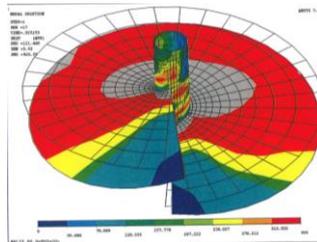
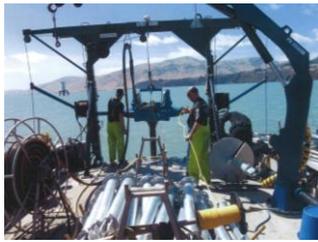


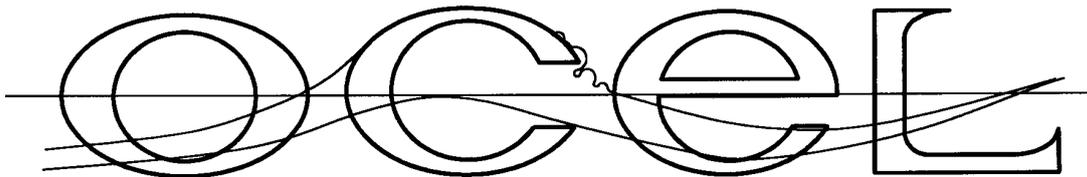
NEW ZEALAND KING SALMON

**ENGINEERING FEASIBILITY OF THE  
PROPOSED SALMON FARM AT  
HORSESHOE BAY (SITE 124)  
WAITATA REACH**



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by



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### **EXECUTIVE SUMMARY**

The purpose of this document is to report on the engineering feasibility study of the proposed Horseshoe Bay salmon farm in Waitata Reach. The work, commissioned by New Zealand King Salmon Company Limited (King Salmon) and carried out by OCEL Consultants NZ Limited (OCEL), encompassed a preliminary structural design and mooring analysis as part of determining the engineering feasibility of the proposal.

The Horseshoe site is located in 30 - 50 m water depth in a region of moderate to strong tidal currents – maximum tidal current velocity ranging up to 0.5 m/sec recorded throughout most of the water column. The NZKS farms in Waitata Reach are different from the other King Salmon sites in the Sounds in that the farms are exposed both to locally generated short period waves characteristic of the Sounds and to longer period swell waves generated on the open sea fetch to the north east into the South Taranaki Bight. The long period swell waves though infrequent can be a governing load case for the structural design of the farm structure.

The design of the floating farm structure is based on offshore engineering principles adapted to account for the flexible nature of the marine farm structures and suspended nets. As part of the confirmation of the theoretical approach a hydrodynamic force monitoring program will be implemented – the same as has been done for the King Salmon farms on Waitata Reach (Waitata and Richmond) and in the Tory Channel high current area – to check the actual loads experienced by the structure. The dimensions of the proposed farm are several multiples of the incident swell wave length so the net or global wave induced force on the farm structure is close to zero. Wave induced forces are significant locally within the structure and will be designed for. Tidal current induced hydrodynamic loading dominates and produces the forces the mooring system must resist. The mooring system is designed to achieve a factor of safety of 5 for the mooring line elements.

The farm will be anchored by screw anchors. These are lightweight and efficient and can be installed with a high degree of accuracy. They can also be installed diverless which is important given the water depth (close to 65 m) on the outside boundary of the farm. Screw anchors cause minimal disturbance to the seabed during installation. The connecting warp is the only evidence of their presence at seabed level. Monitoring the installation torque provides a good indication of the anchor pullout capacity. A pullout test will also be performed on a representative anchor to check screw anchor capacity and to confirm the relationship between installation torque and pullout capacity. The mooring lines will incorporate elastic Marine Flex units both to accommodate the high tidal range (4 m) at the mouth of the Pelorus and to eliminate snatch loading in the mooring system under swell wave loading.

The proposed salmon farm at Horseshoe Bay is fully feasible from a mooring and structural safety standpoint and the already established farms in Waitata Reach at Waitata and Richmond. It will use existing proven technology, based on experience with the Te Pangu and Clay Point farms and will benefit from King Salmon's ongoing development and refinement work to ensure a safe secure structure with known factors of safety.

## **1.0 INTRODUCTION**

King Salmon is proposing build, a new salmon farm site at Horseshoe Bay in the lee (with respect to the North Reach) of Te Kaiangapipi Point on Waitata. This report reviews the suitability of the proposed site based on engineering considerations and identifies a design for the location.

