Acoustical Reverberation Level Modeling of Underwater Riverine System

19981026 100

Submitted By: Brantley Bain
20 August 1998
ME599B
Advisor: Peter Dahl

ABSTRACT:

Sonars used to count migrating salmon in the Pacific Northwest must operate in a complicated and variable acoustic environment. This paper discusses the acoustic properties which affect the performance of salmon enumeration methods. The methods used must be able to take into account variable site geometry and river bed characteristics. From this information, a background and target reverberation levels can be calculated. Using this information, guidelines for sonar site selection and configuration can be established.

INTRODUCTION:

As the numbers of North American Pacific salmon (Oncorhynchus spp.) dwindle in the Pacific Northwest, a greater emphasis is being placed on the proper management of the species. A primary management objective is determining and maximizing the numbers of salmon that escape from local fisheries into individual spawning areas. These spawning objectives are reached by varying commercial harvest areas and times. In order to implement a management scheme that can maximize the catch while sustaining the species, daily counts of escapement need to be determined (Gaudet).

Traditional techniques used to determine the escapement include erecting towers along the banks or rivers or constructing weirs in the stream. These techniques are very labor intensive and are in many places impractical due to clarity of water and remote locations which are difficult to travel to. The use of gillnets or fish wheels also provide escapement numbers, but these methods are limited by the uncertainty of fish catchability (Thorne).

To provide another tool for determining daily estimates of escapement, research began in the 1960's to design and build sonar counters capable of counting salmon. The use of conventional vessel mounted echo sounders proved to be limited due the small sonar sampling volume beneath the boat and boat avoidance behavior exhibited by the fish, especially in shallow rivers in which salmon typically spawn. Another enumeration technique consisted of using upward looking multiple transducers. This method proved bulky and difficult to operate. Then in 1974, a single horizontally mounted transducer was used to replace the upward looking models. This single transducer looked perpendicularly from shore along the bottom and initially obtained relatively accurate results as compared to manual fish counts (Trevorrow). In the last twenty five years, these techniques have been refined to produce very accurate escapement counts.

However, in order to obtain accurate results using acoustical methods, the sonar signal to noise ratio of the system must equal or be greater than the detection threshold. One of the major contributing factors which often prevents this from happening is the background reverberation level. This reverberation level must take into account the acoustical backscatter of the insonified river cross section. The components of backscatter include interaction with the river surface and bottom sediments.

The scope of this paper is to explain the basic acoustical equations and develop these equation into a model. This paper discusses the acoustic properties that affect the performance of salmon enumeration counters. The methods used must be able to take into account variable site geometry and river bed characteristics. From this information, a background and target reverberation levels can be calculated. Using this information, guidelines for sonar site selection and configuration can be established.

BASIC CONCEPTS:

Sound consists of a repetitive motion of the molecules of an elastic substance such as air or water. Because of the materials elasticity, motion of the particles of the material, such as the motion initiated by the movement of a piston in a tube, propagates to adjacent particles. The sound wave is propagated outward from the source at a velocity equal to the velocity of sound in the material, in fisheries this material is always a fluid. Therefore, a sound wave is a sinusoidal oscillation in the fluid which results in regions of compression and rarefaction relative to the mean pressure (Johanneson and Mitson). These changes in pressure can be detected by a pressure sensitive device such as a transducer. This device converts the acoustical wave into an equivalent electric sinewave.

In a plane wave of sound the pressure p is related to the velocity of the fluid particles u by

$$p = \rho c u \quad (1)$$

where ρ = fluid density [kg/m3]

c = propagation velocity of wave [m/s]

The proportionality factor ρc is called the specific acoustic resistance (impedance) of the fluid. The relationship between pressure, particle velocity and specific acoustic resistance is similar to the relationship that exists between voltage, current and resistance (Urick). Therefore, equation 1 is called Ohm's law for acoustics where particle velocity is analogous to electric current and pressure is analogous to electric voltage. Note: the speed of acoustical waves, c, is dependent on temperature, salinity and depth of the water. For riverine measurements, salinity and depth are not usually significant factors (Johanneson and Mitson).

Sound waves carry mechanical energy with it in the form of the kinetic energy of the particles in motion plus the potential energy of the stresses and strains in the fluid. Because the wave is propagating, a certain amount of energy per second will flow across a unit area oriented normal to the direction of propagation. This amount of energy per second (power) is called the intensity of the wave (Clay and Medwin). Acoustical intensity is analogous to electrical power on the basis of the amount of energy and the time if flows or is used. In a plane wave, described in fisheries acoustics as a wave which exhibits no significant curvature of its wavefront, the intensity is related to the time average acoustic pressure using the equation:

$$I = p^2 / \rho c \quad (2)$$

Another important term which is vital in understanding fishery acoustics is the term decibel (dB). The decibel is not a unit of measured quantity such as meters, kilograms, or seconds. It is the logarithm to base 10 of a ratio, giving the relationship between quantities. In the field of acoustics, large differences occur in intensity and pressure due to propagation losses. By converting these changes to decibels using logarithms it is possible to simplify figures and calculations of these differences. Additionally, since the decibel is based on logarithms, multiplication and division are converted to addition and subtraction.

SONAR EQUATIONS:

Various phenomena and effects associated with underwater acoustics produce quantitative effects on the design and operation of sonar equipment. These effects can be logically and conveniently grouped together quantitatively in a small number of units called the sonar parameters which are related by the sonar equations. These equations relate the various effects of the medium, the target, and the sonar equipment.

The sonar equations are founded on a basic equality between the desired and undesired portions of the received acoustical signal at the desired instant of time when a sonar function is performed. In fisheries acoustics, this function is the detection of a fish target. This function involves the reception of the acoustical wave occurring in a natural acoustic background. The acoustical field received by the transducer can be broken down into two portions: the desired portion is called the signal and the undesired portion is called the background. The background is either noise, the steady state portion not due to sonar insonification, or reverberation, the slowly decaying portion of the background representing the return of the sonar insonification output by scatters in the fluid medium. The goal of setting up a sonar system is increasing the overall response of the sonar to the signal and decreasing the response of the sonar to the background, thus increase the signal to background ratio (Urick).

For a sonar system designed for fish detection, there will be a certain signal to background ration which depend on the desired performance level in terms of "hits" and "false alarms," such as an apparent detection of a fish target when no target is present. If the signal slowly increases in a constant background, fish detection will occur when the signal level equals the level of the background which just "hides" it. In other words, when the sonar's purpose is just accomplished,

Signal Level = background masking level (3)

Note: the equality just stated will exist at only one instant in time when the target approaches the sonar. At short ranges, the signal level will exceed the background masking level and at long ranges the reverse is true (Clay and Medwin).

Equation 3 is expanded in terms of the sonar parameters determined by the equipment, medium and the target. They are listed as follows:

Equipment Parameters
- Projector Source Level: SL
- Self-Noise Level: NL
- Receiving Directivity Index: DI
- Detection Threshold: DT

Medium Parameters
- Transmission Loss: TL
- Reverberation Level: RL
- Ambient Noise Level: NL

Target Parameters
- Target Strength: TS
- Target Source Level: SL

Two pairs of the parameters, SL and NL, have the same designation because they are essentially the same term. The chosen parameters were arbitrarily selected, however, those listed above are the parameters conventially used in underwater sound. The units of these parameters is decibels and are combined together in forming the sonar equations (Urick).

