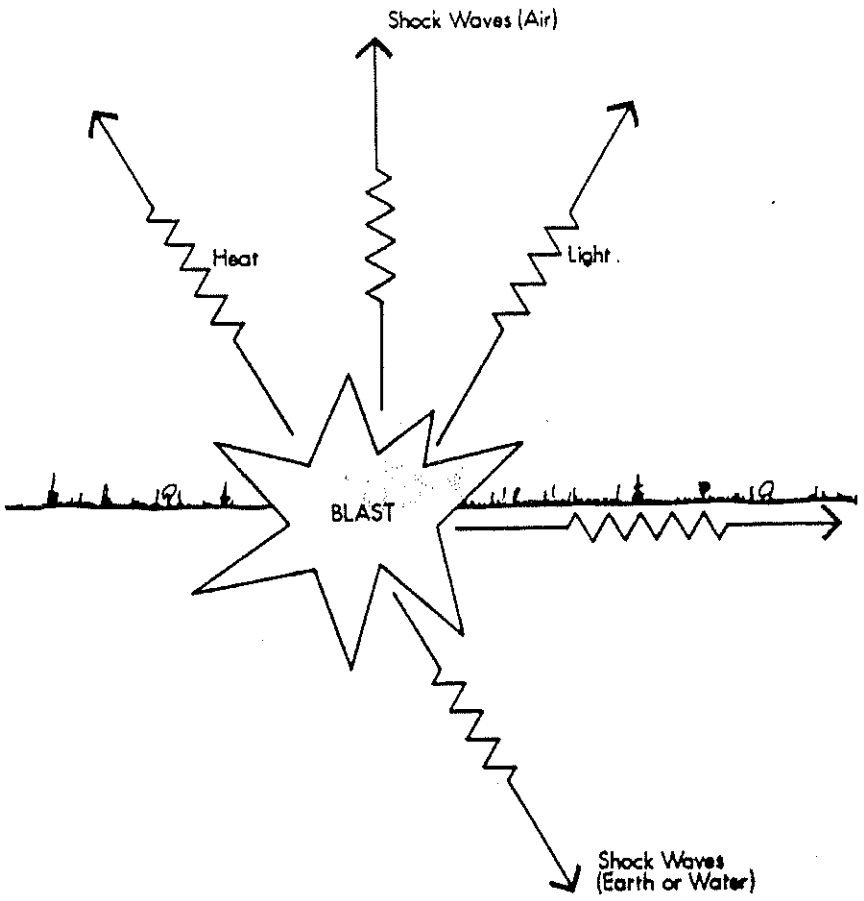
ALASKA DEPARTMENT OF FISH AND GAME



BLASTING STANDARDS

For the Protection of Fish

Rationale for Blasting Standards (11 AAC 95) Developed to Prevent Explosive Injury to Fish

Introduction

As interest in Alaska's resource development grows, the use of high explosives in conjunction with seismic exploration, rock quarrying, and road construction increases. Indiscriminate use of explosives in or near waterbodies, especially critical marine habitat and anadromous and high value resident fish streams and lakes, is potentially harmful to fish. Pursuant to AS 16.05.870 (the Anadromous Fish Act) and 11 AAC 95 (the Forest Practices Act), the Alaska Department of Fish and Game (ADF&G) has developed blasting standards for use near critical fish habitat.

ADF&G's blasting standards (11 AAC 95.248) state that "Without prior written approval from the Department of Fish and Game, no person may discharge an explosive that produces or is likely to produce an instantaneous pressure change greater than 2.7 pounds per square inch (psi) in the swim bladder of a fish or produces or is likely to produce a peak particle velocity greater than 0.5 inches per second (ips) in a spawning bed during the early stage of egg incubation." These standards result from a thorough review of the available literature and represent ADF&G's considered opinion on the maximum allowable blast impact within fish habitat.

Physical Phenomena Associated with Blasting

Explosives are chemical substances which, when detonated, instantaneously release large quantities of energy. Common explosives derive energy from chemical reactions such as oxidation (deflagration) of black powder or breaking of high energy chemical bonds (detonation) as in trinitrotoluene (TNT). In a deflagration, the reaction moves too slowly (less than 3,000 feet per second) to produce significant shock waves and is considered relatively harmless to fish (Hubbs and Rechnitzer, 1952). The detonation velocity of today's commercial explosives ranges from about 5,000 feet per second for ammonium nitrate-fuel oil (ANFO) compounds, up to 22,000 feet per second for detonating cords and certain primers (DuPont, 1980). These are the ranges of detonation velocities that produce the significant shock waves and instantaneous pressure changes that injure or kill fish.

Explosive energy is released as pressure, light, and heat (Figure 1). This energy generates a shock wave through the surrounding medium (air, soil, water). As the wave spreads from the source, its energy is distributed over an area inversely proportional to the radius. Thus, energy per unit area varies inversely to the square of the distance from the source, explaining in part the attenuation of shock waves over distance.

Explosives detonated underground produce pressure or seismic waves within the earth (Figure 2). Two modes of seismic wave

