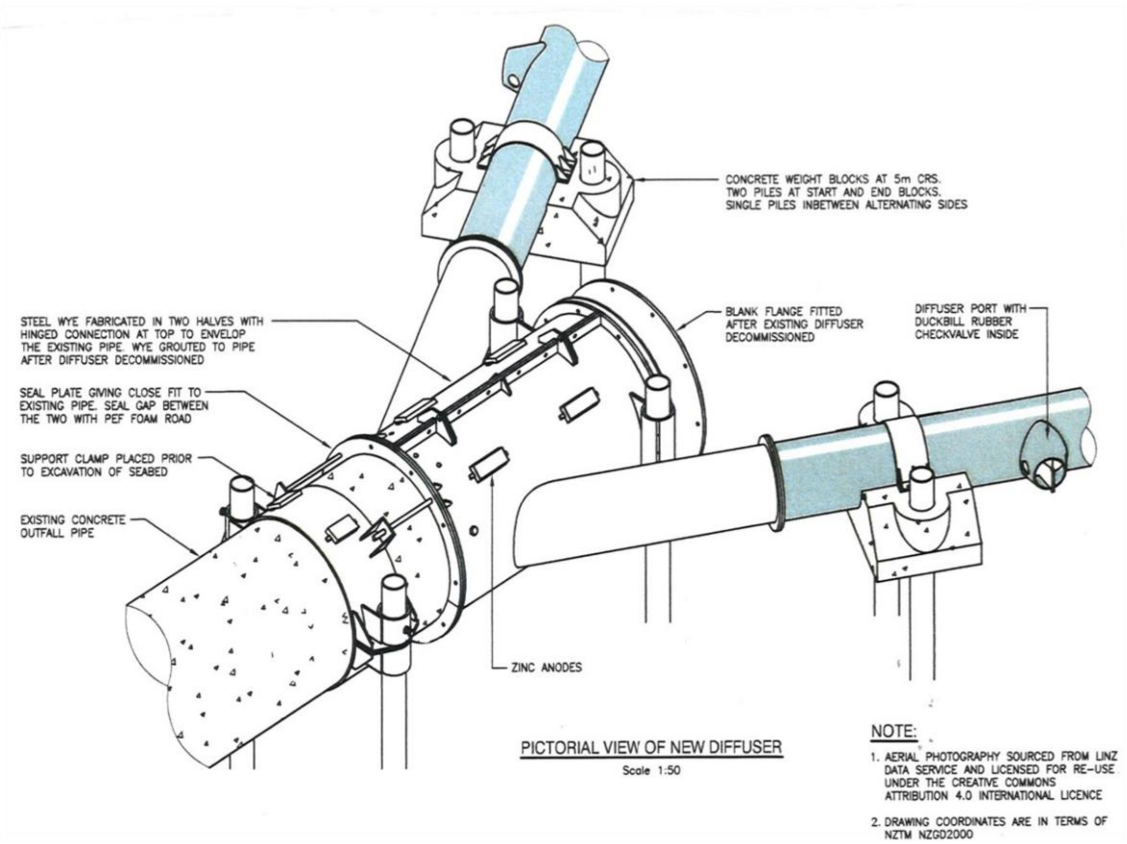
STANTEC

NELSON NORTH WWTP OUTFALL

CONCEPT DESIGN FOR AN IMPROVED MORE EFFICIENT DIFFUSER



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1.0 INTRODUCTION

The Nelson North Waste Water Treatment Plant (WWTP) outfall which discharges into Tasman Bay offshore of the Boulder Bank was installed in 1970 and remains in its as installed configuration, there have been no upgrades since. Stantec acting on behalf of the Nelson City Council (NCC) has commissioned Offshore & Coastal Engineering Ltd. (OCEL), to develop a concept design to improve the dispersion capabilities of the diffuser, essentially by replacing the existing diffuser with an improved extended new diffuser design. The replacement of the existing with a new diffuser has to occur while the existing diffuser continues in operation because of limited storage capacity in the WWTP ponds onshore. The outfall cannot be shut down for an extended period. This requirement mirrors that at the Hastings District Council (HDC) WWTP outfall into Hawkes Bay in 2017 where the original deteriorated diffuser had to be replaced while maintaining the WWTP in operation.

