2017 AEP State Conference

Hydroacoustics 101:

How It Works, Why It Matters, and What To Do With It In CEQA





Panelists

Keith Pommerenck, Acoustical and Air Quality Scientist with Illingworth & Rodkin, Inc.

Daniel Chase, Fisheries Biologist with WRA, Inc.

Justin Semion, Aquatic Ecologist with WRA, Inc.

Panelist Change - Keith Pommerenck

Mr. Pommerenck provides consulting services in the area environmental noise and air quality issues with over 33 years of professional experience (21 years with Caltrans and 12 years with Illingworth and Rodkin) in preparing technical air, noise, and vibration reports for inclusion in CEQA and NEPA environmental documents for transportation projects. Mr. Pommerenck led numerous hydroacoustic field investigations for bridge construction projects. He was the field leader for the Ten Mile River Bridge project that included several months of acoustic measurements and compliance reporting. Mr. Pommerenck's expertise was routinely relied upon for solutions to reduce underwater sound when construction activities were in jeopardy of exceeding permit underwater noise conditions. Mr. Pommerenck also led Illingworth & Rodkin's hydroacoustic monitoring efforts on other notable projects that included the Humboldt Bay Bridges Seismic Retrofit, Mad River Bridge replacement, the Klamath River Bridge emergency repair (during salmon migration), Test Pile portion and the construction portion of the Explosive Handling Wharf 2 project for the navy and several other smaller projects in California, Oregon, and Washington. Mr. Pommerenck has also assisted transportation agencies in assessing sound impacts to wildlife in marine environments (both airborne and underwater).

Panel Overview

History of Hydroacoustic Analysis

Technical Specification of Underwater Sound

Biological Effects of Underwater Sound

Regulatory Application of Hydroacoustic Impacts

CEQA Application of Hydroacoustic Impact Evaluation



Hydroacoustics – Anthropogenic Sounds

Keith Pommerenck

and James Reyff

Illingworth & Rodkin, Inc. Petaluma * Marysville * Denver





Hydroacoustic Impacts - History

- Pile Driving
- Explosives
- Other construction sounds

SFOBB Pile Installation Demonstration Project - conducted in 2000

- Driving 8ft diameter steel piles
- Over 300 feet long
- Tested two sound attenuation systems
- Fish harmed





New Benicia-Martinez Bridge

- Driving 8ft diameter steel piles
- Some hard substrates
- Fish harmed
- Construction stopped



• Successfully attenuated sound to resume



Fisheries Hydroacoustic Working Group

- Developed to improve and coordinate information on fishery impacts due to underwater sound pressure caused by inwater pile driving
- Developed known information on sound effects on fish
- Identified interim sound thresholds
- Developed guidance

Technical Specification of Underwater Sound

- Fundamentals of hydroacoustics
- Anthropogenic sounds
- Underwater sound control
- Underwater sound measurement systems
- Technical guidance

Fundamentals -Basic Sound Descriptors –Peak Pressure (Peak) • Over/under pressure

–Root Mean Square (RMS)
•Pulse
•Continuous time averaged

-Sound Exposure Level (SEL)

• Pulse, pile driving event, workday

Decibel to Describe Sound

"A logarithmic measure of the sound strength"

Or in mathematical terms:

The base 10 Logarithmic function of the ratio of the pressure fluctuation to a reference pressure

Calculation of Sound Pressure Level

$$SPL = 10 \log (p/p_{ref})^2, dB$$

$$SPL = 20 \log (p/p_{ref})$$
, dB

where p_{ref} is the reference pressure:

- For air, $p_{ref} = 20 \mu Pa$
- For water, $p_{ref} = 1 \mu Pa$

– As a result:

 $SPL_{water} = SPL_{air} + 26 \, dB$

1 *PSI* = 6,895 *Pascals* = 197 *dB re* 1μ*Pa*

Sound Level Metrics



Typical Sound Levels

	Sound Pressure Level	
G I G	ID	
Sound Source	dB	Pascals
High explosive at 100m	220	100,000
Airgun array at 100m		0.00 - 2010/00/00
Unattenuated Pile Strike at 100m (SFOBB, Benicia)	200	10,000
	180	1,000
Large ship at 100m	160	100
Fish Trawler passby (low speed) at 20m	140	10
	120	1
Background with boat traffic	100	0.1
	80	0.01
	60	0.001



