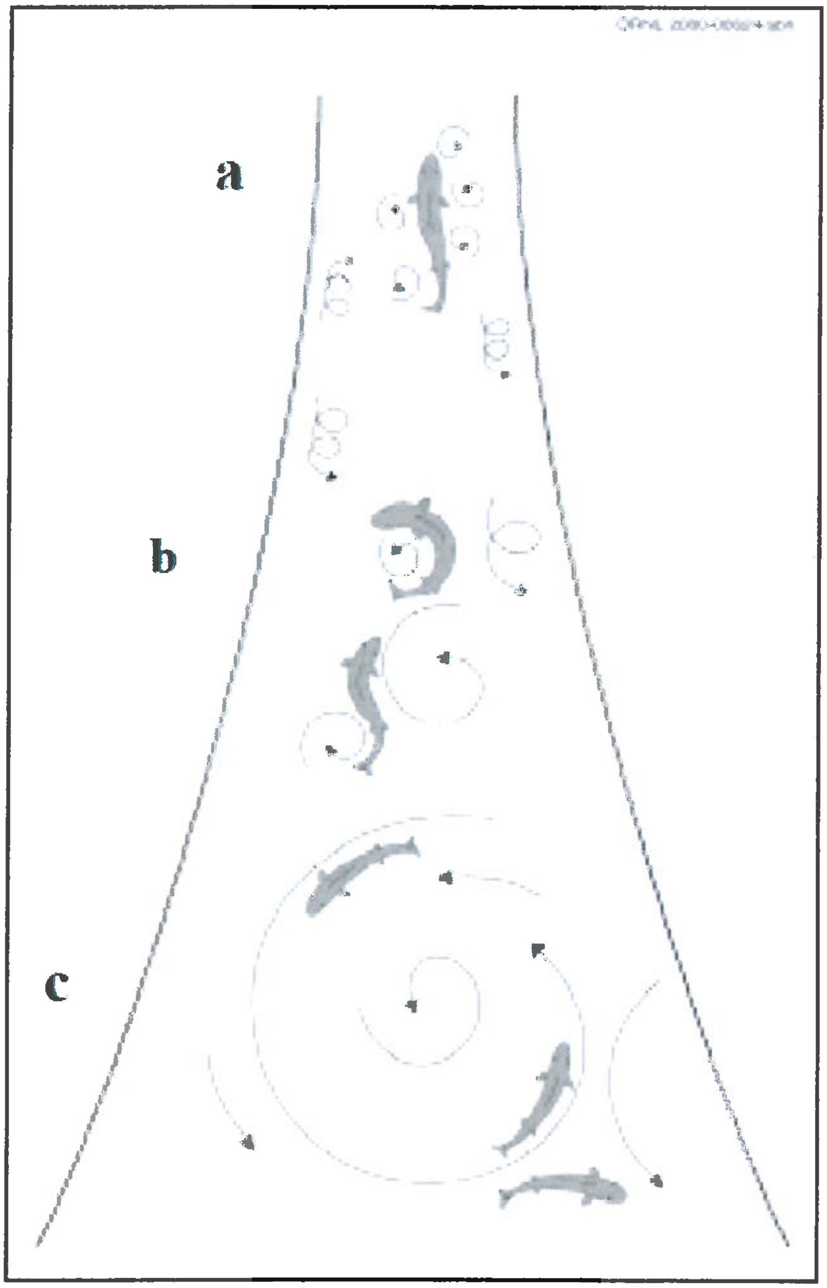

Figure 7: Relationship between size of marine organism and turbulent mixing length scales: a) Organism large relative to Komogorov turbulent mixing length (low likelihood of mortality); b) Organism comparable to Komogorov turbulent mixing length (high likelihood of mortality); and c) Organism small relative to Komogorov turbulent mixing length (moderate likelihood of mortality), [from Cada, 2001].

is large in relation to Komogorov turbulent mixing lengths (Figure 7a). On the other hand, full body distortion occurring when the organism size matches the Komogorov turbulent mixing lengths, (Figure 7b), results in stretching and compression of various surfaces of the organism's outer membrane, leading to membrane rupture, and ultimately the organism being literally torn apart. If the organism is small in relation to Komogorov turbulent mixing lengths (Figure 7c) then the organism can be twirled, rotated and disoriented by turbulent mixing action with a higher probability of mortality occurring from disturbance of the internal order of the organism or behavioral dis-function.

3.3) Shear Sorting of Entrained Organisms

When a physical body is placed in a shear flow, a net circulation, Γ, develops around that body because the ambient velocity shear creates unequal tangential velocities on opposite sides of the body. Here circulation is defined as the contour integral of the tangential velocity component taken around a closed curve; (in the present case the closed curve is the membrane of the organism) , or:

$$\Gamma = \oint_S \vec{u} \bullet d\vec{S} \qquad (2)$$

Where $\vec{u}$ is the vector velocity of the shear flow and $\vec{S}$ is the circumferential surface vector of the membrane surface. The circulation generates a net stress on the organism termed *lift stress*, that acts perpendicular to the flow velocity. The lift stress τ_L acting on the entrained organism has the functional form:

$$\tau_L = \frac{\rho \bar{u} \Gamma}{\overline{D}} = 1/2 \rho C_L \bar{u}^2 \qquad (3)$$

Where ρ is the density of the fluid; $\bar{u}$ is the average flow velocity; $\overline{D}$ is the mean diameter of the organism, and C_L is the lift coefficient. The lift stress can be integrated over the cross-sectional area of the organism to give the lift force. Given the sign convention associated with equation (2) the resultant of the lift stress (lift force) always acts perpendicular to the organism and toward the high velocity side of the organism. In shear flows, the action of the lift force displaces an entrained organism into the higher velocity region of the shear flow, as shown schematically in Figure 8. Because an entrained organism is moving with the general flow, the local velocity field

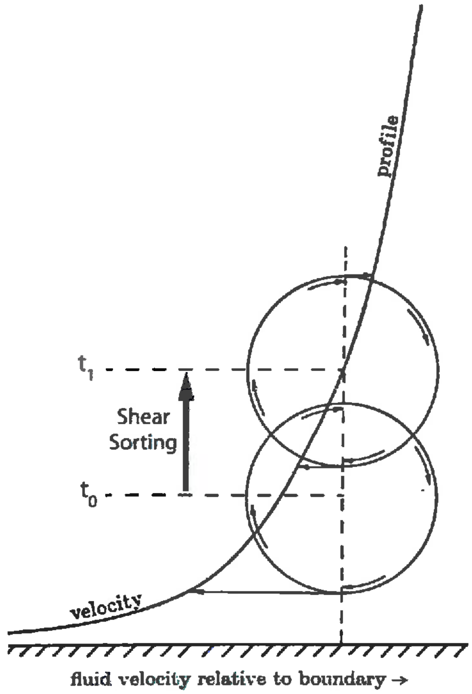

Figure 8: Velocity shear near a wall produces lift force on an entrained organism, subsequently displacing that organism into the higher velocity region of the shear flow, (after Bagnold 1973).

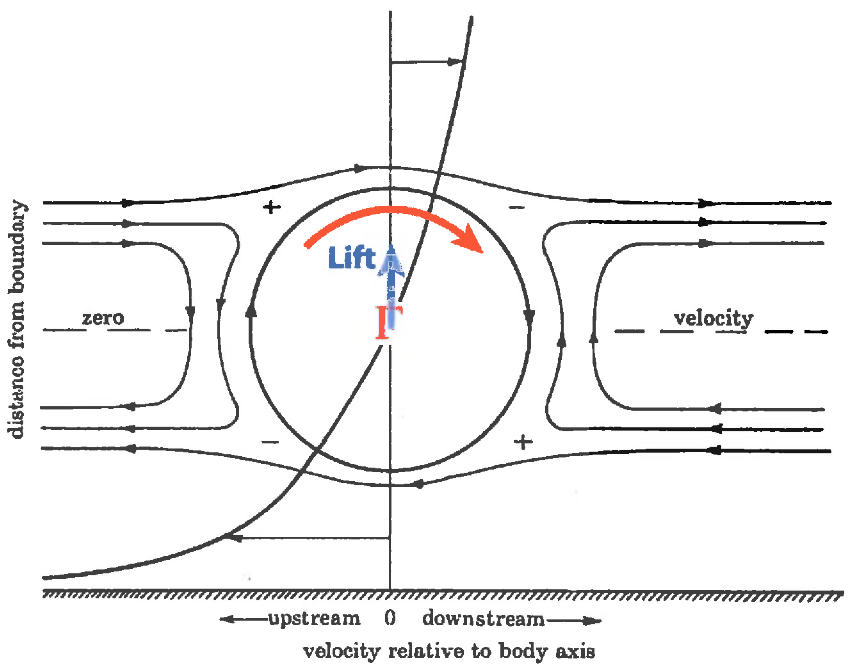

Figure 9: Secondary flow relative to a neutrally buoyant spherical surrogate of an entrained organism in shear flow, as disclosed by dye injection in a laboratory flume, (after Bagnold 1973).

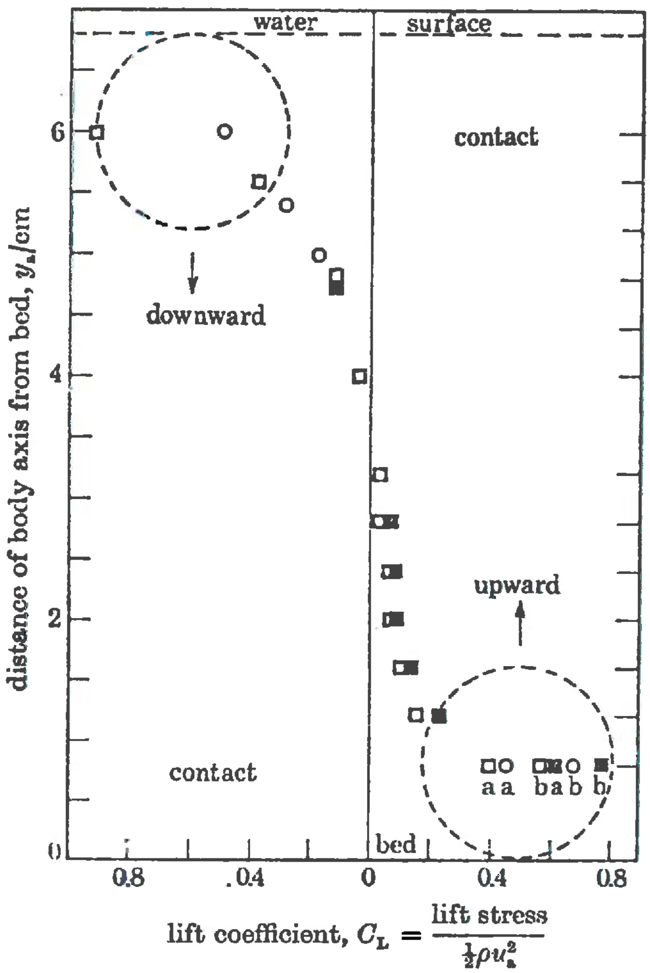

Figure 10a: Lift coefficients for a neutrally buoyant spherical surrogate of an entrained organism in shear flow, as observed in a rectangular laboratory channel, (after Bagnold 1973).

around that organism is not simply the velocity profile of the shear flow itself, put also includes weaker secondary flows as shown in Figure 9 for a neutrally buoyant spherical surrogate of an entrained organism . These secondary flows must be included in the vector velocity formulation used to calculate the circulation in equation (2). This was done in Figure 10a, to generate the lift coefficients for a neutrally buoyant spherical surrogate of an entrained organism in shear flow in a flume. The results show that the resultant of the lift stress (lift force) on the surrogate entrained organism act to displaces the organisms away from the bottom boundary and into the higher velocity region of the shear flow in the middle of the water column. The lift stress also weakens as the organism moves away from the bottom boundary and into the interior of the water column,

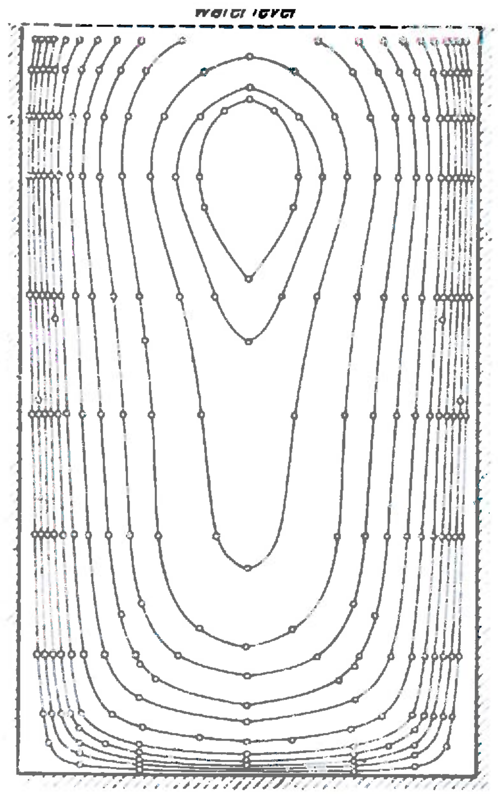

Figure 10b: Curves of constant velocity in a rectangular channel with a free surface, proxy for the discharge channel at the Carlsbad Desalination Project, cf. Figure 10c.

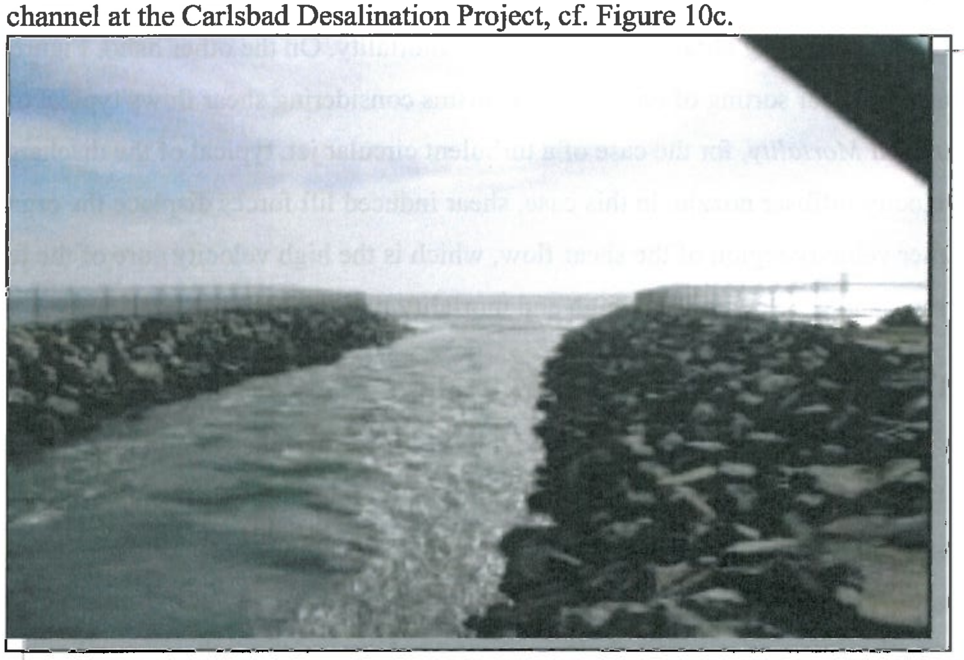

Figure10c: Discharge channel at the Carlsbad Desalination Project.

where the strain rates are less and the velocities are greater. There is a similar velocity shear near the free surface of the flume (Figure 10 b) where the resultant of the lift stress act downward to displace the surrogate organism back into the interior of the water column. Thus there is a lift-induced sorting mechanism in shear flows that preferentially acts to concentrate neutrally buoyant entrained organisms in regions of the flow where the strain rates are smallest and the velocities are greatest.

We now apply these responses of neutrally buoyant particles from first principles and laboratory flume experiments to the discharge strategies of in-plant dilution vs. high velocity diffusers as applied to the site-specific conditions of the Carlsbad Desalination Project. In Figure 11, we consider shear flows typical of the *Confined Entrainment Mortality* scenario of in-plant dilution, where shear flows occur inside conduits and pump casings. Figure 11 presents a schematic of shear sorting of entrained organisms in laminar (smooth, non-turbulent flow) vs. turbulent shear flows in pipes and pumps. For both the laminar and turbulent flow cases (Figure 11) shear induced lift forces displace the organisms into the higher velocity region of the shear flow near the center of the pipe, where strain rates become vanishingly small over a substantial portion of the interior of the pipe. This action reduces the likelihood of organisms impacting the pipe wall and suffering abrasion related impact mortality. On the other hand, Figure 12 gives a schematic of shear sorting of entrained organisms considering shear flows typical of the *Free-jet Entrainment Mortality*, for the case of a turbulent circular jet, typical of the discharge from a high velocity diffuser nozzle. In this case, shear induced lift forces displace the organisms into the higher velocity region of the shear flow, which is the high velocity core of the jet where strain rates and accelerations are high and mortality likely.

3.4) Thresholds for Turbulence Mortality

Three questions arise in regards to thresholds for turbulence mortality: What are the quantitative ranges of 1) pressure gradient forces, 2) intertial forces from acceleration, and 3) shear stress forces which cause immediate and delayed damage to fish eggs and larvae, either by confined or free-jet entrainment? Unfortunately, the existing body of bio-engineering literature does not allow us to segregate turbulence mortality between these three causal mechanisms in situ data, particularly for the marine environment. Almost all data is specific to cases of mortality

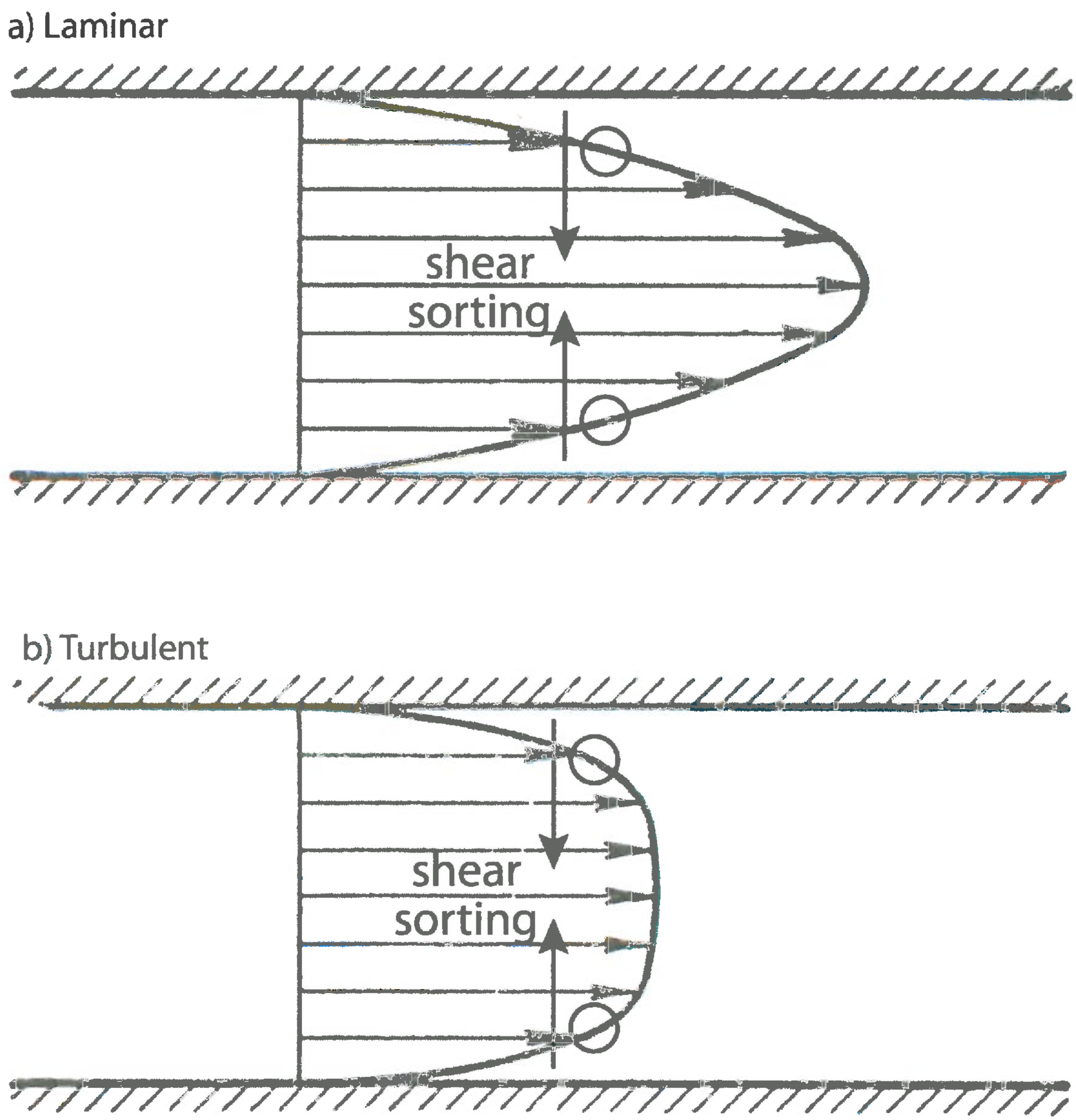

Figure 11: Schematic of shear sorting of entrained organisms in laminar and turbulent shear flows in a pipe. Shear induced lift forces displaces the organisms into the higher velocity region of the shear flow near the center of the pipe, where strain rates become vanishingly small in the case of turbulent flow. This action reduces the likelihood of organisms impacting the pipe wall and suffering abrasion related impact mortality.

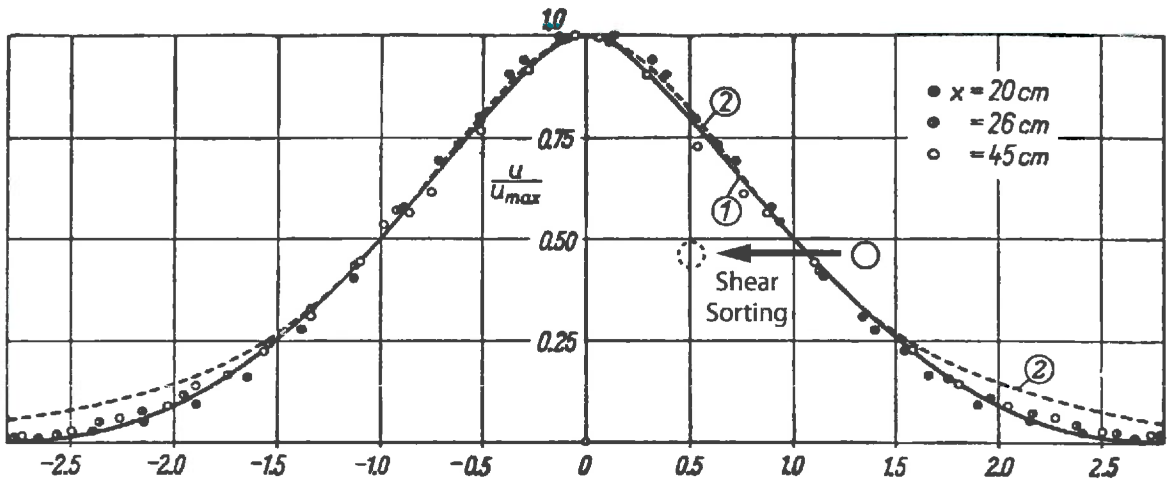

Figure 12: Schematic of shear sorting of entrained organisms in free jets of turbulent flow state. Shear induced lift forces displaces the organisms into the higher velocity region of the shear flow in the high velocity core of the jet, where accelerations are high and impact mortality likely. Data points for non-dimensional velocity distribution across the high speed core of a circular, turbulent jet, (after Schlichting and Gersten 1999).

due to confined entrainment, and very little data is available for mortality associated with free-jet entrainments, particularly in the marine environment. However, there are laboratory data and data derived from the hydro-electric industry for fresh water species that can be extrapolated from confined entrainment to free-jet entrainment on the basis fluid dynamic principles, and establish quantitative mortality threshold criteria for free-jet entrainment states, that are relevant to the marine environment.