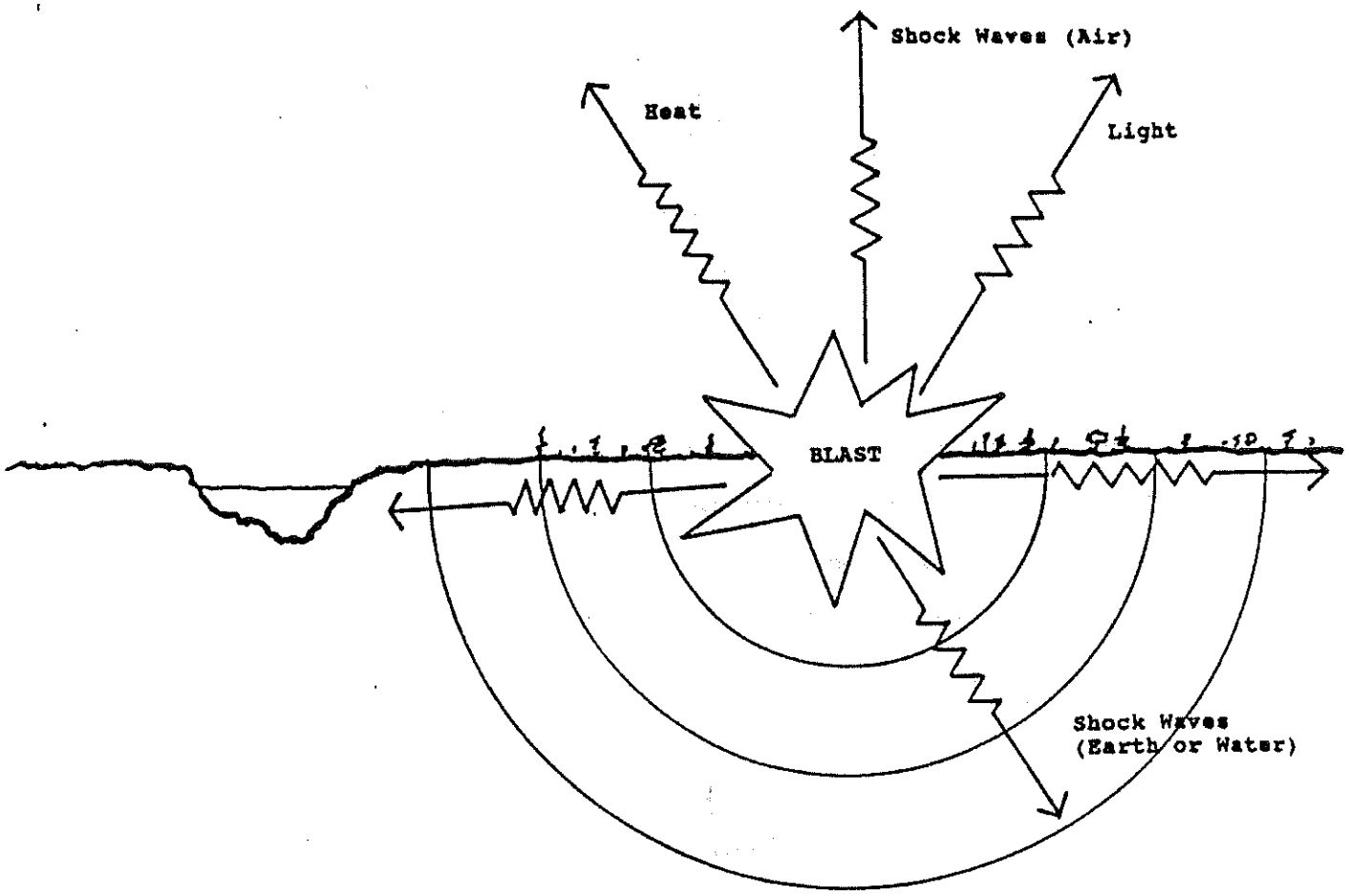


FIGURE 1. DISSIPATION OF EXPLOSIVE ENERGY

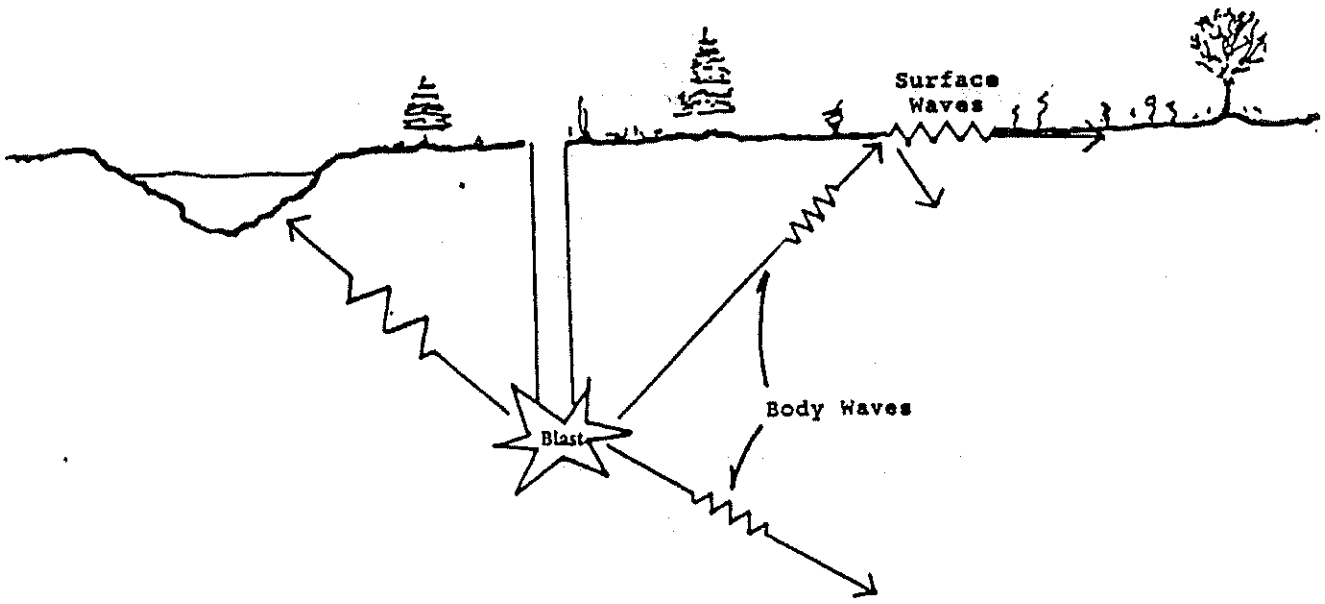


FIGURE 2. SEISMIC WAVES

have been identified; body waves and surface waves. Two types of body waves are propagated through the earth: compressional (Primary or "P") waves and shear (Secondary or "S") waves. Compressional waves have higher velocities than shear waves and are propagated from the earth into water bodies.

The second mode of wave propagation is along the earth's surface. Surface waves are usually produced when a body wave travels to the surface and is reflected back. These waves contribute to ground vibrations that are potentially lethal to incubating fish eggs.

Underwater shock waves generated by explosives are compressional waves with almost instantaneous rise times to peak pressure followed by an exponential decay and negative pressure (rarefaction) relative to ambient conditions (Cole, 1948; Figure 3). In terms of their effect on fish, shock waves generated by inwater explosions have a greater lethal effect than waves propagated from the ground into water because they exhibit a sharper pressure-time signature and, in underground explosions, part of the energy is reflected and lost at the ground-water interface.

Effect of Compression Waves on Fish

High instantaneous peak pressures followed by rarefaction can traumatize and kill fish (Hubbs and Rechnitzer, 1952; Wright, 1982). Injuries range from scale loss to ruptured internal