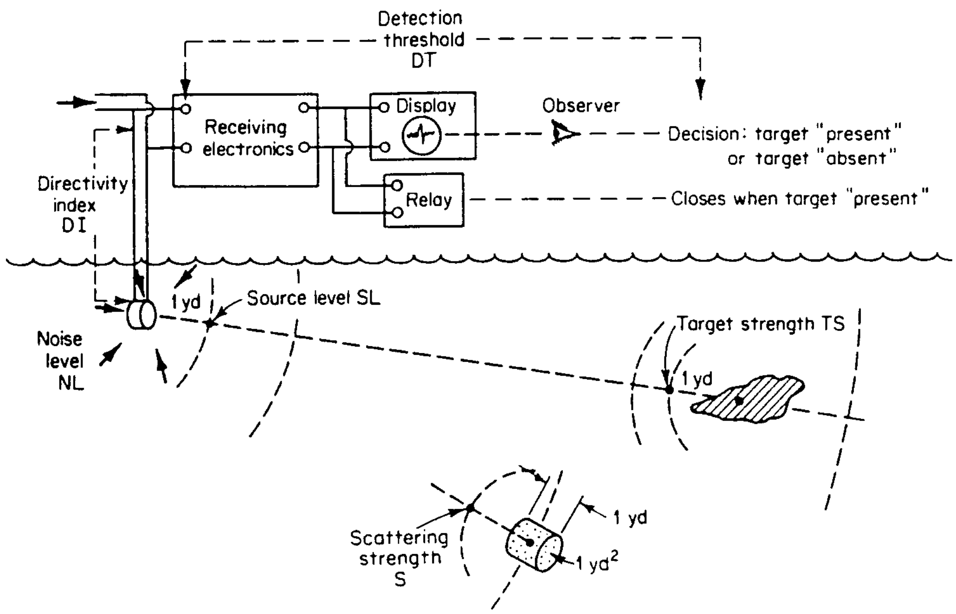

Figure 1: Diagram Showing Sonar Parameters (Urick)

The physical meaning of these parameters can be illustrated in figure 1. For an active sonar, a transducer produces an source level of SL decibels at a unit distance, usually 1 m, on its axis. When the sound wave reaches the target, if the source level is pointed towards the target, its level will be reduced by the transmission loss, and becomes SL-TL. On reflection by the target of target strength TS, the reflected or backscattered will be SL-TL+TS at a distance of 1 m from the acoustic center of the target in the direction back toward the source. The sound wave then is again reduced by transmission loss when traveling back to the source and becomes SL-2TL+TS. This is the echo level at the transducer (Urick).

Assuming the background to be isotropic noise rather than reverberation, it is determined that the background level is simply NL. This level is reduced by the directivity index of the transducer acting as a receiver so that the terminals of the transducer the relative noise power is NL-DI. Since the axis of the transducer is pointing in the direction from which the echo is coming, the relative echo power is unaffected by the directivity index. Therefore, the echo to noise ratio is

SL-2TL+TS-(NL-DI) (4).

In fisheries acoustics, the function of the sonar is the detection fish, or in other words provide a response, such as graphically on a display, whenever a target is present. When the input signal to noise ratio is above a certain detection threshold taking into account probability criteria, a decision will be made using computer software or a human observer that a target is present (Urick). When the input signal to noise ratio is less than the detection threshold, the target is absent. For the case when the target is just detected, the signal to ratio is equivalent to the detection threshold, where

SL-2TL+TS-(NL-DI) = DT (5).

Rearranging terms into a more convenient form results in the equation

SL-2TL+TS=NL-DI+DT (6)

For equation 6, the echo level occurs on the left hand side of the equation and the noise masking background level occurs on the right.

For the case when the background is reverberation rather than noise, equation 6 is modified. For this case, the term DI, defined in terms of an isotropic background, is inappropriate because reverberation is not isotropic. For the case of reverberation, the terms NL-DI are replaced by an equivalent plane wave reverberation level, RL, measured at the transducer terminals (Urick). Thus, the active sonar equation becomes

SL-2TL+TS=RL+DT (7)

Rearranging equation 7, redefining the "two way" transmission loss as TL, vice 2TL, and for the case where DT=0, results in the following form of the sonar equation:

$$RL = SL - TL + TS \quad (8)$$

REVERBERATION LEVEL MODEL:

Reverberation is the sum total of all scattering induced by the physical properties of the acoustic medium. Inhomogeneities form discontinuities in the physical properties and scatter a portion of the acoustic energy traveling through the medium. Two forms of reverberation are: 1) RL due to the background with "no targets" and 2) RL of a target such as a fish. Equation 8 governs both reverberation levels but they each have different components.

Source Level is a function of the acoustic equipment used to insonify the body of water. Therefore, both the background RL and the target RL are going to have the same source level. Source Level is defined as:

$$10 \log (\text{intensity of source/reverence intensity}) \quad (9)$$

where the reference intensity is that of a wave of rms pressure 1μPa. This sonar equipment parameter relates how electrical power, when applied to a transducer becomes acoustic power. Acoustic power is an intensity (Source Level) as produced by the transducer.

The source level in equation 8 can be calculated from this acoustic power using the following equation:

$$SL = 170.8 + 10\log Wa + DI \quad (10)$$

where
Wa = acoustic power [Watts]
DI = Directivity Index

The directivity index can be approximated by the relation:

$$DI \approx 10\log10(16/\Phi^2) \quad (11)$$

There are two components of the transmission loss, TL, experienced by a traveling acoustic wave. The first component of TL is the decrease in acoustical intensity with distance. When acoustic beams are propagated through water they spread so that a constant power covers a continuously increasing area as the wavefront moves away from the sound source. The acoustic intensity is defined as:

$$\text{Intensity} = \text{power/area} \quad (12).$$

The waves radiating from a transducer spread spherically from the transducer. Note: transducers which are designed to keep the acoustic wave in a beam, the beam area is still expanding spherically (Johanneson and Mitson). Knowing that the area of a sphere is $4\pi r^2$, where r is the distance from the transducer, and using equation 12 a relationship can be developed for the decrease in acoustical intensity. This relationship is:

$$4\pi r_1^2\, I_1 = 4\pi r_2^2\, I_2 \quad (13)$$

where r_1 is the reference distance of 1m. This leads to the ratio

$$I_1/I_2 = r_2^2 \quad (14)$$

which in decibel notion is

$$10\log I_1/I_2 = 10\log r_2^2 = 20\log r_2 \quad (15)$$

r_2 is the distance relative to the reference (transducer) and is called R, the range from a source to a given distance. Thus the "two way" transmission loss due to spherical spreading is:

$$TLs = 40\log R \quad (16)$$

Absorption is another component of transmission loss. As acoustic waves travel through water, some of the energy is absorbed by chemical processes. The propagation of energy which is converted is an transmission loss. Absorption, α, is expressed in decibels per distance (Johanneson and Mitson). This loss is linear with distance and is determined using the relationship:

$$TLa = 2\alpha R \quad (17)$$

Therefore, the total transmission loss is calculated using the equation:

$$TL = 40 \log R + 2\alpha R \quad (18)$$

Again, both background RL and target RL are going to have the same transmission loss.