Continuous Pure Tone (400 Hz) at 190 dB Peak

Explosive – Underwater Blast



Single Pile Driving Impulse From SFOBB



Blast (25 PSI, 225 dB), Pile Drive Impulse (203 dB Peak) and 400 Hz Pure Tone (190 dB Peak)



Impact Pile Driving Sounds

30 Inch Pile



Pressure ()

Single Pile Driving Pulse



RMS Sound Pressure Level



Sound Exposure Level

Sound Exposure: time integral of frequency weighted squared instantaneous sound pressure (ANSI S12.7). Proportional to Acoustic Energy

(Richardson, et al. 1995).

SEL



Sound Propagation

Complicated problem

- Well bounded environment
- Extended source
- Ground borne sound
- Sound propagating through saturated soils
- Use of 15 Log drop off (4.5 dB/dd)
- Measured drop off rates

 10 Log to 30 Log considerable range

Anthropogenic Sound Sources

- Pile driving
 - Impact driving (loudest)
 - Vibratory driving
 - Impact near water
- Demolition/explosives
- Continuous sources

Impact Pile Driving



Different Types of Conditions



On Land Near Water



Vibratory Pile Driving

- Much lower amplitude sounds than impact pile driving (20 to 30 dB lower)
- Sounds tend to be more continuous
- Higher Frequency sounds



Minimization Measures

- Air bubble curtains

 Confined / unconfined
- Dewatered cofferdams
- Avoid in water driving

 Move footings out of water
- Construction windows
 - Avoid times when species are prese





Measurement Systems

- Hydrophones
- Signal conditioning
- Signal processing
- Recording
- Descriptors





Pressure Sensors



Caltrans Guidance Manual

Provides biologists, engineers and consultants guidance related to environmental permitting of pile driving projects in or near water

- Fundamentals of hydroacoustics
- Fundamentals of noise effects to fish
- Guidance to assess pile driving impacts to fish (hydroacoustic)
- Appendices

http://www.dot.ca.gov/hq/env/bio/files/bio_tech_guidance_hydroacoustic_effects_110215.pdf



Caltrans Guidance Manual appendices

- Compendium of Pile Driving
 Sound Data
- Procedures for Measuring Pile
 Driving Sound
 - Hydrophone and equipment selection
 - Data analysis/Quality control
 - Reporting



2017 AEP State Conference



Biological Effects of Underwater Sound: Overview for Fish and Marine Mammals

Presented By: Daniel Chase, MS Fisheries Biologist WRA, Inc.

Talk Outline

Fish

- What and how sound is perceived
 - Two Hearing Groups
- Hydroacoustic Effects

Marine Mammals

- What sound is used for
- Five Hearing Groups
- Hydroacoustic Effects
What do fish use sound for?

Determine the direction of a sound source

- Communicate
- Locate prey
- Avoid predators



• Perceive their environment





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Fish Anatomy– How Fish Perceive Sound



1. Otoliths - inner ear structure



Source: thefisheriesblog.com

Fish Anatomy– How Fish Perceive Sound



- 1. Otoliths inner ear structure
- 2. Swim bladder



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Fish Anatomy– How Fish Perceive Sound



- 1. Otoliths inner ear structure
- 2. Swim bladder
- 3. Lateral Line



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Fish Hearing Groups



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NrQ

Fish Hearing Groups

Hearing Specialists

Connection between ear and swim bladder Capable of hearing over a wide range of frequencies

Example Species







Fish Hearing Groups

Hearing Generalists

No connection between ear and swim bladder Narrower range of frequencies

Example Species







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How Hydroacoustics Can Effect Fish



Behavioral Effects

Examples:

- Causing fish to vacate or leave an area,
- Move or leave cover or territories,
- Exposure to predators,
- Interfere with foraging and prey capture,
- Elevated stress response



How Hydroacoustics Can Effect Fish

Behavioral Effects

Examples:

Injury

- Temporary threshold shifts (TTS)
- Permanent threshold shifts (PTS)
- Auditory tissue damage
- Capillary ruptures
- Reduces individuals fitness



How Hydroacoustics Can Effect Fish

Behavioral Effects

Examples:

Injury

Mortality

- Barotrauma
 - Swim bladder and tissue rupture
 - Traumatic brain injury
 - Neurotrauma





Marine Mammals use sound for:

- Communication
- Perceive their environment
- Locate prey
- Avoid predators/protection





Because not all marine mammals use sound or hear the same...