The concomitant of the farm's location at the entrance to a major Sound is a strong tidal current environment. The farm design will be closely similar to the existing proven King Salmon salmon farms on Waitata Reach and those farms on strong tidal current locations in Tory Channel, at Te Pangu and at Clay Point. The Waitata Reach location is different however to the sites within the Sounds to the extent that it has exposure to a long wave fetch to the north east. There is the potential for the site to experience relatively long period ocean swell in addition to the short period seastates characteristic of the Sounds, a feature that has to be allowed for in the design of the farm structures and a feature that can govern the design. The Akva WaveMaster cage system will be used for Horseshoe Bay, the same system as used for the Waitata and Richmond farms.

The design of the floating farm structure is based on offshore engineering principles, however, the calculation methods need to be adapted to account for the flexible nature of the marine farm structures and suspended nets. As part of the confirmation of the theoretical approach a hydrodynamic force monitoring program has been put in place to check the actual loads experienced by existing farm structures. This is part of the King Salmon policy of ensuring the safety and security of the company's farm structures. For the proposed new location the same policy will be implemented. The self recording (and real time readout) load cell devices used to monitor the relatively steady slow fluctuating tidal current loads on the moorings will be complemented by load cell devices that can monitor higher frequency wave loads. The farm components, structural and mooring, will have a known factor of safety.

## **2.0 LOCATION**

The proposed new King Salmon farm at Horseshoe Bay on the eastern side of Waitata Reach at the entrance to Pelorus Sound is in a region of moderate to strong tidal currents - as is to be expected given its location at the entrance of a large sound. In that regard the new farm will be similar to the existing King Salmon salmon farms in strong tidal current locations on Waitata Reach for the Waitata and Richmond farms and in Tory Channel, at Te Pangu and at Clay Point.

The Waitata Reach sites however are different from Tory Chanel sites, and from other King Salmon farm locations in the Sounds, in that the Reach is exposed both to locally generated short period waves on Waitata Reach and to longer period waves ( $T > 8$  secs) swell generated on the open fetch to the north east. None of the other farms are subjected to relatively long period swell.

The long period swell reaching the farm site from the north east fetch, bounded/limited by the North Island will be attenuated by refraction and diffraction effects resulting from the presence of the Chetwode Islands on the wave approach path to the farm site. Although reduced in height from the open sea condition the swell waves will still be an important, even governing, load case for the structural design of the farm structure.

The tidal current speeds at the Horseshoe Bay site are similar to, but less than, the currents experienced at Waitata and Te Pangu. The longitudinal axis of the farm is at roughly  $45^\circ$  to the ebb tidal flows which follow the line of the coast south of the Point.

The proposed farm site is located in water depths ranging from 30 m to close to 50 m. The seabed at the farm location is formed predominantly by soft sediment – sandy mud.

Kaiangapipi Point acts as a control on the current direction forcing it west. The flood current is weak, relative to the ebb.

### **3.0 DEVELOPMENT**

The Horseshoe Bay farm will be closely similar in concept and structure to the existing Waitata and Richmond farms which have established a precedent by using the Norwegian Akva WaveMaster articulated cage system. The structure will incorporate additional buoyancy at the mooring connection points and the lessons learnt through operational experience at the Waitata and Richmond farms.

The mooring design will benefit from the ongoing King Salmon research into quantifying hydrodynamic forces on marine farms.

Marine farming has essentially evolved in a trial and error, pioneering fashion, practical operational personnel developing practical solutions to problems as they arise. This has worked well for King Salmon.

As marine farms have moved out of sheltered environments into more challenging and productive areas subject to higher environmental loads, in particular tidal currents and wave action, engineering input is required to ensure that the farm structures remain safely moored. King Salmon have recognised this requirement and have engaged OCEL for mooring design and structural analysis work.

The engineering approach requires quantification of the environmental forces and the establishment of a safety factor – available resistance/force applied – for the farm. In order to establish a factor of safety for the farm as a whole it is necessary to know the tidal current and wave induced hydrodynamic forces acting on the farm.

Offshore engineering principles can be applied but the fish net cages are not readily amenable to the theoretical analysis of the hydrodynamic forces produced by tidal currents. The cages are flexible and can deform and are partly transparent to water movement. Hydrodynamic coefficients are available for common fixed shapes, and have been established for net structures.