The final component of the reverberation level is the effective target strength. This appears in the form of reverberation producing scattering in the riverine system which interfere with fish echoes. These reverberation producing scatters are of two different classes: volume and surface reverberation. Volume reverberation occurs via inanimate matter distributed in the river such as entrained bubbles produced by wind and rain. Surface reverberation takes into account the reverberation produced by the water surface and the river bottom composition/roughness, i.e. the combination of sand, gravel, and rocks (Dahl).

Figure 2 makes it easier to conceptualize the development of an expression for the volumetric backscattering target strength. In this figure, the volume dV has an end face surface of $R^2 d\Omega$, where R is the range from the transducer and $d\Omega$ is the solid angle in steradians subtended by dV at the transducer.

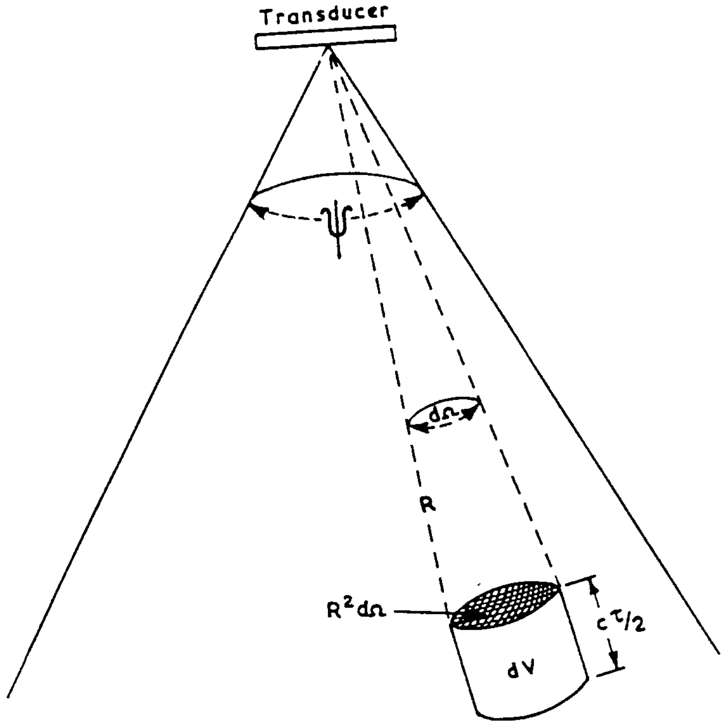

Figure 2: Elemental Insonified Volume (Johannesson and Mitson)

The length of dV is sufficiently small that when insonified by a acoustic wave pulse, all scattering produced by its volume is received by the transducer at the same time. Thus the length of dV is 0.5cτ. The volume, dV is therefore,

$$dV=R^2\,0.5c\tau\,d\Omega \quad (19)$$

In order to determine the intensity of the acoustic backscattering from the volume a new term must be introduced. This new term is called the volumetric backscattering coefficient, s_v. It is defined as the ratio, of backscattered intensity in dB produced by unit volume at 1m from the volume, to the intensity of the incident wave I_1

$$s_v = I_b/I_1 \text{ and } S_v = 10\log s_v \quad (20)$$

Thus the intensity from dV is

$$I_b = s_v R^2\,0.5c\tau\,d\Omega \quad (21)$$

to include the whole beam we substitute Φ for $d\Omega$

$$I_b = s_v R^2 0.5c\tau\,\Phi \quad (22)$$

From equation 22, the target strength component of reverberation level due to volumetric scattering can be developed. If the intensity from the transducer is I_b, it will be reduced in proportion to R^4, 40logR, by the journey to and from the volume dV (Urick). Therefore, in logarithmic terms, the target strength due to volume reverberation can be expressed as

$$TSv=10\log(0.5c\tau\Phi R^2) + S_v \quad (23)$$

Surface reverberation is reverberation produced by scatterers distributed over a nearly plane surface, rather than a volume. Examples of scattering surfaces are the surface of the water and the bottom of the body of water. Most of the reverberation resulting from the phenomena results from the bottom surface interface. The contribution by the surface contributes much less than other sources (Dahl).

The development of the surface reverberation takes place much the same as in the volume reverberation except that you are interested in the insonified surface area of the acoustic pulse vice the insonified volume. The elemental area insonified can be written in the form

$$dA = 0.5c\tau R/\cos\theta d\Omega \quad (24)$$

As in volume reverberation, in order to determine the intensity of the acoustic backscattering from the surface a new term must be introduced. This new term is called the surface backscattering coefficient, s_b. It is defined as the ratio, of backscattered intensity in dB produced by unit surface at 1m from the volume, to the intensity of the incident wave I_1. This coefficient is a strong function of the grazing angle, θ.

$$s_b(\theta)= I_b/I_1 \text{ and } S_b(\theta)= 10\log s_b \quad (25)$$

Thus the intensity from dA is

$$I_b = 0.5 s_b R c\tau / \cos\theta \; d\Omega \quad (26)$$

to include the whole beam we substitute Φ for $d\Omega$

$$I_b = 0.5 s_b R c\tau \, \Phi / \cos\theta \quad (27)$$

From equation 27, the target strength component of reverberation level due to surface scattering can be developed. If the intensity from the transducer is I, it will be reduced in proportion to R^4, 40logR, by the journey to and from the area dA (Urick). Therefore, in logarithmic terms, the target strength due to surface reverberation can be expressed as

$$TS_b = 10\log(0.5 c\tau\Phi R/\cos\theta) + S_b(\theta) \quad (28)$$

The target strengths due to volume and surface phenomena are not a part of the reverberation level due to the target. For the case where the target is a typical sized salmon, the target strength is generally assumed to be TS=-30 dB.

