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Application Note

Detection Performance of
Lines of VR2W/VR3 Receivers

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Table of Contents

1. The Role of Range Testing **1**

2. Suggested Range Testing Procedure **2**
- 2.1 Variations 3

3. Using Range Test Data to Determine Receiver Separation **4**

4. Line Performance **5**
- 4.1 With Suggested Receiver Spacing 5
- 4.2 Modest Increase in Separation 6
- 4.3 Larger Separation 7

5. A Quantitative Look at Line Performance through Simulation **8**
- 5.1 Simulator Assumptions and Parameters 8
- 5.2 Receiver Spacing 9
  - 5.2.1 Performance Limits with Suggested Spacing (Figure 4-1) 9
  - 5.2.2 Increased Receiver Spacing 9
- 5.3 Variability of Results 9
  - 5.3.1 Sampling Size 9
  - 5.3.2 Examples of Variability with Sampling Size 10
  - 5.3.3 Variable Test Conditions 12

List of Tables

Table 5-1: Impact of Receiver Separation (Swimming Speed = 15 metres per Average Tag Delay Period) 9

Table 5-2: Potential Error with 50 Detections at a Line 10

Table 5-3: Uncertainty Arising from Assumption that Line Detection Percentage on One Run Can be Extended to a Subsequent Run for a Sample Size of Approximately 100. 11

Table 5-4: Demonstration of Uncertainty Arising from Assumption that Line Performance on One Run Can be Extended to a Subsequent Run for a Sample Size of Approximately 100 and Including the Effect of Different Acoustic Conditions between Runs. 12

List of Figures

Figure 2-1: Data from a Typical Range Test 3

Figure 3-1: Probability of Detection versus Range 4

Figure 4-1: Line Performance for Two Receivers at the Suggested Separation Based on at Least Two of Five Transmissions being Detected 5

Figure 4-2: Line Performance for Two Receivers Separated by Approximately 20% More Than Recommended Separation (at Least Two of Five Transmissions Detected) 6

Figure 4-3: Line Performance for Two Receivers Separated by Approximately 75% More Than Recommended Separation (at Least Two of Five Transmissions Detected) 7

Figure 5-1: Test to Test Variability of Detection Percentage with Sample Size 10

1. The Role of Range Testing

The detection range of a receiver is highly dependent on noise levels (caused, for example, by weather, boats, marine life, etc.) and absorption (which depends on conductivity, temperature and depth). As well, wave bending produced by temperature gradients and other effects can impact range for some signal paths and, in some cases, even produce shadow zones. All of these factors can vary significantly from one location to another and with time in a particular location. This needs to be taken into account when installing a line of receivers with the objective of detecting all passing fish.

While it is possible to predict range under various conditions in the open ocean, the acoustic conditions in many (if not most) areas where lines are installed can be quite different and, therefore, it is important to do some range testing prior to deployment of the line. This testing should be carefully planned in order to produce relevant results and should focus on areas and conditions of planned deployment.

2. Suggested Range Testing Procedure

The overall objective is to determine range performance under all anticipated conditions with a view to determining receiver separation necessary to provide complete coverage. This will usually involve some tradeoffs between completeness of the data and time and resources available for range testing. However, as will be shown later, errors (i.e. the potential of undetected fish) are not large if the receiver separation requirement is only overestimated by a modest amount.

The procedure is straightforward:

- Use a transmitter(s) with power the same as that of the weakest tags to be used. Ideally, fixed Delay tag(s) should be used so you know exactly how many transmissions occur.
- Deploy a line of receivers at representative ranges (For example, one every 100 metres).
- Place a transmitter near one end of the line. Alternately, if transmitter depth is thought to be a factor, use more than one transmitter with each one at a representative depth. In this case, fixed delays and start times of the tags need to be organized so that no collisions occur.
- Allow receivers to detect long enough that representative conditions (e.g. weather, biological and manmade noise) are encountered. This will be on the order of days or weeks. Seasonal effects, particularly in rivers and estuaries, also need to be considered.
- Collect the data and determine the percentage of transmissions that were detected over representative time periods for each range (see Figure 2-1 for example).