Five basic hearing groups have been established





3 Cetacean Groups

Low-Frequency



[humpback whale, blue whale]



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3 Cetacean Groups

Low-Frequency



[humpback whale, blue whale]

Mid-Frequency



[killer whale, bottlenose dolphin]



ENVIRONMENTAL CONSULTANTS

3 Cetacean Groups

Low-Frequency



[humpback whale, blue whale]

Mid-Frequency



[killer whale, bottlenose dolphin]

High-Frequency



[harbor porpoise]



<u>3 Cetacean Groups</u>: Low-Frequency; Mid-Frequency; High-Frequency

2 Pinniped Groups:

Phocids



[elephant seal, harbor seal]



<u>3 Cetacean Groups:</u> Low-Frequency; Mid-Frequency; High-Frequency

2 Pinniped Groups:

Phocids



[elephant seal, harbor seal]





[sea lions, sea otters]



How Hydroacoustics Can Effect Marine Mammals

Behavioral Effects

Examples:



- Vacate or leave an area haul out locations
- Auditory masking,
- Interfere with communication,
- Distress and elevated stress response,
- Interfere with foraging and prey capture



How Hydroacoustics Can Effect Marine Mammals

Behavioral Effects

Examples:

Injury

- Temporary threshold shifts (TTS)
- Permanent threshold shifts (PTS)
- Auditory tissue damage
- Lung or gastrointestinal tract injury
- Reduces individuals fitness





How Hydroacoustics Can Effect Marine Mammals

Behavioral Effects

Examples:

Injury

Mortality

- Stranding
- Barotrauma
 - Traumatic brain injury
 - Neurotrauma





Summary

Fish and Marine Mammals

- Underwater sound important for perceiving and interacting with the environment
- Species hear and use sound different hearing group categories
- Elevated hydroacoustic levels can cause harmful effects – behavioral, injurious, and/or potentially fatal







Thank you!

Contact:

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Regulatory Application of Hydroacoustic Impacts

Keith Pommerenck

and James Reyff

Illingworth & Rodkin, Inc. Petaluma * Marysville * Denver



Thresholds for Fish

Interim acoustic criteria – 2008

- Onset of injury expected:
 - Peak pressure <a>206 dB
 - SEL_{12hr} = 187 dB (fish <u>>2grams</u>)*
 - SEL_{12hr} = 183 dB (fish <2grams)* *150dB SEL_{strike} = effective quiet
- Effect area = >150 dB RMS (Behavioral)

Except for very short events, SEL is dominant threshold

Assessing Effect Areas - Fish

- Determine near source sound levels

 Use compendium type, size, environment, etc...
- Estimate sound propagation rate (use 15 Log if unknown)
- Identify amount of activity

 #piles, pile strikes, locations
- Effect of sound control measures

NMFS Fish Calculator

- Simple model relying on available data
- Uniform spreading loss
- Applies effective quiet to SEL levels
- Spreadsheet inputs in Green Cells

Project Title	AEP Project
Pile information (size, type,	36-inch diameter steel shell pile, 1 hour pile driving 1
number, pile strikes, etc.)	strike every 1.5 seconds = 2,400 strikes

Fill in green cells: estimated sound levels and distances at which they were measured, estimated number of pile strikes per day, and transmision loss constant.