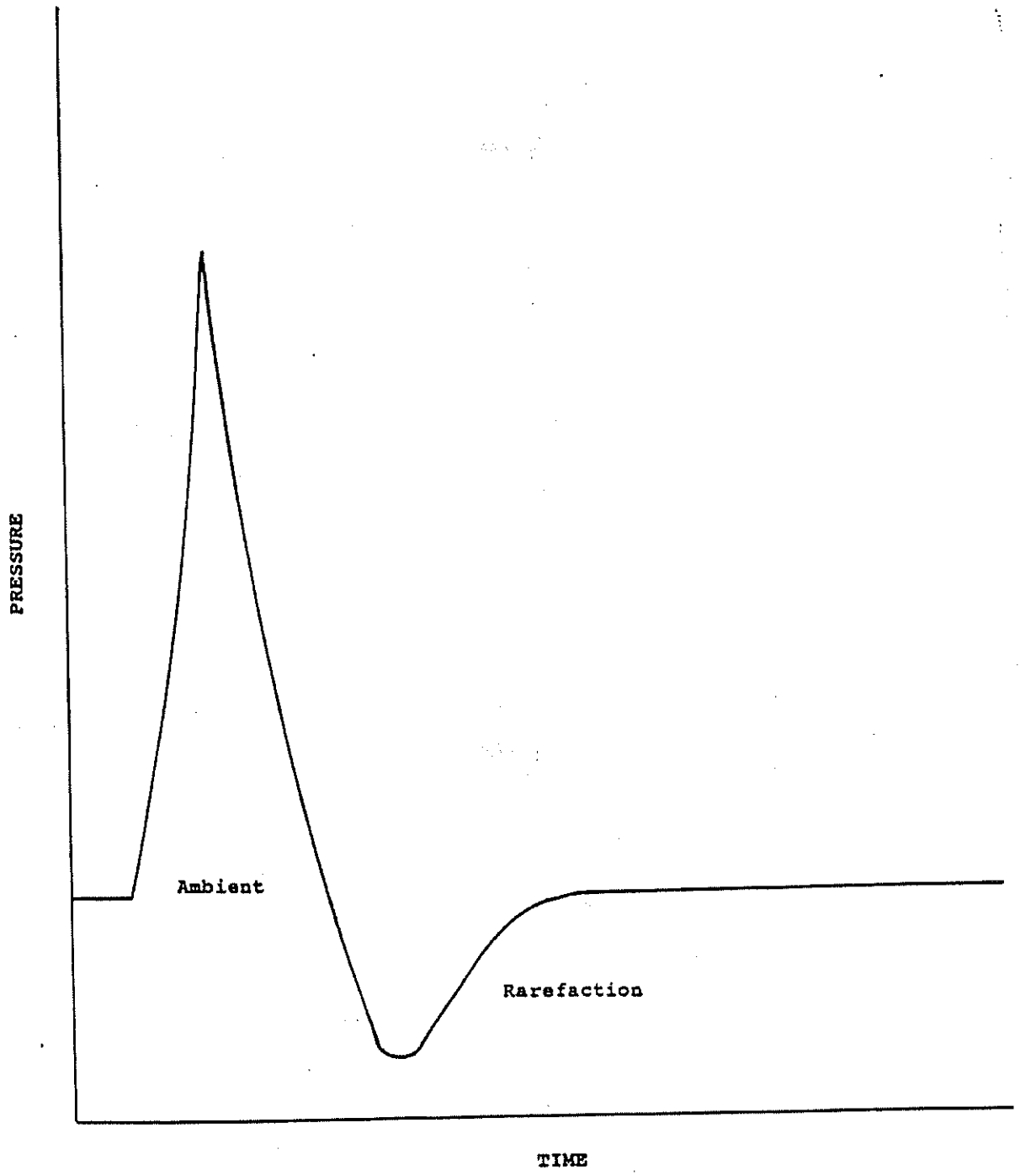


FIGURE 3. SIGNATURE OF UNDERWATER PRESSURE WAVE PRODUCED BY EXPLOSION

organs. While heart, kidney, blood vessels, spleen, liver, and gonads may be injured, the swim bladder is most sensitive to pressure change (Alpin, 1947; Hubbs and Rechnitzer, 1952; Christian, 1973; Falk and Lawrence, 1973; Yelverton, et al., 1975; Wright, 1982). Fish without swim bladders are relatively insensitive to underwater shock waves (Alpin, 1947). However, almost all Alaskan fish species important to sport, commercial, and subsistence fisheries have swim bladders.

The swim bladder is the hydrostatic organ that maintains buoyancy and stability in fish. Swim bladders can respond to a wide range of pressure changes; however, exposure to rapid pressure variations caused by explosions may not be accommodated. When subjected to pressure variations greater than the limits of accommodation, the swim bladder will experience trauma ranging from slight tissue strain to complete rupture leading to massive internal hemorrhaging. Mortality is caused either directly by trauma or indirectly through loss of equilibrium resulting in increased susceptibility to predation or inability to feed. No difference in response has been noted between fish that have ducted bladders (physotomatous) and those with closed swim bladders (physoclistous).

Body shape and orientation with respect to the wavefront affects susceptibility to pressure changes. Fish with cylindrical bodies are less likely to be injured by rapid pressure changes than those with dorsoventrally flattened bodies exhibiting a high surface area to volume ratio. Body size also has been

correlated to injury (Yelverton, et al., 1975). Smaller fish are more likely to be injured than larger fish. This factor places the small rearing juvenile salmonids at particular risk. Studies (Dames & Moore, 1987) demonstrate that fish closer to the water surface are more susceptible to physiological damage. The killing power of the rarefaction wave is greater near the air-water interface because of lower ambient pressures. Fish are less apt to be injured at greater depths because the increasing hydrostatic pressure soon exceeds the maximum negative pressure that can be generated by the rarefaction wave (Trasky, 1976). Again, rearing juvenile salmonids and spawning adults are at particular risk as they typically inhabit shallow water.

Blast Effects on Eggs and Larvae

Fish eggs are extremely sensitive to shock from the second day of fertilization until eye pigment forms. Eggs subjected to shock or movement during this period may die (FRED, 1983). Smirnov (1954, 1955) demonstrated that sensitivity varies with developmental stage (Table 1). The magnitude of agitation produced by Smirnov's testing approximates ground vibrations with a displacement of 0.12 inches and a frequency of three cycles per second. This falls within the range of ground vibrations generated by blasting activities.

Table 1. Mortality of pink salmon eggs subjected to mechanical agitation during incubation at temperatures between 46° to 49° F (Smirnov, 1954).

Age after Fertilization	Stage	Mortality in Percent
0	Prior to placing eggs in water	1
30 min.	During water absorption	95
2 hours		16
3 hours		5
1 day		24
2 days		26
3 days		56
9 days	Embryonic streak 2 mm.	75
18-19 days	Blastopore closing	30
22-24 days	Pigment in eyes	2
28-30 days	Eyes grey	0
39-40 days	Appearance of abdominal fins	0
51 days	Beginning of gill formation	0
63 days	Prior to hatching	0

Salmonid embryonic development is temperature regulated. Eggs developing in cold Alaskan waters require more time to reach the developmental stages shown in Table 1. Generally, 250-300 Temperature Units (1 T.U. = 1 centigrade degree day) are required by salmon to reach the eyed stage.

Table 1 demonstrates the high degree of sensitivity that salmonid eggs have to shock and vibration until the closing of the blastopore. This confirms fish culturists' observations that eggs become shock resistant with "eyeing-up," the stage of development just following blastopore closing.

Damage, due to compression shock, to eggs and developing embryos consist of deformation and compression of the membrane, spiral curling of the embryo, displacement of the embryo, and disruption of the vitelline membrane (Smirnov, 1954).

Newly hatched herring and salmon fry are less sensitive to shock waves than are eggs or post-larval fish in which the swim bladder has developed. Once the yolk sac has been absorbed and

formation of the swim bladder has begun, fry will die if exposed to pressures exceeding 2.8 psi (Bishai, 1961; Rasmussen, 1967). It should be noted that Bishai's results were recorded from laboratory studies. Field studies to measure pressure impacts on fish and to test predictive models for determining lethal ranges have produced more variable results.

In one study which monitored the effects of highway construction blasting in the Lowe River (Keystone Canyon) near Valdez, Bird and Roberson (1984) found no mortality in chum and coho salmon exposed to recorded peak overpressures of up to 2.7 psi. These overpressures were created by 102-1,673 pound shots set back 85-90 feet from the Lowe River. These low overpressures given large charge weights, were attributed to the special site conditions where blasting was done. The charges were placed in cliffs above the river and the blast energy was not confined within the material (Rasmussen and Mulcahy, 1985). In another study which measured the effects of buried (0.5-1.2 pound) dynamite charges in a gravel beach and in rock boulders at Lowell Point near Seward, Coastline Environmental Services (1987) found up to 40% mortality in coho salmon smolts exposed to peak overpressures (and underpressures) as low as 7.2 psi. Other studies (Dames & Moore, 1987; Munday, et. al., 1986) have found 50% mortality of salmon smolts with peak overpressures in the range of 19.3-21 psi and 8% mortality occurring as low as 4.4 psi. These studies have documented the difficulties both with developing reliable models to predict lethal ranges and with comparing data taken from different investigations due to

variable test conditions and lack of standardized calibration of monitoring equipment and reporting of results.

Rationale for Blasting Standards

Numerous physical models have been advanced to predict and relate fish trauma to explosive shock waves. All models have inherent weaknesses in predicting the effects of explosions under actual field conditions. This is particularly true for blasting adjacent to waterbodies where geologic conditions, local topography, and the ground-water interface act to attenuate, reflect, and refract shock waves.

Until further research develops a consistent model for predicting fish mortality, the best approach to protect valuable fish populations is to limit instantaneous hydrostactic pressure change in fish habitats to levels below those known to be harmful to fish. A pressure change of 2.7 psi is at the level recorded by Bird & Roberson (1984) where no fish mortality occurred. Moreover, 2.7 psi is 1.7 to 4.5 psi below the level where fish mortality has recently been observed (Dames & Moore, 1987; Coastline Environmental Services, 1987; Munday, et. al., 1986).

It should be noted that these investigations were unable to establish a "safe" (0 % mortality) lower limit. Until a safe limit has been established through additional research, a high level of protection should be achieved by limiting overpressures to 2.7 psi.