3.4.1) Impact Mortality Data: The immediate bottleneck in evaluating impact mortality on entrained organisms is the paucity of bio-engineering data to answer the first two questions. In a reasonably intensive literature search, this writer has discovered that most of what is known about impact mortality pertains to fish in early life stages (juvenile and immature adults). Few attempts have been found to gauge the effects of pressure gradients and acceleration upon fish eggs and larvae, none of which was stimulated by power plant or waste-water diffuser considerations.

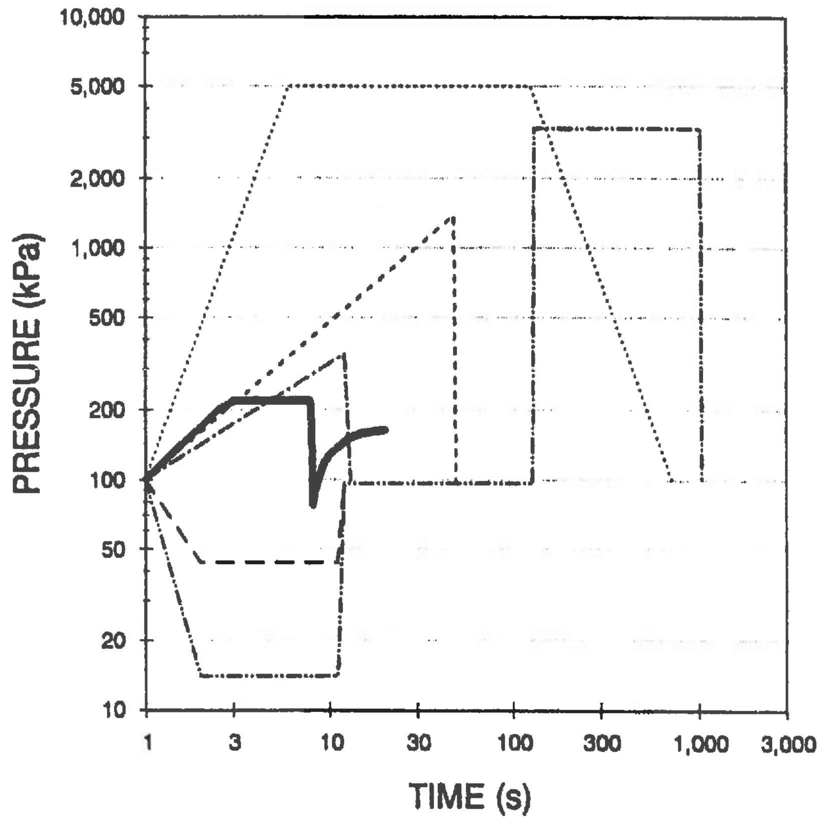

Figure 13. Hydrostatic pressure regimes that resulted in little or no mortality of fish early life stages in laboratory studies, (from Cada, 1990).

Several laboratory studies have examined mortality of fish early life stages under more severe pressure conditions. These pressure regimes, depicted in Figure 13, were applied to a wide variety of freshwater fish species (e.g., whitefish, carp, rainbow trout, white bass, bluegill, and channel catfish). In all cases, mortality was very low or not significantly different from controls. It appears from these studies that the range of pressures experienced by most young fish during hydroelectric turbine passage (or passage through a pump impeller of a power plant) will not result in significant mortality.

Pressure-induced impact mortality data of ichthyoplankton appears vague. Acceleration generated by shock waves from underground nuclear explosions was considered as possibly detrimental to trout eggs in the vicinity of nuclear test sites (Post et al., 1973). Maximum peak accelerations in the order of 0.9 g were expected along one major trout stream. Post and associates, therefore, constructed a series of simulated rainbow trout eggs in one-liter glass aquaria. An accelerometer was attached to replicate pairs of aquaria and the apparatus was dropped onto a resilient mat. Mean accelerations could be controlled to within 10 percent. Pairs of aquaria were subjected to peak acceleration of 1, 2,5, and 10 g's at biological development stages of 37.5, 75, 125, and 250 TU (one TU per hour is the product of the water temperature in degrees Fahrenheit above freezing divided by 24). Experiments were repeated at 8.3°C and 11.1°C. The survival rates of hatching (72-84 percent) did not differ significantly in any way from the experimental controls. Extrapolation of these negative results should be done with caution. Ulanowicz, (1976) suggest, more fragile eggs, such as those of the striped bass, could prove to be more sensitive. Also, the larval stages of the stressed eggs should be examined for possible malformation or premature mortality. Subsequently, ichthyoplankton surveys from the Connecticut Yankee nuclear power plant in combination with results from power plant CFD simulations at the Voith Siemens Power Generation Station (Cada, 2001) , and subsequent laboratory experiments (Neitzel, 2004) indicate that abrupt changes in flow speed of as little as 1 m/s near turbine blades and across free jets, causing impulsive pressure changes of dynamic pressure $\Delta p = 1/2\, \rho \Delta(u^2) \approx$ 5,000 dynes/cm^2 (500 Pa) can cause mortality to juvenile fish, and certainly to ichthyoplankton as well.

The most detailed information on impact mortality is related to impact of juvenile fish and ichthyoplankton with solid surfaces, typically turbine blades and pump impellors. The size of an entrained organism (length) has been found to be one of the most important variables affecting turbine mortality. Collins and Ruggles (1982), in testing trout of three size categories (65 mm - 99 mm, 100 mm - 119 mm, and 120 mm – 159 mm) passed through a Francis turbine, found that mortality increased approximately proportional to fish length. A similar relationship was identified via multiple regression analysis of survival data from 95 tests of axial flow turbines (Headrick 2001). Logically, the probability that entrained fish or ichthyoplankton will be struck by a turbine blade is a function of fish size as well as the characteristics of the turbine (runner velocity, number of blades, blade angle, and area of water passage). Formulas used to predict the probability of a blade strike incorporate fish length as a direct multiplier (Von Raben 1957; DOE 2003; Waporo 1987; Bell 1991). The probability that an entrained egg, larvae, or juvenile fish will be struck by a turbine blade is given by Cada (1990) based on Von Raben (1957) as:

$$P_b = \frac{\lambda n \omega a \cos\alpha}{Q} \qquad (4)$$

Where:

$P_b =$ probability of blade contact (percent);
$\lambda =$ characteristic length of enrtrained organism length (cm);
$n =$ number of impeller blades;
$\omega =$ pump rotation rate, revolutions per second (rpm)
$a =$ cross-sectional area/m^2) of water passage, i.e., π (impeller diameter^2- hub diameter^2)/4;
$\alpha =$ impeller blade angle,
$Q =$ discharge (m^3/s).

Because of the small sizes of ichthyoplankton, the probability of impellor blade contact will also be relatively small. For example, the estimated chance of an entrained 1.0-mm-diameter fish egg being struck by a turbine blade turning or pump impellor spinning at 300 rpm is 0.1% or less, (Cada 1990). Probabilities for most larvae are 2% or less. Juvenile fish (4 cm total length) have an estimated probability of contact of 5% or less at 300 rpm, (Cada 1990).

The probability-of-strike equation (4) provides a surrogates to estimate mortality. While often the strike probability has closely matched empirically derived mortality estimates, technically, the strike formula alone does not account for all the variables known to affect mortality. On one hand, the formula underestimates mortality where other injury sources, such as hydraulic shear and pressure changes, are involved. On the other hand, the formula overestimates mortality because not all blade strikes result in mortality. Turnpenny et al, (1992) derived a regression equation that estimates the mortality-to-strike ratio (K) to the length of the entrained fish or ichthyoplankton:

$$K = 0.153(ln\ \lambda)+0.012 \qquad (5)$$

Here *ln* is the natural logarithm. To obtain an estimate of impact mortality due to a impellor blade strike requires multiplying the strike probability in equation (4) by the mortality-to-strike ratio in equation (5), or impact mortality due to impellor blade strike is $M_I = P K$. Applying this calculus to a 10-cm fish entrained through a 300 rpm pump, for example, would result in a predicted impact mortality from pump impellor blade strike of 36 percent. For ichthyoplankton with a characteristic size of 1 mm, impact mortality due to blade strike would be 100 times less, or 0.36 percent.

3.4.2) Turbulent Shear Mortality Data:

Most of what is known quantitatively about turbulence mortality has been related to the action of turbulent shear stress. However, it should be noted that turbulent flows are stochastic by nature and certain complicated geometries can only be approximated.

The earliest work on turbulent shear mortality for ichthyoplankton involved an environmental impact study of the widening and deepening of the Chesapeake and Delaware Canal,(Morgan et al., 1974; Ulanowicz,1976) performed a series of simple experiments to assess the damage to striped bass, Norone saxatilis, and white perch, N. americana, eggs from shear fields. From the measurements, it was possible, to calculate the maximum shear stress within the flow field and thereby provide reasonable values of shear to associate with observed impacts. Eggs and larvae of relevant species were studied under long-term and short-term exposures. Long-term experiments were conducted monitoring organisms exposed to flows with characteristic shear stresses that ranged from 0.64 to 86.0 dynes/cm^2 for a period of two days. Long-term experiments involved maximum shear levels ranging from 76 to 504 dynes/cm^2 effective over exposure times of from 1 to 20 minutes completed the program.

Replication of the results of these experiments were very good. The lethal doses of shear required to kill half the specimens (LD_{50}) were calculated by polynomial regression from the experimental results and appears in APPENDIX-A. For purposes of providing an engineering number for thresholds of shear mortality, the lethal doses of shear stress for short period exposures is generally on the order 500 dynes/cm^2 (50 Pa) for eggs and larvae and 16,000 dynes/cm^2 (1,600 Pa) for juvenile fish, (Cada, 2006). These short period exposure thresholds would apply to entrained organisms passing through a pump or a high velocity diffuser jet. For longer exposures, (where 4 minutes is typical of passage time through the Encina Power Station conduits, condenser pipes and and discharge channel), the thresholds for shear mortality (LD_{50}) are lower, on the order of 150 dynes/cm^2 to 170 dynes/cm^2 (15 Pa to18 Pa) for eggs and larvae, and 1,000 dynes/cm^2 (100 Pa) for juvenile fish, (Cada, 2006). These figures are based on a Reynolds' number for flows on the order of 6 x10^6.

Laboratory experiments on fresh water juvenile fish have shown that turbulent shear mortality is not only a function of the magnitude of shear stress to which the organisms are subject, but also to the strain rate, per second as well (Neitzel et al., 2000 & 2004, Cada, 2001). Video images of juveniles of 4 freshwater species were acquired using high-speed cameras positioned to view the fish as they exited a deployment tube and entered the shear zone created by the underwater high velocity jet 0(5 m/s). These images were reviewed to verify fish orientation and injury mechanisms. Lazar measurements showed that velocities in the high-speed, submerged jet were non-uniform and turbulent, especially at the edge of the jet. Immediately downstream of the jet nozzle, the vertical profile of the axial velocity showed a sharp decrease at the shear layer edge. The sharp decline in axial velocity at the jet edge created a velocity gradient and shear to which fish were exposed. The maximum exposure strain rate occurred just downstream of the nozzle exit near the jet edge. Computed strain rates were nearly constant where a test fish initially intersected the jet, but the magnitude of the fluid strain decreased with increasing distance downstream from the nozzle as the jet expanded into the ambient fluid, similar to a near bottom diffuser jet plume (Figure 1).

The strain rate experienced by the juvenile fish varied by about only 3–6%, based on measured axial velocity turbulence intensities (root mean square of the velocity fluctuations) within the jet. The effects of entering a shear environment were determined for six groups of test fish in a headfirst orientation and three groups in a tail first orientation. The strain rates were measured at which 10% of the population would be affected by either minor or major injury (LC_{10}). The LC_{10} results and associated confidence intervals are plotted in Figure 14. The threshold for injury of these fresh water juvenile fish subjected to turbulent shear flow by a free jet occurs at strain rates of about 300 sec^{-1} to 400 sec^{-1}. No corresponding lethal strain rate data exists for ichthyoplankton, but the lethal shear stress data for eggs and larvae from Appendix-A indicates it would be substantially less, on the order of 100 sec^{-1}, (because shear stress is proportional to strain rate).

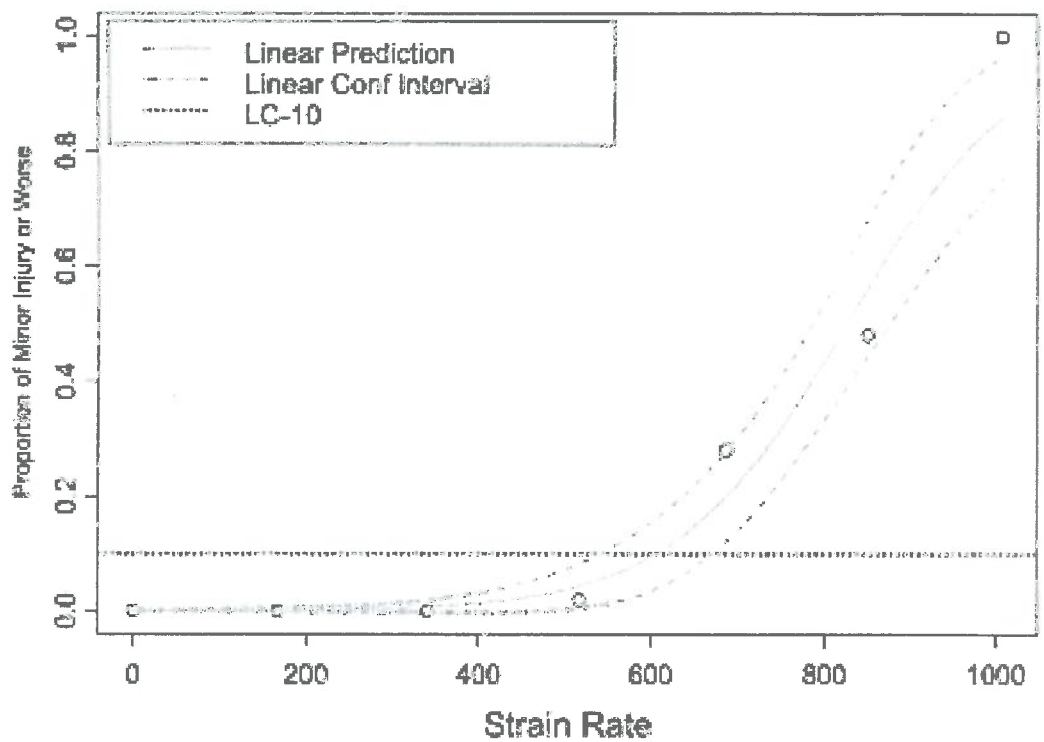

Figure 14: Proportional plot showing strain rates resulting in major injury or worse for age-1 fall Chinook salmon across the range of strain rates tested. Upper and lower 95% confidence limits about the LC-10 are shown by the dashed line.

3.5) Criteria for Minimizing Turbulence Mortality

The bio-engineering literature on thresholds for turbulence mortality that was reviewed in Section 3.4 provides some useful criteria for assessing and minimizing turbulence mortality that is applicable to both the in-plant dilution and high velocity diffuser discharge strategies. In order to minimize turbulence mortality by either discharge strategy, it is desirable to:

1) **Minimize turbulent shear stresses**. Limit shear stresses for short period exposures (on the order of 1 min.) to less than 500 dynes/cm^2 (50 Pa) for eggs and larvae and to less than 16,000 dynes/cm^2 (1,600 Pa) if juvenile fish are present. Limit shear stresses for longer period exposures (on the order of 4 min.) to less 150 dynes/cm^2 to 170 dynes/cm^2 (15 Pa to17 Pa)

2) **Minimize Strain Rates:** Limit strain rates in turbulent flows to less than $\frac{d\bar{u}}{dr} \approx$ 100 sec $^{-1}$; and to less than $\frac{d\bar{u}}{dr} \approx$ 300 sec $^{-1}$, if juvenile fish are present.
3) **Minimize the Komogorov turbulent mixing lengths.** Limit Komogorov turbulent mixing lengths to substantially less than the size of entrained organisms, (cf. Figure 7) $\eta = \left(\nu^3 / E_D\right)^{1/4} << \lambda$.
4) **Minimize abrupt changes in flow velocity.** Limit impulsive pressure changes of dynamic pressure to less than $\Delta p = 1/2\, \rho \Delta(u^2\,) \approx$ 5,000 dynes/cm^2 (500 Pa).
5) **Minimize Probability of Impeller Blade Strike during Pump Passage.** Limit pump rpm and numbers of impellor blades while increasing impeller blade angle as much as possible.

4.0) Species Size & Abundance at Southern California Sites:

In nearly all forms of turbulence mortality, the thresholds for lethality are strongly dependent on the size of the organism. The size spectra of small organisms in the coastal waters of Southern California is very broad. For in-plant dilution, essentially all of the mortality that occurs to entrained organisms is the result of pump passage, where impellor blade strike probability is directly proportional to organism size (cf. Section 3.4.1). With high velocity diffusers, it is generally extremely difficult to satisfy all of the criteria for minimizing turbulence mortality listed in Section 3.5 for all sizes of ichthyoplankton and juvenile fish. For example, if one tries to limit turbulence mortality by minimizing the shear stress and strain rates with reduced velocities, then the Komogorov turbulence scales tend to increase (because the dissipation rate tends to decrease); and turbulence mortality will likely still occur through the interactions between the turbulent eddies and the organisms as diagramed in Figure 7 b & c.

Species Size & Abundance Data Relevant to In-plant Dilution: This data is based on the Entrainment Impingement Study at Encina Power Station, (Tenera, 2008). During the June

2004 – May 2005 entrainment monitoring period with power generation occurring at Encina Units 1–5, a total of 3.63 $x10^9$ fish larvae, and 162,000 target invertebrate larvae were entrained. Tenera, (2008) estimated that the entrainment of $1.82x10^7$ fish larvae and eggs occurred daily, based on an average seawater intake rate of 658 million gallons per day for power generation during the monitoring period of June 2004 through May 2005. However, only 200 mgd of by-pass sweater are required to achieve in-plant dilution of discharge salinity below chronic toxicity during stand-alone desalination project operations. From the *flow-proportional principle* of entrainment, in-plant dilution would be expected to result in the entrainment of 5.53 $x10^6$ fish larvae and eggs daily, substantially less than what was measured in the 2004-2005 Entrainment Impingement Study, (Tenera, 2008). Regardless, two groups of fishes, gobies and blennies, will comprise over 91% of the total entrainment, with anchovy larvae the third most abundant taxon at approximately 4%. Given the characteristic sizes of the larval and egg life phases of these species from inspection of the monthly abundance tables in the technical appendices of Tenera (2008), it is concluded that only about 0. 8% of the entrained organisms at Encina were representative of the size spectra in APPENDIX B & C for mature larvae and juvenile fish, (1mm -10 mm size group). This gives an estimate of 4.51 $x10^4$ mature larvae and juvenile fish entrained per day in 200 mgd of dilution water, based on the flow proportional principle. It should be noted that the mesh size of the intake screens for Encina Units 1–4 is 9.5 mm, while the mesh size for Unit 5 is 16 mm. Hence the largest organism measured in APPENDIX-B & C is capable of becoming entrained into the seawater circulation system at Encina Power Station.

It should be acknowledged that an earlier study of entrainment at Encina Power Station (SDGE 1980) measured the concentrations of larval fishes, fish eggs, and various groups of invertebrate zooplankton in the cooling water supply during the sampling period of February 1979 through January 1980. The total annual ichthyoplankton entrainment estimates were 4.2 x 10^9 and 6.7 x 10^9 individuals annually for the 505 micron sampling mesh and 335 micron sampling mesh, respectively, with 86% of the total consisting of fish eggs. The entrained abundance of fish larvae from February 1979 through January 1980 was estimated at 0.92 x 10^9 individuals, which was approximately one-quarter of the total numbers estimated during the 2004-2005 survey by Tenera (2008).

Species Size & Abundance Data Relevant to Offshore Diffusers: These data have been measured by Tenera Environmental at the intakes to the Redondo Beach Generating Station

(RBGS) and the SeaLife intakes to the West Basin Desalination Demonstration Facility (APPENDIX-B), and from the intakes to the El Segundo Generating Station (ESGS) and Scattergood Generating Station (APPENDIX-C) . The species represented by this data are ubiquitous throughout the waters of the Southern California Bight, and are regarded as representative of species residing in the coastal waters off the Carlsbad Desalination Project. The median length of organisms in the APPENDIX B & C data sets is 2.5 mm, while the smallest size class is 1.5 mm. The largest organism is in the 10.5 mm size class, but these rare, with a probability of occurrence of about 0.1%. Therefore, in order to minimize the turbulent mortality of the mature larvae and juvenile adults life phases, the diffuser discharge strategy must produce Komogorov turbulent mixing lengths substantially smaller than 1.5 mm, and ideally about an order of magnitude less.

5) Turbulence Mortality for In-Plant Dilution Discharge Strategies

Figure 15 gives a hydraulic flow diagram for in-plant dilution as currently permitted at the Carlsbad Desalination Plant. The flow pathway involves the following steps:

1) Under the desalination Project's minimum flow requirement of 304 MGD of seawater enters the power plant intake facilities and after screening is pumped through the plant's condensers to the discharge channel.
2) The Carlsbad desalination plant intake structure is connected to the end of this discharge canal and under minimum flow requirements would divert 104 MGD of the 304 MGD of cooling water for production of fresh water; 200 mgd remains in the discharge channel for in-plant dilution of the brine discharge.
3) 50 MGD of the diverted cooling seawater would be converted to fresh drinking water via reverse osmosis membrane separation.
4) The remaining 54 MGD would have salinity approximately two times higher than that of the ocean water (65 ppt vs. 33.5 ppt).
5) This seawater concentrate would be returned to the power plant discharge canal downstream of the point of intake for blending with the remaining cooling water prior to conveyance to the Pacific Ocean.