Finally, plugging the various sonar parameters into both the background reverberation level equation and the target reverberation model leads to the following equations:

$$RLb = 170.8 + 10\log Wa + 10\log 10(16/\Phi^2) - 40\log R - 2\alpha R + 10\log(0.5 c\tau\Phi R/\cos\theta) + S_b(\theta) +$$

$$10\log(0.5 c\tau\Phi R^2) + S_v \quad (29)$$

and

$$RLf = 170.8 + 10\log Wa + 10\log 10(16/\Phi^2) - 40\log R - 2\alpha R - 30 \quad (30)$$

Noting as the beam gets wider with increasing range, R, the wavefront area increases. The resulting decrease in intensity with range is compensated for by applying a variable amplification of the received signals according to the signals range from the transducer. This variable amplification is called the time varied gain, TVG (Johanneson and Mitson). For the case where the TVG function exactly matches spherical spreading loss, 40logR, then the equation modeling the background reverberation level is:

$$\mathbf{RLb = 170.8 + 10logWa + 10log10(16/\Phi^2) + 10log(0.5c\tau\Phi R/cos\theta) + S_b(\theta) +}$$

$$\mathbf{10\ log(0.5c\tau\Phi R^2) + S_v - 2\alpha R} \quad (31)$$

and

$$\mathbf{RLf = 170.8 + 10logWa + 10log10(16/\Phi^2) - 2\alpha R - 30} \quad (32)$$

where,

Wa= transducer acoustic power [Watts]
c=sound speed [m/s]
τ=sonar pulse length [seconds]
Φ=nominal beamwidth of transducer [degrees]
θ=grazing angle for bottom scattering [degrees]
α=freshwater attenuation [dB/m]
S_b=scattering strength coefficient for the river bottom [dB]
S_v=volumetric scattering strength coefficient for wind and rain generated bubbles [dB]

In order for a target to detected against the background reverberation level, there needs to be some separation between the two components. Generally, 10 dB is an acceptable difference between the background and target reverberation levels to ensure the equipment can differentiate between the 'loud' background and the target. Putting this into equation form:

$$RLb = RLf + 10 \quad (33)$$

MODEL RESULTS:

In order to simulate to the relationship of the background and target reverberation levels, equations 31 and 32 were programmed into MATLAB (See Appendix 1). In addition to estimates of the variables in these equations, implementing the program required information on a particular site such as water depth, bottom slope and transducer height above bottom. Therefore, the calculated reverberation levels were based on an actual sonar set up from an Alaskan river. Figure 3 shows the approximate sonar set up. The underwater system consisted of a 420 kHz transducer located 20cm off the river floor. The beam width of the sonar was 4.7°. Additionally, the slope of the river bottom, θ_s, was determined to be 8.53° and the grazing angle, θ, was calculated to be 6.18°. Freshwater attenuation coefficient is 0.0109 dB/m and the sound of speed in water is 1500 m/s.

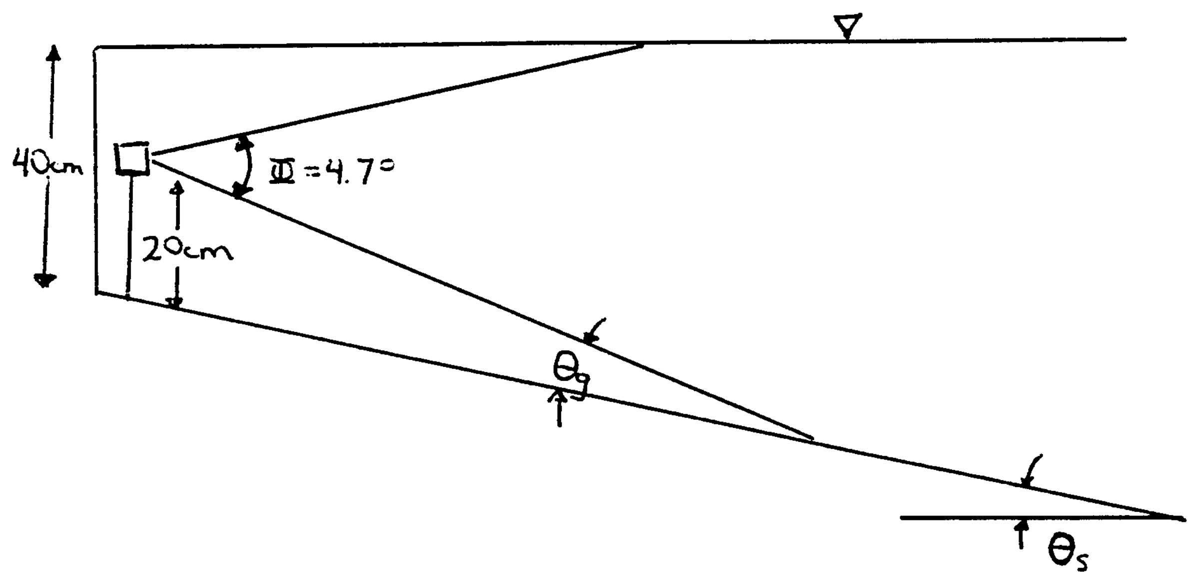

Figure 3: Schematic of Simulated Test Case

To better understand the occurrences of the sonar system several parameters were varied. Such variations included changing the scattering coefficients associated with differing bottom compositions, changing the volumetric coefficients associated with a windy or calm day, and changing sonar acoustic power.

Values for the scattering strength coefficient for the bottom, S_b, were obtained off figure 4. This graph was developed by applying a cubic spline fit to experimental data provided from actual measurements. For a grazing angle of 6.18° the coefficients were determined to be -12 dB for a rough rock bottom and -30 dB for both cobble and sandy gravel. Additionally, two coefficients of volumetric scattering were used. They were -40 for a calm day and -20 for a windy day.

Figure 5 illustrates case 1. The values of the variables selected for this case were Wa=1, S_b = -12 (rocky bottom) and S_v = -40 (calm day). The background and fish reverberation levels intersected at about 420 meters. The intersection point is also about 140 dB.

Figure 6 illustrates case 2. The only difference between case 1 and 2 is the sonar wattage, i.e. power put into the body of water, 1 watt and 100 watts respectively. As expected, if you put more power into the water you will get more backscattering, or a higher reverberation level. This is shown by noting that the point of intersection is now at 160 dB, versus 140 dB for the case of 1 Watt. The intersection point still occurs at 420 meters. Therefore, for more power input, the performance of the system is no better than a low power system. This is evident by looking at both the background and target reverberation levels. This result is due to the equivalent source level in both equations. Therefore, the source level is essentially a constant which cancels out.

Figure 7 shows case 3. Case three is under the most ideal of circumstances. The bottom composition is sandy gravel or cobble which is much more quite than a rough