Protection of incubating fish eggs can be achieved by limiting ground vibrations in spawning beds during the early stage of egg incubation to low levels. Ground vibrations with a peak particle velocity of 0.5 inches per second (ips) are perceptible to humans but are 1.5 ips lower than the vibrations Smirnov (1954) found caused significant egg mortality. Interestingly, Smirnov found significant mortality occurring at 2 ips which is the safe limit established by the U.S. Bureau of Mines for structural vibrations from blasting (Nicholls, et al., 1971).

More recently, the Surface Mining Control and Reclamation Act (P.L. 95-87) has limited maximum particle velocity at sensitive sites to between 0.75 and 1.25 ips (Table 7). Even though the Office of Surface Mining (OSM) does not limit maximum particle velocities to levels as low as those proposed by ADF&G, in all cases OSM's standard setbacks are significantly more conservative than ADF&G's (Figures 5, 6, and 7). OSM's standard setbacks for a given charge weight incorportate a safety margin to accomodate variations from predicted blast impacts. ADF&G's setbacks do not incorporate these safety margins but rather rely on standards set below the level where mortality has been observed.

ADF&G's setbacks consider four parameters that help determine the impact of a given explosion: charge weight, distance from charge to waterbody, substrate type, and (in specific cases) local topography.

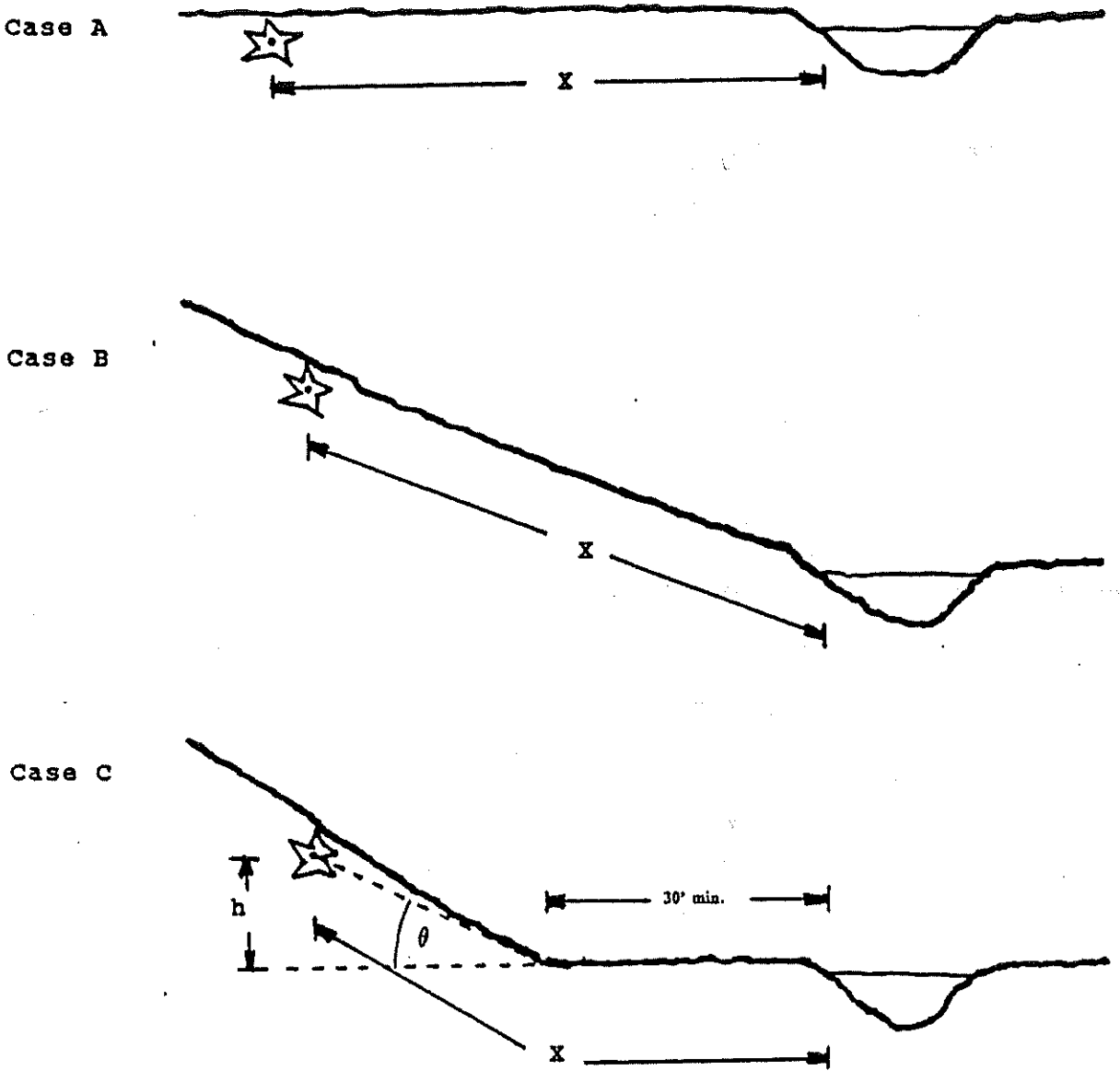
Empirical evidence demonstrates that energy released from an explosion is attenuated over distance proportional to the square of the distance from the blast point, and released energy is proportional to the size (weight) of charge used. Propagation of wave energy in different materials (i.e. bedrock, saturated soil, unsaturated soil, ice, frozen soil, water) varies based on the material's density and compressional wave velocity. Although empirical data are not available, there are indications that, in specific cases, topography and geology play a role in determining blast impacts. Investigations in Keystone Canyon indicate that blasting in materials located in cliffs above streams can induce significantly lower overpressures and ground vibrations than blasting on level ground adjacent to streams (Rasmussen and Mulcahy, 1985).

Analyses

The following analyses were used to derive the charge-distance-slope setbacks necessary to protect aquatic life in fish-bearing waters. The equations were adapted from Dupont (1977) and Nicholls, et al. (1971) to meet the standards described in the above rationale.

Three topographic conditions (Figure 4) are considered in the setbacks: horizontal ground between blast point and waterbody (Case A), a slope leading directly from blast point to waterbody(Case B), and a slope leading from the blast point to a horizontal plain adjacent to the waterbody (Case C).

FIGURE 4. THREE TOPOGRAPHIC CASES CONSIDERED IN ADF&G'S PROPOSED BLASTING STANDARDS



X = Total setback in feet from blast point to high value fish habitat. X is less than 30 feet only when reviewed on a case by case basis.

θ = Angle in degrees between valley floor and blast point.

h = Height in feet of center of charge above valley floor.

For given charge weight and distance, cases A and B are presumed to yield identical stream impacts. Where a slope descends directly to a waterbody, the effect of the blast will be the same as if on level ground. This is because seismic waves propagate spherically from the source, irrespective of the slope and direction (refer to Figure 1).

Case C is treated differently from cases A or B. The mathematical approach used to calculate these standards assumes that blast energy reaching the stream decreases as the angle between the valley floor and the center of charge increases. That is, the resultant impact on the stream decreases proportionally with the cosine of the angle between the valley floor and the center of charge.

The distinction between Case B and Case C is that the distance between the waterbody and the slope break must be at least 30 feet to meet the criteria of Case C (Figure 4). The 30 feet is a safety factor to ensure that there is a sufficient offset from the waterbody to avoid unpredictable propagation and refraction of seismic waves. In all three cases (A, B, or C), the minimum distance between the center of charge and waterbody for all charge weights is 30 feet. Proposed blasting within 30 feet will be reviewed on a case by case basis.