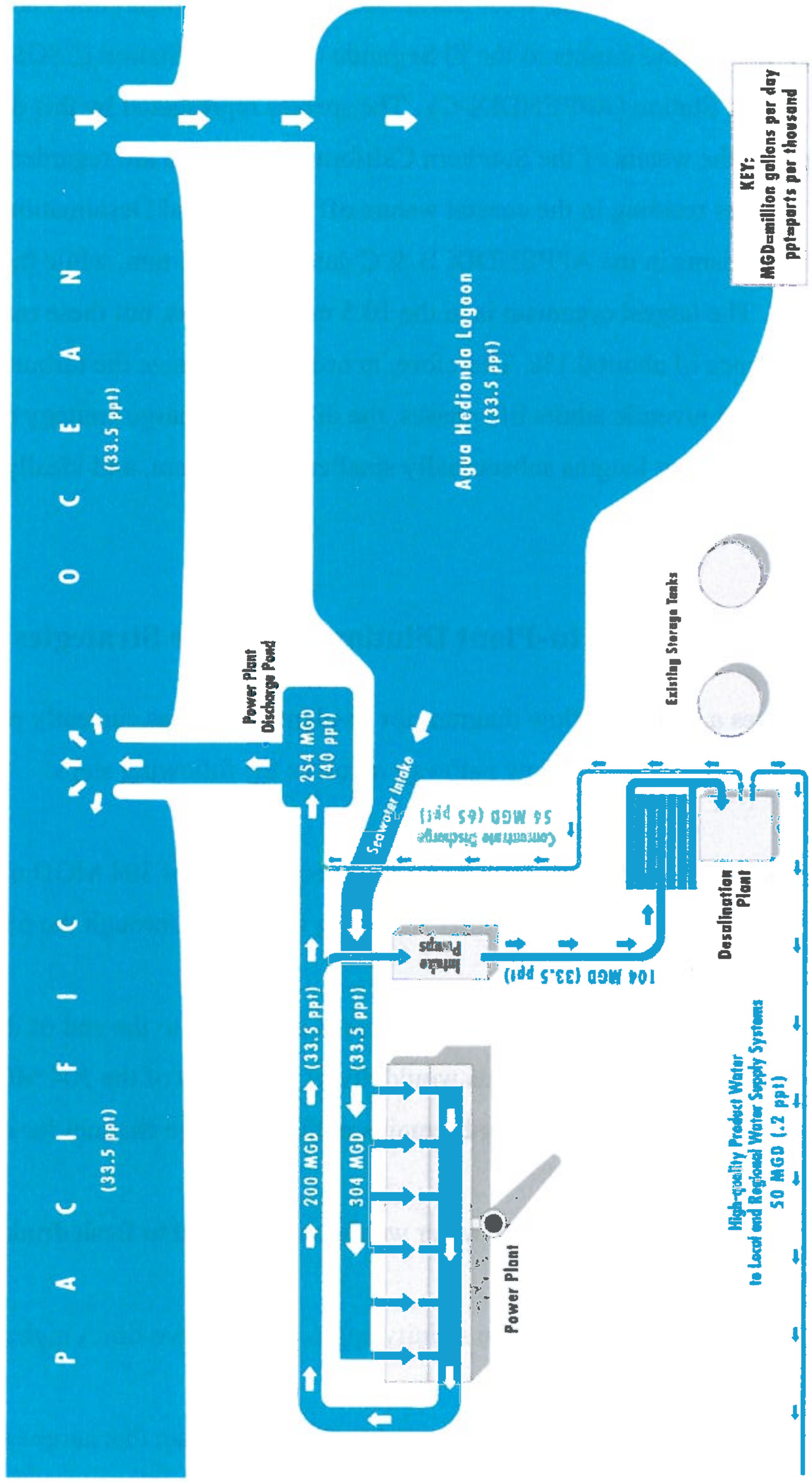

Figure 15: Hydraulic flow diagram for in-plant dilution under existing baseline conditions at the Carlsbad Desalination Plant

6) The Regional Water Quality Control Board found that the survival or reproduction of marine organisms would not be significantly affected at salinity concentrations of 40 ppt or less.

7) To ensure that marine organisms are not harmed by the desalination plant discharge, the RWQCB issued a discharge permit for the project that limits average day effluent salinity concentrations in the discharge pond to 40 ppt.

8) The Regional Water Quality Control Board found that the 40 ppt salinity concentration will not violate Ocean Plan acute or chronic toxicity standards. Receiving water salinity concentrations outside the zone of initial dilution (1,000' radius from the end of the discharge channel) will approach ambient conditions, and salinity concentrations within the zone of initial dilution will be 40 ppt or less.

5.1) Mortality with In-Plant Dilution under Existing Baseline Conditions: The Entrainment Impingement Study conducted at Encina Power Station from June 2004 through May 2005, (Tenera, 2008), assumed 100% mortality to all organisms entrained into the in-plant flow pathway diagramed in Figure 15. The basis for this assumption was that power generation at the Encina Power Station occurred throughout this study period , and hot condenser tubes made mortality to thermal shock a virtual certainty. To the extent that the required cooling water flow from the Encina Power Station is equal to or greater than 304 mgd, there is no additional entrainment mortality associated with the Carlsbad Desalination Project operations. However, if the EPS is circulating less than 304 mgd in its once-through cooling system, the Carlsbad Desalination Project is accountable for entrainment mortality in any additional daily flow increments, ΔQ, that are required to meet its 304 mgd flow requirements, where: $\Delta Q = 304 - \langle Q_{EPS} \rangle$ is the *short-fall* flow rate increment , and $\langle Q_{EPS} \rangle$ is the *reduced-flow rate* for EPS operations during days when that flow rate is less than 304 mgd. We quantify entrainment losses related to mortality from in-plant dilution under these existing baseline permit conditions based on the *a priori* assumption of 100% mortality to organisms entrained by the cumulative daily short-fall flow increments, $\sum \Delta Q$. To quantify $\sum \Delta Q$, it is necessary to look at the operating history of Encina Power Station relative to the combination of existing pumps capable of producing 304 mgd. In computing $\sum \Delta Q$ from the EPS operating history, it should be noted that the cumulative daily short-fall flow rate is an unusual statistic. Unlike similar and more commonly used statistics, such as the cumulative residual (cumulative departures from the mean), there is no offset in the calculation of the cumulative daily short-fall from days when EPS flow rates exceed 304 mgd. In other words, no offseting credits are given against potential entrainment impacts by the desalination project when EPS pumps more than 304 mgd through its seawater circulation system.

Figure 16 gives the daily flow rate history (red) and the cumulative daily short-fall flow rate (blue) at Encina Power Station for the eleven-year period 1999-2010. During peak user demand months for power (summer), plant flow rates are typically between 635 and 670 mgd, but it is not uncommon for flow rates to spike to peak flow rate capacity (808 mgd) for several days to a week at a time during summer heat waves. There were 660 days in this eleven year record when daily seawater flow rates required by operations of the Encina Power Station (EPS) were less than 304 mgd; 122 of these low-flow days occurred between 1999 and 2006, while 538 low flow days occurred in the more recent 2006-2010 time period. The increase in number of low-flow days after 2006 is attributable to the commissioning of the Palomar cogeneration facility in April 2006; but recent de-commissioning of the San Onofre Nuclear Generating Station is expected to reverse that trend. In view of these external factors, it is sensible to consider two sets of statistics from Figure 16: the complete eleven-year record representative of the long-term average operating environment; and the 2006-2010 subset of that record, representing a potential short-term, worst-case.

Figure 16 indicates that over the long term,(1999-2010), EPS operated its seawater circulation systems at 92.6% of the operating need of the Carlsbad Desalination Project, resulting in a cumulative short-fall , $\sum \Delta Q$, that averaged 22.6 mgd, or 7.4% of the 304 mgd minimum requirement for desalination operations (black dotted line in Figure 16). In the short-term worst-

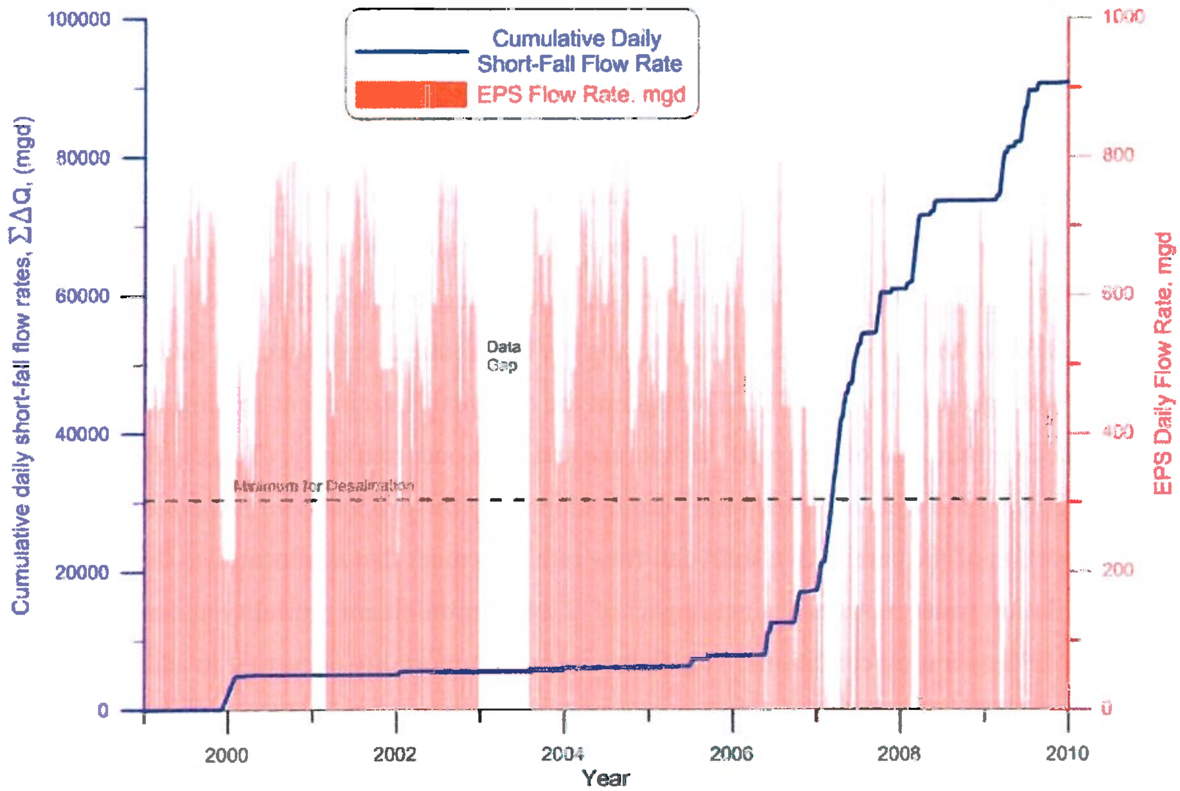

Figure 16: Once-through flow rate at Encina Power Station, Carlsbad, CA, for the period 1999-2010. Daily flow rate monitoring history shown in red. Cumulative daily short-fall flow rates shown in blue, where $\sum \Delta Q = \sum(\Delta Q\!=\!304 - \langle Q_{EPS} \rangle)$, and $\langle Q_{EPS} \rangle$ is the *reduced-flow rate* for Encina Power Station operations during days when that flow rate is less than 304 mgd.

case environment (2006-2010), EPS operated its seawater circulation systems at 81.3% of flow rate requirements for baseline desalination operations, or a cumulative short-fall , $\sum \Delta Q$ = 56.7 mgd, about 18.7% of the 304 mgd required minimum. The long term average short-fall flow rates represent 3.4% of the flow rates that occurred during the June 2004 – May 2005 Entrainment-Impingement Study when EPS flow rates averaged 658 mgd, (where 22.6mgd/658mgd x 100% = 3.4%). For worst-case operating conditions, the short-fall flow rates represent 8.6% of the flow rates occurring during the Entrainment-Impingement Study (where 56.7mgd/658mgd x 100% = 8.6%). Throughout the one-year Entrainment-Impingement Study, an estimated entrainment of 1.82 $x10^7$ fish larvae and eggs occurred daily, (Tenera, 2008).

Applying the well-excepted (and permit-adopted) *flow-proportional principle*, we find that the portion of the cumulative short-fall flow rate increment that is allocated to the 200 mgd in-plant dilution water represents a net impact of 2.24% entrainment mortality under average long-term EPS operating conditions. This figure represents mortality occurring in additional seawater taken for dilution beyond the amount of dual-use water provided by operations of the Encina Power Station ; (where : 200mgd/304 mgd x 0.034 x 100% mortality = 2.24%). This net impact is equivalent to an estimated daily loss of 3,323 mature larvae and juvenile adults and 407,680 eggs and immature larvae. Under short-term worst-case EPS operating conditions, in-plant dilution water produces a net impact of 5.66% entrainment mortality; (where : 200mgd/304 mgd x 0.086 x 100% mortality = 5.66%). Net impact for this worst-case assessment is equivalent to an estimated daily loss of 8,398 mature larvae and juvenile adults and 1,030,120 eggs and immature larvae.

Shear stress calculations for the hydraulic pathway of the Carlsbad Desalination Project presented in APPENDIX-E, Equations (6) – (11), indicate that pump passage is the predominant cause of mortality to entrained organisms with in-plant dilution, particularly when EPS is operating in *stand-by mode* and the condenser tubes are cold (when no thermal shock is occurring to entrained organisms). The pumps that circulate seawater through Units 1-5 at Encina Power Station are constant speed centrifugal pumps. Figure 17 shows the internal flow typical of a centrifugal pump used in the Carlsbad Desalination Project. The driving mechanism is a rotating impellor disk with blades that causes the fluid inside the pump case rotate, developing high centrifugal accelerations that force the fluid to the outer circumference of the pump case where there is a discharge port fitting that couples to the conveyance conduit. The

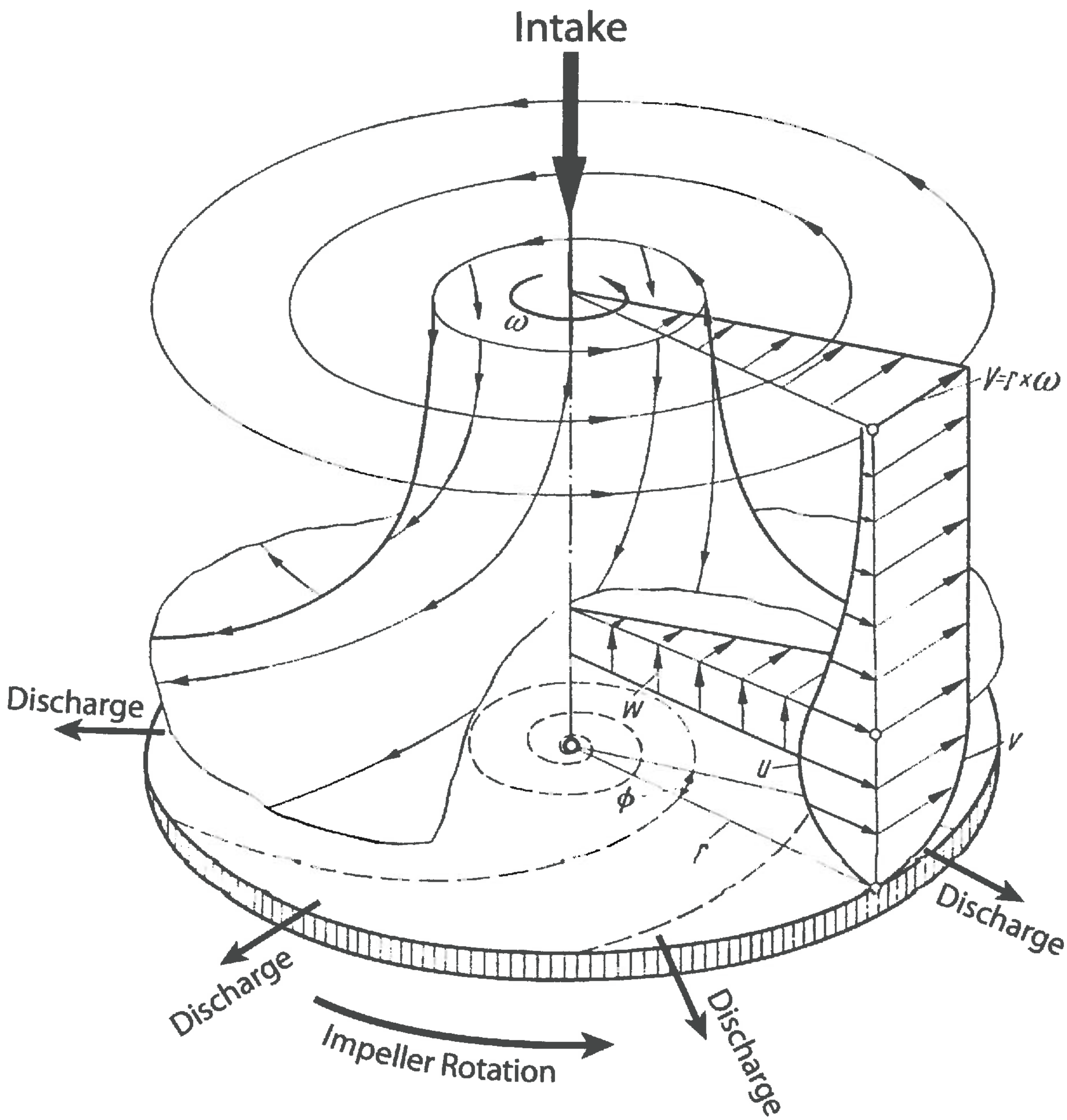

Figure 17: Internal flow for centrifugal pumps as used in the existing baseline version of the Carlsbad Desalination Project

pump intake is orthogonal to the impeller disk and discharge port, located at the top of the pump and aligned parallel to the axis of rotation of the impellor disk. Entrained organisms entering the pump are subjected to all three causal forces of turbulence mortality: 1) pressure gradient forces resulting from impeller blade strike and the pressure difference between the intake and discharge ports of the pump case; 2) inertia forces associated with the rapid centrifugal accelerations developed by the rotating impeller disk, and 3) shear stresses and friction forces arising from velocity shear induced by the rotating impeller disk. The velocity shear occurs both radially between the inner and outer portions of the impeller, and circumferentially, and is particularly strong along the outer edges of the impeller. To assess the lethality of these forces internal to the pump, we examine the operating points of the various pumps that drive the seawater circulation system at Encina Power Station.

The EPS pumps detailed in APPENDIX-D are nominally low pressure pumps that develop approximately 100 kPa of total head pressure. Figure 13 suggests that pressure changes of this order of magnitude that would be experienced by entrained organisms passing between the intake ports and discharge ports of the pumps in APPENDIX-D would not experience lethal pressure changes. However, impact mortality from impellor blade strike is another matter. Applying Equations (4) & (5) to the pump data in APPENDIX-D makes it clear that blade strike mortality with existing high rpm EPS pumps is the largest single cause of mortality to entrained organisms under existing baseline conditions.

5.2) Retrofit of EPS Intake with Low-Impact Pumps for In-Plant Dilution:

The opportunity exists to retrofit the existing cooling water pumps with new technologies that remediate entrainment impacts following the de-commissioning of the EPS OTC system. Equations (4) & (5) indicate that impact mortality from impellor blade strike increases directly with pump rpm and size of the entrained organisms. Therefore, it is sensible to consider alternative ultra-low rpm pump options, particularly since pump rpm exerts such a strong influence on that mortality. Of particular interest in this regard are the large *screw-pumps* that have been used previously in at Sea World, San Diego (Figure 18). The screw pump relies on an Archimedes screw to thread through the water mass and push the water along the hydraulic

Figure 18: Low-impact screw-pumps as used at SeaWorld, San Diego, to be retrofitted for use with by-pass water flows for in-plant dilution at the Carlsbad Desalination Project. Operating impeller rotation rate, ω = 20 rpm.

pathway; rather than spin the water mass up to high rpm and eject the water with large centrifugal accelerations along a discharge pathway, the way a centrifugal pump performs., (cf Figure 17). Figure 19 presents a hydraulic flow diagram showing how 4 large screw-pumps (manufactured by Spaans-Babcock) would be retrofitted under stand-alone conditions to implement in-plant dilution at the Carlsbad Desalination Plant. The retro-fit would involve removal of a portion of side-wall to the intake tunnel in order to allow seawater to flow into a triangular-shaped intake forebay where the traveling fish-screens are located at a velocity of less than 0.5 feet per second in conformance with best available technology requirements for minimizing impingement impacts. Behind the traveling screens, a pump box (measuring 50 ft. x 60 ft.) will contain the 4 Spaans-Babcock screw pumps that will divert 200mgd of pre-screened intake water directly into the existing discharge tunnel to affect dilution of the brine discharge.