In the absence of readily applicable theory field measurement of the actual forces can supply the answers. King Salmon have instituted programs at the Waitata, Richmond, Te Pangu and Clay Point farms to measure mooring line tensions using load cell devices connected in line in the mooring arrangement. The target maximum tension in any of the mooring lines is less than 5 tonne.f. Where monitoring shows that this load is being exceeded then the reasons for that are investigated, the cause identified and the situation rectified to bring the tension down to the desired maximum, consistent with keeping the factor of safety for the system at 5. The same policy will be followed for the proposed new farm location. The moorings will also be kept pretensioned, in conformance with King Salmon mooring practice, to spread the load evenly between the moorings.

Knowing the maximum force and the minimum breaking load (MBL) of each element in the mooring line assembly allows a factor of safety (FoS) to be established for the mooring line and ultimately for the whole farm. The target FoS is 5.

The wave loading on the farm structure results in a low net or overall mooring load on the farm because the length of the farm structure is similar to the swell wave length – deepwater wavelength  $L_o = 1.56.T^2 = 98$  m for an 8 second period wave - and several multiples of the short period wave length. The wave induced hydrodynamic force on the structure is forward, in the direction of wave advance, under the wave crest and backward under the trough. The forces cancel out over a complete wave length.

While the wave forces are localised and largely cancel out over structures longer than the wave length the structure must be flexible enough to ride the wave profile so that the structural elements, in this case the pipe sections, do not have to span between wave crests. The Akva WaveMaster cage system is an articulated galvanised steel frame structure, supported by sealed floats, flexible enough to ride the swell wave profile reducing wave loads on the structure. The farm steel frame elements with integrated walkways are connected by rubber hinge pin connections.

An indicative farm structure layout, shown in drawing DR-150902-001 Rev 2 shows four 40 m x 40 m cage units in a single row configuration.

## 4.0 ENVIRONMENTAL CONDITIONS

### 4.1 Wind Conditions

The location is subject to high wind speeds however the wind loading on the farm structure is small in relation to the tidal current and wave loading, essentially only walkway handrailing and nets project any distance above water level. The wind loading is important for the independent barge moorings.

### 4.2 Wave climate

The location is subject to locally generated wind waves on Waitata Reach and to swell waves generated on the open sea fetch to the north at the western entrance to Cook Strait and further north into the Taranaki Bight.

The wave climate in the Waitata Reach at the entrance to Pelorus Sound was assessed by NIWA for OCEL in 2008 to generate design wave information for the design of the proposed salmon farm structure at White Horse Rock on the western side of the Reach. The principal interest is in the longer period waves, considered as swell for the study, generated by north easterly winds on the 100 to 150 km fetch extending into the South Taranaki Bight and the Greater Cook Strait area up to Wanganui, north east of Waitata Reach. True ocean swell entering the Greater Cook Strait from the Tasman Sea does not reach the farm site because of topographic sheltering effects. The site is only open to longer period waves through a narrow north easterly window that acts as a wave direction filter.

The wave climate was assessed based on available wind records using empirical relationships for fetch-limited wave growth. As no suitable wind or wave data were available in the vicinity of the site a linear transformation was applied to the wind data that was available – for Stephens Island and the Brothers – with the parameters of the transformation tuned by comparing the resulting wave statistics against available spectral wave generation modelling results.

NIWA predicted the maximum significant wave height  $H_s$  generated on the north east fetch to be 1.1 m although noted there was some uncertainty in the high energy tail of the predicted wave height distribution which is very sensitive to the possibility of a small number of events in which the local wind speed is not markedly scaled down from the highest speeds observed at Stephens Island. A few such events could considerably increase the maximum predicted

significant wave heights to values over 1.5 m. A value of  $H_s = 1.5$  m has been taken for the design. The associated peak energy wave period was taken as  $T_p = 4.6$  seconds. The significant wave height  $H_s$  is used to characterise the sea state spectra. The maximum wave height, used for the design occurring in a 4 hour period is taken as  $H_m = 1.8 H_s$ . For design purposes the maximum wave height was taken as  $H_m = 3$  m. The wave length is taken as  $L = g/2\pi.T_p^2 = 1.56T_p^2 = 33$  m.

As noted in the foregoing the NIWA wave climate study was for the entrance from the open sea to Waitata Reach. The Horseshoe Bay site is at the southern end of Waitata Reach tucked in behind Kaiangapipi Point. Swell waves can reach the farm location through the process of diffraction around Kaiangapipi Point because of the relatively long wave period but the wave height will be approximately 50% less than for the northern end of Waitata Reach.