Additionally, in Case C situations, the height of the center of charge above the valley floor (Figure 4) will not be less than the appropriate distances listed in Tables 5a-5e and 6. These minimum heights above the valley floor are based on the charge weight and slope and derive from the equation:

$$h = \sqrt{W} \sin\theta$$

Where h = height (feet) of center of charge above valley floor

W = charge weight (lbs) per interval

θ = Angle (degrees) between valley floor and center of charge

General Equations

Equation (A) is used to describe the transfer of shock pressure from the substrate to the water:

$$(A) \quad P_w = \frac{2\,\frac{Z_w}{Z_r}\,P_r}{1 + \frac{Z_w}{Z_r}}$$

Where P_w = pressure (lbs/in^2) in water

P_r = pressure (lbs/in^2) in substrate

Z_w = acoustic impedance (lbs/ft^2-s) of water

Z_r = acoustic impedance (lbs/ft^2-s) of substrate

Equation (B) is used to describe the relationship between acoustic impedance and the density and velocity of the medium through which the compressional wave travels:

$$(B) \quad \frac{Z_w}{Z_r} = \frac{D_w C_w}{D_r C_r}$$

Where D_w = density of water = 62.5 pounds per cubic foot (lbs/ft^3)

D_r = density (lbs/ft^3) of substrate

C_w = compressional wave velocity in water = 4,800 feet per second (ft/s)

C_r = compressional wave velocity (ft/s) in substrate

The following values were used for D_r and C_r for various substrate types:

	D_r		C_r
	lbs/ft^3	g/cm^3	ft/s
Rock	165	2.64	15,000
Frozen Soil	120	1.92	10,000
Ice	61	0.98	10,000
Saturated Soil	130	2.08	4,800
Unsaturated Soil	120	1.92	1,500

Equation (C) describes the relationship between the peak particle velocity (V_r) and the pressure, density, and compressional wave velocity in the substrate:

$$(C) \quad V_r = \frac{2P_r}{D_r C_r}$$

Equation (D) is known as the scaled distance relationship and is used to equate the peak particle velocity to charge weight, distance, and slope:

$$(D) \quad V_r = 160\left(\frac{R}{\sqrt{W}\cos\theta}\right)^{-1.6}$$

Where V_r = peak particle velocity (in/s)

R = distance (ft) between blast and waterbody

W = charge weight (lbs)

θ = angle (degrees) between valley floor and blast point

Example solution for calculating Case C charge-distance setbacks to meet 2.7 psi limit for blasting in rock using a 100 pound charge and a 30° angle between the valley floor and the blast point.

1. From equation (B): $$\frac{Z_w}{Z_r} = \frac{(\frac{62.5\ lbs}{ft^3})(\frac{4,800\ ft}{s})}{(\frac{165\ lbs}{ft^3})(\frac{15,000\ ft}{s})} = 0.1212$$

2. From equation(A): $$P_r = \frac{P_w(1 + 0.12)}{2(0.12)}$$

3. Limit P_w to 2.7psi: $$P_r = \frac{(\frac{2.7\ lbs}{in^2})(1.12)}{(2)(0.12)} = \frac{12.5\ lbs}{in^2}$$

4. Convert psi to gram-centimeters per second squared:

$$(\frac{12.5\ lbs}{in^2})(\frac{4.4482\ x\ 10^5\ dynes}{lbs})(\frac{1\ in^2}{6.4516\ cm^2})(\frac{\frac{1\ g\text{-}cm}{s^2}}{dyne})$$

$$= \frac{\frac{8.61\ x\ 10^5\ g\text{-}cm}{s^2}}{cm^2} = \frac{8.61\ x\ 10^5\ g}{cm\text{-}s^2}$$

5. From equation (C):

$$V_r = \frac{2(\frac{8.61\ x\ 10^5\ g}{cm\text{-}s^2})}{(\frac{2.64\ g}{cm^3})(\frac{15,000\ ft}{s})(\frac{30.48\ cm}{ft})} = \frac{1.43\ cm}{s}$$

6. Convert $\frac{cm}{s}$ to $\frac{in}{s}$ (ips): $(\frac{1.43\ cm}{s})(\frac{0.39\ in}{cm}) = \frac{0.56\ in}{s}$

7. From equation (D): $V_r = 160(\frac{R}{\sqrt{W}\cos\theta})^{-1.6}$

$$R = \sqrt{W}\cos\theta(\frac{V_r}{160})^{-0.625}$$

$$= (\sqrt{100\ lbs})(\cos 30°)(\frac{\frac{0.56\ in}{s}}{\frac{160\ lbs\text{-}in}{s\text{-}ft}})^{-0.625}$$

$$= (10\ lbs)(0.87)(\frac{34\ ft}{lbs}) = 298\ ft$$
295.8

Example solution for calculating charge-distance setbacks to meet 0.5 ips limit in spawning beds

1. From equation (D): $V_r = 160(\frac{R}{\sqrt{W}\cos\theta})^{-1.6}$

$$R = \sqrt{W}\cos\theta(\frac{Vr}{160})^{-0.625}$$

$$= (\sqrt{100\ lbs})(\cos 30°)(\frac{\frac{0.50\ in}{s}}{\frac{160\ lbs\text{-}in}{s\text{-}ft}})^{-0.625}$$

$$= (10\ lbs)(0.87)(\frac{38\ ft}{lbs}) = 319\ ft$$

TABLE 3: CASE A AND B SETBACKS FROM ANADROMOUS FISH WATERS (2.7 psi Standard) (in feet)[1/]

	Explosive Charge Weight (in pounds)[2/]							
Material	1	2	5	10	25	100	500	1000
Rock	34	49	77	109	172	344	769	1088
Frozen Soil	32	45	72	102	161	322	719	1017
Ice	30	41	64	91	144	288	644	910
Saturated Soil	30	41	65	91	145	289	647	915
Unsaturated Soil	30	30	45	63	100	200	448	633

1/ The straight line distance through the material from the center of the charge to the waterbody, assuming that the blast energy is confined within the material. Uncontained blasts or explosive charges with a detonation velocity of less than 5,000 feet per second will be reviewed on a case-by-case basis.

2/ The scaled distance relationships apply to single shots of a given weight of explosive or single shots in a multiple charge if each charge is separated by an eight millisecond or longer delay. For example, a 500 pound shot on level ground in rock requires a setback distance from a waterbody of 769 feet; a 500 pound shot in rock in charges of 100 pounds each separated by eight millisecond or longer delays requires a setback distance of 344 feet.

TABLE 4: CASE A AND B SETBACKS FROM SPAWNING BED (0.5 ips Standard) (in feet)[1/]

	Explosive Charge Weight (in pounds)[2/]							
	1	2	5	10	25	100	500	1000
All Materials	37	52	82	116	184	368	823	1163

1/ The straight line distance through the material from the center of the charge to the waterbody, assuming that the blast energy is confined within the material. Uncontained blasts or explosive charges with a detonation velocity of less than 5,000 feet per second will be reviewed on a case-by-case basis.

2/ The scaled distance relationships apply to single shots of a given weight of explosive or single shots in a multiple charge if each charge is separated by an eight millisecond or longer delay. For example, a 500 pound shot on level ground in rock requires a setback distance from a waterbody of 823 feet; a 500 pound shot in rock in charges of 100 pounds each separated by eight millisecond or longer delays requires a setback distance of 368 feet.

TABLE 5a: CASE C SETBACKS FROM ANADROMOUS FISH WATERS (2.7 psi Standard) (in feet)[1/]

Material: Rock

Explosive Charge Weight (in pounds)[2/]

		1	2	5	10	25	100	500	1000
Slope	10°	34(0)	48(0)	76(0)	107(1)	169(1)	339(2)	758(4)	1072(5)
	20°	32(0)	46(0)	72(1)	102(1)	162(2)	323(3)	723(8)	1023(11)
	30°	30(0)	42(1)	67(1)	94(2)	149(2)	298(5)	666(11)	942(16)
	40°	31(1)	37(1)	59(1)	83(2)	132(3)	264(6)	589(14)	834(20)
	50°	31(1)	31(1)	49(2)	70(2)	111(4)	221(8)	495(17)	699(24)
	60°	31(1)	31(1)	38(2)	54(3)	86(4)	172(9)	385(19)	544(27)
	70°	31(1)	31(1)	32(2)	37(3)	59(5)	118(9)	263(21)	372(30)
	80°	31(1)	31(1)	32(2)	33(3)	35(5)	60(10)	134(22)	189(31)
	90°	31(1)	31(1)	32(2)	33(3)	35(5)	40(10)	52(22)	62(32)

(N) = Minimum height in feet of center of charge above valley floor (see text and Figure 4).