In some areas where there are severe echoes and especially if powerful transmitters are used, one may experience low detection rates at very short ranges with normal behaviour further out. The cause of this is explained in a VEMCO FAQ. This phenomenon will have little effect on overall array performance since a fish can't pass through these "nulls" without crossing large areas of high detection probability.

Figure 2-1 is a presentation of the results of such a test conducted by VEMCO in Shad Bay over a 45 day period with each data point representing one day of data.

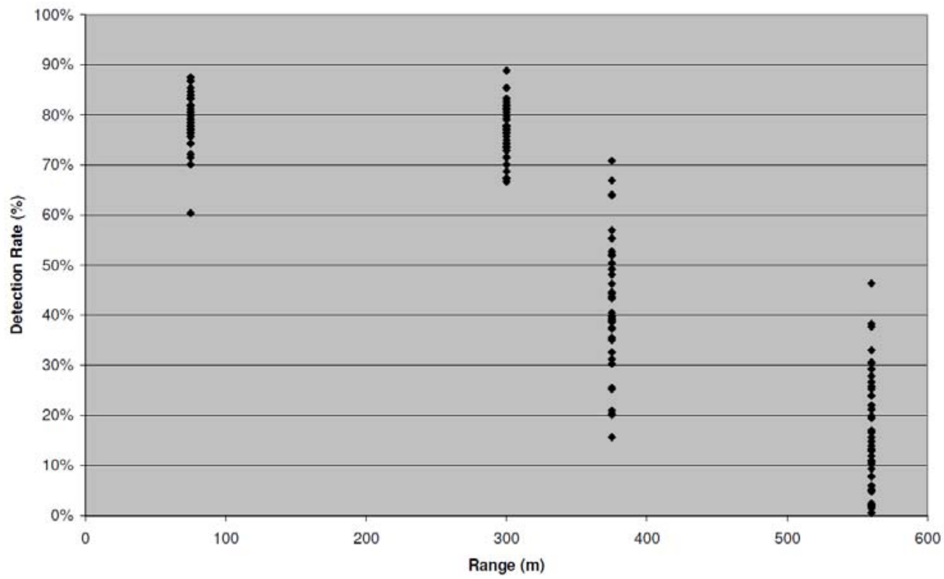

Figure 2-1: Data from a Typical Range Test

2.1 Variations

If the above is too time consuming or requires more equipment than might be available, the following variations can be considered.

- If the number of receivers available is insufficient to provide an adequate data set, conduct one test and the reposition the receivers for a new test to provide additional range points. In the limit, a single receiver can be used at the expense of a very long test period and no guarantee of the same range of acoustic conditions for each range point.
- Use a single receiver with transmitters positioned at desired range points. As the number of transmitters increases, more and more care is required to ensure there are no collisions.

3. Using Range Test Data to Determine Receiver Separation

Assuming that the range test included the worst conditions likely to be encountered during the deployment, the starting point is to plot the minimum probability of detection against range. This is the "Worst Conditions" curve in Figure 3-1. This figure also shows the maximum probability of detection versus range ("Best Conditions Curve") as this will be used in to show overall line performance.

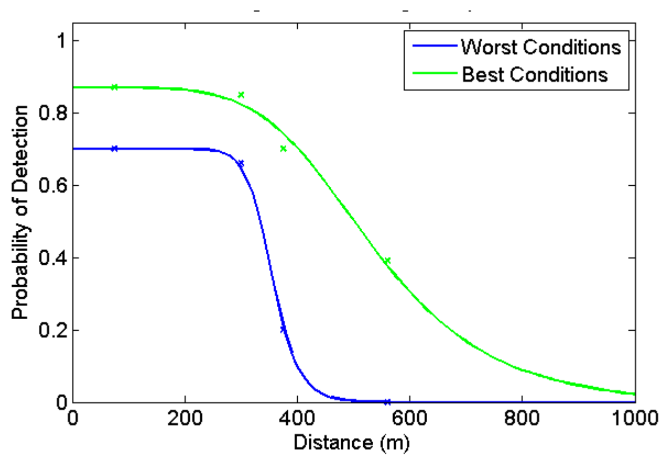

Figure 3-1: Probability of Detection versus Range

We suggest that the point where detection probability in the worst case conditions falls to 50% be taken as the limit of where tags can be reliably detected. In this case, that is just under 340 metres.