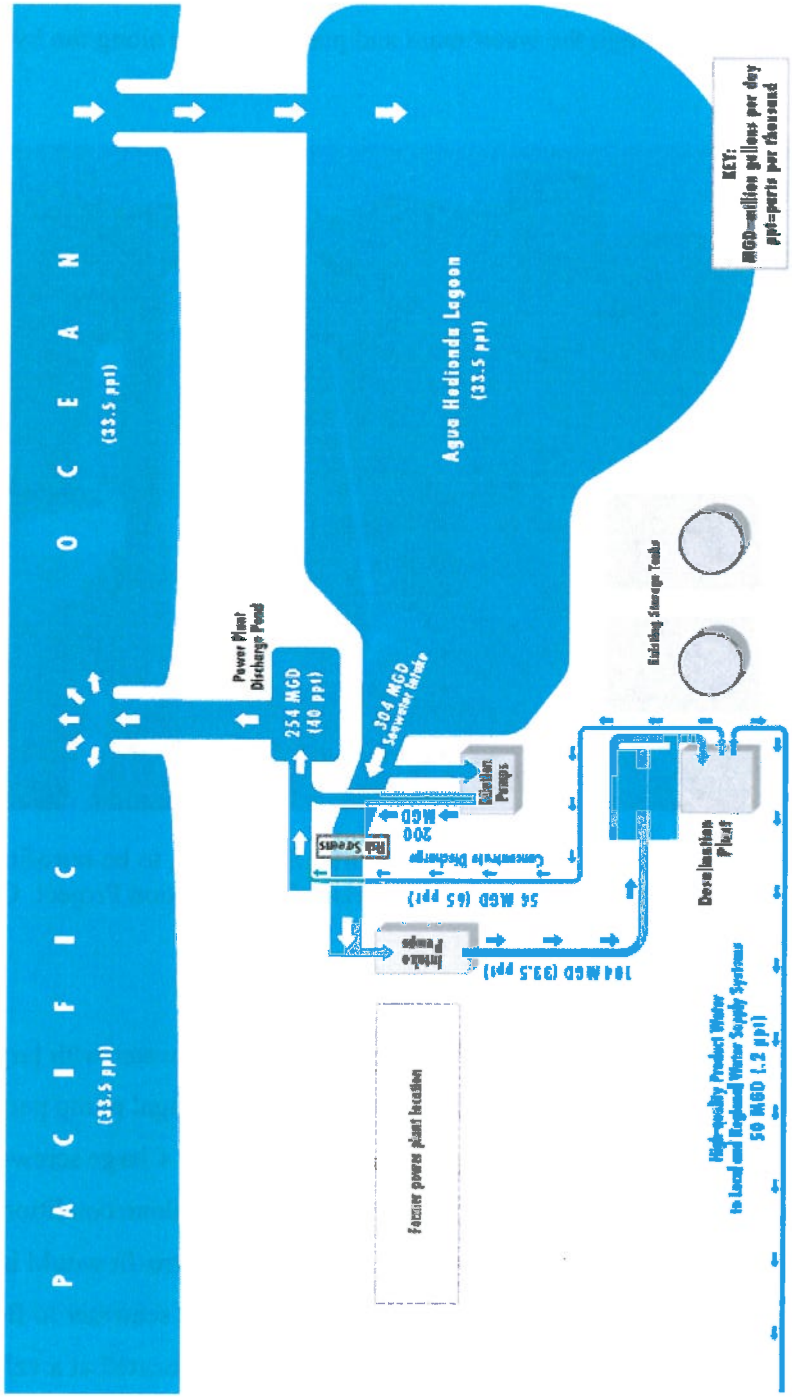

Figure 19: Hydraulic flow diagram for in-plant dilution under stand-alone conditions at the Carlsbad Desalination Plant with low-impact screw-pumps (4 ea.) in the Dilution Pump Box.

In this way the dilution water by-passes all of the down-stream, internal conduits and condenser tubes of the existing EPS infrastructure. The bypassing of dilution water from the screw pumps to the discharge tunnel is conveyed through an elevated discharge channel and drop structure that are sized to maintain flow speeds at less than 1m/s, and shear stresses in a sub-lethal range of 100 dynes/cm2 to 120 dynes/cm2 (10 Pa to12 Pa), well below the published LD50 values of threshold shear stresses for turbulence mortality under long exposures, as reported in APPENDIX-A and detailed in Section 3.4.

Screw pumps are generally low pressure pumps, but the hydraulic layout in Figure 19 requires only 3 m of vertical lift to move the 200 mgd of by-pass water from the screw pumps to the discharge tunnels at Encina Power Station. With these low rpm screw-pumps, Equations (4) & (5) indicate mortality to entrained organisms during pump passage can be reduced by an order of magnitude. At the low end of the organism size spectra from Section 4, we calculate that mortality during pump passage with the screw-pumps would be reduced to 0.035 % of the entrained species, amounting to a daily loss of only 16 mature larvae and juvenile adults and 1,975 eggs and immature larvae. At the high end of the organism size spectra mortality during passage through the screw-pumps would be 0.25 % of the entrained species amounting to a daily loss of 114 mature larvae and juvenile adults and 13,934. No mortality is expected through the elevated discharge channel, or the remaining downstream discharge conveyance system (discharge tunnel, discharge pond, and jettied discharge channel), based shear stress results in APPENDIX-E. Potentially, the screw-pump retrofit to the stand-alone Carlsbad Desalination Project could reduce entrainment mortality (best case) to 206 times less than the100% mortality assumption relied upon in the project approvals; and worst case, reduce entrainment mortality to 74 times less than what was assumed for the project approvals.

6) Evaluation of Turbulence Mortality for High-Velocity Diffuser Installed at the Carlsbad Desalination Project

To evaluate potential marine life impacts due to implementation of the high velocity diffuser strategy at the site of the Carlsbad Desalination Project, we pose the layout in Figure 20. A major capital intensive feature of this layout is a buried 72 inch diameter pipeline to transport 50 mgd of raw brine at 65 ppt offshore from existing shore-side discharge infrastructure to a depth of at least – 10m MSL, in order to avoid direct discharge into the existing kelp beds. At the end of this pipeline, we pose a conventional linear diffuser, consisting of five discharge riser/diffusers structures at 20 m spacings that and extend above the seabed from a buried manifold pipe. A physical example of such a linear diffuser is shown in Figure 21. The discharge riser/diffuser manifold consists of a 54 inch diameter pipe buried below the seafloor that delivers the brine discharge to 5 diffuser risers. Each of the 5 risers for the 50 mgd design is 16 inches in diameter. Each riser is fitted with a Tideflex duckbill nozzle angled upward at a 60 degree angle. The duckbill nozzles are self-adjusting to variable flow rate to maintain optimal jet nozzle diameter, and each duckbill stands 7 ft above the seafloor atop it's riser to isolate the discharge nozzles from burial effects and to protect against damage from bottom debris moving about in the wave and current surge.

The 50 mgd linear diffuser was evaluated using four distinct hydrodynamic models. 1) The basic riser and diffuser internal flow simulations were performed using a commercially available hydraulics design software known as ***COSMOS/ FLowWorks***. Many design iterations were performed with this software until the desired combination of axial discharge velocity, shear stresses, strain rates and turbulence length scales were achieved at exit ports of the diffuser. 2) The subsequent kinetics of the discharge plume upon exiting the diffuser ports was evaluated using a computational fluid dynamics model, the ***Vortex Lattice CFD Model*.** This model is known as a $\overline{v}^2 - f$ model and was evaluated by Iaccarino (2000) on diffuser problems and found to give self-consistent results in almost perfect agreement with known results. It was used herein to compute the jet core velocities, shear stress, strain rates and Komogorov turbulent mixing lengths in the outflow regions of the turbulent mixing zone as well as the flow structure of the entrainment region, see Figure 1 for definition of these brine plume flow regions. 3) The nearfield dilution performance of the hypothetical diffuser design was evaluated by another

Ocean Outfall/Diffuser System

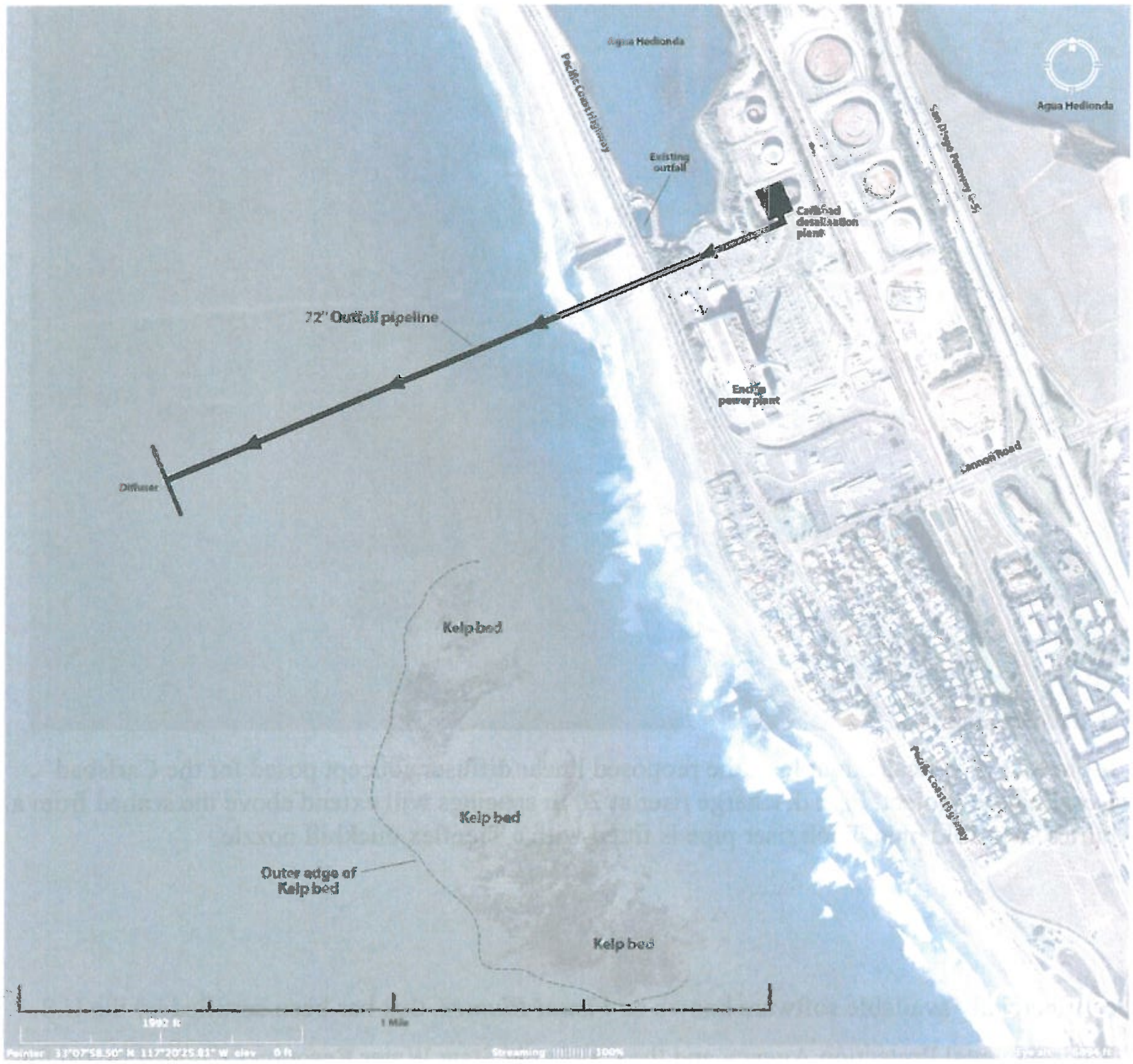

Figure 20: Layout for a hypothetical offshore diffuser system for the Carlsbad Desalination Project

Figure 21: Physical example of the proposed linear diffuser concept posed for the Carlsbad Desalination Project. Five discharge riser at 20 m spacings will extend above the seabed from a buried manifold pipe. Each riser pipe is fitted with a Tideflex duckbill nozzle.

commercially available software known as ***Visual Plumes***, that has been certified by the U.S. Environmental Protection Agency and the California State Water Resources Control Board for use in diffuser design and nearfield dilution. 4) Finally, a fully 3-dimensional far field dispersion model ***SEDXPORT*** was used to assess the large scale trajectory of the brine plume. This model is a processed-based stratified flow model with the complete set of littoral transport physics including tidal transport, and wind & wave induced transport and mixing.

These models were powered by the same overlapping long-term records for the eight controlling model input variables used in EIR appendices in studies Jenkins and Wasyl, (205; 2007). These input variable time series were developed by a process of *data fusion*. Data fusion involves merging archival data bases with site monitoring data of the marine environment in the Oceanside Littoral Cell and the neashore waters around Agua Hedionda Lagoon.

Figure 22 shows a cross-section simulation of a discharge flow of the 50 mgd design passing (into the page) through the buried 54-inch manifold pipe that distributes 10 mgd to the Port-1 riser/diffuser structures Maximum discharge velocity is 5 m/s. The simulation in Figure 22 was based on discharge into a perfectly quiet ocean with no waves or current motion in the receiving water. Some head losses are apparent at the junction of the feeder pipe with the riser pipe. Because of these head losses combined with the additional pressure required to drive the high velocity jets, an additional 6 psi over ambient ocean pressure at 10 m depth will be required to drive the 50 mgd linear diffuser. This raises the total head pressure requirements to 143 kPa for the shore-side pumps needed to drive the brine pipeline and linear diffuser. To generate this amount of total head pressure will require substantial amendments to the shore-side infrastructure (discharge pond, conduits, etc.).

Figure 23 shows a nearfield simulation of the streamlines and flow trajectories resulting from 10 mgd brine discharge from one of the five riser/diffuser nozzles in the linear diffuser system as posed for the Carlsbad Desalination Project. The essential flow features are: 1) the high velocity jet emerging from the nozzle at 5 m/s and maintaining 1 m/s velocities in the core of the jet out into the interior of the fluid for a distance of about 50 jet diameters; 2) the outflow region that extends further into the interior of the fluid where the jet core becomes unstable under the action of turbulent shear forces and breaks up to form the *turbulent mixing zone*; and 3) the entrainment region where shear forces draw surrounding fluid inward to be dragged along by the core of the jet, resulting in rapid changes of velocity and direction of the entrained fluid as well as high internal shear stresses and strain rates. The initial dilution provided by the diffuser is based on two principals, 1) turbulent mixing provided by disintegration of the high velocity jet in the outflow region to form the outer turbulent mixing zone, and 2) entrainment of surrounding ambient seawater by internal shear stresses along the edges of the jet. Entrainment is believed to be the more powerful of these two dilution mechanisms, and the entrainment hypothesis (Fischer et al. 1979) states that fluid is entrained at the plume radius b with a velocity u_e that is proportional to the mean centerline velocity, u_m :

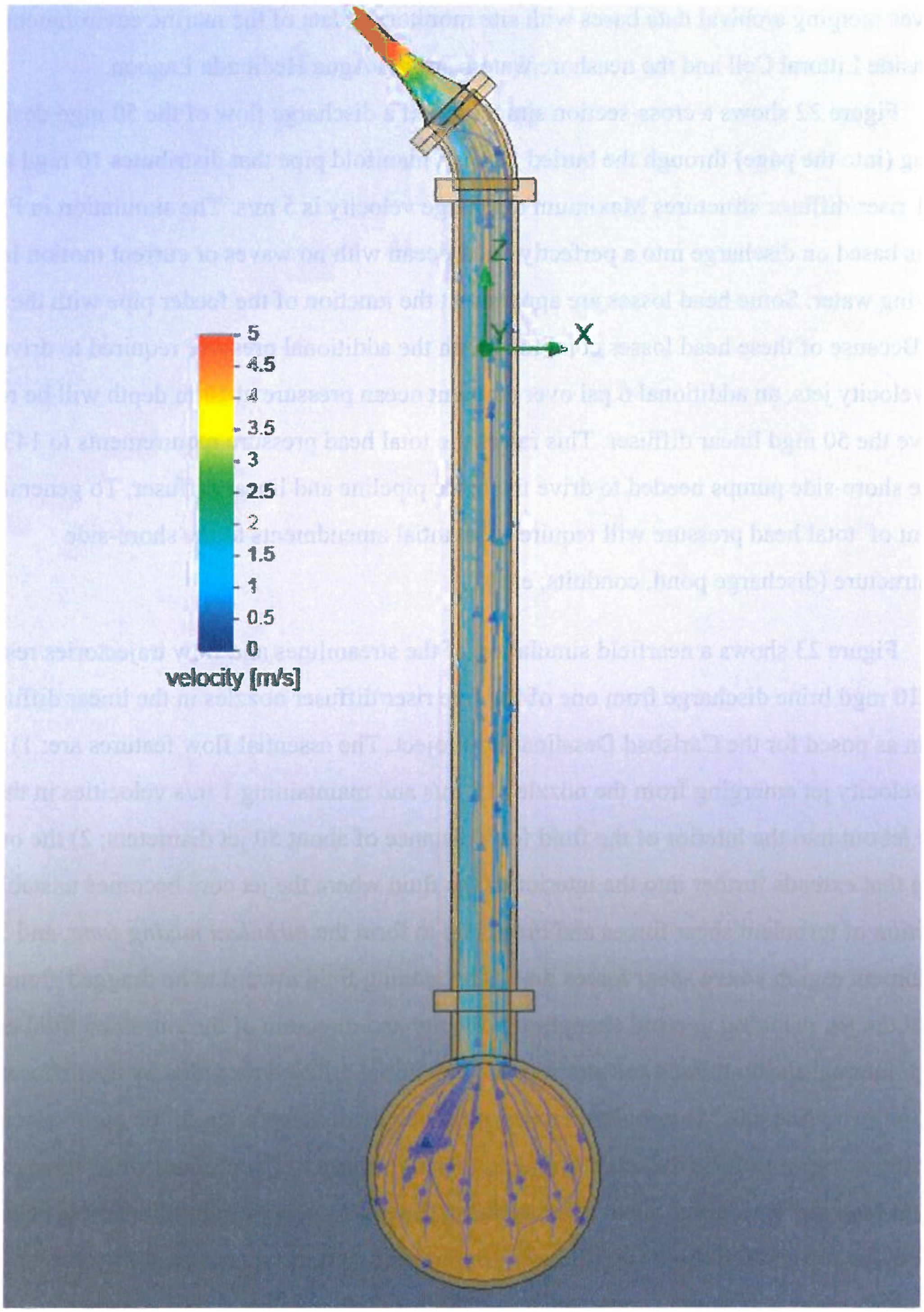

Figure 22. Still water simulation of discharge flow in cross-section through the buried manifold pipe and a single riser/diffuser nozzle. Discharge flow through each nozzle is 10 mgd, with a maximum jet discharge velocity of 5 m/s.

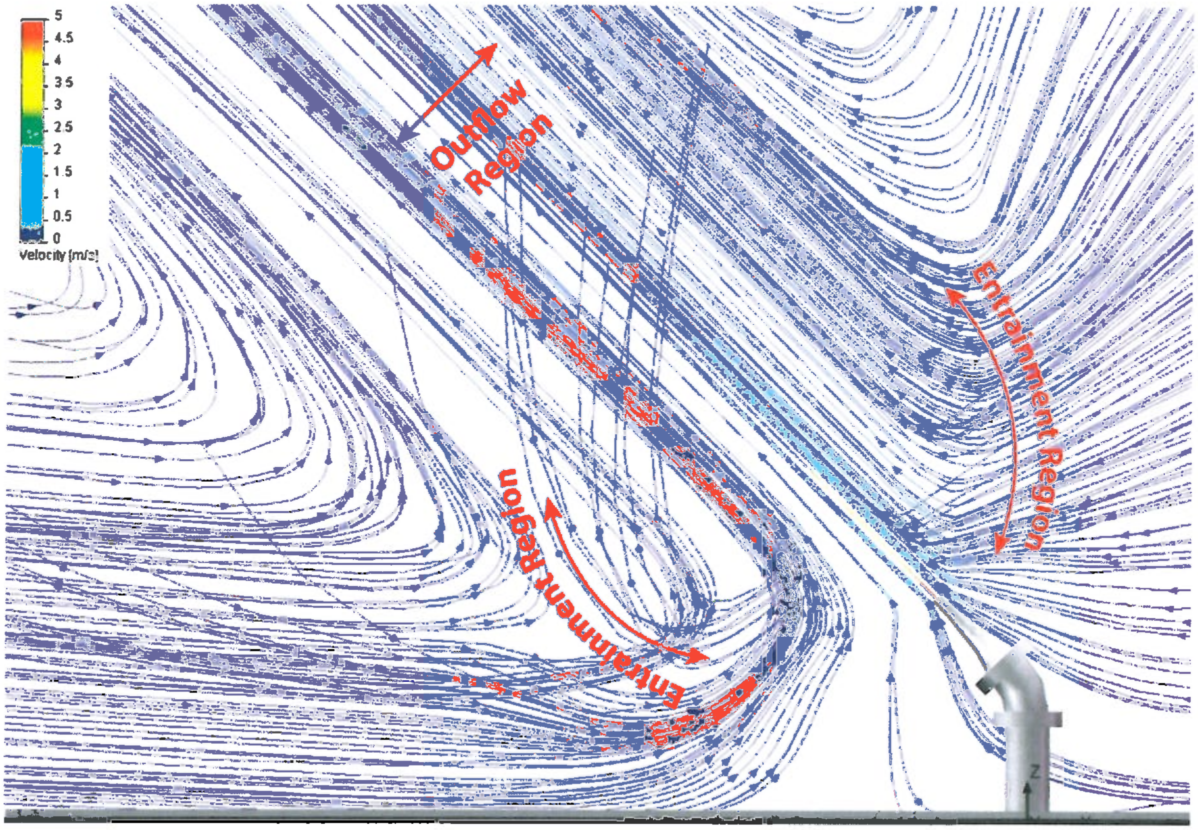

Figure 23: Hydrodynamic simulation of outflow and entrainment regions in the nearfield of a conventional TideFlex nozzle diffuser alternative for the Carlsbad Desalination Project. Total discharge: 5 nozzles x 10 mgd ea. = 50 mgd total brine discharge at 65 ppt end-of-pipe.

$$u_e = \alpha u_m \qquad (12)$$

where α is the entrainment coefficient (whose value is different for jets and plumes). The rate of change of volume flux Q in the plume with distance s is then given by:

$$\frac{dQ}{ds} = 2\pi\alpha b u_m \qquad (13)$$

Equations (12) and (13) are the essence of the entrainment principles, and form the basis for most entrainment diffuser designs.

6.1) Diffuser-Induced Turbulence Mortality: Entrainment feeds the turbulent mixing zone where further dilution occurs. Here organisms swept up by jet entrainment become immediately exposed to all of the causal forces of turbulence mortality. Organisms that are entrained into the high velocity core of the diffuser jet in Figure 24 experience abrupt changes in flow velocity that accelerate them from 0.03 cm/s to as much as 1 m/s to 5 m/s, resulting in an impulsive pressure changes of dynamic pressure on the order of $\Delta p = 1/2\,\rho\Delta(u^2) \approx$ 5,000 dynes/cm^2 to 25,000 dynes/cm^2 (500 Pa to 2,500 Pa). This "fire hose blast effect" exceeds the lethal limit for juvenile fresh water fish, and certainly and ichthyoplankton as well, (Cada, 2001 , and Neitzel, 2004). These accelerations occur tangentially along the jet axis over distances on the order 1 cm and produce strain rates on the order of $\frac{d\bar{u}}{dr} \approx$ 100 sec $^{-1}$ to $\frac{d\bar{u}}{dr} \approx$ 500 sec $^{-1}$; exceeding the threshold strain rates for injury to both ichthyoplankton and fresh water juvenile fish subjected to turbulent shear flow by a free jet, as measured by Neitzel, (2000; 2004). These strain rates result in high internal shear stresses in both the jet core and inner portions of the entrainment and outflow regions.