1/ The straight line distance through the material from the center of the charge to the waterbody, assuming that the blast energy is confined within the material. Uncontained blasts or explosive charges with a detonation velocity of less than 5,000 feet per second will be reviewed on a case-by-case basis.

2/ The scaled distance relationships apply to single shots of a given weight of explosive or single shots in a multiple charge if each charge is separated by an eight millisecond or longer delay. For example, a 500 pound shot on a 10° slope in rock requires a setback distance from a waterbody of 758 feet; a 500 pound shot in rock in charges of 100 pounds each separated by eight millisecond or longer delays requires a setback distance of 339 feet.

TABLE 5b: CASE C SETBACKS FROM ANADROMOUS FISH WATERS (2.7 psi Standard) (in feet)[1/]

Material: Frozen Soil

		Explosive Charge Weight (in pounds)[2/]							
		1	2	5	10	25	100	500	1000
Slope	10°	32(0)	45(0)	71(0)	100(1)	158(1)	317(2)	708(4)	1001(5)
	20°	30(0)	43(0)	68(1)	96(1)	151(2)	302(3)	676(8)	955(11)
	30°	30(0)	39(1)	62(1)	88(2)	139(2)	278(5)	623(11)	881(16)
	40°	31(1)	35(1)	55(1)	78(2)	123(3)	246(6)	551(14)	779(20)
	50°	31(1)	31(1)	46(2)	65(2)	103(4)	207(8)	462(17)	654(24)
	60°	31(1)	31(1)	36(2)	51(3)	80(4)	161(9)	359(19)	508(27)
	70°	31(1)	31(1)	32(2)	35(3)	55(5)	110(9)	246(21)	348(30)
	80°	31(1)	31(1)	32(2)	33(3)	35(5)	56(10)	125(22)	177(31)
	90°	31(1)	31(1)	32(2)	33(3)	35(5)	40(10)	52(22)	62(32)

(N) = Minimum height in feet of center of charge above valley floor (see text and Figure 4).

1/ The straight line distance through the material from the center of the charge to the waterbody, assuming that the blast energy is confined within the material. Uncontained blasts or explosive charges with a detonation velocity of less than 5,000 feet per second will be reviewed on a case-by-case basis.

2/ The scaled distance relationships apply to single shots of a given weight of explosive or single shots in a multiple charge if each charge is separated by an eight millisecond or longer delay. For example, a 500 pound shot on a 10° slope in frozen soil requires a setback distance from a waterbody of 708 feet; a 500 pound shot in frozen soil in charges of 100 pounds each separated by eight millisecond or longer delays requires a setback distance of 317 feet.

TABLE 5c: CASE C SETBACKS FROM ANADROMOUS FISH WATERS (2.7 psi Standard) (in feet)[1/]

Material: Ice

		Explosive Charge Weight (in pounds)[2/]							
		1	2	5	10	25	100	500	1000
Slope	10°	30(0)	40(0)	63(0)	90(1)	142(1)	283(2)	634(4)	897(5)
	20°	30(0)	38(0)	60(1)	86(1)	135(2)	271(3)	605(8)	855(11)
	30°	30(0)	35(1)	56(1)	79(2)	125(2)	249(5)	557(11)	788(16)
	40°	31(1)	31(1)	49(1)	70(2)	110(3)	221(6)	493(14)	697(20)
	50°	31(1)	31(1)	41(2)	59(2)	93(4)	185(8)	414(17)	585(24)
	60°	31(1)	31(1)	32(2)	46(3)	72(4)	144(9)	322(19)	455(27)
	70°	31(1)	31(1)	32(2)	33(3)	49(5)	98(9)	220(21)	311(30)
	80°	31(1)	31(1)	32(2)	33(3)	35(5)	50(10)	112(22)	158(31)
	90°	31(1)	31(1)	32(2)	33(3)	35(5)	40(10)	52(22)	62(32)

(N) = Minimum height in feet of center of charge above valley floor (see text and Figure 4).

1/ The straight line distance through the material from the center of the charge to the waterbody, assuming that the blast energy is confined within the material. Uncontained blasts or explosive charges with a detonation velocity of less than 5,000 feet per second will be reviewed on a case-by-case basis.

2/ The scaled distance relationships apply to single shots of a given weight of explosive or single shots in a multiple charge if each charge is separated by an eight millisecond or longer delay. For example, a 500 pound shot on a 10° slope in ice requires a setback distance from a waterbody of 634 feet; a 500 pound shot in ice in charges of 100 pounds each separated by eight millisecond or longer delays requires a setback distance of 283 feet.

TABLE 5d: CASE C SETBACKS FROM ANADROMOUS FISH WATERS (2.7 psi Standard) (in feet)[1/]

Material: Saturated Soil

		Explosive Charge Weight (in pounds)[2/]							
		1	2	5	10	25	100	500	1000
Slope	10°	30(0)	40(0)	64(0)	90(1)	142(1)	285(2)	637(4)	901(5)
	20°	30(0)	38(0)	61(1)	86(1)	136(2)	272(3)	608(8)	859(11)
	30°	30(0)	35(1)	56(1)	79(2)	125(2)	250(5)	560(11)	792(16)
	40°	31(1)	31(1)	50(1)	70(2)	111(3)	222(6)	495(14)	701(20)
	50°	31(1)	31(1)	42(2)	59(2)	93(4)	186(8)	416(17)	588(24)
	60°	31(1)	31(1)	32(2)	46(3)	72(4)	145(9)	323(19)	457(27)
	70°	31(1)	31(1)	32(2)	33(3)	49(5)	99(9)	221(21)	313(30)
	80°	31(1)	31(1)	32(2)	33(3)	35(5)	50(10)	112(22)	159(31)
	90°	31(1)	31(1)	32(2)	33(3)	35(5)	40(10)	52(22)	62(32)

(N) = Minimum height in feet of center of charge above valley floor (see text and Figure 4).

1/ The straight line distance through the material from the center of the charge to the waterbody, assuming that the blast energy is confined within the material. Uncontained blasts or explosive charges with a detonation velocity of less than 5,000 feet per second will be reviewed on a case-by-case basis.

2/ The scaled distance relationships apply to single shots of a given weight of explosive or single shots in a multiple charge if each charge is separated by an eight millisecond or longer delay. For example, a 500 pound shot on a 10° slope in saturated soil requires a setback distance from a waterbody of 637 feet; a 500 pound shot in saturated soil in charges of 100 pounds each separated by eight millisecond or longer delays requires a setback distance of 285 feet.