OCEL developed a design and installation procedure for a new diffuser for the HDC diffuser and the experience gained on that project has provided the starting point for the concept design for the Nelson North outfall.

2.0 EXISTING DIFFUSER

The Nelson North WWTP outfall pipe which discharges into Tasman Bay in 12 m water depth offshore of the Boulder Bank is a post tensioned 36" (0.914 m) internal diameter concrete pipe outfall of a type that was relatively popular in NZ in the 1970's. The Hastings and Napier WWTP outfalls are of the same construction although the original diffuser for the Hastings outfall was a fibreglass pipe. This type of pipeline is now a relic of the past, concrete pipes have been replaced by High Density PolyEthylene (HDPE) pipes which are much more flexible than the concrete and longer lasting the HDPE material being inert and non-corroding.

The diffuser for the North Nelson WWTP is an extension of the outfall pipe and relatively short at only 20 m long. There are 9 discharge ports, approximately 300 mm x 300 mm, equi-spaced along the top of the diffuser pipe section offset alternately at approximately 30^{o} off either side of the pipe Top Dead Centre (TDC). The diffuser pipe ends in a conical reducer section with a 300 mm diameter central outlet. This is shown in photograph no.1. A Nelson based diving contractor, Diving Services NZ, has produced a simple as built sketch of the diffuser included here as figure no.1. The end detail in the photograph does not match the supposed as built drawing.

Photograph no.1

The diffuser outlet ports are open holes without the one-way outlet valves commonly known as duckbills fitted over the outlets on modern diffusers. The combined outlet port area is greater than, not less than, the internal pipe area as it is for a modern diffuser design.

The discharge from the outlet ports is not uniformly distributed along the diffuser length as it should be for a well designed diffuser but issues only from the ports at the start of the diffuser, there is no discharge from the end port.

The discharge just wafts up from the outlet ports as shown in photograph nos. 2 and 3., there is no discharge jet evident.

Photograph no.2

Photograph no.3

The diffuser pipe is sitting directly on the seabed. The outfall pipe at the start of the diffuser emerges onto the seabed from the trench is buried in back up to and under the Boulder Bank onshore. The trench was created by the dredge 'W H Orbell' and the pipeline pulled along it during installation. The Sealord outfall further south along the Boulder Bank also sits directly on the seabed, a replacement diffuser could be expected to do the same, the seabed is stable.