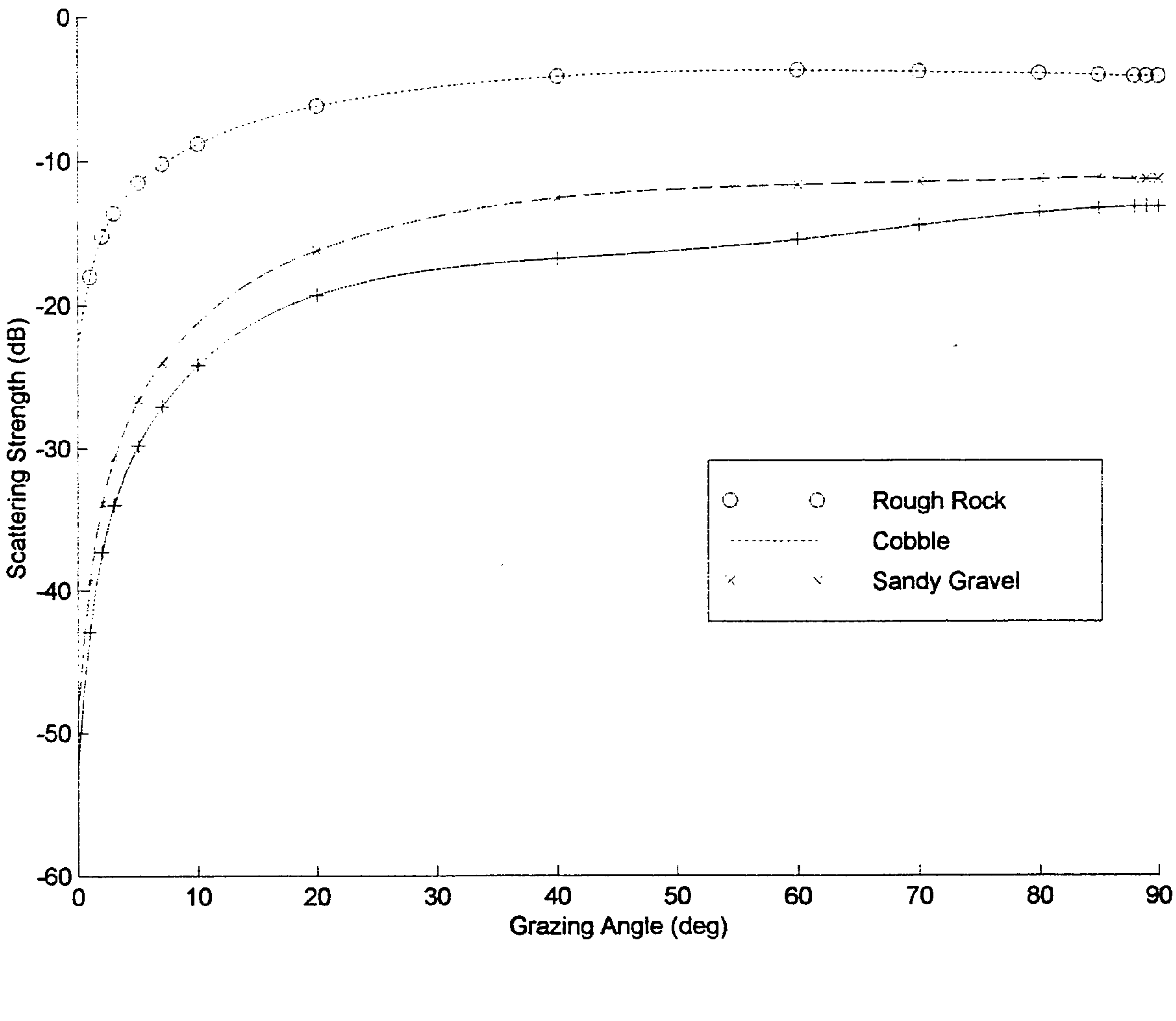

Figure 4: S_b for Differing Bottom Conditions

Watts = 1

$S_r = -40$

$S_B = -12$

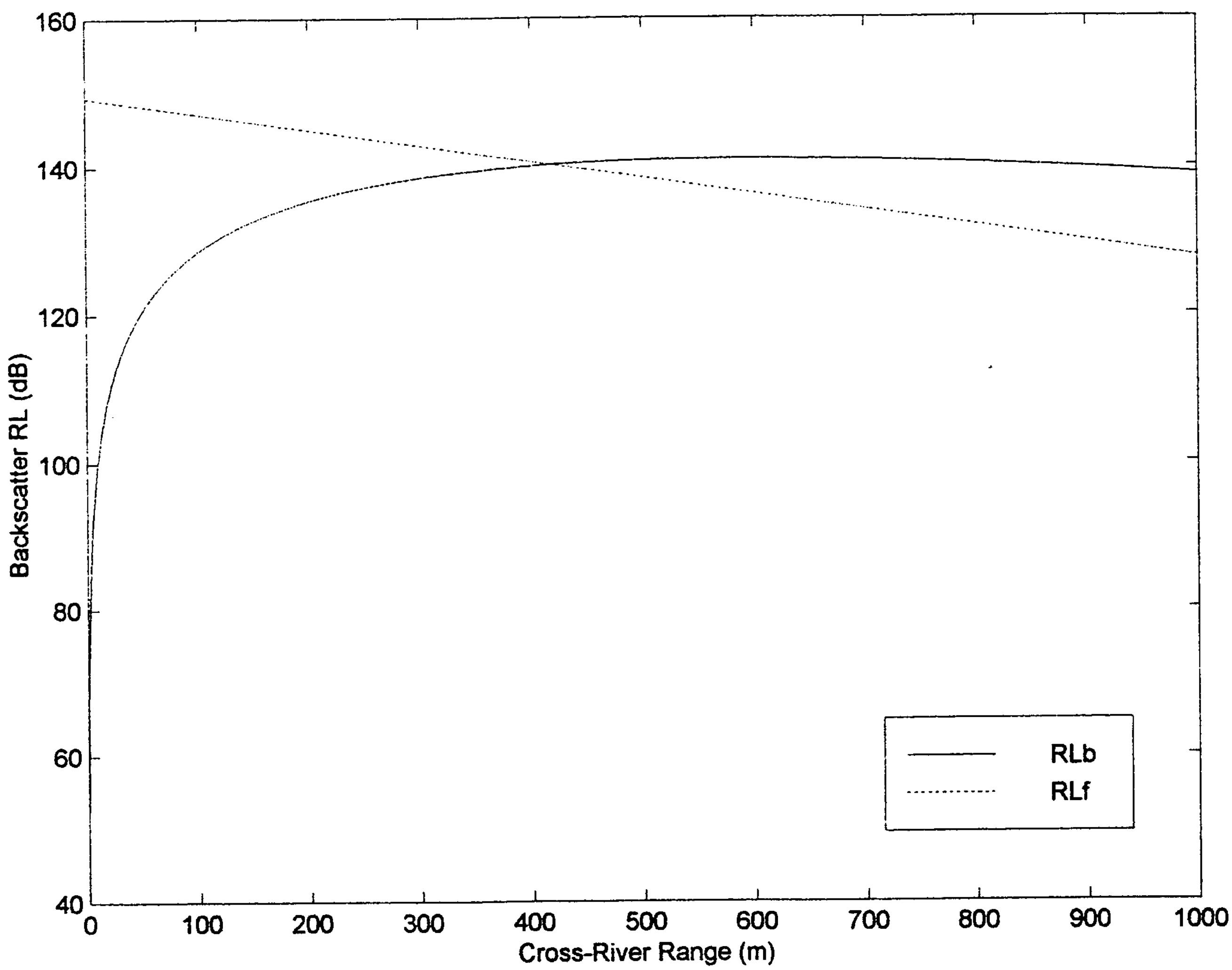

Figure 5: Case 1

Watts = 100
$S_V = -40$
$S_B = -12$

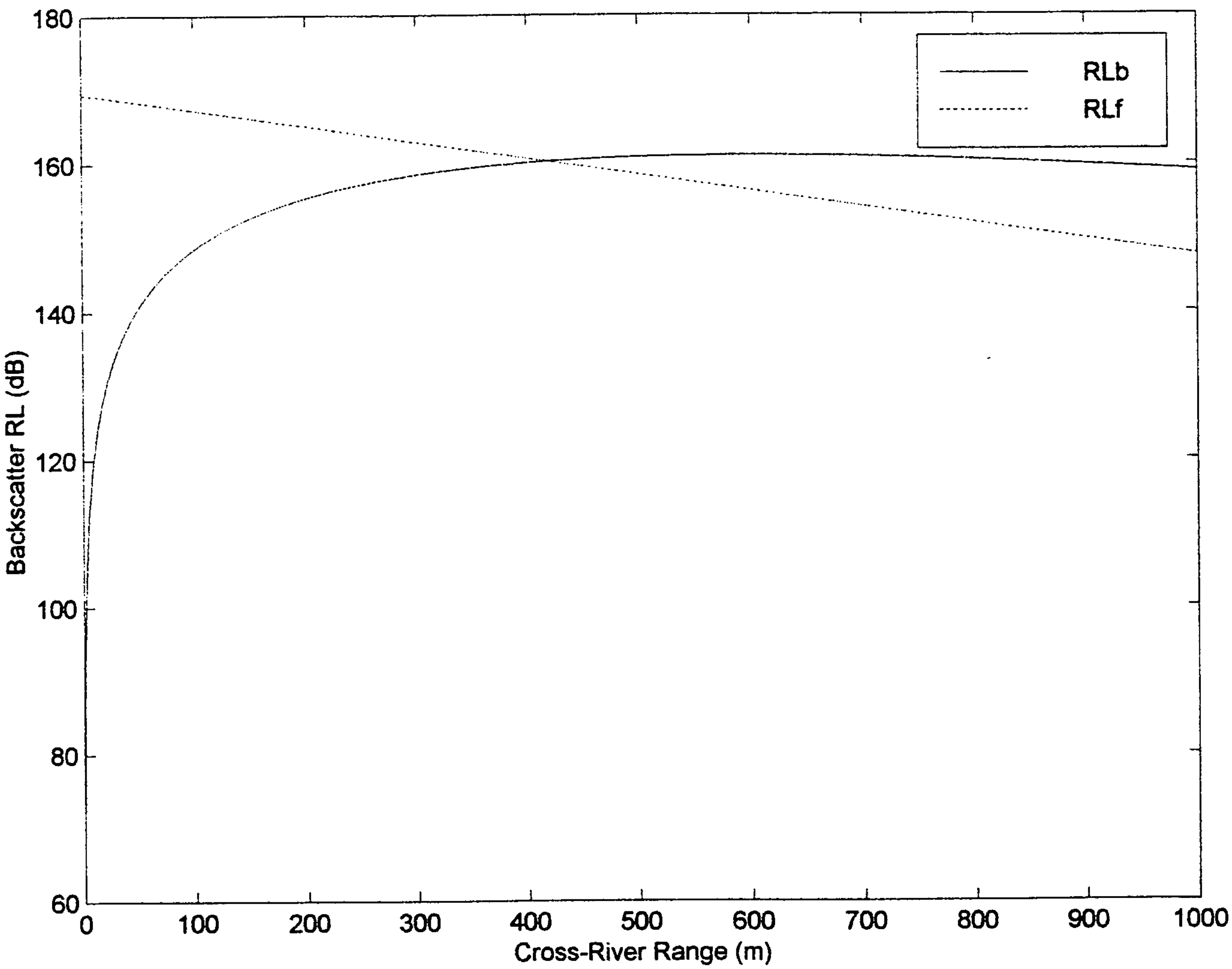

Figure 6: Case 2

WaHs = 1

S_v = -40

S_B = -30

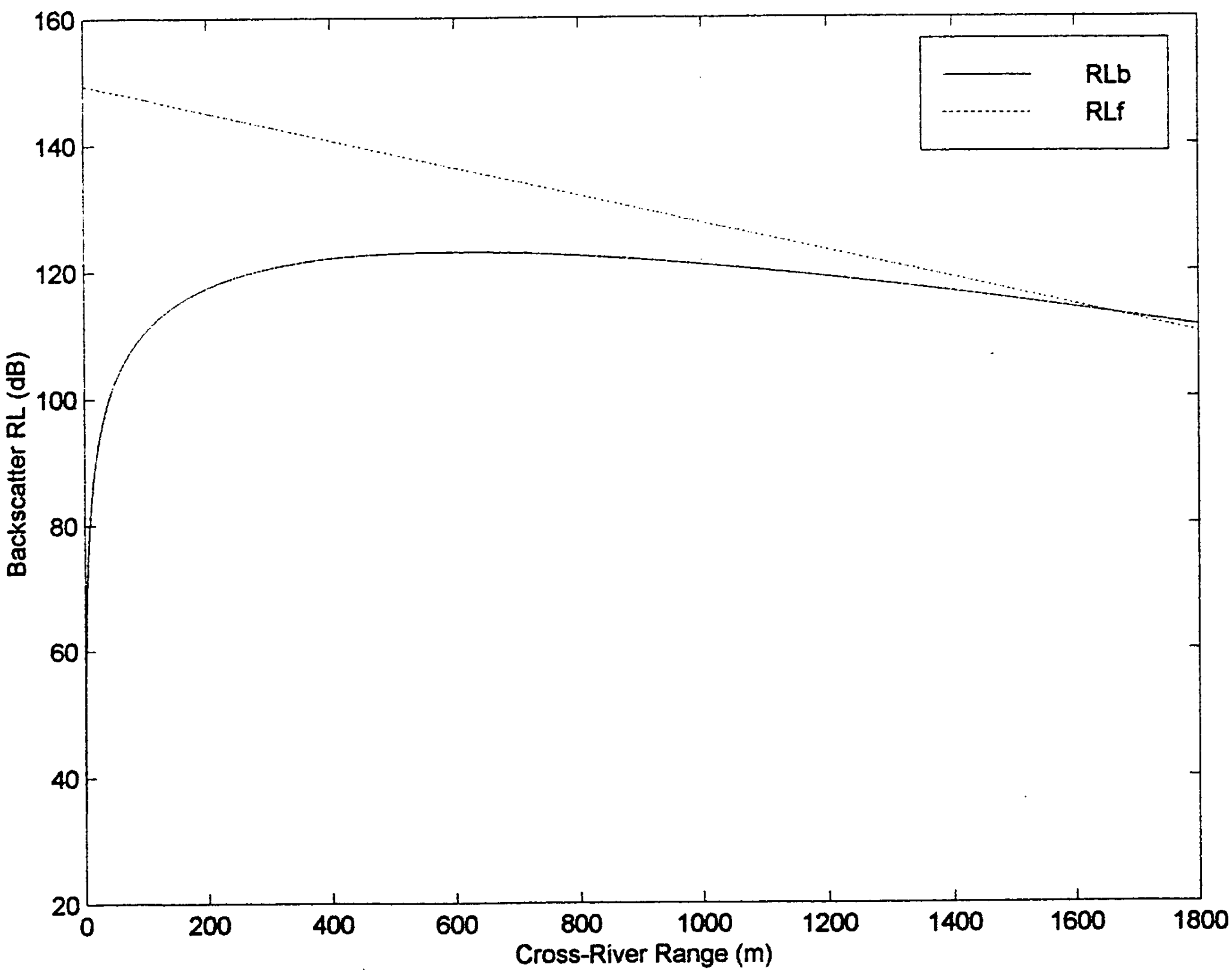

Figure 7: Case 3

rock bottom composition leading to a bottom scattering coefficient of -30 dB. Additionally, this case is for a calm day with no wind. This leads to a volume scattering coefficient of -40 dB. Simulating this data with a sonar with 1 watt of power, the fish and background reverberation models intersect at 1600 meters and 115 dB. This is a significant improvement in detection range of the previous cases. In fact this is the best case of all as far as detection range is considered.