The shear flow structure shown in Figure 23 produces the internal shear stress distribution in the receiving water shown in Figure 24 for one of the five Tideflex diffuser nozzles that comprise the linear diffuser array posed for the Carlsbad Desalination Project. Numerical integration of the 3-dimensional shear stress field associated with Figure 24 reveals

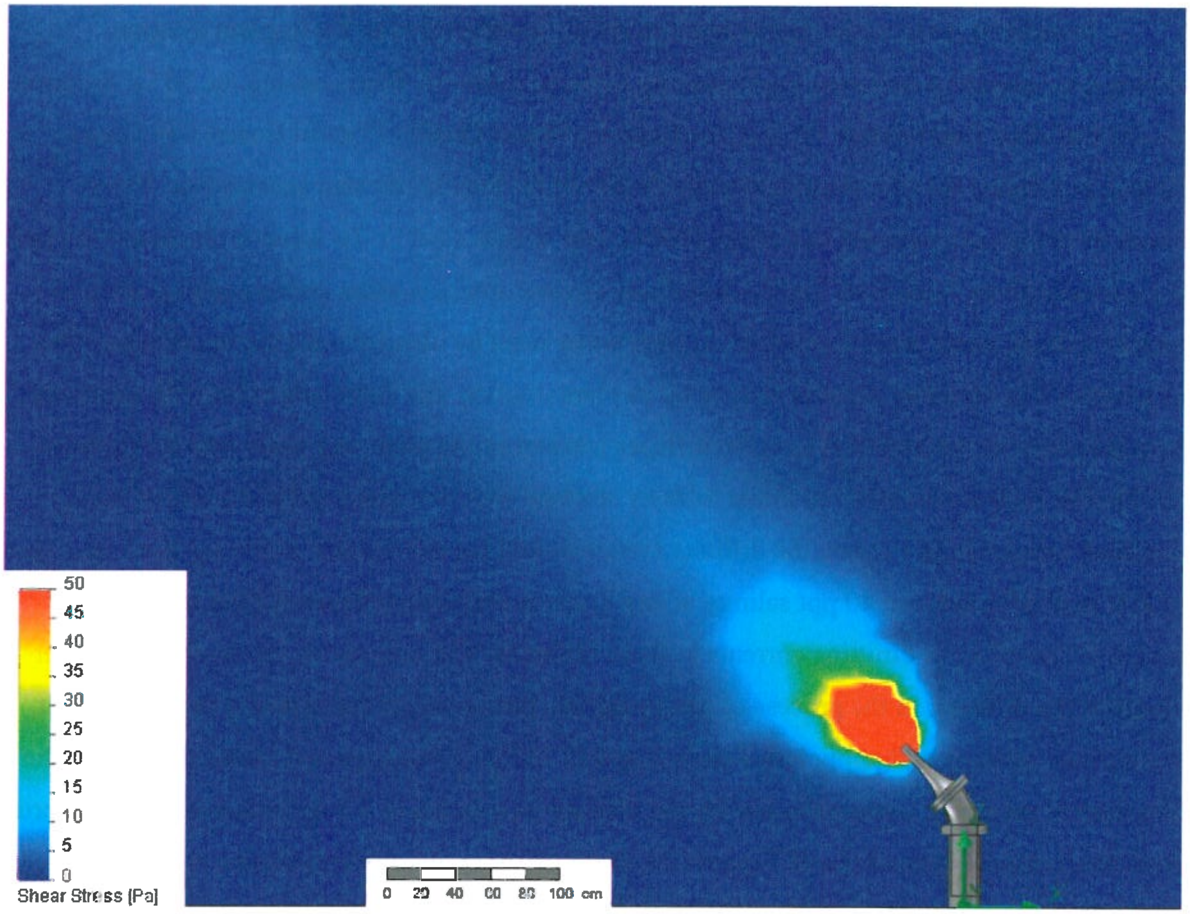

Figure 24: Hydrodynamic simulation of internal shear stress in the nearfield of a conventional TideFlex nozzle diffuser alternative as posed for the Carlsbad Desalination Project. 5 such nozzles discharge 10 mgd each of brine or a total of 50 mgd total brine discharge at 65 ppt end-of-pipe salinity.

that internal shear stresses equal or exceed the brief-exposure lethal limit of 50 Pa for eggs and larvae in about 10.7% of the total water mass entrained by the diffuser jet. Integrating over the velocity field of all five diffuser jets in the linear diffuser array for still water, we find that entrainment flux of receiving water through the lethal shear stress zone (where F_{xx}, F_{xy}, F_{yy} > 50 Pa) is 0.94 m^3/sec, while the total entrainment flux to dilute to 40 ppt is 8.76 m^3/sec. The flux of entrained organisms through the lethal shear stress zone of the diffuser plume is promoted by the effects of shear sorting, which concentrates entrained organisms in the high velocity core of the diffuser jet.

In order to make direct entrainment mortality comparisons to the in-plant dilution strategy, we assume a common hyper-salinity toxicity standard. When issuing the NPDES permit for the Carlsbad Desalination Project, the Regional Water Quality Control Board, San Diego Region concluded that the chronic toxicity threshold for locally relevant species was 40 ppt, based on bio-assays reported in LePage (2004), and Welch, (2011). To achieve dilution of 65 ppt brine to any given "safe level" for hypersalinity chronic toxicity, mass conservation principles require that the exact same amount of dilution water must be blended with the brine; regardless of whether that blending process is done by in-plant dilution that combines brine with additional by-pass water; or whether it is done by diffuser jets entraining receiving water into the diffuser jet. Therefore, if a conventional linear diffuser strategy were implemented at the site of the Carlsbad Desalination Project, the diffuser system would have to entrain receiving water at a rate of 200 mgd of to achieve 40 ppt salinity at any given point of compliance for the chronic toxicity. The effect of omitting currents in these estimates will only move the compliance point closer to the diffuser. In the process of satisfying this particular chronic toxicity threshold limit, the diffuser strategy will apply lethal shear stress to 10.7% of the eggs and larvae that live in the 200 mgd of receiving water entrained by the diffuser jets each day. Using bulk abundance figures from the technical appendices of Tenera (2008) for offshore monitoring stations at Agua Hedionda Lagoon, a conventional diffuser discharge strategy would induce an estimated daily loss of 4,838 mature larvae and juvenile adults and 593,233 eggs and immature larvae. These mortality figures are about 1.5 times worse than the average case estimate for the in-plant dilution strategy using existing Encina pumps, (cf. Section 5). If the in-plant dilution strategy were up-graded with screw pumps, then it would have a compelling 40 to 300 times advantage over conventional diffuser strategies in terms of reducing project mortality to eggs, larvae and juvenile fish at equivalent dilution levels.

The entrainment results above, derived from the *COSMOS/ FLowWorks* CFD model in Figues 21-23, can be cross-checked with another simpler 1-dimensional, steady-state model known as *Visual Plumes*, that has been certified by the U.S. Environmental Protection Agency and the California State Water Resources Control Board for use in diffuser design and nearfield dilution. Figure 25 gives a Visual Plumes one-dimensional simulation of dilution of brine for the 10 mgd, single-jet scenario. Visual Plumes has no wave or tidal current transport physics, so the Figure 25 result represents dilution in a perfectly quiet ocean with no ambient motion, the same as was the case in the CFD shear stress simulation in Figure 24. This is the receiving water condition required for the implementation of the daily maximum acute toxicity receiving water quality objective of 0.3 TUa (acute toxicity units), per Requirement III.C.4(b) of the *California Ocean Plan.* In Figure 25, discharge salinity is shown in red and scaled against the right hand axis as a function of radial distance outward from one of the 5 Tideflex diffuser jet nozzles. Dilution factor in Figure 25 is plotted in blue according to the left hand axis, also as a function of radial distance outward from one typical of 5 diffuser jets. Brine discharge salinity is 65.0 ppt end-of-pipe brine salinity. Ambient ocean (background) salinity is 33.5 ppt. The Visual Plumes model results show in Figure 25 that a single Tideflex diffuser nozzle dilutes brine salinity to 40 ppt at a distance of only 0.9 m from the point of discharge, referred to as *dilution radius,* r_D. Because this is a 1-dimensional solution the instantaneous volume of water that the jet entrains in order to dilute brine to 40 ppt can be approximated by a hemi-sphere with 0.94 m radius, or entrainment volume $V_e = \frac{2}{3}\pi r_D^3$ = 1.74 m^3 x 5 jets = 8.7 m^3 . Since Visual Plumes is also a steady state model, Figure 25 implies a total entrainment flux of 8.7 m^3/sec to dilute to 40 ppt, nearly the same result as derived from the CFD simulation in Figure 24; and, dilutes brine salinity to only 5% over ambient (35.2 ppt) at a distance of 5 m from the point of discharge. A Phase-1 diffuser nozzle dilutes the brine to only 1.2% over ambient ocean salinity at a distance of 10.7 m from the point of discharge.

A potentially new regulatory standard on discharges from ocean desalination seem possible during the foreseeable future, based on the findings and recommendations of California Water Resources Control Board Science Advisory Panel listed in their report entitled, "Management of Brine Discharges to Coastal Waters Recommendations of a Science Advisory Panel", see Jenkins, et al., (2012). Proposed amendments to the California Ocean Plan based on this report could set a numeric water quality objective limited to 5% over ambient ocean salinity at the limit of a *Regulatory Mixing Zone* measuring 100 m (330 ft) in radius around the

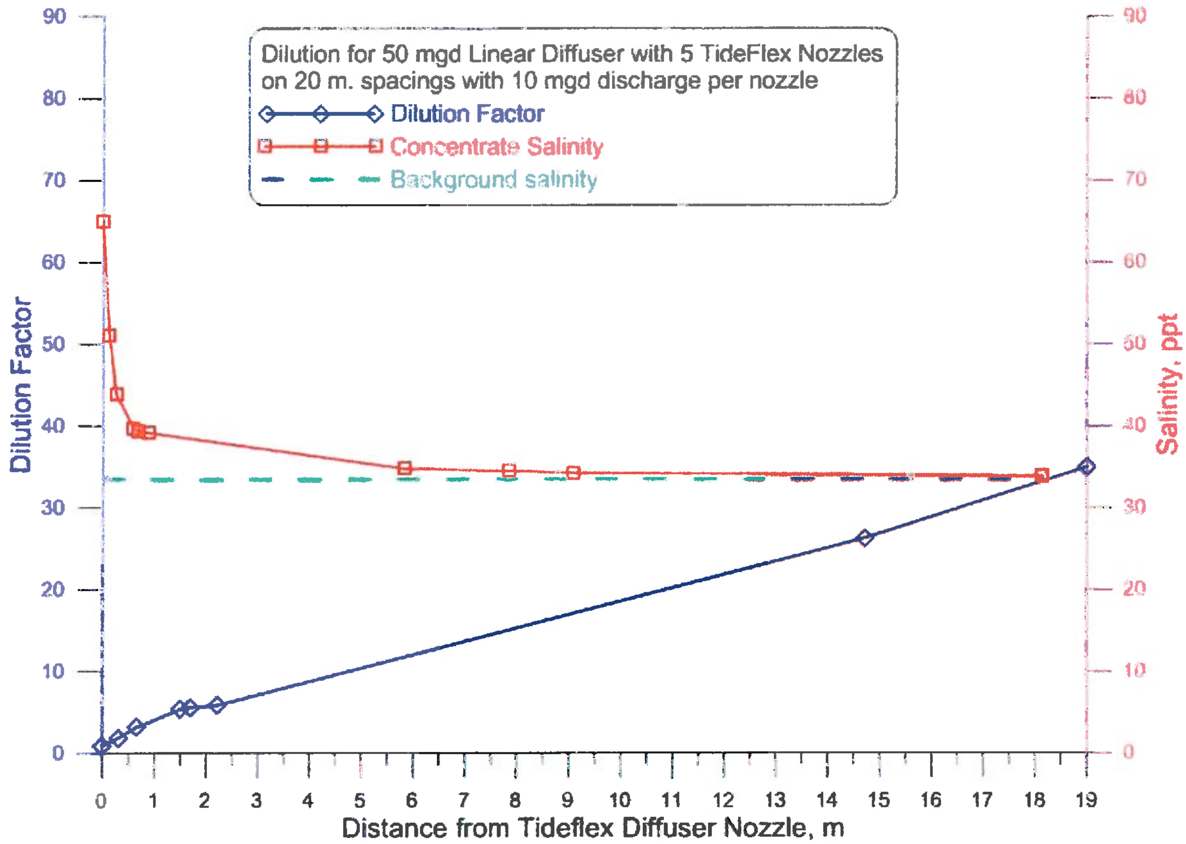

Figure 25: Visual Plumes one-dimensional simulation of still water dilution of brine for the hypothetical diffuser. Discharge salinity (red, right hand axis) as a function of radial distance outward from one typical of 5 diffuser jets; 1 ea. per discharge riser, (cf Figure 22). Dilution factor (blue, left hand axis) as a function of radial distance outward from one typical diffuser jet. Each diffuser jet discharging 10 mgd through a Tideflex nozzle. Total discharge: 5 nozzles x 10 mgd ea. = 50 mgd total brine discharge at 65 ppt end-of-pipe.

discharge (referred to as *The 5% Rule*). The 5% rule essentially requires an initial dilution of 20 to 1 at a 100 m compliance point.

Inspecting the Visual Plumes dilution results in Figure 25, reveals that a single Tideflex diffuser nozzle dilutes brine 20 to 1 (salinity to 35.2 ppt) at a distance of about 8 m from the point of discharge. This requires the diffuser jet to entrain about 950 mgd or about 41.63 m^3/sec. Between 1 and 8 m meters away from the discharge, entrained organisms are beyond the high speed core of the diffuser jet, but well inside the turbulent mixing zone where they can linger for some time and experience longer exposures to elevated shear stresses and a variety of potentially injurious shearing and straining activities from chaotic turbulent eddies, as diagramed in Figure 7. Figure 24 shows that shear stresses in a large portion of this turbulent mixing zone between 1 and 8 m from the discharge are in the lethal range of 15 Pa (150 dynes/cm^2) for longer exposure periods of entrained eggs and larvae. The water mass entrained into the region of the turbulent mixing zone between 1 and 8 m from the discharge is V_e = 41.63 m^3/sec - 8.76 m^3/sec = 32.87 m^3/sec . Contour integration of the 3-dimensional shear stress field associated with Figure 24 reveals that entrainment into 15 Pa longer-exposure lethal portion of the turbulent mixing zone is 6.1 % of the 32.87 m^3/sec total entrainment through the diffuser plume in the region between 1 and 8 m from the discharge. Mortality to eggs and larvae from longer-term exposure in the15 Pa shear stress portion of the turbulent mixing zone must be added to the mortality figures already compiled for entrainment into the inner 50 Pa lethal zone (the red spot in Figure 24). This yields a net equivalent entrainment mortality of 16.8%, and an estimated daily loss of 930,563 eggs and larvae from operations of an offshore diffuser under The 5 % Rule, or 2.3 times more than the average case assessment of operations of the Carlsbad Desalination Project with in-plant dilution under the presently issued permits; and 67-480 times more than would occur if screw-pumps were retrofitted under those same permit conditions. (Shear stresses on the order of 15 Pa are unlikely to cause mortality to juvenile fish, and consequently mortality estimates for the mature larvae and juvenile fish remain as previously stated).

Efforts to reduce turbulence mortality in diffuser system s are difficult. Turbulence mortality in free-jets is a multi-variable function where it is difficult to simultaneously adjust all the variables in the appropriate direction that limits turbulence mortality. There is much more control over these variables with in-plant dilution, because shear sorting concentrates the entrained organisms in regions of the confined spaces of pipe and channel flow (near the center axis) where shear stress and strain rate are minimal. With diffuser jets in the open receiving waters, if one tries to limit turbulence mortality by minimizing the shear stress and strain rates with reduced jet velocities, then the Komogorov turbulence scales tend to increase (because the dissipation rate tends to decrease); and turbulence mortality will likely still occur through the through the action of turbulent eddies that are either comparable to or larger than the entrained organism (cf. Figure 7 b & c). One approach that has been investigated in CFD simulation is the *Four-jet Rosetta Swirl-Chamber Diffuser* , (Jenkins and Wasyl, 2013), that reduces the maximum discharge velocities of a Tideflex diffuser by a factor of 4, but maintains small Komogorov turbulence scales by increasing the dissipation rate with a swirl chamber, that pre-turbulate the brine effluent by inducing rotation prior to discharge. This diffuser concept can maintain Komogorov turbulence scales in the discharge plume that are small relative to the larger mature larvae and juvenile adults, but not for the entire size spectrum of entrained organisms, particularly the small eggs and juvenile larvae.

6.2) Diffuser-Induced Bottom Turbidity: The installation of a brine diffuser system in Carlsbad may introduce artificially high levels bottom turbulence to offshore areas of seafloor where such high turbulence levels do not occur naturally, and consequently where the seabed sediments may not have adequate grain size to resist onset of motion due to these high turbulence levels. Figure 26 provides case evidence for this type of diffuser-induced marine impact at the nearby San Onofre Nuclear Generating Station (SONGS). Resuspension of bottom sediments by entrainment was induced by linear discharge diffusers from SONGS Units 2 and 3. Longshore drift of these re-suspended bottom sediments resulted in reduction of ambient light levels and failure for kelp to recruit at the neigboring San Onofre kelp forest. Significant mitigation requirements were required for the SONGS project in order to receive a Coastal Development Permit from the California Coastal Commission, (SCE, 2000).

The SONGS discharge involved a buoyant rising discharge plume of thermal effluent, and entrainment by that rising plume resuspended bottom sediment in a manner analogous to a

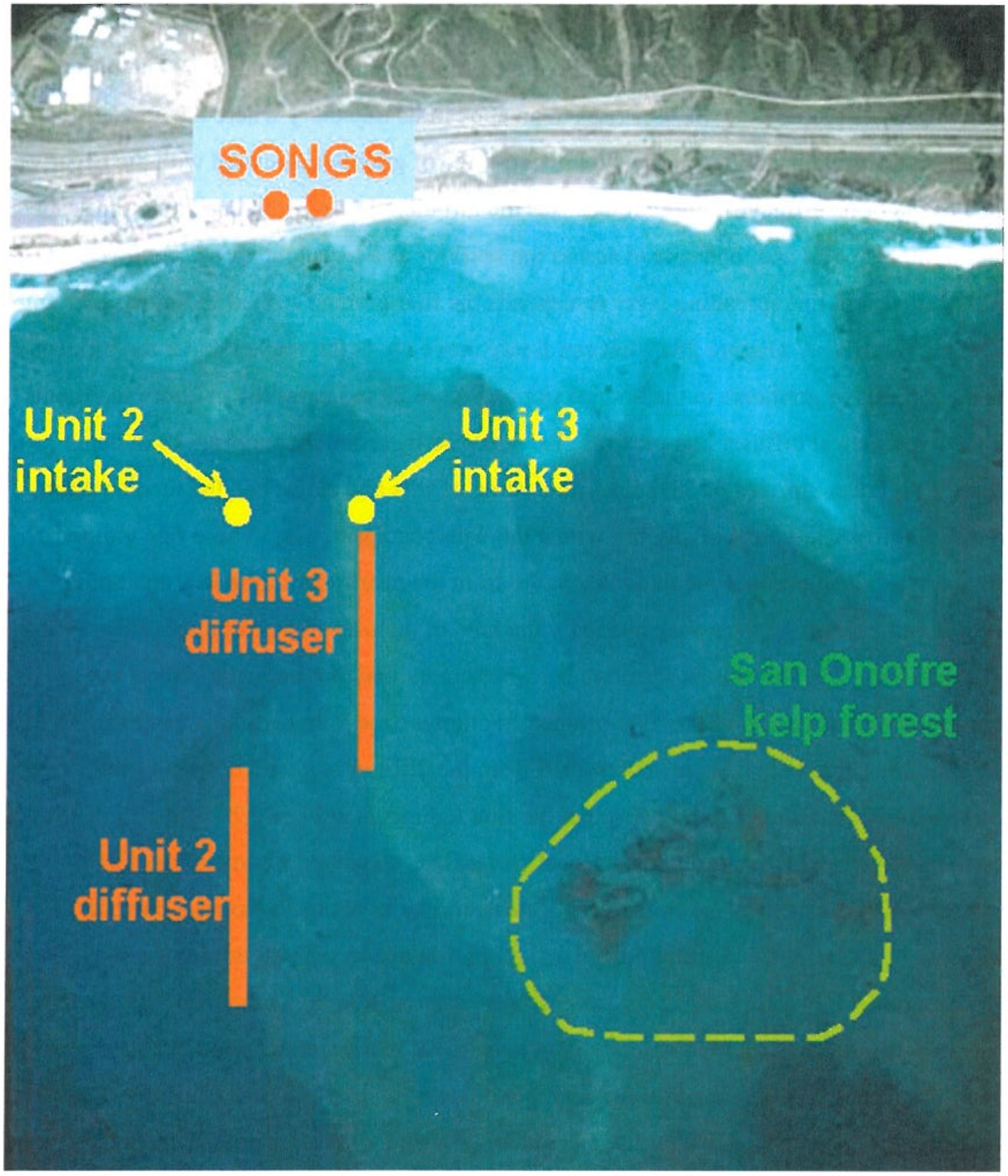

Figure 26: Resuspension of bottom sediments by entrainment induced by linear discharge diffusers from Units 2 and 3 of the San Onofre Nuclear Generating Station (SONGS). Longshore drift of these re-suspended bottom sediments resulted in reduction of ambient light levels and failure for kelp to recruit at the neigboring San Onofre kelp forest. Significant mitigation requirements wewre required for the SONGS project in order to receive a Coastal Development Permit from the California Coastal Commission, (SCE, 2000).

dust devil in the atmosphere. Resuspension by heavy brine effluent from a brine diffusser involves a different flow mechanism, and is illustrated schematically in Figure 27. The turbulent brine effluent discharged by the diffuser rises to an apex in its trajectory where the upward flux of turbulent momentum is haulted by the downward force of gravity associated with the negative buoyancy of the brine effluent. This action causes the turbulent brine to fall back onto the seabed at an initial impact point and then spread across the seafloor as a turbulent ***spreading layer***. The residual turbulence in this spreading layer resuspends the fine-grained seabed sediments forming a ***turbid density current***, (Figure 28), that can freely move about the seabed under the influence of ambient currents or gradients in the bottom slope. Figure 29 indicates the offshore sediments around the hypothetical diffuser complex (as characterized by sediment cores at -10 m depth near Oceanside, CA) are comprised of 50% fines consisting of silts and clays; and the median grain size is only 52 microns, typical of silt, but with a large percentage of clay. These fine grained fractions are wash load products of flood discharge from the nearby San Luis Rey and Santa Margarita Rivers, are prone to re-suspension by the kind of diffuser-induced bottom shear stress illustrated in Figure 23. The closest sensitive hard-bottom habitat that might be effects by winnowing and re-suspension of this fine-grained fraction are the kelp beds adjacent the diffuser site in Figure 20. These kelp beds are down-drift from the diffuser site, and bottom turbidity induced by diffuser turbulence that re-suspend the fine sediments in Figure 29, and will drift into these beds under the advective influence of local currents, as measured Figures 30 and 31.