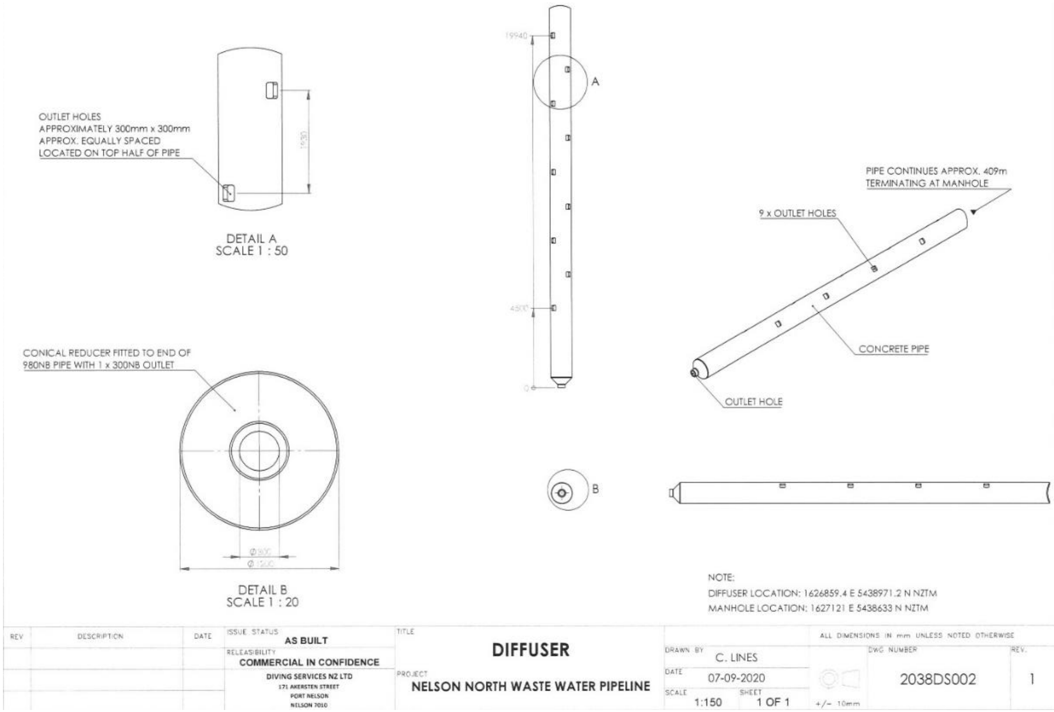


Figure no.1

3.0 IMPROVING DIFFUSER EFFICIENCY

The purpose of the diffuser is to sufficiently dilute the outfall discharge with the ambient water to render the resulting mixture harmless. The dilution is immediately increased by discharging the effluent over a wider area by increasing the length of the diffuser and the number of ports.

As noted the existing diffuser is short and the holes are large. The port area for the existing diffuser is approximately 10 x 0.3 x 0.3 = 0.9 m^2. The internal area of the diffuser pipe is $(\pi/4) \cdot (0.914^2) = 0.656$ m^2, the area ratio A_r is then 0.9/0.656 = 1.37. A rule of thumb experience based area ratio – $A_r = \sum($ Port area sum ports 1-n)/Internal pipe area is $A_r = 0.67$. The ports should be designed to achieve about the same discharge from each port along the diffuser. This can be done by increasing port diameter and reducing the diffuser diameter along the pipe while keeping the port spacing constant.

The ports can be simple orifices with rounded corners in the side of the diffuser pipe or they can be a nozzle-riser configuration. The diffuser port detail used on the HDC outfall diffuser is illustrated in figure no.2. The diffuser ports discharge horizontally from alternate sides of the diffuser pipe. This is done to produce less interaction between the jets of adjacent ports achieving more dilution and mixing than if they were aligned vertically. When the jets are directed horizontally the trajectory of the jet is longer before reaching the surface than one directed vertically thereby providing a longer mixing length and greater dilution.