TABLE 5e: CASE C SETBACKS FROM ANADROMOUS FISH WATERS (2.7 psi Standard) (in feet)[1/]

Material: Unsaturated Soil

Explosive Charge Weight (in pounds)[2/]

		1	2	5	10	25	100	500	1000
Slope	10°	30(0)	30(0)	44(0)	62(1)	99(1)	197(2)	441(4)	624(5)
	20°	30(0)	30(0)	42(1)	60(1)	94(2)	188(3)	421(8)	595(11)
	30°	30(0)	31(1)	39(1)	55(2)	87(2)	173(5)	388(11)	548(16)
	40°	31(1)	31(1)	34(1)	49(2)	77(3)	153(6)	343(14)	485(20)
	50°	31(1)	31(1)	32(2)	41(2)	64(4)	129(8)	288(17)	407(24)
	60°	31(1)	31(1)	32(2)	33(3)	50(4)	100(9)	224(19)	317(27)
	70°	31(1)	31(1)	32(2)	33(3)	35(5)	68(9)	153(21)	217(30)
	80°	31(1)	31(1)	32(2)	33(3)	35(5)	40(10)	78(22)	110(31)
	90°	31(1)	31(1)	32(2)	33(3)	35(5)	40(10)	52(22)	62(32)

(N) = Minimum height in feet of center of charge above valley floor (see text and Figure 4).

1/ The straight line distance through the material from the center of the charge to the waterbody, assuming that the blast energy is confined within the material. Uncontained blasts or explosive charges with a detonation velocity of less than 5,000 feet per second will be reviewed on a case-by-case basis.

2/ The scaled distance relationships apply to single shots of a given weight of explosive or single shots in a multiple charge if each charge is separated by an eight millisecond or longer delay. For example, a 500 pound shot on a 10° slope in unsaturated soil requires a setback distance from a waterbody of 441 feet; a 500 pound shot in unsaturated soil in charges of 100 pounds each separated by eight millisecond or longer delays requires a setback distance of 197 feet.

TABLE 6: CASE C SETBACKS FROM SPAWNING BED (0.5 ips Standard) (in feet)[1/]

Material: All Substrates

Explosive Charge Weight (in pounds)[2/]

		1	2	5	10	25	100	500	1000
Slope	10°	36(0)	51(0)	81(0)	115(1)	181(1)	362(2)	810(4)	1146(5)
	20°	35(0)	49(0)	77(1)	109(1)	173(2)	348(3)	773(8)	1093(11)
	30°	32(0)	45(1)	71(1)	101(2)	159(2)	319(5)	712(11)	1008(16)
	40°	31(1)	40(1)	63(1)	89(2)	141(3)	282(6)	630(14)	891(20)
	50°	31(1)	33(1)	53(2)	75(2)	118(4)	236(8)	529(17)	748(24)
	60°	31(1)	31(1)	41(2)	58(3)	92(4)	184(9)	411(19)	582(27)
	70°	31(1)	31(1)	32(2)	48(3)	63(5)	126(9)	281(21)	398(30)
	80°	31(1)	31(1)	32(2)	33(3)	35(5)	64(10)	143(22)	202(31)
	90°	31(1)	31(1)	32(2)	33(3)	35(5)	40(10)	52(22)	62(32)

(N) = Minimum height in feet of center of charge above valley floor (see text and Figure 4).

1/ The straight line distance through the material from the center of the charge to the waterbody, assuming that the blast energy is confined within the material. Uncontained blasts or explosive charges with a detonation velocity of less than 5,000 feet per second will be reviewed on a case-by-case basis.

2/ The scaled distance relationships apply to single shots of a given weight of explosive or single shots in a multiple charge if each charge is separated by an eight millisecond or longer delay. For example, a 500 pound shot on a 10° slope in unsaturated soil requires a setback distance from a waterbody of 810 feet; a 500 pound shot in unsaturated soil in charges of 100 pounds each separated by eight millisecond or longer delays requires a setback distance of 362 feet.

TABLE 7: SETBACKS FROM SENSITIVE SITES
(in feet)

Office of Surface Mining (Code of Federal Regulations, 1990)

	Explosive Charge Weight (in pounds)							
	1	2	5	10	25	100	500	1000
Setback (ft)	50	71	112	158	250	550	1230	1739

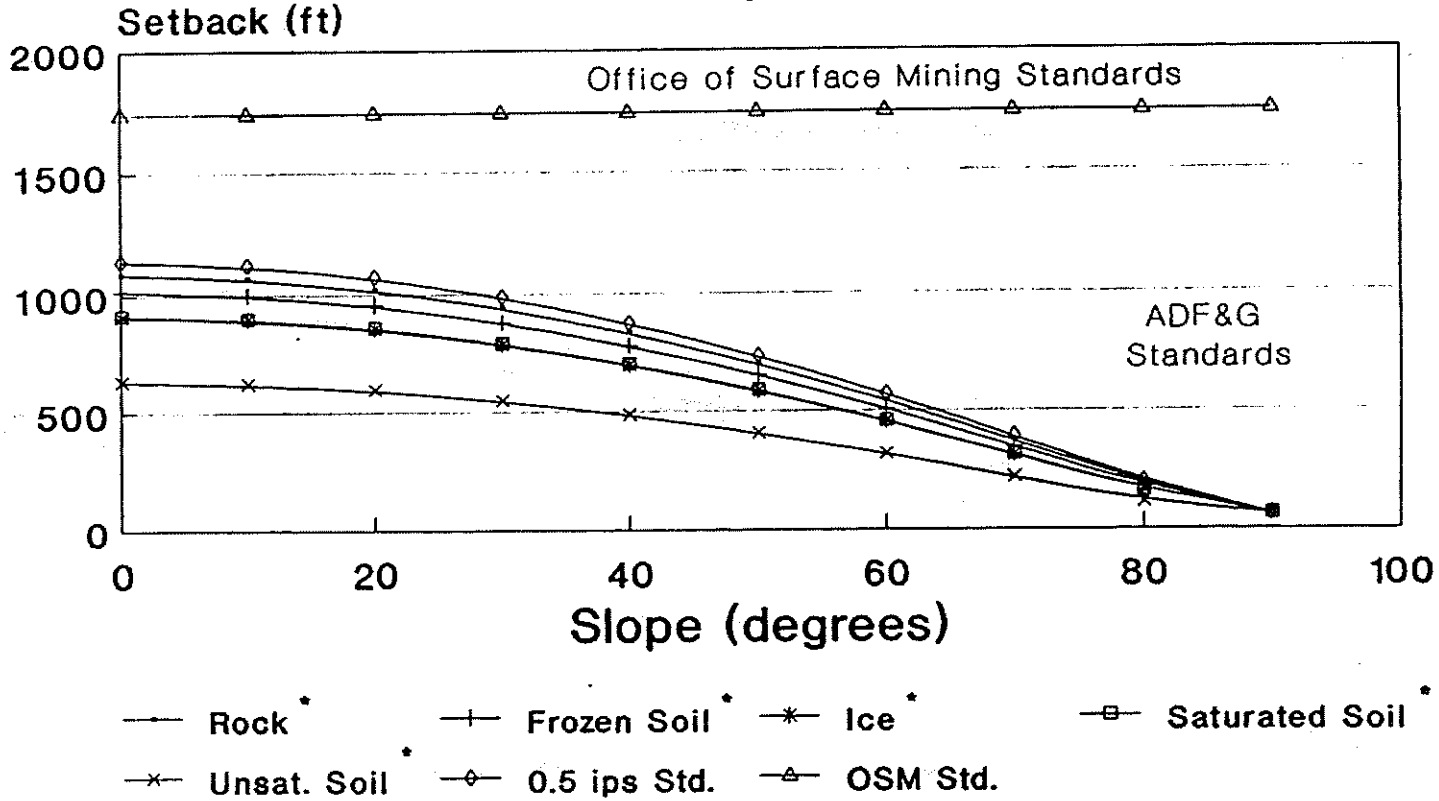
Setbacks for a given charge weight are calculated with the equation $D=W^{1/2}D_s$; where D=Distance, in feet, from the blasting point to nearest sensitive site; W=charge weight; D_s=scaled distance factor as listed below:

Distance (D) from blasting site, in feet	Maximum allowable peak particle velocity (Vmax) for ground vibration, in inches/second	Scaled-distance factor to be applied without seismic monitoring
0 to 300.....	1.25	50
301 to 5,000.....	1.00	55
5,001 and beyond.....	0.75	65