Figure 8 is a graphical representation of case 4. This case simulates the most severe reverberation case. The volume scattering coefficient is for a windy day, -20 dB, and the bottom coefficient is for rough rock, -12 dB. This coefficients lead to high background reverberation level which severely reduces the target detection range of the sonar system. The background and fish reverberation levels intersect at 100 meters and 145 dB. This is a significant decrease in performance from all previous cases, especially case 3.

Figure 9 illustrates the final case, case 5. This simulation uses volume scattering coefficient of -20 dB which represents a windy day. This model also uses a bottom composition coefficient of -30 dB which represents sandy or cobble bottom. This background and fish target reverberation levels intersect at about 350 meters and 140 dB. This closely matches the performance of case 1, with coefficient of -40 dB and -12 dB. This similarity is due to the equivalent total contribution of the scattering coefficients, -50 dB for case 5 versus -52 dB for case 1.

Watts = 1
Sv = -20
S_B = -12

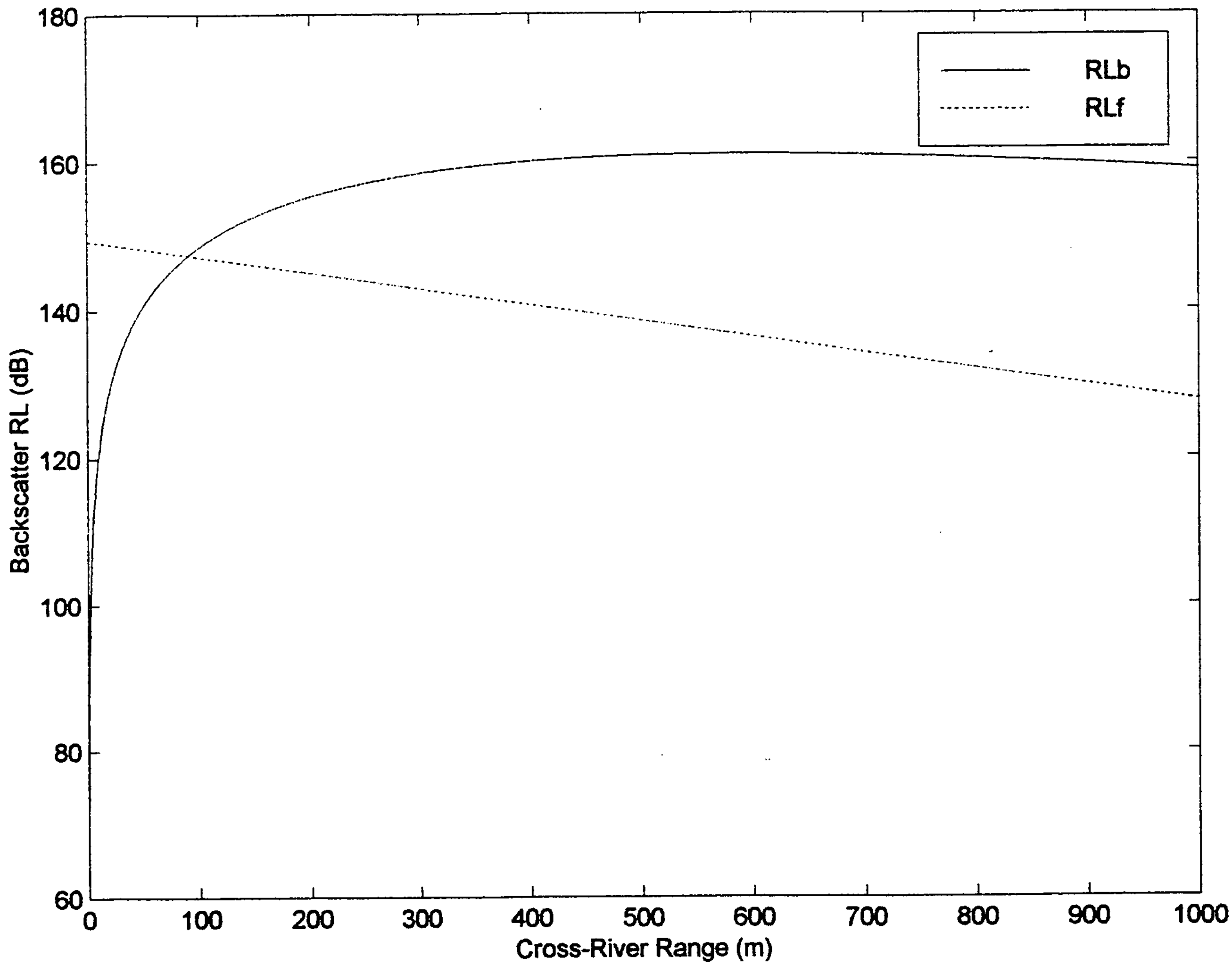

Figure 8 : Case 4

Watts = 1

$S_v = -20$

$S_B = -30$

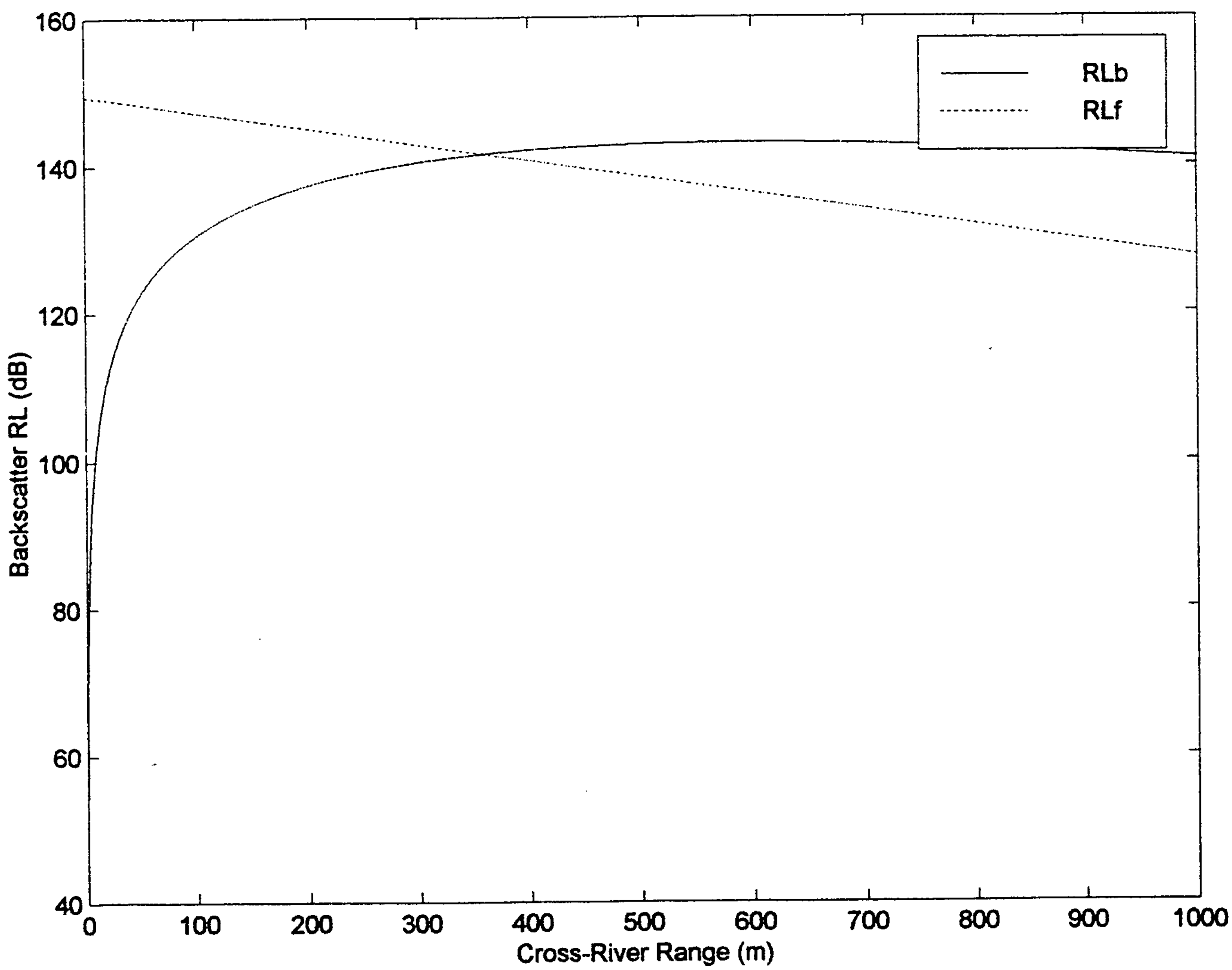

Figure 9: Case 5

EXPERIMENTAL DATA:

The purpose of this research was to develop the reverberation model and then compare the results with data obtained from a site in Alaska. From here, corrections and/or recommendations could be made to increase the accuracy of the reverberation model. Unfortunately, the data proved difficult to obtain.

CONCLUSIONS:

This paper aimed at investigating the components of reverberation which affect the range of target detection. Results from a simulation were originally going to be compared with data from an actual acoustic insonification of a river. Unfortunately, this goal was not realized. However, several important conclusions can be made by looking at the data obtain from modeling the background versus target reverberation levels. The first of these conclusions is that using sonars which insonify part of the river surface are strongly susceptible to interference from wind, boat wakes, or other disturbances of the water surface. Therefore, when implementing this type of device in actual practice it may be best to steer the acoustic beam so that it does to intersect the surface inside of the expected target detection range. Also, meteorological conditions should be closely measured to determine the impact on the surface conditions.

Additionally, bottom composition had a strong affect on the performance of the sonar system in detecting fish. The performance of such systems was noticeably less when the bottom composition consisted of a "noisy" surface such as large rocks. Therefore, when implementing this type of sonar system it would be best to set this system up in areas with a bottom composition which would allow optimal performance. Such sites would consist of sandy or cobble bottoms.