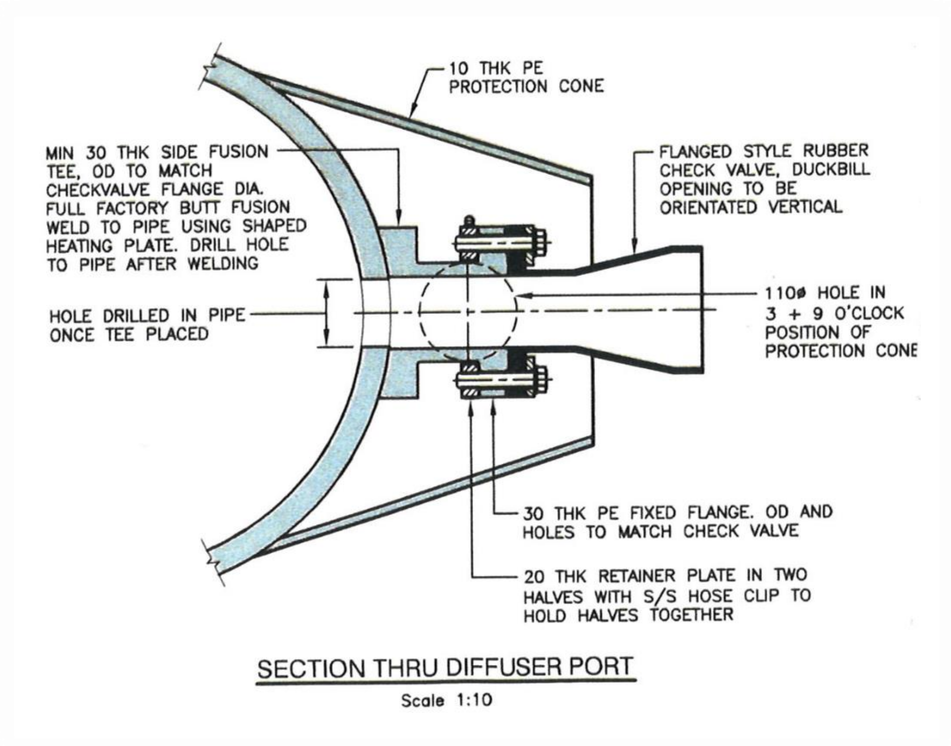


Figure no.2

The effluent from a properly designed diffuser issues as a jet from the port, not as the gentle buoyancy driven plume from the existing diffuser ports. If the Reynolds number, R, of the jet is great enough - $R = u \cdot D/v > 4000$ where u is the velocity, D the port diameter and v the dynamic viscosity - fully turbulent mixing between the jet and the ambient fluid will occur. As mixing occurs the velocity of the resulting mixture decreases with linear distance from the port and radial distance from the centreline of the jet. The mixing action is initially driven by the momentum of the jet but within a relatively short distance of the port buoyant effects will control mixing and the resulting flow pattern is called a plume. The hydraulic head to drive the diffuser will be close to but in excess of 1 m.

4.0 OUTFALL OPERATING PROCEDURE

The outfall discharge is driven by gravity and affected by the tide. It is understood that there is no settling out that occurs with the existing pipeline. There are one way tidal flaps on the discharge from each of the WWTP wetlands to prevent seawater flowing back up the system. On more modern outfalls the duckbill valves on the diffuser act as backflow preventers and stop seawater flowing into the diffuser and back up the outfall pipe. The duckbill valves only discharge once the pressure inside the diffuser exceeds the external pressure. The water level within the WWTP wetlands is controlled by weirs to provide the necessary head for gravity discharge.

There are no special operating procedures currently relating to the discharge, the outfall just discharges when it is able to which is understood to be under most tidal conditions, close to continuous rather than intermittently once head has been built up as the tide falls. During large storm events increased volumes of waste water augmented by stormwater may need to be managed within the available capacity of the ponds and buffer area until it can be discharged.

It is understood that the original design of the outfall allowed for installation of a pump station but that has not been required to date. Extending the length of the outfall diffuser and using 1 m of the available head to drive the diffuser, increasing the effluent jet velocities to improve dispersion and overcoming the minor headloss at each diffuser port, would not necessarily mean the end of gravity driven flow but it would restrict operation at the top of the tide. In the longer term with ongoing climate change driven Sea Level Rise (SLR) – 0.57 m by2070 under the SSP5-8.5H+ scenario - operating windows within a tidal cycle will be further limited and some pumping may be required. To identify the head required to drive the outfall and what dilution is achieved a detailed hydraulic analysis is required.

5.0 CONSTRUCTION

The new diffuser arms have to be installed while the outfall continues in operation. This can be achieved by installing a purpose built wye chamber around the outfall pipe at the start of the existing diffuser and attaching the two new diffuser arms to the wye chamber either side of the existing diffuser. The concept is illustrated in figure no.3, an excerpt taken from drawing no. DR-230503-001 attached in Appendix A to this report. The cylindrical wye structure fabricated from steel and built in two identical half sections hinged together along the spine of the wye barrel cylinder, closes around, and is clamped to, the existing outfall pipe, allowing the outfall to continue discharging through the wye. The diffuser arms which are made of HDPE pipe bolt to the wye arm flanges either side of the existing pipe. The new diffuser can be installed, connected to the wye and secured in position against the maximum wave induced hydrodynamic loads by installing piles through the precast concrete ballast weights clamped to the HDPE pipe arms while the existing diffuser continues in operation.