4. Line Performance

The actual performance of a line is somewhat more complex than the simple curves of Figure 3-1. A passing fish will normally transmit at least several times while potentially within range and, to ensure that false positives are not accepted, at least two of these need to be detected. Because of this, it is important in what follows to differentiate between Line Performance and Range Test Probability of Detection as follows:

> **Transmission Probability of Detection** is the probability that an individual transmission will be detected at a particular range and acoustic conditions

> **Line Probability of Detection** at a given range as the percentage of fish for which at least two of five transmissions will be detected

4.1 With Suggested Receiver Spacing

Using the range test data above, one can construct Figure 4-1 to illustrate the performance of the line using the suggested separation (i.e. 675 metres where the "worst case" 0.5 probability points of the two receivers will cross). In Figure 4-1 and in Figures 4-2 and 4-3 which follow, the curves labeled "Line" represent the Line Probability of Detection while those labeled "Range Test" represent the Transmission Probability of Detection measured during Range Testing.

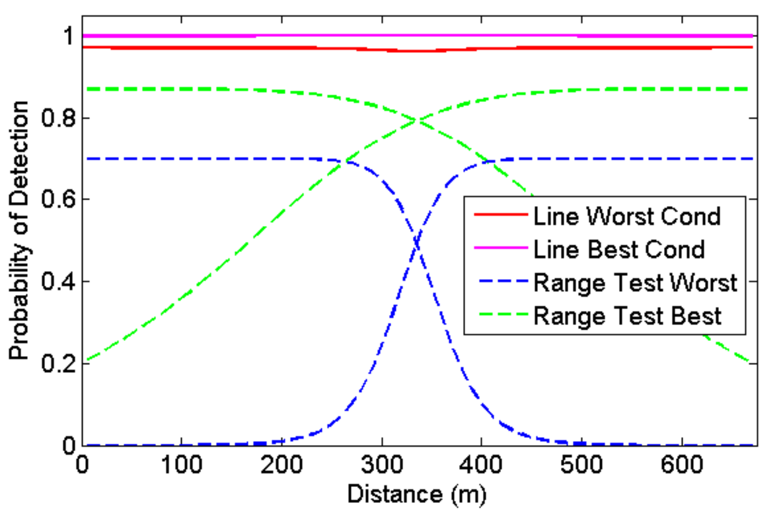

Figure 4-1: Line Performance for Two Receivers at the Suggested Separation Based on at Least Two of Five Transmissions being Detected

4.2 Modest Increase in Separation

Figure 4-2 shows line performance if we increase receiver spacing in the above example to 800 metres. As can be seen, line performance is good unless conditions are at or near the worst case. In the worst case, there is a band somewhat wider than 100 metres in which the probability of detecting a fish (for the criterion used) falls under 70% (and as low as 20% at the midpoint between the two receivers.