Figure 30 plots the near-bottom currents measured by an acoustic-Doppler current profiling current meter, (ADCP) from profile cell #1 (2.4 m above seabed) during the site monitoring period 11/14/11-11/24/12 for the east-west current velocity component (a); north-south velocity component (b); total velocity amplitude (c) at a mooring location in at nearby Oceanside, CA. Figure 31 decomposes the near-bottom total velocity amplitudes into probability densities (red bars) and cumulative probability (blue). We find rather large maximum near bottom currents on the order of 50 cm/s (~1.0 kt) in the neighborhood of the hypothetical diffuser discharge, while average near bottom currents are considerably less, on the order of only 5 cm/s, but having a persistent southeastward flowing direction.

Figures 32 give hydrodynamic simulations that quantify the bottom turbulence effects illustrated qualitatively by the brine plume schematic in Figure 27. Figure 32 shows the bottom shear stress around the 5- riser/jet linear diffuser structure aligned in an on/offshore orientation

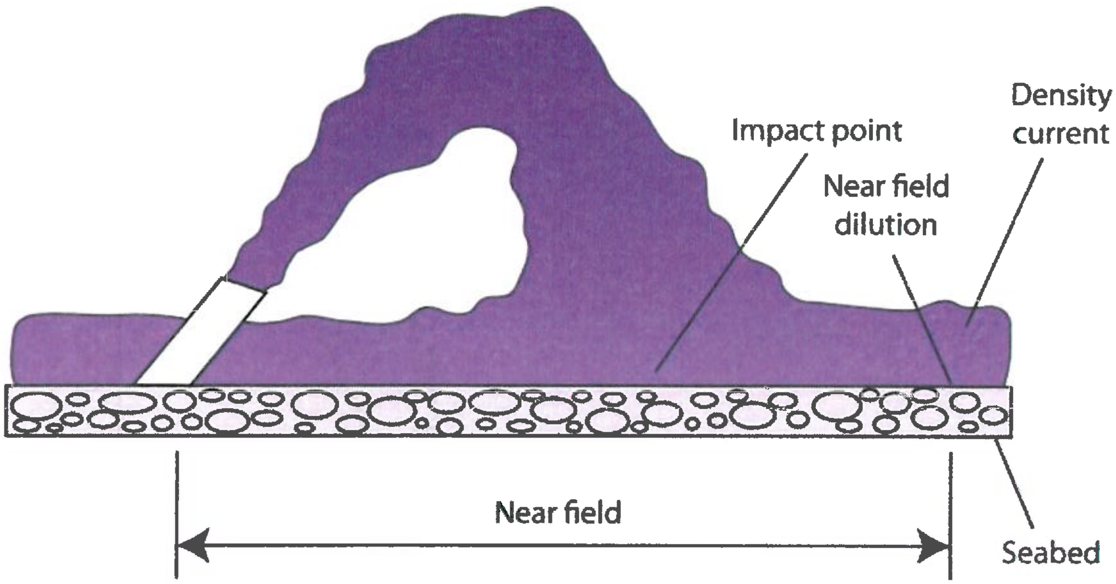

Figure 27: Schematic of brine discharge plume discharged from a near-bottom diffuser (from Jenkins, et. al., 2012,).

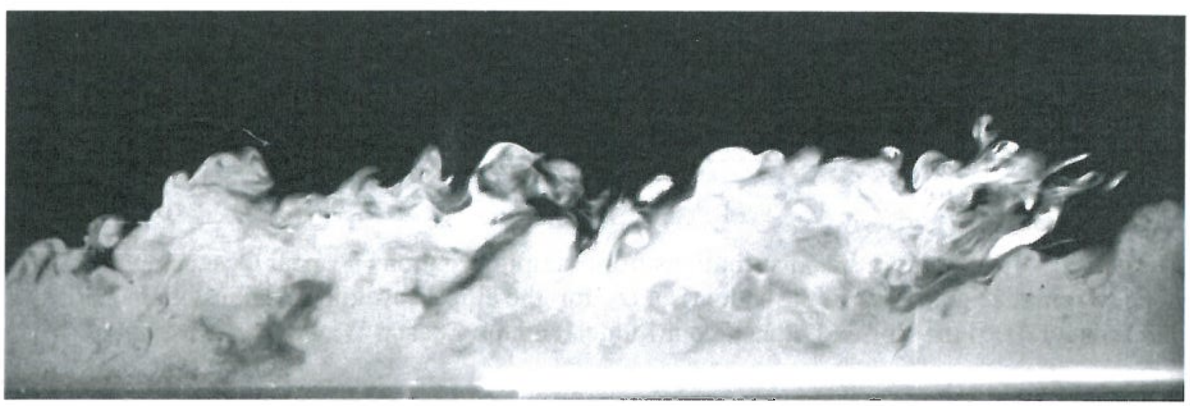

Figure 28: The residual turbulence in the brine-diffuser spreading layer re-suspending the fine-grained seabed sediments, forming a *turbid density current* that can freely move about the seabed under the influence of ambient currents or gradients in the bottom slope (from Jenkins, et al., 1992)

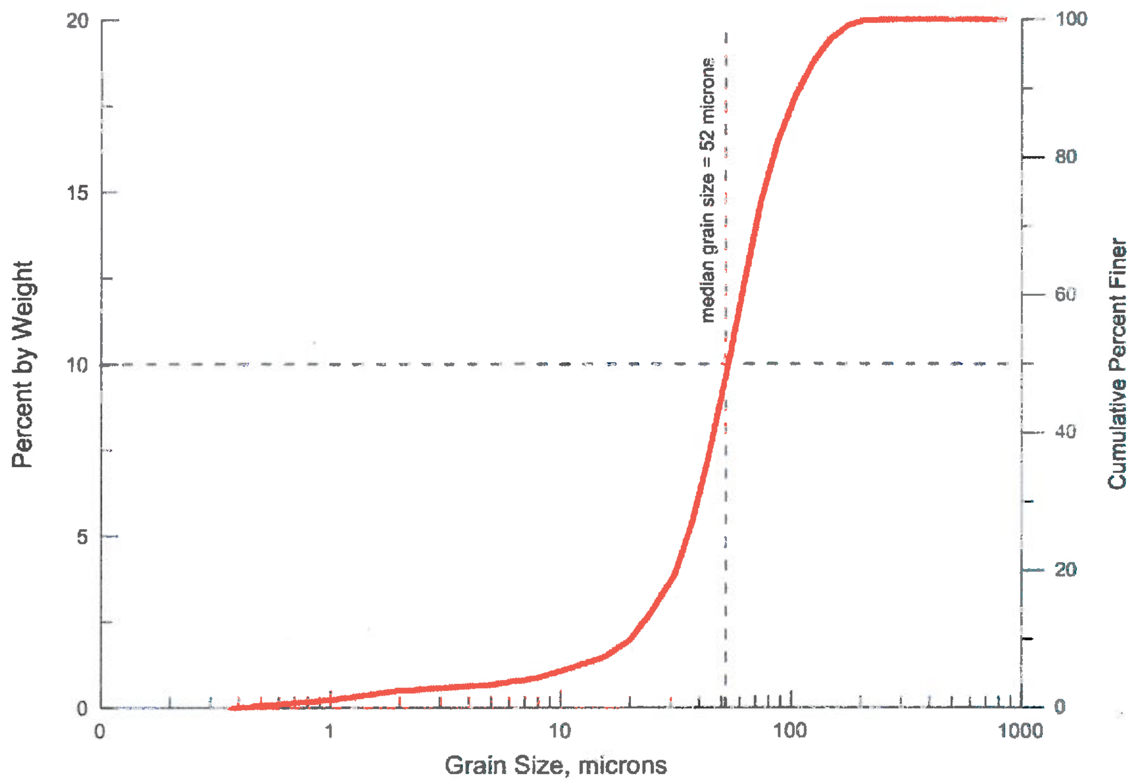

Figure 29: Offshore grain size distributions from sampling stations B1 near Oceanside, CA. Used to initialize grain size in the shore rise, D_2, for the elliptic cycloid solutions after Jenkins and Inman (2006) the Vortex Lattice Scour Model, and the Coastal Water Clarity Model .

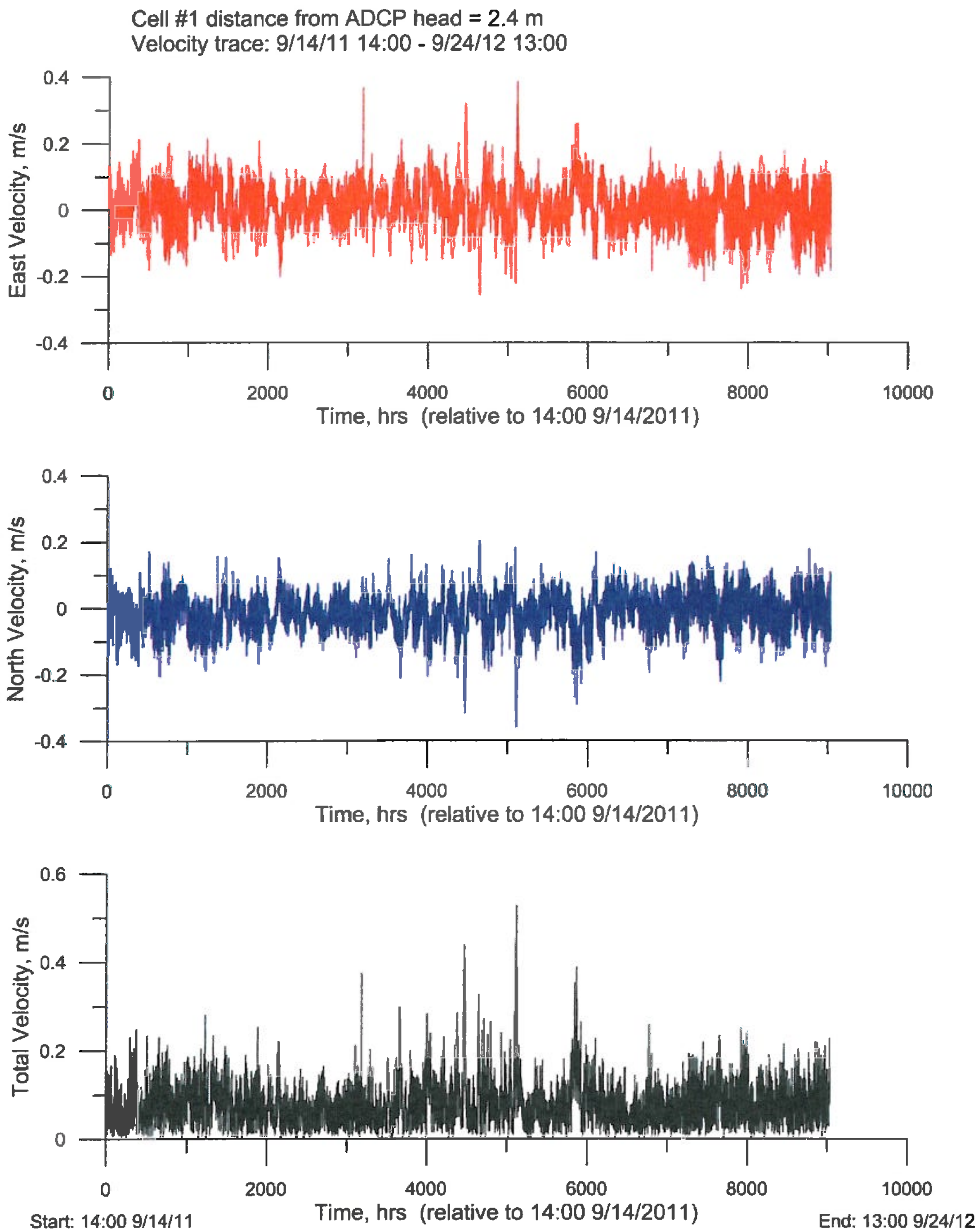

Figure 30: Near-bottom currents (2.4 m above seabed) at in –10m of local water depth near Oceanside, CA.. Measurements by Acoustic Doppler Current Profiler (ADCP) under the MBC *Applied Environmental Sciences* (MBC) Marine Environment Studies Work Plan investigations, 11/14/11-11/24/12. East-west current velocity component (a); north-south velocity component (b); total velocity amplitude (c).

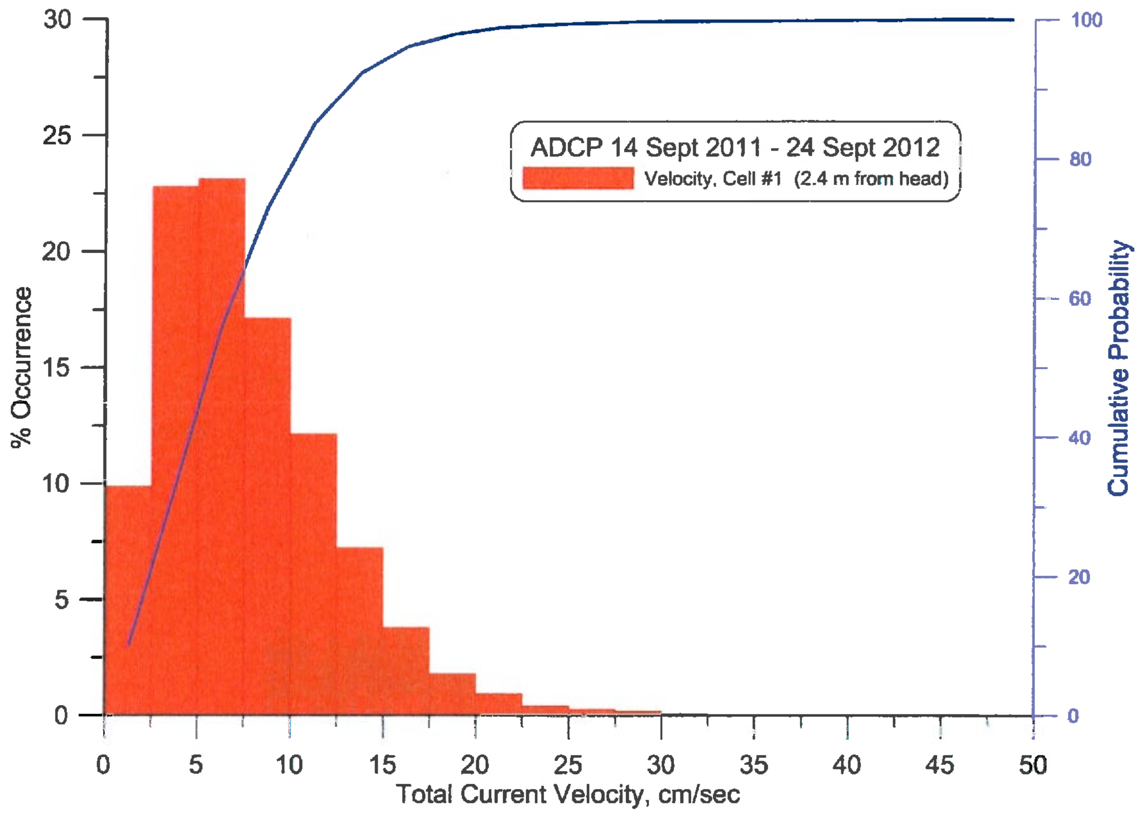

Figure 31: Histogram (probability density) and cumulative probability of near-bottom currents (2.4 m above seabed) in –10m MSL of local water depth near Oceanside, CA. Measurements by Acoustic Doppler Current Profiler (ADCP) under the MBC *Applied Environmental Sciences* (MBC) Marine Environment Studies Work Plan investigations, 11/14/11-11/24/12.

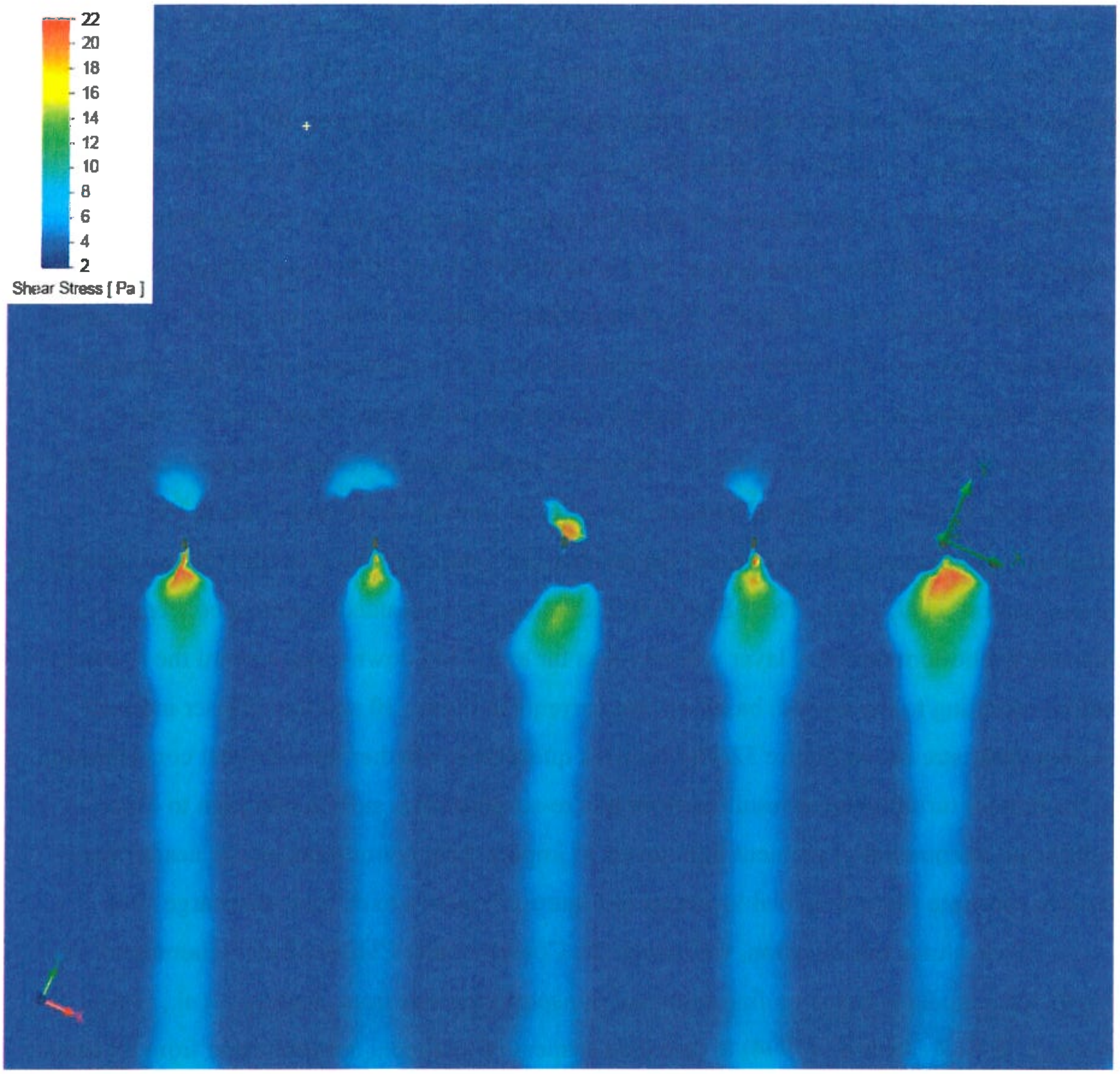

Figure 32: Vortex Lattice simulation of bottom shear stress induced by hypothetical offshore diffuser system for the Carlsbad Desalination Project. Based on a 5-riser/Tideflex nozzle linear diffuser. Shear stress contours in look-down horizontal plan view with a 5 cm/s southward flowing longshore current. North is toward the top of the figure and onshore is toward the left hand side of the figure.

with a mean southward flowing longshore current of 5 cm/s. Threshold bottom shear stress is for re-suspension of the native bottom sediments is on the order of 7 Pa (typical of silty fine-grained sediments having a sediment grains size distribution like Figure 29). Thus, the native sediments appear in equilibrium with the 5 cm/s mean longshore current. However, when diffuser jet-induced shear stresses are added on top of the ambient mean bottom stress, then large super-critical shear stress areas appear, on the order of 15 Pa to 20 Pa over ambient bottom shear stress, particularly in the nearfield of the five diffuser risers where the "red/green" spots appear in Figure 32. These shear stress *hotspots* induce scour and re-suspension of the fine-grained seabed sediments that form a bottom turbidity layer that drifts with the ambient currents. Although the hotspots appear small, the fine grain sediments they re-suspend re-settle to the seabed very slowly, with settling rates on the order of 1 cm/hr to 10 cm/hr, due to the combination of small particle size and the residual eddy stirring effects in the turbulent spreading layer (Jenkins, et al, 1994). The SEDXPORT solutions of suspended sediment concentration indicate the bottom turbidity layer will travel as far as 2.1 km down-coast toward the southeast before resettling to the seabed, based on the currents in Figure 30 and the diffuser induced bottom shear stresses in Figure 32.The decisive question is whether the sediment concentration in the bottom turbidity layer resulting from this re-suspension is sufficiently high to cause significant attenuation of ambient light levels to impact kelp recruitment on the nearby hard-bottom substrate (note kelp bed locations in Figure 20 relative to diffuser discharge site)

To evaluate this question, we invoke the Coastal Water Clarity Model (Hammond, et al., 1994). This model is based on fine sediment transport relations from Jenkins, et al., (1994) and Aijaz, S. & S. A. Jenkins, (1994) to calculate suspended sediment concentration from jet-induce turbulence, and subsequent advective current dispersion. These concentrations are used to calculate the diffuse attenuation coefficient, k_d, for photosynthetically available irradiance, according to (Hammond, et al. 1995):

$$k_d = \left[C^{2}(z) + 0.256 \;\; C(z)\, b(D) \;\right]^{2} \tag{14}$$

where *C(z)* is the suspended sediment concentration at depth *z,* and *b(D)* is the slope of the suspended sediment size distribution curve in the silt and clay regime of Figure 29 (D < 60 microns). In the absence of the diffuser, the Coastal Water Clarity Model typically calculates a diffuse attenuation coefficient of $k_d = 0.60$ cm^{-1} and a visibility distance of $S = 300/k_d = 500$ cm

(5m) over the sandy/silty seabed in the nearfield of the diffuser; and a $k_d = 0.51\ cm^{-1}$ and a visibility distance of S = 590 cm in the farfield over the rocky bottom in the kelp beds shown in Figure 20. The modeled sediment concentrations from the jet induced bottom shear stresses in Figure 32 produce a worst-case diffuse attenuation coefficient of $k_d = 27\ cm^{-1}$ and a visibility distance of $S = 300/k_d = 11$ cm in the nearfield of the diffuser and a $k_d = 3\ cm^{-1}$ and a visibility distance of only S = 100 cm for worst-case in the kelp beds. Thus diffuser induced turbidity has significantly reduced ambient light levels in and around the kelp beds shown in Figure 20. The bottom turbidity induced by the scour action of the diffuser would reduce the photosynthetically available radiation (light spectrum between 400 and 700 nm referred to as "PAR") in the nearby kelp beds by 85 % in worst-case. Because the fine-grained sediments re-suspended by the diffuser re-settle very slowly, the average case suspended sediment particle number concentrations in the bottom turbidity layer range from 100,000 to 250,000 particles per ml in the kelp beds, sufficient to cause, on average, a 20% reductions in PAR. Figure 33 gives a histogram of percent reductions in PAR in the nearby kelp beds due to bottom turbidity layers generated from brine diffuser activity at the Carlsbad Desalination Project. These results are based on grain size data in Figure 29 and current data from Figures 30 and 31. Extrapolating from well documented turbidity impacts observed near the outfall of the San Onofre Nuclear Generating Station (SONGS), it seems quite possible from the % reductions in PAR shown in Figure 33 that the turbidity impacts induced by diffuser operations could cause similar impairment and recruitment degradation to kelp beds near the diffuser site in Figure 20.