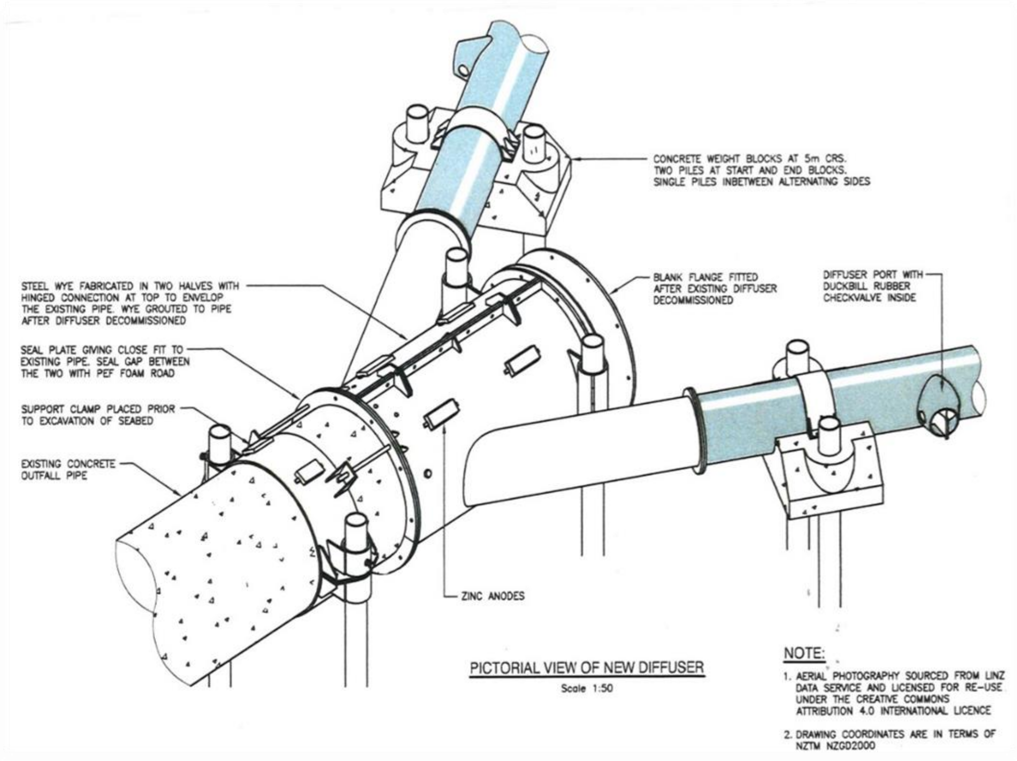


Figure no.3

To install the wye in position of the existing outfall pipe a hole has to be dredged under the pipe at the wye location to allow the wye halves to close around the pipe and the wye to be clamped together. The weight of the wye will need to be taken both by piles installed through pile guides in the wye structure and by a separate clamp clamped around the outfall pipe upstream of the wye and supported by piles to take bending stress off the existing outfall pipe. The support elements are illustrated in drawing no. DR-230503-001.

To effect the changeover between the new and the old diffuser the outfall discharge is stopped and a 4 m length of the existing diffuser pipe is cut out of the diffuser outside the wye using a diamond wire rope saw - one cut just outside the wye barrel and the second cut 4 m distant offshore. The 4 m length is then recovered to surface leaving the end of the wye clear. The diffuser pipe length inside the wye is then cut using the diamond rope saw run through a slot provided in the top of the wye barrel. Once the pipe section is cut it is pulled out of the wye using a hydraulic winch line secured back to the remaining length of the original diffuser as a reaction point and the cutoff length recovered to surface.