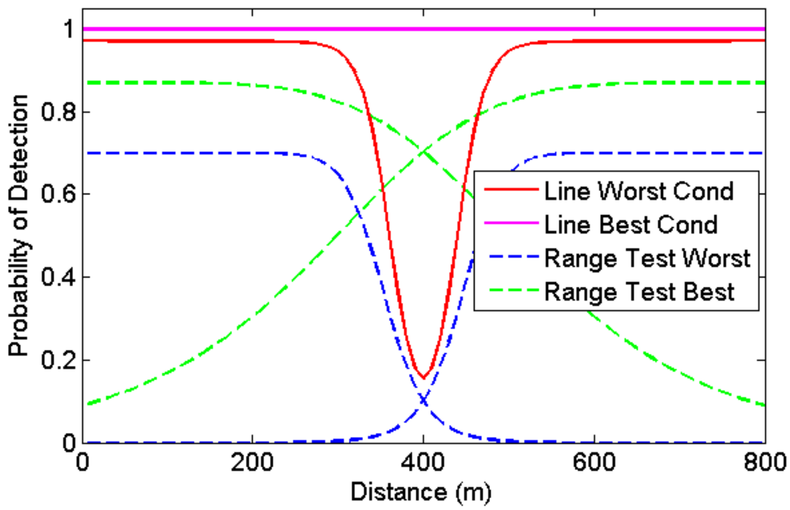

Figure 4-2: Line Performance for Two Receivers Separated by Approximately 20% More Than Recommended Separation (at Least Two of Five Transmissions Detected)

It is important to keep in mind that, in this scenario, all fish passing between the receivers will still be reliably detected UNLESS:

They pass near the midpoint between the receivers

AND

They pass rapidly enough so that there are few transmissions when they are potentially within range

AND

Acoustic conditions are close to the worst found during testing.

Intuitively this would represent a small percentage of missed fish.

4.3 Larger Separation

Figure 4-3 shows line performance if we increase receiver spacing to 1000 metres. This example illustrates the risk of designing a line based on testing which does not include poor acoustic conditions. In this case, virtually all fish are still detected when conditions are good but, as conditions deteriorate, there will be an area between the receivers where no fish are detected (almost 200 metres wide in worst case conditions).

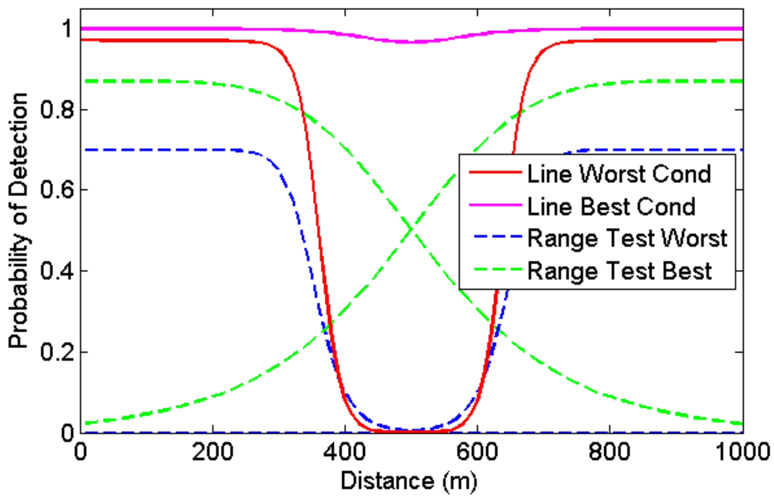

Figure 4-3: Line Performance for Two Receivers Separated by Approximately 75% More Than Recommended Separation (at Least Two of Five Transmissions Detected)

5. A Quantitative Look at Line Performance through Simulation

While Figure 4-1, Figure 4-2 and Figure 4-3 help illustrate the effect of increasing receiver separation and potential vulnerabilities (or improvements) as receiver spacing is changed or actual Transmission Probabilities of Detection characteristics are different from that used to design the line, they don't support any quantitative estimates. For example, the discussion associated with Figure 4-2 suggests that only a small percentage of fish would not be detected with that spacing; but this begs questions like how small and can spacing be further increased and the percentage remain acceptably small.

More importantly, the role of **sample size** (i.e. the number of fish actually crossing the line) needs to be understood since the area covered by the receivers is large and detection probabilities vary significantly in space and time through it. Therefore, one might expect that one migration of, say, 25 fish might be subject to very different conditions from another.

To help answer these and similar issues and support some of the conclusions below, we simulated a line based on receivers having arbitrary detection characteristics and used it to predict performance for a line of receivers with detection characteristics as shown in Figure 3-1.