FIGURE 5

Setbacks in Various Substrates
By Slope

ADF&G Case C only (see text and Fig. 4)



See Table 7 for description of OSM standards

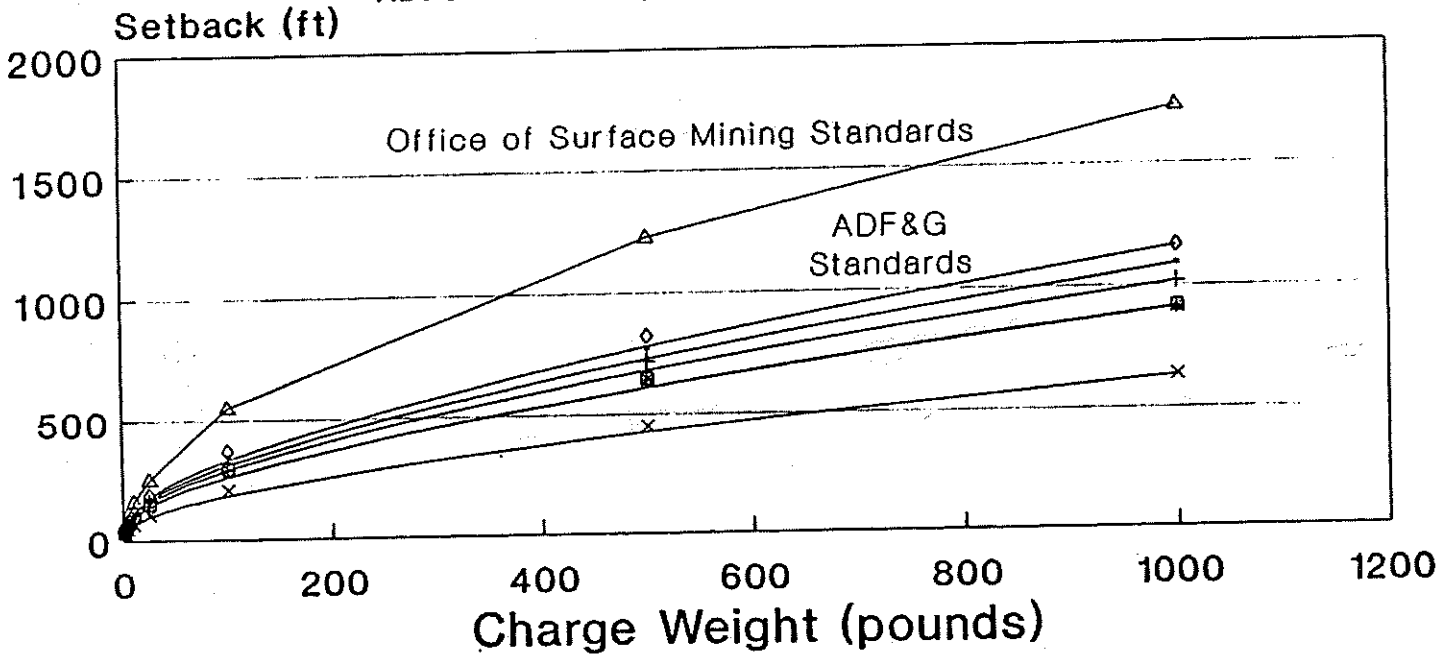
Setback for a 1000 pound charge

* 2.7 psi standards

FIGURE 6

Setbacks in Various Substrates
On level ground

ADF&G Cases A, B, and C (see text and Fig. 4)



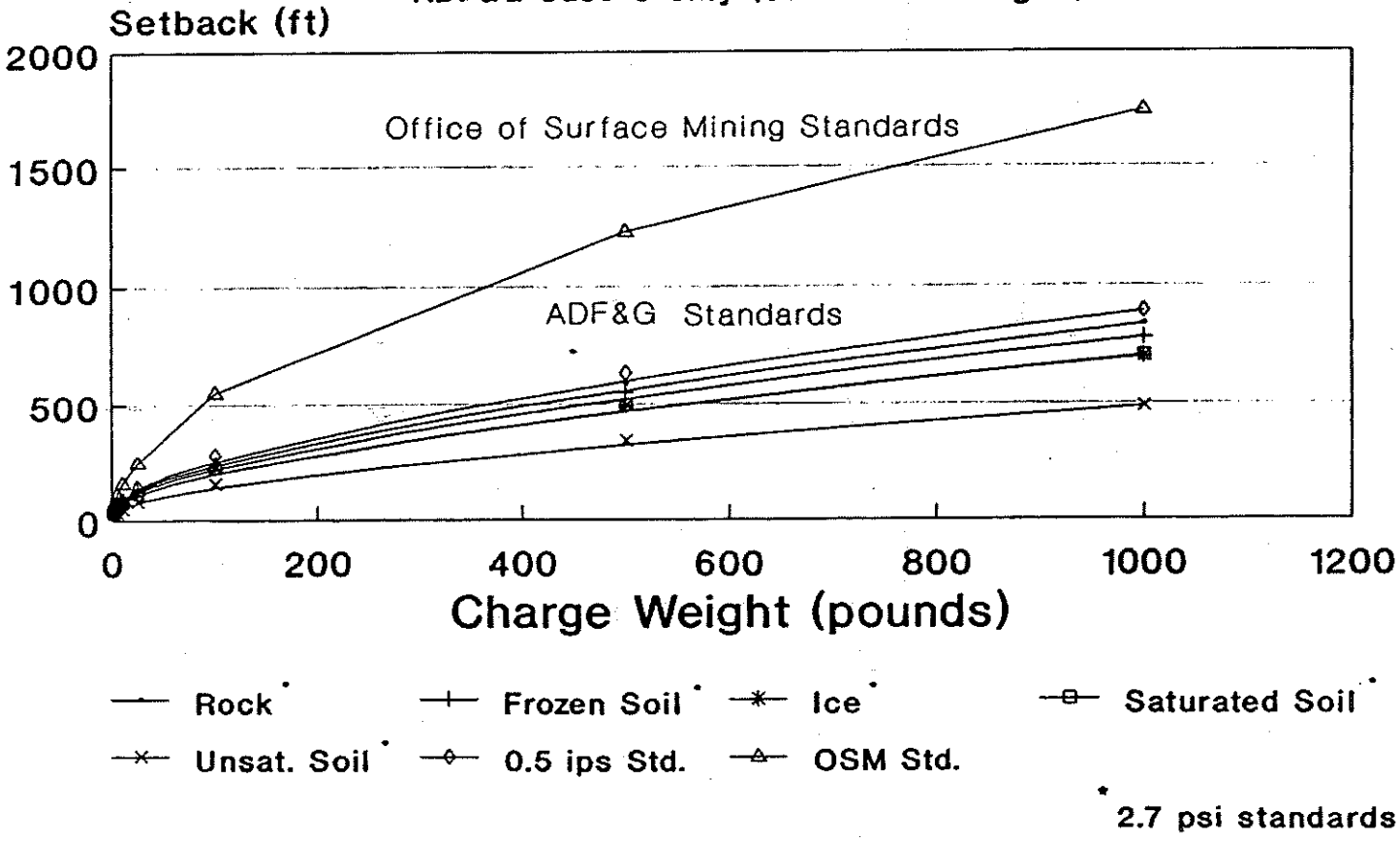
Note that for a 1000 lbs. charge, the OSM setback is between 52 and 162% larger than the ADF&G setbacks

FIGURE 7

Setbacks in Various Substrates

40 Degree Slope

ADF&G Case C only (see text and Fig. 4)



Note that for a 1000 lbs. charge, the OSM setback is between 99 and 242% larger than the ADF&G setbacks

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