A steel blind flange is then bolted to the end of the wye sealing it off following which the outfall flow can be turned back on to discharge through the new diffuser arms. The changeover can be completed inside a working day with all the tools set up ready to start the moment the outfall flow is shut down.

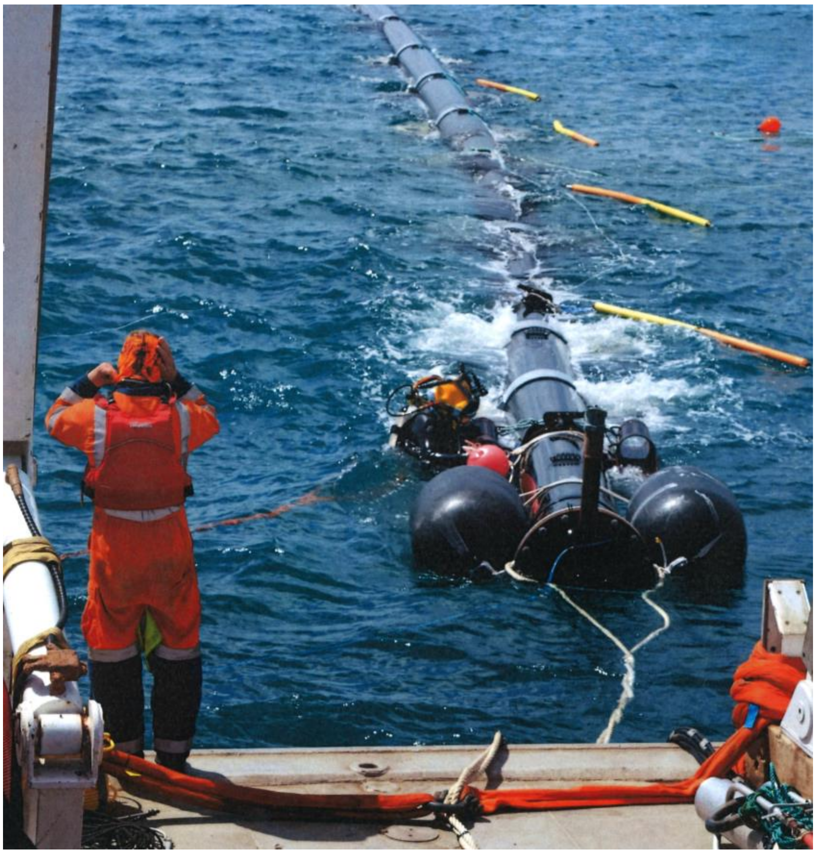
6.0 INSTALLATION OF THE DIFFUSER ARMS

The 100 m long diffuser arms, nominated as 630 mm OD, SDR 21 HDPE pipe, will be fabricated as continuous pipestrings, the individual pipe joints being fusion butt welded together. Each pipestring will be fitted with concrete ballast weights at 5 m centres, with diffuser ports at 2.5 m centres on alternate sides of the pipe. The pipestrings will be installed using the float and sink method, a pipelay method enabled by the flexibility of the HDPE. The bending radii for the pipe at allowable stress is $\approx 40 \cdot D$. The pipestrings can be fabricated offsite at a suitable location such as a boat ramp at a sheltered location, and launched air filled and floating to be towed to site.

The net buoyancy/m of the pipestring floating is set close to the submerged weight of the pipe/m flooded.to have a balanced S curve transition from the pipe floating on surface to the pipe laying on the seabed. The pipestring is stable on the seabed but will require small diameter piles to be jetted through the pile guides incorporated in the precast concrete ballast weight to achieve lateral stability under the maximum design wave height condition.