The longer period north easterly waves approach the proposed farm structure (heading north) at approximately  $45^\circ$  to the farm alignment after the swell waves have diffracted around the Point. The structure will ride the swell principally in the heaving and pitching modes. The farm cross member elements will be subject to peak wave induced velocities along their full length as the wave crest or trough passes through. This will result in relatively high bending moments in the plane of the deck which the structure is designed to take. The wavelengths are less than the plan dimensions of the structure so the net force on the structure from wave action is zero.

### 4.3 Tidal Currents

The dominant environmental force on the farm is the hydrodynamic drag exerted by the tidal currents in the Sound.

The tidal currents were measured at the Waitata farm site by the Cawthron Institute in 2015 using a 3D Acoustic Doppler Current Profiler (ADCP) self recording directional current meter. An ADCP uses the Doppler shift to measure ocean currents. Data measuring full water column currents were collected every 10 minutes with varying bin sizes dependent on site characteristics. Each depth measured is referred to as a bin and the full column of bins is referred to as a profile. A well known limitation of ADCP's is the loss of data near the surface due to the spreading of the acoustic beams on the instrument (~10% of water depth). Therefore each profile from an ADCP provides current measurements from close to the seabed to within the top 10% of water depth where the instrument was deployed.

Flow charts in the form of a current rose plot of current speed and directions for all bins and a plot of average direction and magnitude in each bin taken from the NIWA Benthic Ecological Assessment report, are shown in Figure No 1. Note that the current rose plots indicate the direction the water is moving to not where the water has travelled from. The strongest surface current speeds were at the surface. The strongest current measured was 0.5 m/sec, one knot. The mean near bottom current speed was 0.12 m/sec and more than 5% of the currents were measured above 0.25 m/sec, even at the lowest recorded depth, indicating that current speeds are moderate to high. The current rose plot for all measured depth bins in Horseshoe Bay indicates a weak tidal signature with net movement of water to the northwest.

By way of comparison the maximum current speed at the Clay Point site was .93 cm/sec (close to 2 knots).

## **5.0 MARINE FARM STRUCTURE AND LAYOUT**

### **5.1 Farm Structure**

The farm structure will be similar to the structure of the Waitata and Richmond farms, in its use of the WaveMaster articulated cage system, 4 number pens 40 m x 40 m, one behind the other in line. The nets are suspended from the elements. The mooring lines attach to strong points on the WaveMaster. The mooring lines attach to mooring bars at the corner of the farm and to pen corners within the farm. The latter connections are perpendicular to the alignment of the farm. The mooring bar connections are at various angles. The bars are supported by float elements hinged to the farm structure, the floats being required to take the vertical components of the mooring line tensions. The Akva Group, the owners of the WaveMaster, warrant that the WaveMaster structure is designed for the site conditions. Successful precedents exist in the shape of the Waitata and Richmond farms.

### **5.2 Mooring Arrangement**

The indicative mooring arrangement is shown in drawing DR-150902-001 Rev 2. The mooring lines are pre-tensioned to 10 kN to ensure an even distribution of the total load on the farm to the mooring lines. The mooring lines are pretensioned using a hydraulic ram to take up on the mooring line. Once the desired pretension is reached the line is shackled off. Each mooring line will consist of a 40 mm diameter polypropylene rope strop connected directly to the anchor at one end and to a chain tail at the top end. The purpose of the chain tail is to allow fine adjustment of the line length and thus mooring line tension. The chain is connected via a shackle to the anchor padeyes on the farm structure. The ends of the polypropylene strops terminate in spliced eyes with hard thimbles and the connection to the anchor and the chain is via shackles. This eliminates the need for knots which can significantly reduce the strength of the polypropylene line below the minimum breaking load (MBL). The use of spliced eyes and thimbles with connecting shackles keeps the strength of the mooring line close to the MBL of the polypropylene rope. Drift algae may attach to the moorings but the additional drag is not significant and will not compromise the moorings or have an impact on the factor of safety.

A MarineFlex elastic mooring unit will be incorporated in each mooring line to accommodate the high (4 m) tidal range at the mouth of Pelorus Sound. The mooring lines are relatively steep to keep the farm within the consented seabed footprint and the polypropylene rope is relatively inflexible. The MarineFlex units provide the elastic extension to accommodate the change in mooring line length required and the elastic element prevents snap loading of the mooring lines.