		Acous	tic Metric	
	Peak	SEL	RMS	Effective Quiet
Measured single strike level (dB)	211	184	192	150
Distance (m)	10	10	10	
Estimated number of strikes	2400			
Cumulative SEL at measured distance				
217.80				
		Distance (r	n) to threshold	ł
	Onse	et of Physical	Injury	Behavior
	Peak	Cumulativ	e SEL dB**	RMS
	dB	Fish ≥ 2 g	Fish < 2 g	dB
Transmission loss constant (15 if unknown)	206	187	183	150
15	22	1131	1848	6310
** This calculation assumes that single strike	SELs < 150 (dB do net acc	<mark>cumulate to co</mark>	use injury
(Effective Quiet)				
Notes (source for estimates, etc.)				

NMFS Fish Calculator

- Same as previous
- Air Bubble Curtain -8 dB

Project Title	AEP Project
Pile information (size, type, number, pile strikes, etc.)	36-inch diameter steel shell pile, 1 hour pile driving 1 strike every 1.5 seconds = 2,400 strikes

Fill in green cells: estimated sound levels and distances at which they were measured, estimated number of pile strikes per day, and transmision loss constant.

		Acous	tic Metric	
	Peak	SEL	RMS	Effective Quiet
Measured single strike level (dB)	203	176	184	150
Distance (m)	10	10	10	
Estimated number of strikes	2400			
Cumulative SEL at measured distance				
209.80				
		Distance (r	n) to threshold	t t
	Onse	t of Physical	Injury	Behavior
	Peak	Cumulativ	e SEL dB**	RMS
	dB	Fish ≥ 2 g	Fish < 2 g	dB
Transmission loss constant (15 if unknown)	206	187	183	150
15	6	331	541	1848
** This calculation assumes that single strike	SELs < 150 c	dB do not acc	umulate to ca	ause injury
(Effective Quiet)				
Notes (source for estimates, etc.)				

Sensitivity of Transmission Loss Constant

		Acous	tic Metric	
	Peak	SEL	RMS	Effective Quiet
Measured single strike level (dB)	211	184	192	150
Distance (m)	10	10	10	
Estimated number of strikes	2400			
Cumulative SEL at measured distance				
218				
		Distance (r	n) to threshold	
	Peak	Cumulati	ve SEL**	RMS
Transmission loss constant (15 if unknown)	208 dB	187 dB	183 dB	150 dB
15	22	1131	1848	6310

		Acous	tic Metric			
	Peak	SEL	RMS	Effective Quiet		
Measured single strike level (dB)	211	184	192	150		
Distance (m)	10	10	10			
Estimated number of strikes	2400					
Cumulative SEL at measured distance						
218						
	Distance (m) to threshold					
	Peak	Cumulati	ve SEL**	RMS		
Transmission loss constant (15 if unknown)	208 dB	187 dB	183 dB	150 dB		
17	20	648	1000	2955		

PTS Onset Criteria (used for Level A)

- Continuous and impulsive thresholds
- Peak and SEL thresholds
- Functional hearing groups
 - Low-frequency cetaceans (7 Hz to 35 kHz)
 - Mid-frequency cetaceans (150 Hz to 160 kHz)
 - High-frequency cetaceans (275 Hz to 160 kHz)
 - Phocid pinnipeds (e.g., harbor seals) (50 Hz to 86 kHz)
 - Otariid pinnipeds (e.g., sea lions) (60 Hz to 39 kHz)

	PTS Onset Act (Recei	oustic Thresholds [*] ived Level)
Hearing Group	Impulsive	Non-impulsive
	Cell 1	Cell 2
Low-Frequency (LF) Cetaceans	Lpk,flat: 219 dB	<i>L</i> _{E,LF,24h} : 199 dB
Octaccans	<i>L</i> _{E,LF,24h} : 183 dB	
	Cell 3	Cell 4
Mid-Frequency (MF) Cetaceans	Lpk,flat: 230 dB	<i>L</i> _{E,MF,24h} : 198 dB
Octaceans	<i>L</i> _{E,MF,24h} : 185 dB	
	Cell 5	Cell 6
High-Frequency (HF)	Lpk,flat: 202 dB	<i>L</i> _{E,HF,24h} : 173 dB
Octaccans	<i>L</i> _{E,HF,24h} : 155 dB	
	Cell 7	Cell 8
Phocid Pinnipeds (PW) (Underwater)	<i>L</i> pk,flat: 218 dB	<i>L</i> _{E,PW,24h} : 201 dB
(onderwater)	<i>L</i> _{E,PW,24h} : 185 dB	
	Cell 9	Cell 10
Otariid Pinnipeds (OW) (Underwater)	<i>L</i> pk,flat: 232 dB	<i>L</i> E,OW,24h: 219 dB
(Onderwater)	<i>L</i> _{E,OW,24h} : 203 dB	
* Dual metric acoustic thresholds for calculating PTS onset. If a non-impu- thresholds associated with impulsive	r impulsive sounds: Use whichever ilsive sound has the potential of ex-	results in the largest isopleth for ceeding the peak sound pressure level