Finally, wattage was not a good indicator of sonar performance. One might automatically think that if you use a higher power system, higher performance will result. Unfortunately this is not true. The more power you put into the system the more background reverberation, and target reverberation, that the sonar system will receive. Therefore, it is not an advantage is increase the power of the system.

In all, this paper has discussed the possibility of using sonar systems to detect targets such as fish in riverine environments. If the system is properly set up allowing optimal performance, fish targets can be detected at great ranges. This would allow a much more accurate technique of counting migrating salmon. This would have a great impact on how the various species of salmon were managed by the fisheries departments of the Pacific Northwest.

REFERENCES:

Clay, C. and Medwin, H. Acoustical Oceanography: Principles and Applications. John Wiley and Sons.

Dahl, P. Environmental Acoustic and Salmonid Target Strength Properties That Affect the Performance of Riverine Sonars. (1997).

Gaudet, D. Enumeration of migrating salmon populations using fixed location sonar counters. Rapp. P.-V. Reun. Cons. Explor. Mer, 189:197-209 (1990).

Johannesson, K. and Mitson, R. Fisheries Acoustics: A Practical Manual for Aquatic Biomass Estimation. FAO Fisheries Technical Paper 240. Food and Agriculture Organization of the United Nations (1983).

Thorne, R.E., 1979. Hydroacoustic Estimate of Adult Sockeye Salmon (Oncorhynchus nerka) in Lake Washington, 1972-75. J. Fish. Res. Board Can. 36:1145-1149.

Trevorrow, M. V., 1997. Detection of Migrating salmon in the Frasier River using 100-kHz sidscan sonars. Can. J. Fish. Aquat. Sci. 54: 1619-1629 (1997)

Urick, R. Principles of Underwater Sound. McGraw Hill (1975).

APPENDIX 1: MATLAB Program

```
% Model Acoustical Reverberation in Underwater Riverine Sys.

%Defined Variables at 420kHz
f=420; %kHz
N=10; %number cycles transmitted
Wa=10; %acoustic power of sys-Watts
W=1000 %width of stream [m]
a=0.0109; %db/m -acoustic absorption
c=1500; %m/s sound speed
t=1/(f*1000)*N; % seconds sonar pulse length
L=c*t; %[m] pulse length
phe1=4.7; %beamwidth degrees
phe=4.7*pi/180;  %beamwidth radians
Sv=-50; %dB
Sb=-30 %dB Cobble and Sandy Gravel
%Sb=-12 %dB Rough Rock
thetap=phe/2; %half angle of beam width radians
m1=-.75/5;
m2=-tan(thetap);
B=((m2-m1)/(1+m1*m2));  %grazing angle radians
thetag=atan(B); %*180/pi%grazing angle in degrees
TSf=-30; %target str of fish

%Directivity Index
DI=10*log10(10*(16/phe1^2));

R=0.1:0.5:W;
time=R/1500;

%Target Strength of Bottom Reverb
TSb=10*log10(c*t*0.5*phe*R/cos(thetag))+Sb;

%TS of Volume Reverb
TSv=10*log10(R.^2*c*t*0.5*phe)+Sv;

%freshwater attentuation factor
attn=2*a*R;

%source level
SL=170.8+10*log10(Wa)+DI;

%Background RL and
%Sonar Eqn where TVG=40*logR
RLb=SL-attn+TSb+TSv;

%Fish RL where TVG=40logR
RLf=SL-attn+TSf;

%plot
plot (R,RLb,'-',R,RLf,':')
xlabel('Cross-River Range (m)')
ylabel ('Backscatter RL (dB)')
legend ('RLb', 'RLf')
```