### **5.3 Anchors**

The farm will be anchored by screw anchors. The seabed sediment at the proposed farm location is suited for the use of screw anchors based on experience elsewhere in the Sounds. The diameter of the screw anchor plate used is tailored to the strength of the seabed sediment at the location to achieve the desired pullout resistance. Screw anchors are a particularly efficient way to anchor marine farms. They are lightweight in relation to the holding power or pull out resistance developed and do not require heavy marine plant for their installation and can be installed diverless. They can also be installed with a high degree of accuracy using a Differential Global Positioning System (DGPS) receiver positioned vertically above, and on, the installation axis. The diverless feature is important for the Horseshoe Bay farm site given the water depth on the outside boundary of the site of close to 50 m which is beyond the limit for air diving. The particular type of screw anchor used for the Horseshoe Bay farm will be shaftless screw anchors.

Another advantage of screw anchors is that the installation process causes very little disturbance to the seabed. The anchors screw in like a wood screw only the soil in the helix described by the anchor as it screws into the soil is disturbed. This is why close to full pullout strength is obtained immediately after installation. The soil shear strength on the circumference of the cylinder of soil directly above the screw anchor auger plate in its as installed position is virtually undisturbed. Once the screw anchor is in only the shaft or rope projecting above the seabed is evidence of its presence.

The standard screw anchor, as used on mussel farms in the Marlborough Sounds, features the use of an 800 mm diameter steel auger/anchor plate at the end of a 6 m long shaft. Such an anchor is excellent for resisting vertical pullout loads but the principal hydrodynamic forces exerted on farm structures by waves and tidal currents are lateral or horizontal loads. In a Sounds type application the screw anchors resist lateral forces by bending above the anchor plate into approximate line with the applied load. The bending is a permanent or plastic deformation – indicated by slotting in the seabed – which is acceptable if the anchor is not subject to load reversals and the level of strain is limited. Load reversals are a constant of a strong tidal environment, the anchors must be provided with a means of resisting the lateral load. Shaftless screw anchors avoid the need to provide for separate lateral earth pressure resistance. They are installed using a temporary shaft threaded over the top of the polypropylene rope connected to the anchor. Once the anchor has been screwed down to depth the shaft is withdrawn. Inclined loads cause the anchor to rotate into line with the applied load, there is no yielding or bending of a shaft.

Screw anchors fail by pulling out, either the soil fails or the anchor itself fails. The anchors are designed so that failure occurs in the soil not the anchor itself. They do not drag like gravity block anchors.

Screw anchors will be used for all the Horseshoe Bay farm moorings. A combination of screw anchors and gravity blocks is problematic because when the gravity anchors fail by dragging the load previously taken by the anchor block is transferred to the adjacent screw anchors resulting in the failure of the mooring lines and a cascade failure effect as successive mooring lines fail following load transfer caused by anchor dragging. The target pullout capacity for the anchor is the same or higher than the MBL of the polypropylene anchor rope and shackle connectors to achieve a factor of safety equal to 5.

The amount of torque used to install the anchor gives a good indication of the pullout capacity through a simple linear relationship of the form  $P$  (pullout capacity) =  $k$  (constant)  $\times$   $T$  (torque). Standard soil mechanics solutions exist to determine the pullout capacity of screw anchors if the seabed soil strength parameters are known. For the case of the Horseshoe Bay location the seabed soil strength parameters are not known. A pullout test will be carried out to determine the screw anchor capacity and from the results of this test the relationship between installation torque and pullout capacity will be known. The pullout capacity of all the anchors installed on the site can then be accurately predicted.

## **6.0 CONCLUSION**

The proposed salmon farm at Horseshoe Bay is fully feasible from a mooring and structural safety standpoint. It will use existing proven technology, based on experience with both the existing Waitata Reach farms, Waitata and Richmond and the Te Pangu Bay and Clay Point farms, and will benefit from King Salmon's ongoing development and refinement work to ensure a safe secure structure with known factors of safety. Screw anchors will be used to moor the farm structure and a level of redundancy provided. Test pullout loading of a representative anchor will be carried out to confirm the anchor pullout capacity.