5.1 Simulator Assumptions and Parameters

Clearly, in any simulation, assumptions are necessary. The key ones for the current simulator are:

- Passage is uniformly random in time and space and in a straight line which is perpendicular to the line joining the receivers
- The Detection Probability versus Range curve (Determined by Acoustic conditions) is fixed for the time of passage of each fish (usually the case in practice)
- A fish is logged as detected if the individual probabilities of detection for each transmission from that fish are such that at least two detections will occur (99 times out of 100)

Unless otherwise stated, the simulations data presented below are based on the following:

- Acoustic Conditions such that the Best and Worst case Detection probability characteristics are as in Figure 3-1.
- The actual detection probability characteristic experienced by a particular fish passing is chosen randomly (uniform distribution) between the Worst and Best cases of Figure 3-1.
- Swimming speed is constant for all fish (normalized to 15 metres per average Tag Delay period)

5.2 Receiver Spacing

5.2.1 Performance Limits with Suggested Spacing (Figure 4-1)

Since this spacing provides complete coverage one would expect that the detection rate would be close to 100% unless fish are swimming too fast to produce the required number of transmissions while in range. The detection rate is indeed 100% for swimming speeds up to about 25 metres per average Tag Delay period and falling off at higher speeds (e.g. 95% at a speed of 50 metres per average Tag Delay period).

5.2.2 Increased Receiver Spacing

Table 5-1 shows degradation of performance as receiver separation is increased. As discussed in connection with Figure 4-2, performance fall off will not be large if separation is modestly over the amount we suggest.

Separation (metres)	Percent of Fish Detected
675	100%
800	99%
1000	93%
1200	83%
1400	74%

Table 5-1: Impact of Receiver Separation (Swimming Speed = 15 metres per Average Tag Delay Period)

5.3 Variability of Results

5.3.1 Sampling Size

The results shown in Table 5-1 assume that the number of samples is large enough that there is little variation from one run to the next. As one would expect, if the sampling size is smaller, results will vary from run to run. In fact, simulation results show that, for a number of runs with a given sample size, Detection Percentages are typically fairly uniformly distributed within one standard deviation of the mean. Therefore, from Figure 5-1, which shows Standard Deviation versus Sample Size for two representative receiver separations, we can see how results will vary from run to run – e.g. for a Receiver Separation of 1000 metres and a Sample Size of 100, the Mean Detection rate is 93% with a Standard deviation of 4%; so Detection Percentage would normally fall between 89% and 97%.

As can be seen, standard deviation (i.e. variability of results from test to test) increases with decreasing sample size and increasing receiver separation.

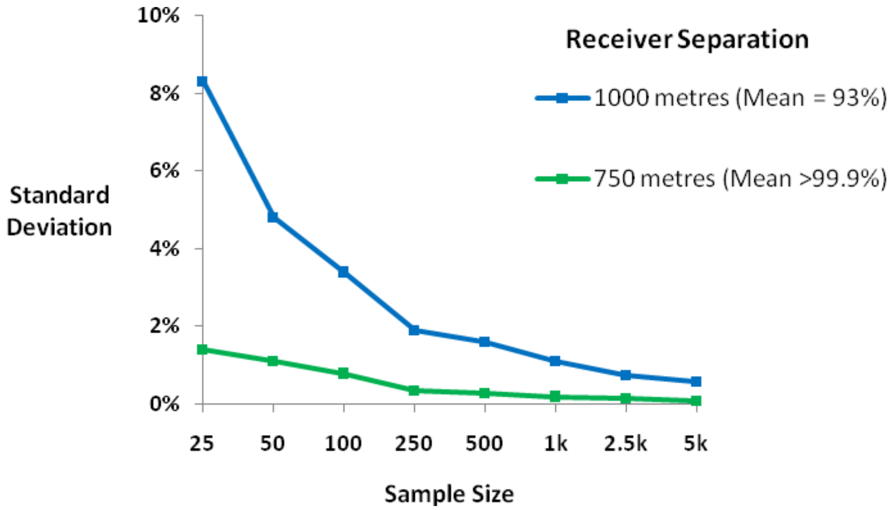

Figure 5-1: Test to Test Variability of Detection Percentage with Sample Size

5.3.2 Examples of Variability with Sampling Size

We will consider two examples using the same simulation parameters as for Table 5-2.