It should be noted that turbidity impacts to the kelp beds off Agua Hedionda Lagoon are not possible with the in-plant dilution strategy that discharges pre-diluted brine effluent into the surfzone. This is due to the fact that turbulence bottom stresses from surfzone breaking wave action have winnowed away all of the fine grained sediments from the beach surf zone sediment deposits, allowing only coarse sandy sediments to remain. Figure 34 gives a grain size distribution of beach sediments at South Beach near the discharge channel. The beach material is very well sorted and contains no size fractions in the silt and clay grain size regime. The median grain size of this beach material is 2.5 to 4 times coarser than the median grain size of the offshore sediments in Figure 29. Sandy beach sediments as in Figure 34 simply do not cause turbidity.

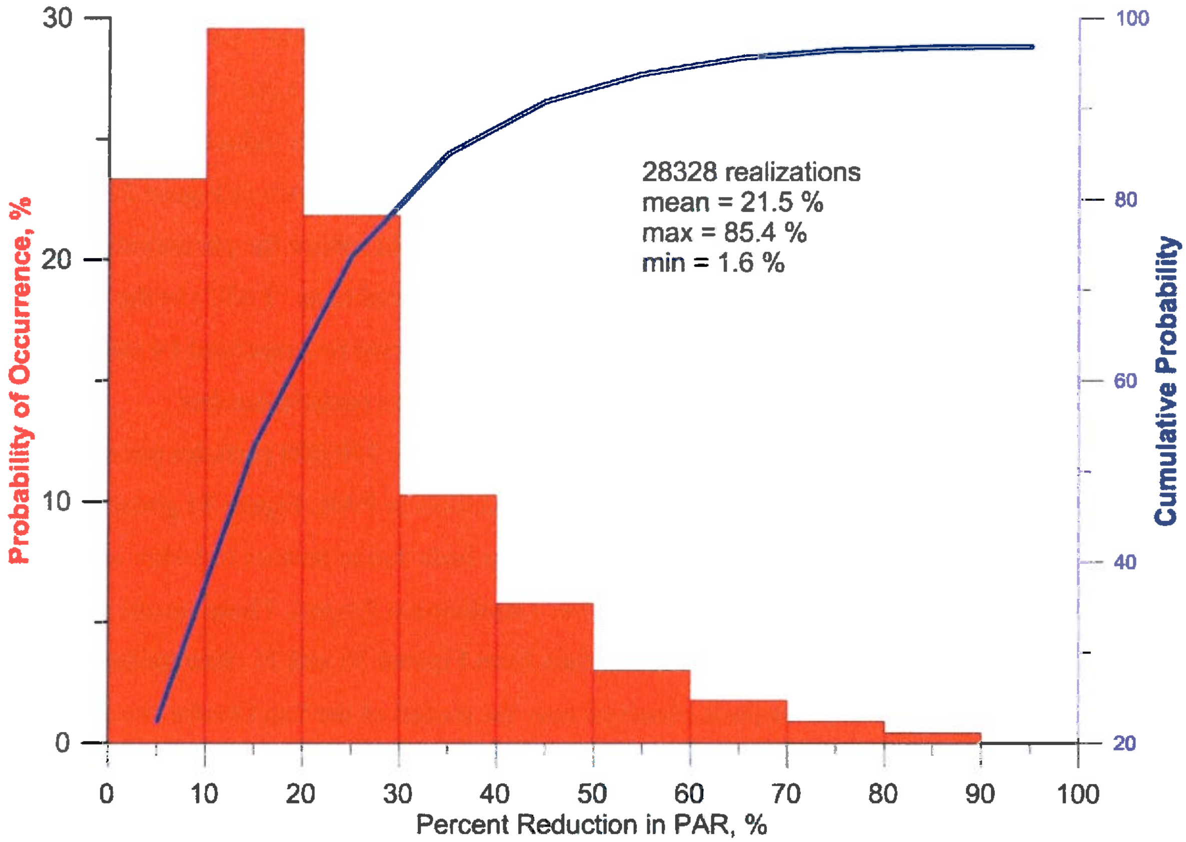

Figure 33: Histogram (probability density) and cumulative probability of percent reductions in photosynthetically available radiation (light spectrum between 400 and 700 nm referred to as "PAR") at the centroid of the footprint of the Carlsbad kelp beds due to bottom turbidity layers generated by elevated bottom shear stresses from brine diffuser activity at the Carlsbad Desalination Project. Based on grain size data in Figure 28 and current data from Figures 29 and 30.

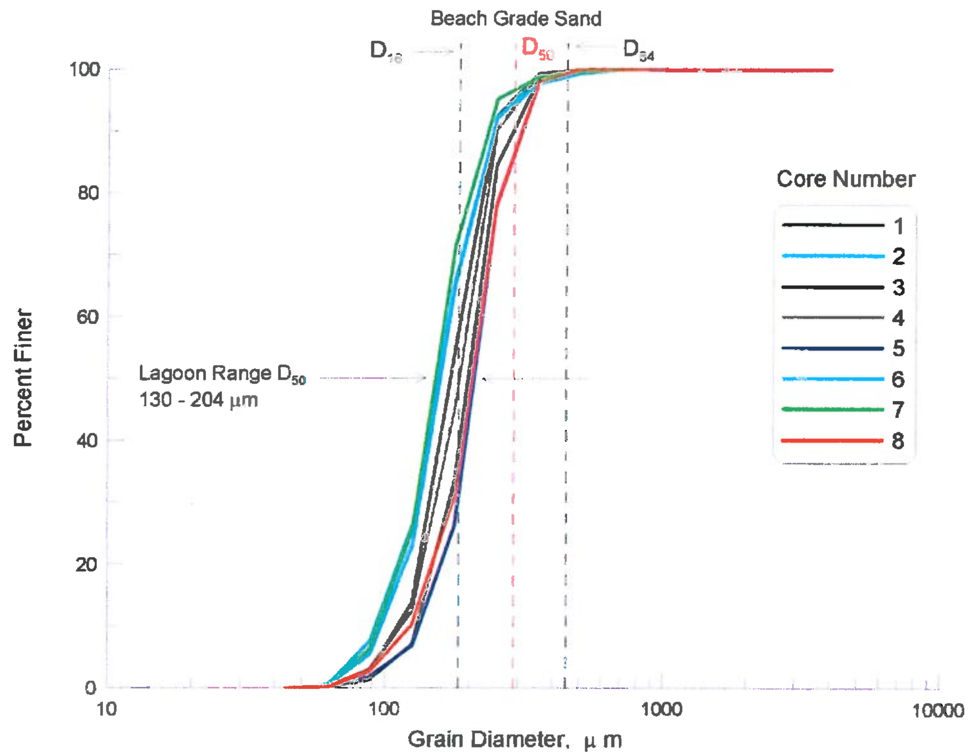

Figure 34: Grain size distribution of beach sediments at South Beach near the discharge channel.

7) Conclusions:

We address implications of the findings and recommendations of California Water Resources Control Board Science Advisory Panel listed in their report entitled, "Management of Brine Discharges to Coastal Waters Recommendations of a Science Advisory Panel", see Jenkins, et al., (2012). Here, diffuser-based discharge strategies are presented as *the preferred discharge technology*, although that section also admits: "*Different discharge strategies can be used, depending on site-specific considerations. There is no single discharge strategy that is optimum for all types of anticipated scenarios*." In addition, a potentially new regulatory standard may follow from this report for discharges from ocean desalination plants. Proposed amendments to the California Ocean Plan based on this report could set a numeric water quality objective limited to 5% over ambient ocean salinity at the limit of a *Regulatory Mixing Zone* measuring 100 m (330 ft) in radius around the discharge point (referred to as *The 5% Rule*). Our concern is that the diffuser-based discharge strategy may not be the best available technology where certain site specific conditions are present, as is the case for the Carlsbad Desalination Project; which has otherwise been fully permitted based on *in-plant dilution* using the once-through sea water circulation system of the Encina Power Station (EPS) in Carlsbad, CA.

Our analysis evaluates present and potential future operating conditions for the Carlsbad Desalination Project, including: 1) existing, fully-permitted, baseline operating conditions where desalination operations occur utilizing heated seawater effluent from power generation by the Encina Power Station (EPS) ; 2) potential future *stand-alone* operating conditions where the desalination plant is withdrawing seawater independent of power generation following retirement of the EPS once-through cooling system . Such future action might occur because the host EPS re-powers and converts to air-cooling systems, or because the EPS generators are decommissioned. In the stand-alone scenario, there is no mortality to entrained organisms by *thermal shock* due to passage through hot condenser tubes. Regardless of present or future operating conditions, our general conclusion is that the high velocity diffuser strategy does not present a compelling advantage over the in-plant dilution strategy at the Carlsbad site when measured in terms of offering further reductions in project mortality to eggs, larvae and juvenile fish. Pump replacement with the in-plant dilution strategy under stand-alone conditions can potentially provide significant reductions in such mortality; whereas the diffuser strategy risks expanding marine life entrainment impacts to fish species originating from neighboring kelp beds, and inducing formation of bottom turbidity layers with diffuser-induced turbulence that has the potential to significantly degrade those kelp beds. The details of this conclusion are summarized in Table 2, and elaborated below.

Analysis Methods: To quantify mortality likelihood for entrained organisms passing through the in-plant dilution pathway of the Carlsbad Desalination Project; or alternatively, through the turbulent mixing zone of an offshore diffuser system, we invoke standard hydraulic calculus, supplemented by computational fluid dynamic (CFD) computer analysis. Thresholds for the various types of entrainment mortality were based on laboratory and field measurements of lethal and sub- lethal pressure gradients, accelerations and turbulent shear stresses, strain rates and turbulence mixing scales; largely derived from the hydro-electric literature for eggs, larvae and juvenile adults of fresh water species. These measurements were applied to in-situ samples of size and abundance of locally relevant marine species. In comparing in-plant vs. diffuser dilution strategies, we assume both are based on 104 mgd of ocean water intake flow (the permitted amount) that unavoidably will cause 100% entrainment mortality on this harvested fraction of source water as a result of the action of the pre-treatment train and RO processes. To provide a common reference point, we first evaluate both in-plant and diffuser-based discharge strategies for a common dilution standard, namely that approved by the Regional Water Quality Control Board, San Diego Region; and then compare those findings to results based on recommendations of California Water Resources Control Board Science Advisory Panel under dilution standard of *The 5 % Rule.*

In-Plant Dilution Strategy: Under the fully-permitted baseline conditions, this strategy requires 104 mgd of seawater for processing in the desalination facility (as described above) and 200 mgd of dilution water, yielding a total of 304 mgd of seawater intake, derived from Agua Hedionda Lagoon. We quantify the turbulence mortality for these conditions based on the assumption of 100% mortality to organisms entrained in incremental flow required for desalination facility operation when EPS is operating at less than 304 mgd cooling water intake flow rates, (referred to as *short-fall* flow increments).This follows from permit conditions for operating the Encina Power Station (EPS), whence the Carlsbad Desalination Project was granted its permits for the *dual-use* of the heated seawater effluent from the power plant. In the

Table 2: Comparison of Environmental Impacts of Brine Discharge Alternatives

	Carlsbad Desalination Project Permitted Operating Conditions (co-located with Encina Power Plant)	**Carlsbad Desalination Potential Operating Conditions (following retirement of Encina Power Plant)**	**Staff's Proposed Ocean Plan Amendments**
Brine discharge salinity (ppt)	40.0	40.0	65.0
Receiving water salinity (ppt)	33.5	33.5	33.5
Salinity reduction requirement and discharge technology	Reduce salinity from 65 ppt to sublethal level of 40 ppt prior to discharge through in-plant dilution. Remainder of dilution achieved through natural mixing via low velocity (1 to 3 feet per second) discharge into high energy surf zone seaward of the point of discharge. Zone of initial dilution (the "ZID") extends 1,000 feet from end of the discharge channel.	Similar to permitted operating conditions *See*	Mechanical mixing achieved through pressurized diffuser used to reduce full strength brine salinity to from 65 ppt to 35.5 ppt through high velocity (5 m/s) turbulent mixing in receiving water. ZID extends 100 meters from the point of discharge.
Initial dilution	5:1 prior to discharge and 15:1 in the ZID.	5:1 prior to discharge and 15:1 in the ZID.	20:1 in the ZID
Habitat present in the vicinity of the discharge	Sandy bottom	Sandy bottom	Silty seabed at diffuser site with rock with kelp forest immediately south (down-drift from the diffuser).
Volume of seawater exposed to entrainment impacts to achieve required salinity level	200 MGD of seawater is pumped through the Encina Power Station once-through cooling water system for in-plant dilution to achieve 5:1 dilution.	200 MGD of seawater is transferred from the Encina Power Plant intake to the discharge channel using low impact, low-rpm screw- pumps to achieve 5:1 dilution. These pumps minimize turbulence and impeller blade-strike impact mortality.	Up to 950 MGD of seawater is entrained by 5 high velocity jets turbulent/high-velocity jets to achieve 20:1 dilution. Shear sorting in the diffuser discharge plume causes entrained organisms concentrate in the high velocity jet core where shear stresses and strain rates are significantly above lethal limits.

Entrainment mortality	Estimated net impact of 2.24% entrainment mortality, occurring in additional seawater taken for dilution beyond the amount of dual-use water provided by average operating conditions of the Encina Power Station (407,680 eggs and larvae).	Mortality estimated to be 0.035% of the entrained organisms for best case scenario. The absolute worst case mortality estimate is 0.25 % of the entrained organisms (1,975 eggs and larvae to 13,934 eggs and larvae).	Mortality estimated to be 16.8% of organisms entrained by 5 diffuser jets; or 2.3 times greater than average mortality estimates for permitted project; 67 to 480 times greater than mortality estimates for in-plant dilution with screw pumps (930,563 eggs and larvae).
Organisms in entrained water	Due to the intake location in Agua Hedionda Lagoon, ninety-five percent of the larval organisms entrained are lagoon based species that have saturated Agua Hedionda Lagoon (e.g., gobies and blennies makeup over 80% of the entrained fish larvae). Less than 0.5% of the entrained organisms are recreationally or commercially important species; no threatened or endangered species were identified.	Same as permitted operating conditions.	Due to the diffuser location off shore and its proximity to the Carlsbad kelp bed, the diffuser would entrain significantly greater numbers of commercially and recreationally important fish and invertebrates than the lagoon based intake. Additionally, the higher level of dilution (20:1 vs. 5:1) would result nearly a five-fold increase in entrainment.
Marine organisms exposed to lethal level of brine concentration?	The marine organisms entrained in the dilution water are briefly exposed to lethal levels of salinity up to 65 ppt. The brine is rapidly reduced to sub-lethal levels (40 ppt) in discharge tunnel and pond system prior to discharge.	The marine organisms entrained in the dilution water are briefly exposed to lethal levels of salinity up to 65 ppt. The brine is rapidly reduced to sub-lethal levels (40 ppt) in discharge tunnel and pond system prior to discharge.	The marine organisms entrained in the high velocity diffuser jets are briefly exposed to lethal levels of salinity up to 65 ppt. The brine is rapidly reduced to sub-lethal levels in the receiving water.

Potential for increased turbidity and sediment flux down coast from the discharge to create a long-term negative effect on kelp reproduction in the nearby kelp beds	No. Low velocity discharge over sandy beach and surfzone sediments that contain no silts or clays to cause turbidity.	No. Low velocity discharge over sandy beach and surfzone sediments that contain no silts or clays to cause turbidity	Yes. High velocity discharge coupled with silty offshore seabed sediments will cause bottom turbidity layers that reduce ambient light intensities in nearby kelp beds. Photosynthetically available radiation (PAR) in the nearby kelp beds reduced by 90 % in worst-case; and on average, reduced by 20 % to 25 % . Similar experience with diffuser technology at the San Onofre Nuclear Generating Station that had a long-term negative effect on kelp reproduction in the nearby San Onofre kelp bed, with significant losses of kelp plants, the failure of adult recruitment of new kelp plants, and a dramatic decline in the fish and shellfish that had depended on the now damaged or destroyed kelp forest for habitat, cover and food.
Other environmental impacts	None	None	Impacts associated with construction of a new ocean outfall and diffuser extending one mile offshore. Increased energy consumption.

operating history of EPS over the last decade or so, there were 660 days when daily seawater flow rates required by operations of the Encina Power Station (EPS) were less than 304 mgd; 122 of these low-flow days occurred between 1999 and 2006, while 538 low flow days occurred in the more recent 2006-2010 time period. The increase in numbers of low-flow days after 2006 can be correlated with the commissioning of the Palomar cogeneration facility in April 2006; but recent de-commissioning of the San Onofre Nuclear Generating Station seems likely to reverse that trend. In view of these external operating factors, it is sensible to consider two sets of flow rate statistics: the historic record of the last 11 years representative of the long-term average operating environment; and the 2006-2010 subset of that record, representing a potential short-term, worst-case.

Over long term conditions, EPS operated its seawater circulation systems at 92.6% of the baseline operating need for in-plant dilution. During worst-case operating conditions (represented by 2006-2010), EPS operated its seawater circulation systems at only 81.3% of flow rate requirements for permitted baseline desalination operations. Applying the well-excepted (and permit-adopted) *flow-proportional principle*, we find that the net impact of in-plant dilution under the permitted baseline is 2.24% entrainment mortality under average long-term EPS operating conditions. This figure represents mortality occurring in additional seawater taken for dilution beyond the amount of dual-use water provided by operations of the Encina Power Station. This net impact is equivalent to an estimated daily loss of 3,323 mature larvae and juvenile adults and 407,680 eggs and immature larvae. Under worst-case EPS operating conditions, in-plant dilution water produces a net impact of 5.66% entrainment mortality. Net impact for this worst-case assessment is equivalent to an estimated daily loss of 8,398 mature larvae and juvenile adults and 1,030,120 eggs and immature larvae.

Following decommissioning of the EPS OTC system, the in-plant dilution strategy for the Carlsbad Desalination Project can be improved by retrofitting the existing cooling water pumps with ultra-low rpm pump options; because pump rpm exerts a strong influence on entrainment mortality. Introducing new technologies that remediate entrainment impacts is contemplated under the various approvals issued for the Carlsbad Desalination Project. Of particular interest in this regard are the large *screw-pumps* that have been used previously in seawater circulation systems for aquariums and mammal tanks at Sea World, San Diego. The screw pump relies on an Archimedes screw to thread through the water mass and push water along the in-plant dilution pathway, rather than spin the water mass to high rpm and eject it at high velocity and acceleration along the dilution pathway in the manner of the existing EPS centrifugal pumps. Mortality during pump passage is dependent on the size of the entrained organisms. With 4 Spaans-Babcock screw pumps diverting 200 mgd directly into the discharge tunnel (by-passing existing EPS conduits and condenser tubes) mortality at the small end of the organism size spectra would be reduced to 0.035% of the entrained organisms, amounting to a daily loss of only 16 mature larvae and juvenile adults and 1,975 eggs and immature larvae. At the high end of the organism size spectra, mortality during passage through a screw-pump would be 0.25% of the entrained species, amounting to a daily loss of 114 mature larvae and juvenile adults and 13,934 eggs and immature larvae. Potentially, the screw-pump retrofit to the stand-alone Carlsbad Desalination Project could reduce entrainment mortality (best case) to 206 times less than the100% mortality assumption relied upon in the project approvals; and worst case, reduce entrainment mortality to 74 times less than what was assumed for the project approvals.

High Velocity Diffuser Strategy: There seems to be a general assumption that diffusers avoid all forms of marine life impact. However, there is an emerging body of published evidence that entrainment mortality by a free-jet is a very real phenomenon, whereby physical damage to eggs, larva and juvenile fish can occur in open, free-stream turbulent environments, such as the *turbulent mixing zone* of high pressure diffuser systems. The effect of turbulence on larval mortality was studied in the field by Jessopp (2007), who found that even turbulent *tidal flows* produce significantly increased mortality to thin-shelled veligers of gastropods and bivalves. In fresh water, Neitzel et al., (2000) demonstrated that a turbulent jet in a laboratory tank would cause major and minor injury to four different freshwater species of juvenile fish. A significant flow mechanism that causes injury and mortality in diffuser jets is shear sorting of the jet-entrained organisms. Shear induced lift forces concentrate the organisms in the higher velocity region of the shear flow, which is the high velocity core of the jet where both strain rates and accelerations are high and mortality likely.

To evaluate potential marine life impacts due to implementation of the high velocity diffuser strategy at the site of the Carlsbad Desalination Project, we evaluated a conventional linear diffuser, consisting of five discharge riser/diffusers structures in 10 meters of water depth at the end of a 72 inch diameter brine discharge pipeline, seaward of existing kelp beds. In order to make direct entrainment mortality comparisons to the in-plant dilution strategy, we assume a common hyper-salinity toxicity standard, namely the 40 ppt limit that was adopted for the NPDES permit for the Carlsbad Desalination Project by the Regional Water Quality Control Board, San Diego Region. Therefore, the diffuser would have to entrain receiving water at a rate of 200 mgd in order to achieve a comparable dilution to the in-plant dilution strategy. In the dilution process, the diffuser strategy will apply lethal shear stress to 10.7% of the eggs and larvae entrained by the diffuser jets that live in the receiving water. Using bulk abundance figures from the technical appendices of Tenera (2008) for offshore monitoring stations adjacent Agua Hedionda Lagoon, a conventional diffuser discharge strategy would induce an estimated daily loss of 4,838 mature larvae and juvenile adults and 593,233 eggs and immature larvae. These mortality figures are about 1.5 times worse than the average case estimate for the in-plant dilution strategy using existing Encina pumps, (cf. Section 5). If the in-plant dilution strategy were up-graded with screw pumps, then it would have a compelling 40 to 300 times advantage over conventional diffuser strategies in terms of reducing project mortality to eggs, larvae and juvenile fish at equivalent dilution levels.