The long axis of the structure will be at a 45° angle to the tidal vector rather than directly in line to minimize the mooring forces. The mooring lines have been designed to take the higher side loadings that occur because of the 45° angle. The farm dimensions are greater than the wave length of the incident, infrequent, swell waves from the north east so the net global wave force on the farm will be close to zero however the local wave forces on individual members of the farm will be significant and the farm structure will be designed to resist those.

Monitoring of the actual hydrodynamic forces exerted on the farm by tidal currents and waves will be undertaken, the same as is done for the Tory Channel farm structures, to confirm that the loadings are within the design loads used. The cause of any load exceedance will be investigated and rectified

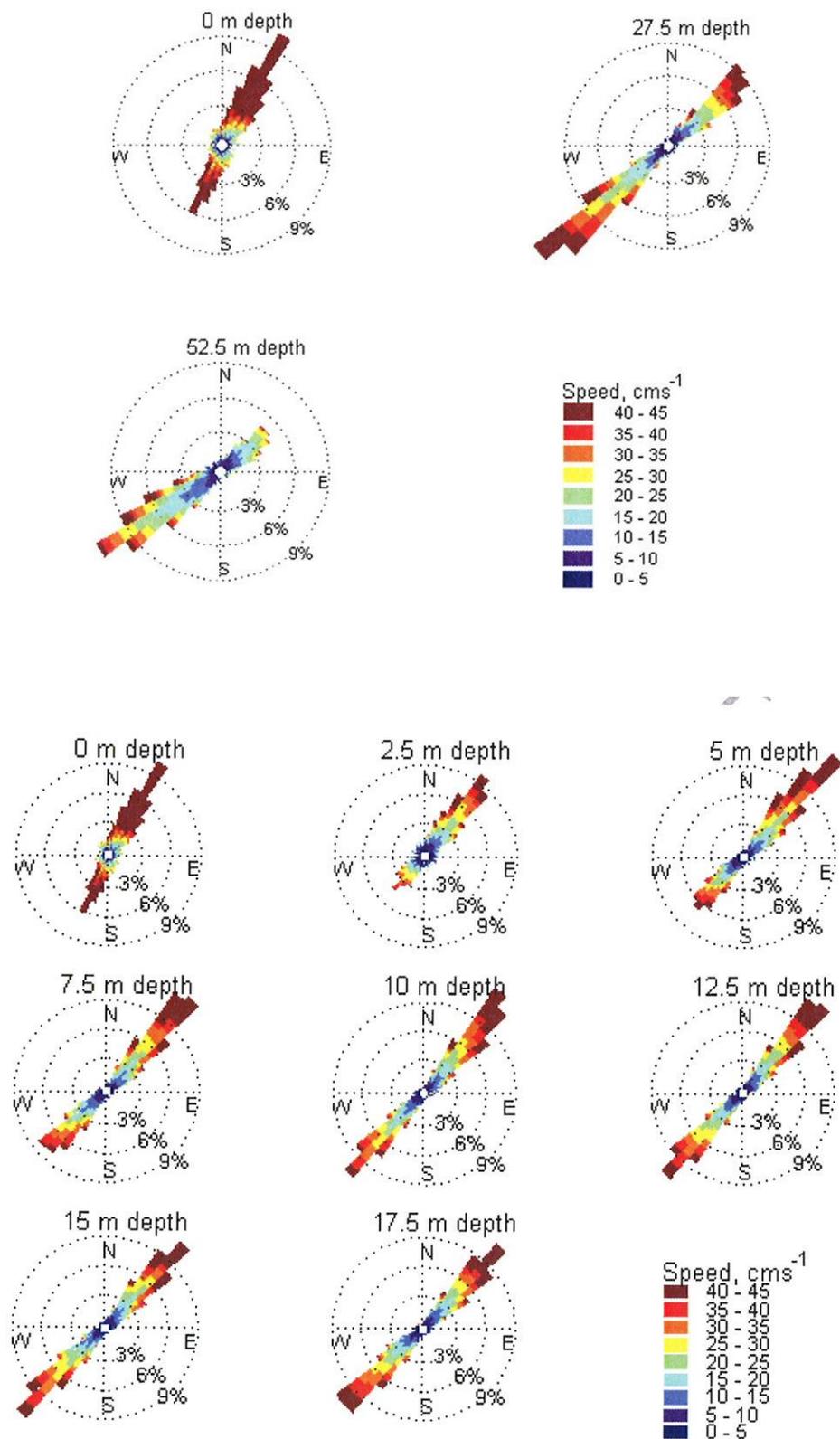


Figure No 1