To install each pipestring the pipestring is towed to the location and lined up on surface with its final position on the seabed. Once directly above the alignment and held in position by workboats at either end – photograph no.4 shows a pipestring floating at the stern of the supporting workboat ready to be pulled down, diver attaching rigging - the inshore end of the pipestring is pulled down to the seabed to mate with the corresponding flange on the subsea wye pipe stub. The end of the pipe is pulled straight down to give a J shaped transition as illustrated in figure no.4. Halfway down the flooding valve on the pulldown head is opened, the offshore end of the pipe is kept closed. As the pipe is pulled down flooding as it goes the J shape transition changes to an S shape and stabilises.

The internal water level in the pipestring S transition is at approximately half the depth and the pressure of the air in the floating section corresponds to half the water depth hydraulic head at the pulldown end – approximately 0.5 x 12 x 10 = 60 kPa for the Nelson North WWTP case. If air is slowly released from the offshore end the S curve becomes a dynamic feature and progresses along the pipestring as the pipe is laid on the seabed. When the S curve reaches the end of the pipestring the end is lowered to the seabed.



Photograph no.4

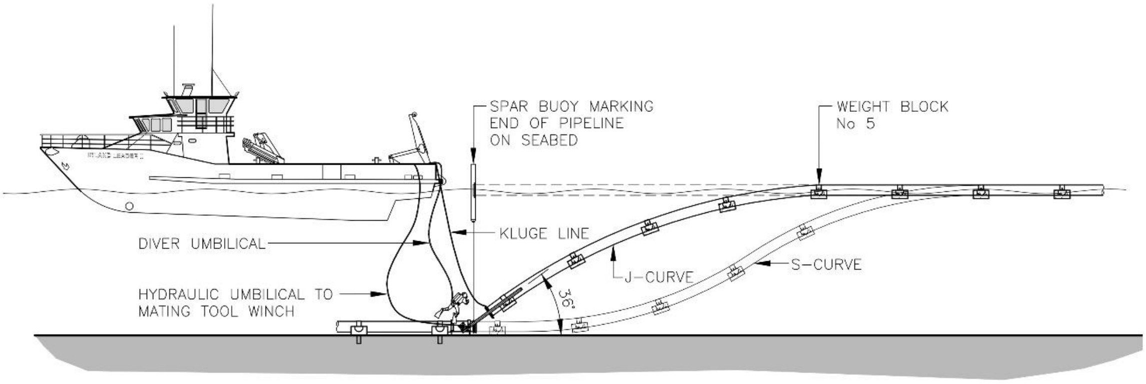


Figure no.4

7.0 CONCLUSION

The existing Nelson North WWTP diffuser is a very basic simple outlet for the WWTP outfall pipe, it is essentially a continuation of the existing post tensioned concrete outfall pipe with holes in it, 20 m long. The efficiency in terms of the dilution achieved can be greatly improved by following good design principles – setting the total port area to less than the internal area of the outfall pipe, promoting higher port exit velocities to maximise dilution before the jet evolves into a plume, discharging horizontally and increasing the length of the diffuser. Any redesign of the diffuser needs to be accompanied by a detailed hydraulic analysis of the diffuser, this report addresses the general principles of a good design.

The outfall is driven by gravity and should be able to continue using gravity by stopping discharge in the vicinity of high tide but analysis is required to check at what times in the tidal cycle the outfall can discharge at maximum efficiency.

Any modification of the diffuser has to proceed in parallel with the running of the outfall. There is insufficient storage to allow a lengthy shutdown. The replacement of the Hastings District Council outfall diffuser in Hawkes Bay provides a successful precedent that has been drawn on for this report. The replacement diffuser was installed using the float and sink installation method connecting a lengthened new diffuser to an existing post-tensioned concrete outfall pipe using a wye connection clamped over the existing pipe to which the new diffuser was connected. The changeover was completed in a short time, in hours rather than days, by cutting the existing diffuser once the new wye and the diffuser were in place, pulling the old pipe section out of the wye and installing a blind flange over the hole needed to accommodate the old pipe through the wye while discharge continued through it. The same method would work for the Nelson North diffuser replacement.

APPENDIX - Drawing