If The 5 % Rule is invoked, then estimates of mortality to entrained organisms by diffuser jets are increased by increases in the entrained water mass required in order to achieve higher dilution levels. As a result, additional turbulence mortality will occur in an expanded turbulent mixing zone, further away from the discharge point, where exposure times to elevated shear stresses are greater, and smaller shear stresses are required to induce injury and death. Under the 5% Rule, conventional diffusers incur a net equivalent entrainment mortality of 16.8%, resulting in an estimated daily loss of 930,563 eggs and larvae. This is 2.3 times more entrainment mortality than the average case assessment of operations of the Carlsbad Desalination Project with in-plant dilution under the presently issued permit; and 67-480 times more than would occur if screw-pumps were retrofitted under those same permit conditions.

Brine diffuser systems introduce artificially high levels of bottom turbulence to offshore areas of seafloor where such high turbulence levels do not occur naturally, and consequently where the seabed sediments may not have adequate grain size to resist onset of motion due to these high turbulence levels. The turbulent brine effluent discharged by the diffuser rises to an apex in its trajectory where the upward flux of turbulent momentum is haulted by the downward force of gravity associated with the negative buoyancy of the brine effluent. This action causes the turbulent brine to fall back onto the seabed at an initial impact point and then spread across the seafloor as a turbulent *spreading layer*. The residual turbulence in this spreading layer resuspends the fine-grained seabed sediments forming a *turbid density current* , that can freely move about the seabed under the influenc of ambient currents or gradients in the bottom slope. The concern at the available offshore diffuser sites for the Carlsbad Desalination Project is that a diffuser-induced turbidity layer might spread into nearby kelp beds and reduce ambient light levels, thereby impacting kelp recruitment. To evaluate this concern, we invoke the Navy's Coastal Water Clarity Model. Based on recent current data and offshore sediment grain size data, we find that bottom turbidity induced by the scour action of a diffuser would reduce the photosynthetically available radiation (light spectrum between 400 and 700 nm referred to as "PAR") in the nearby kelp beds by 90% in worst-case; and on average, cause a 20% to 25% reductions in PAR in these beds. Extrapolating from well documented turbidity impacts observed near the outfall of the San Onofre Nuclear Generating Station (SONGS), it seems quite possible from these percent reductions in PAR that the turbidity impacts induced by diffuser operations could cause similar impairment and recruitment degradation to kelp beds near the available diffuser sites for the Carlsbad Desalination Project .

Efforts to reduce turbulence mortality in diffuser systems are difficult. Turbulence mortality in free-jets is a multi-variant function where it is difficult to simultaneously adjust all the variables in the appropriate direction that limits turbulence mortality. With diffuser jets in the open receiving waters, if one tries to limit turbulence mortality by minimizing the shear stress and strain rates with reduced jet velocities, then two negative feed-back factors result: 1) the dilution rates in the brine plume decline, and hyper-salinity toxicity in the inner regions of the turbulent mixing zone become an issue; and 2) the Komogorov turbulence scales (the turbulence scales where most dissipation occurs) tend to increase (because the dissipation rate tends to decrease with decreases in maximum jet velocities); and turbulence mortality will likely still occur through the action of turbulent eddies that are either comparable to or larger than the entrained organism. Efforts to reduce bottom turbidity impacts of diffusers are equally difficult, particularly when offshore sediment deposits contain significant amounts of silts and clays. The negative buoyancy of a diffuser brine plume invariably brings the turbulence in that plume into direct contact with the seabed; and efforts to reduce the sediment transport capacity of that turbulence by reducing jet velocities sets up the same negative feed-back processes mentioned above.

The primary issue that has been addressed in the present study is whether conventional high velocity diffuser systems are actually a "preferred technology" at the site of the Carlsbad Desalination Project, as some might otherwise infer from The Brine Panel Report and the language of the proposed 5% rule; or alternatively, is the in-plant dilution strategy better suited to this particular site in terms of being more protective of resident marine life. This question hinges on which discharge strategy has lesser potential impacts on marine life associated with turbulence mortality and bottom turbidity, since both are capable of producing dilution below acute and chronic hyper-salinity toxicity levels. Table 2 above summarizes the quantitative and process-based comparisons of environmental impacts between in-plant dilution and high velocity diffuser strategies. From these comparisons, it appears that there are greater quantifiable impacts and greater uncertainties associated with diffusers; and consequently that discharge strategy can not considered the best available technology for the site specific conditions at the Carlsbad Desalination Project.

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APPENDIX-A. Estimated LD_{50} values for time shear exposure in both dynes per square centimeter and in Pascal units for experiments and computer simulations after Morgan et. al., (1974); and *Cada, (2006).

Organism	Exposure Time	LD_{50}, dynes/cm^2	(Pa)
Striped Bass Eggs	1 min	450	(45)
	2 min	290	(29)
	4 min	170	(17)
	2 days	70	(7)
Striped Bass Larvae	1 min	540	(54)
	2 min	435	(43.5)
	4 min	310	(31)
White Perch Eggs	1 min	385	(38.5)
	2 min	385	(38.5)
	5 min	150	(15)
	10 min	150	(15)
	20 min	150	(15)
	2 days	57	(5.7)
White Perch Larvae	1 min	435	(43.5)
	2 min	402	(40.2)
	4 min	365	(36.5)
	2 days	88	(8.8)
*Composite of Juveniles	1 min	16,000	(1,600)
	5 min	1,000	(100)

APPENDIX-B: Species Size Distribution from West Basin and Redondo Beach Generating Station (from Tenera Environmental, 2012)

Taxon	Common Name	Min	Max	Average	Count
Hypsoblennius spp.	combtooth blennies	1.68	13.07	2.28	725
CIQ goby complex	gobies	1.67	15.28	2.63	600
Genyonemus lineatus	white croaker	1.31	9.47	2.67	347
Atherinopsidae (all)	silversides	4.54	10.76	9.27	262
Hypsypops rubicundus	garibaldi	2.07	3.21	2.59	262
Labrisomidae	labrisomid blennies	2.73	7.62	3.94	165
Cottids (all)	smoothhead sculpin	1.92	3.97	2.83	146
Engraulidae (all)	anchovies	1.34	21.76	4.71	144
Gibbonsia spp.	kelpfishes	3.51	17.08	5.49	136
Typhlogobius californiensis	blind goby	2.23	3.25	2.71	126
Pleuronichthys spp. (all)	turbots	1.18	11.09	2.57	108
Gobiesox spp.	clingfishes	2.33	5.21	3.33	87
Seriphus politus	queenfish	1.57	5.67	2.98	85
Paralichthys californicus	California halibut	1.54	7.79	2.78	67
Sciaenidae	croakers	0.96	6.15	1.99	63
Citharichthys spp. (all)	sanddabs	1.60	2.78	2.24	38
Paralabrax spp. (all)	sea basses	1.05	2.82	1.63	29
Parophrys vetulus	English sole	1.93	5.10	2.94	29
Scorpaenidae	scorpion fishes	1.46	6.09	3.34	28
Syngnathidae (all)	pipefishes	6.51	14.42	8.44	28
Clupeidae	herrings	1.21	4.09	2.41	19
Scorpaenichthys marmoratus	cabezon	3.61	4.77	4.27	18
Merluccius productus	Pacific hake	1.99	3.06	2.68	15
Ophidiidae (all)	cusk-eels	1.41	3.07	2.36	15
Sphyraena argentea	Pacific barracuda	1.60	3.05	2.25	15
Pleuronectidae	righteye flounders	1.59	3.94	2.35	14
Oxyjulis californica	senorita	1.00	2.45	1.79	13
Stenobrachius leucopsarus	northern lampfish	2.62	4.01	3.20	13
Oxylebius pictus	painted greenling	3.10	3.63	3.42	12
Rhinogobiops nicholsi	blackeye goby	1.72	2.89	2.33	12
Cheilotrema saturnum	black croaker	1.30	2.98	1.91	10
Menticirrhus undulatus	California corbina	1.51	3.08	1.93	10
Cottidae	sculpins	2.34	3.31	2.68	9
Neoclinus spp.	fringeheads	4.37	5.32	4.69	8
Labridae	wrasses	1.37	2.28	1.78	7
Xystreurys liolepis	fantail sole	1.57	2.63	2.10	7
Zaniolepis spp.	combfishes	2.82	3.81	3.79	7
Halichoeres semicinctus	rock wrasse	1.74	2.05	1.88	5
Rimicola spp.	kelp clingfishes	3.10	6.19	3.89	5
Leptocottus armatus	Pacific staghorn sculpin	4.14	6.25	4.81	4
Bathymasteridae	ronquils	3.17	3.96	3.62	3
Heterostichus rostratus	giant kelpfish	4.98	6.89	5.91	3
Lepidogobius lepidus	bay goby	3.20	5.28	4.00	3

Leuroglossus stilbius	California smoothtongue	4.36	4.75	4.62	3
Medialuna californiensis	halfmoon	2.05	2.34	2.19	3
Pleuronectiformes	flatfishes	1.66	2.36	1.91	3
Semicossyphus pulcher	California sheephead	1.92	2.22	2.10	3
Symphurus atricaudus	California tonguefish	1.59	2.05	1.85	3
Hippoglossina stomata	bigmouth sole	2.86	3.12	2.99	2
Paralichthyidae	sand flounders	2.16	2.97	2.56	2
Peprilus simillimus	Pacific butterfish	1.59	1.65	1.62	2
Sardinops sagax	Pacific sardine	3.61	11.71	7.66	2
Blennioidei	blennies	4.46	4.46	4.46	1
Chaenopsidae	tube blennies	5.94	5.94	5.94	1
Chilara taylori	spotted cusk-eel	2.71	2.71	2.71	1
Chromis punctipinnis	blacksmith	2.31	2.31	2.31	1
Clupeiformes	herrings and anchovies	1.47	1.47	1.47	1
Gillichthys mirabilis	longjaw mudsucker	2.39	2.39	2.39	1
Girella nigricans	opaleye	1.66	1.66	1.66	1
Pleuronectoidei	flatfishes	0.78	0.78	0.78	1
Roncador stearnsii	spotfin croaker	2.64	2.64	2.64	1
Trachurus symmetricus	jack mackerel	2.35	2.35	2.35	1

APPENDIX-C: Species Size Distribution from El Segundo and Scattergood Generating Stations (from Tenera Environmental, 2012)

Taxon	Common Name	Min	Max	Average	Count
Engraulidae (all)	anchovies	1.53	25.14	5.81	318
Sciaenidae	croakers	0.79	6.74	1.56	303
Genyonemus lineatus	white croaker	1.30	14.00	3.39	301
CIQ goby complex	gobies	1.79	12.26	3.69	296
Pleuronichthys spp. (all)	turbots	1.37	6.60	2.43	275
Paralichthys californicus	California halibut	1.21	5.74	1.88	211
Paralabrax spp. (all)	sea basses	0.91	2.67	1.67	198
Stenobrachius leucopsarus	northern lampfish	2.23	4.17	3.16	156
Citharichthys spp. (all)	sanddabs	0.85	24.10	1.72	154
Hypsoblennius spp. (all)	combtooth blennies	1.75	4.92	2.50	144
Seriphus politus	queenfish	1.31	6.14	1.90	137
Sphyraena spp. (all)	barracudas	1.55	3.04	2.31	124
Atherinopsidae (all)	silversides	5.76	12.76	8.07	123
Ophidiidae (all)	cusk-eels	1.52	3.55	2.53	102
Oxyjulis californica	senorita	1.02	2.49	1.78	85
Haemulidae	grunts	1.40	2.53	1.83	81
Parophrys vetulus	English sole	2.13	13.80	3.15	71
Menticirrhus undulatus	California corbina	1.35	3.48	1.82	70
Lepidogobius lepidus	bay goby	2.26	7.12	4.04	50
Cheilotrema saturnum	black croaker	1.35	3.76	2.02	48
Pleuronectidae	righteye flounders	1.14	2.78	1.96	42
Symphurus atricaudus	California tonguefish	1.30	23.43	2.34	38
Xenistius californiensis	salema	1.48	2.35	1.87	35
Anisotremus davidsonii	sargo	1.50	3.28	1.97	29
Halichoeres semicinctus	rock wrasse	1.55	2.25	1.86	29
Xystreurys liolepis	fantail sole	1.45	2.35	1.88	29
Semicossyphus pulcher	California sheephead	1.49	3.07	2.19	26
Merluccius productus	Pacific hake	2.32	3.37	2.90	17
Cottidae (all)	sculpins	2.18	5.61	3.00	13
Hippoglossina stomata	bigmouth sole	2.09	3.48	2.95	13
Paralichthyidae	sand flounders	1.48	2.35	1.98	9
Hypsypops rubicundus	garibaldi	2.30	2.63	2.49	8
Gibbonsia spp.	kelpfishes	3.43	6.69	5.38	7
Leptocottus armatus	Pacific staghorn sculpin	3.90	6.00	5.22	7
Sardinops sagax	Pacific sardine	2.28	4.90	3.79	7
Zaniolepis spp.	combfishes	2.99	3.73	3.43	6
Pleuronectiformes	flatfishes	1.08	2.54	1.87	5
Scorpeanidae	rockfish + thornyheads	2.11	3.97	2.94	5
Chilara taylori	spotted cusk-eel	2.58	3.40	3.04	4
Gillichthys mirabilis	longjaw mudsucker	2.47	3.71	3.11	4
Labridae	wrasses	1.58	1.99	1.76	4
Syngnathus spp.	pipefishes	9.15	12.46	10.45	4
Triphoturus mexicanus	Mexican lampfish	2.16	3.26	2.64	4
Kyphosidae	sea chubs	2.38	2.54	2.44	3
Labrisomidae	labrisomid blennies	3.71	5.73	4.60	3

Microstomus pacificus	Dover sole	4.17	5.06	4.68	3
Typhlogobius californiensis	blind goby	2.57	2.90	2.77	3
Acanthogobius flavimanus	yellowfin goby	4.26	4.31	4.28	2
Gobiesox spp.	clingfishes	3.83	4.16	3.99	2
Myctophidae	lanternfishes	2.42	2.83	2.63	2
Oxylebius pictus	painted greenling	2.58	3.28	2.93	2
Pomacentridae	damselfishes	1.87	2.40	2.13	2
Roncador stearnsii	spotfin croaker	1.72	2.09	1.91	2
Ruscarius creaseri	roughcheek sculpin	5.18	5.96	5.57	2
Atractoscion nobilis	white seabass	2.48	2.48	2.48	1
Bathymasteridae	ronquils	3.98	3.98	3.98	1
Chaenopsidae	tube blennies	5.40	5.40	5.40	1
Chromis punctipinnis	blacksmith	2.50	2.50	2.50	1
Clupea pallasii	Pacific herring	2.45	2.45	2.45	1
Clupeiformes	herrings and anchovies	2.99	2.99	2.99	1
Diaphus theta	California headlight fish	2.61	2.61	2.61	1
Etrumeus teres	round herring	3.74	3.74	3.74	1
Girella nigricans	opaleye	2.01	2.01	2.01	1
Hexagrammidae	greenlings	3.66	3.66	3.66	1
Isopsetta isolepis	butter sole	2.52	2.52	2.52	1
Peprilus simillimus	Pacific butterfish	2.42	2.42	2.42	1
Psettichthys melanostictus	sand sole	2.62	2.62	2.62	1
Rhinogobiops nicholsi	blackeye goby	3.62	3.62	3.62	1

APPENDIX-D. COMBINATIONS OF EXISTING ENCINA PUMPS OF TOTAL CAPACITY WITHIN 5 % OF 304 MGD

Operational Condition 1 – 304.7 MGD

Unit 1 (Both Pumps)		=	68.3 MGD
		Subtotal =	104.3 MGD (Desal Intake)
Unit 2 (2 S Pump)		=	36.0 MGD
Unit 3 (Both Pumps)		=	63.9 MGD
		Subtotal =	200.4 MGD (Dilution)
Unit 4 (4 W Pump)		=	136.5 MGD
	Total	=	304.7 MGD (0.2 % above 304 MGD)

Operational Condition 2 – 306.3 MGD

Unit 4 (Both Pumps)		=	270.4 MGD
Unit 1 (1 S Pump)		=	35.9 MGD
	Total	=	306.3 MGD (1 % above 304 MGD)

Operational Condition 3 – 306.4 MGD

Unit 4 (Both Pumps)		=	270.4 MGD
Unit 2 (2 S Pump)		=	36.0 MGD
	Total	=	306.4 MGD (1 % above 304 MGD)

Operational Condition 4 – 315.4 MGD

Unit 4 (4 E Pump)		=	133.9 MGD
Unit 5 (5 W Pump)		=	157.0 MGD
Unit 2 (2 N Pump)		=	24.5 MGD
	Total	=	315.4 MGD (3.8 % above 304 MGD)

Operational Condition 5 – 315.4 MGD

Unit 5 (Both Pumps)		=	315.4 MGD
	Total	=	315.4 MGD (3.8 % above 304 MGD)

Operational Condition 6 – 302.1 MGD

Unit 1 (Both Pumps)		=	68.3 MGD
	Total =		104.3 MGD (Desal Intake)
Unit 2 (2 S Pump)		=	36.0 MGD
Unit 3 (Both Pumps)		=	63.9 MGD
	Total =		197.8 MGD (Dilution)
Unit 4 (4 E Pump)		=	133.9 MGD
	Total	=	302.1 MGD (0.6 % below 304 MGD)

APPENDIX-D (continued)

Rotation rates for the existing seawater circulation pumps rpms at Encina Power Plant:

Unit 1 CW Pump = 585 RPM
Unit 1 is typical for Unit 2 and Unit 3

Unit 4East CW Pump = 252 RPM
Unit 4West CW Pump = 252 RPM

Unit 5East CW Pump = 273 RPM
U5 East is typical for Unit 5 West

APPENDIX-E: Discussion of Entrainment Mortality during *Stand-by Mode* for Encina Power Station Operations.

The Entrainment Impingement Study conducted at Encina Power Station from June 2004 through May 2005, (Tenera, 2008), assumed 100% mortality to all organisms entrained into the in-plant flow pathway diagramed in Figure 16. This assumption is based in large part on the fact that the Encina Power Station was generating power throughout the study, and that any organisms surviving pump passage were killed in the condenser tubes by thermal shock. However, the present analysis is based on a stand-alone operation of the desalination project during which the sea water condenser tubes are "cold"; and power is either not being generated because of de-commissioning of the power plant, or the power plant has been re-powered with air-coolers. There is abundant evidence that mortality is negligible to organisms passing through cold condenser tubes.

A number of studies have examined the component stresses of thermal power plant entrainment independently, for example, by quantifying effects of turbulence and shear forces on fish early life stages without concomitant thermal and biocidal stresses. For example, seven species of freshwater fish larvae were passed through 2.2-cm-diam condenser tubing (identical size to Encina Power Station) at velocities of up to 5.8 m/s (Kedl and Coutant 1976). The stresses generated by rapid passage through these narrow tubes resulted in less than 5% mortality. O'Connor and Poje (1979) exposed striped bass larvae to shear in condenser tubes at velocities as high as 3.0 m/s. Mortalities were not significantly different from controls. The power plant simulator used by Cada et al. (1981) subjected fish larvae and juveniles not only to moderate pressure changes (56 to 146 Pa) but also to shear forces associated with passage through 3.2-cm-diam pipes at velocities of 2.4 m/s. The combined stresses caused high mortalities among carp larvae but insignificant mortalities among larval bluegill, channel catfish, and largemouth bass. These empirical studies indicate that the shear stresses caused by average bulk flow velocities through a cold condenser system are unlikely to cause mortality among fish eggs and larvae. Although fragile early life stages should be sensitive to shear damage, their small size in combination with shear sorting (Section 3.3) and sub-lethal shear stresses (Section 3.4) apparently minimizes their mortality.

To quantify mortality likelihood to entrained organisms passing through the in-plant hydraulic pathway of the Carlsbad Desalination Project, we invoke some standard hydraulic calculus, supplemented CFD computer analysis. Let q_x, q_y represent mass flux components through the hydraulic pathway in Figure 16:

$$q_x = \rho \int_{-h}^{\eta} \bar{u} dz \qquad (6)$$

$$q_y = \rho \int_{-h}^{\eta} \bar{v} dz \qquad (7)$$

and q_I is the mass flux through the discharge channel at the ocean outlet where water surface elevation changes in response to tides:

$$q_I = \rho \frac{\partial}{\partial t} \left(\frac{\partial s}{\partial \eta} \right) \qquad (8)$$

Let F_p be the pressure force resultant while F_{xx}, F_{xy}, F_{yy} are "equivalent" internal stress resultants due to turbulent and dispersive momentum fluxes

$$\begin{aligned} F_p &= \int_{-h}^{\eta} p dz = \frac{\rho g H^2}{2} \\ F_{xx} &= 2\varepsilon \frac{\partial}{\partial x} q_x \\ F_{yy} &= 2\varepsilon \frac{\partial}{\partial y} q_y \\ F_{yx} = F_{xy} &= \varepsilon \left(\frac{\partial}{\partial y} q_y + \frac{\partial}{\partial x} q_x \right) \end{aligned} \qquad (9)$$

and ε is the eddy viscosity. B_x and B_y are the pipe wall and bottom stress components

$$B_x = \tau_x + \rho g H \frac{\partial h}{\partial x}$$
$$B_y = \tau_y + \rho g H \frac{\partial h}{\partial y} \qquad (9)$$

In equation (9), τ_x and τ_y are the bottom shear stress components that are quasi-linearized by Chezy-based friction using Manning's roughness factor, n_o:

$$\tau_x = -\frac{g}{\rho H^2 C_z^2} q_x \left(q_x^2 + q_y^2\right)^{1/2}$$
$$\tau_y = -\frac{g}{\rho H^2 C_z^2} q_y \left(q_x^2 + q_y^2\right)^{1/2} \qquad (10)$$

where $\mathbf{C_z}$ is the Chezy coefficient calculated as:

$$C_z = \frac{1.49}{n_0} H^{1/6} \qquad (11)$$

Applying the velocities and pipe diameters detailed above, and taking Manning's roughness factors that range from 0.0025 to 0.008, based on pipe flow in the 10^6 to 10^8 Reynolds number regimes, shear stress at the walls of the Encina intake tunnels, plant pipelines, condenser tubes and discharge channel would range from 72 to 140 dynes/cm^2 (7.2 Pa to 14 Pa), where the highest shear stresses occur in the condenser tubes. Not only do these values fall below the range of LD_{50}'s for short-term exposures in Appendix-A, (385-540 dynes/cm^2), but shear sorting in turbulent pipe flow will also concentrate the fish larvae and eggs near the center of the conveyance pipelines (see Section 3.3), further diminishing the possibility of exposure to high shear stress. Therefore, mortality in the conveyance portion of the hydraulic pathway (pipes, condenser tubes and discharge channel) would seem vanishingly small, consistent with the previous findings for thermal power plants (Kedl and Coutant, 1976; O'Connor and Poje, 1979; and Cada, et al., 1999). However, higher shear stresses could be expected in the pump, and so we focus our attention on pump-passage mortality as the primary agent for mortality to entrained organisms entering the in-plant hydraulic pathway of the Carlsbad Desalination Project.