Example 1: 50 Fish Detected Crossing the Line

Of course, we don't know exactly how many fish actually crossed the line but, if the receivers are separated by 1000 metres, Figure 5-1 shows that, on average, 93% of passing fish will be detected so that the sample size will be somewhat greater than 50 where the Standard Deviation between runs is roughly 5%. Therefore, 88% and 98% of fish crossing will normally be detected − i.e. Mean (93%) plus or minus Standard Deviation (5%). Therefore, the actual number of fish passing would likely have been anywhere between 51and 57 (i.e. an error of up to 14%). Table 5-2 shows the potential errors for other values of receiver spacing.

Separation (metres)	Potential Error
700	0%
750	2%
800	4%
900	8%
1000	14%

Table 5-2: Potential Error with 50 Detections at a Line

Example 2: 75 Fish Detected at a Line Known to Have Previously Detected 75 of 100 Fish

Sometimes it is possible to know exactly how a line performed during a particular migration; for example, there might be lines known to be highly efficient upstream and downstream so that the number of fish actually crossing the line in question is also known.

Note that a 75% Line Probability of Detection is unlikely to occur unless receivers are fairly widely spaced. In particular, simulation shows that of 75% is only likely for separations from about 1300 to 1500 metres. Below that, the Line Performance is unlikely to be as low as 75% and above that unlikely to be as high.

Can we assume that detection percent will be the same the next time – i.e. that the 75 detections translate into 100 fish passing? Consider the case where receiver separation is 1300 metres. Assuming that conditions correspond to the simulation, the likely percentage of fish detected during any particular run would fall between 73% and 85% (for a sample size around 100). Therefore, 75 detections would correspond to an actual number of fish between 88 and 103 (75/73% to 75/85%); so, the estimate of 100 would have an uncertainty of 15%. This is shown in Table 5-3 along with comparable results for different separations Line Probabilities of Detection observed on a single run. From this we see, that, as the receiver spacing increases beyond that necessary to detect a high percentage of passing fish, repeatability from one run to the next degrades.

Separation (metres)	Known Line Probability of Detection from One Run	Uncertainty in a Future Run
800	0.98	2%
900	0.95	6%
1300	0.75	15%
1700	0.60	23%

Table 5-3: Uncertainty Arising from Assumption that Line Detection Percentage on One Run Can be Extended to a Subsequent Run for a Sample Size of Approximately 100.

5.3.3 Variable Test Conditions

In all of the above, we have assumed that test conditions (i.e. time and space distribution of fish passage and the distribution of acoustic conditions encountered) are the same for every run. If this is not the case, one would expect variability from run to run will be higher. Table 5-4 demonstrates this by showing the impact on the results of Table 5-2 (Sampling errors only) when acoustic conditions vary to the extent that the "Best Case" in Figure 3-1 moves 50 metres to the left (i.e. Detection Probability = 50% at a range of 500 metres instead of 550 metres). As can be seen, the impact for this modest change in conditions becomes significant as receiver spacing increases but has little or no effect for receiver spacing under 900 metres.

Separation (metres)	Known Line Probability of Detection from One Run	Uncertainty Due to Sampling Only	Uncertainty Including Variable Acoustic Conditions
800	0.98	2%	2%
900	0.95	6%	7%
1300	0.75	15%	23%
1700	0.60	23%	38%

Table 5-4: Demonstration of Uncertainty Arising from Assumption that Line Performance on One Run Can be Extended to a Subsequent Run for a Sample Size of Approximately 100 and Including the Effect of Different Acoustic Conditions between Runs.