Point of this slide is that these are complex! Dual thresholds, different types of sounds and frequency weightings

Behaivoral Criteria (used for Level B)

- Continuous and impulsive thresholds
- RMS thresholds
 - Time averaged for continuous
 - Pulse averaged for impulses
- No applicable frequency weightings – next step for NMFS??

Continuous Sounds (e.g., vibratory driving)	= 120 dB (time avg)
Impulsive Sounds (e.g., impact driving)	= 160 dB (pulse avg)

In Air Disturbance (used for Level B)

- RMS thresholds (time averaged)
 - 90 dB phocid pinnipeds (harbor seals)
 - 100 dB otariid pinnipeds (sea lions)
- Typically applied at haul outs

Explosives (Level A)

Several types for injury

NMFS User Spreadsheet

- Simple model relying on available data
- Uniform spreading loss
- Computes duty cycle for SEL computations
- <u>NO</u> effective quiet applied to SEL levels
- Frequency adjustments are key inputs

	KEY									
		Action Proponent	Provided Informat	ion						
		NMFS Provided In Resultant Isopleth	formation (Acous	tic Guidance)						
	STER & CENERAL PROJECT INCO	PMATION								
	PROJECT TITLE	KMATION								
	PROJECT/SOURCE									
	INFORMATION									
	Please indude any assumptions									
	PROJECT CONTACT									
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	Weighting Factor Adjustment (kHz)*	2								
	^V Broadband: 95% frequency contour percentile	(kHz) OR Narrowband:								
	frequency (kHz); For appropriate default WFA: 5 tab	ee INTRODUCTION								
			† If a user relies on	alternative weigh	nting/dB adjustment	rather than relyin	ig upon the			
			WFA (source-spec	ific or default), th	ey may override the	Adjustment (dB)	(row 64), and			
			enter the new value documentation sur	e directly. Howev porting this mod	er, they must provid lification.	e additional supp	oort and			
				1						
	* BROADBAND Sources: Cannot use	WFA higher than m	aximum applicabl	e frequency (Se	e GRAY tab for m	re information	on WFA applica	ble frequencies		
	STEP & SOURCE SPECIFIC INFO	MATION								
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NMFS User Spreadsheet 5 different types

- Non-impulsive stationary continuous
- Non-impulsive stationary intermittent
- Non-impulsive mobile continuous
- Non-impulsive mobile intermittent
- Impulsive Stationary
- Impact Pile Driving
- Impulsive mobile
- WFA Weighting Factor Adjustments
 - Default single factors
 - Develop factors or weighted levels using guidance weighting functions applied to signal

CEQA and Permitting Impacts Analysis

Hydroacoustic Effect



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Overview Hydroacoustics Impacts Analysis

- CEQA and Permitting
 Thresholds
- Factors and Uncertainties Affecting Thresholds
- Impacts Analysis
- Mitigation Approach




CEQA Significance Thresholds

Appendix G Biological Resources

- a) Have a substantial adverse effect, either directly or through habitat modifications, on any species identified as a candidate, sensitive, or special status species in local or regional plans, policies, or regulations, or by the California Department of Fish and Game or U.S. Fish and Wildlife Service?
- d) Interfere substantially with the movement of any native resident or migratory fish or wildlife species or with established native resident or migratory wildlife corridors, or impede the use of native wildlife nursery sites?



CEQA Significance Thresholds

Substantial Adverse Effect

- substantially reduce the habitat of a fish or wildlife species
- cause a fish or wildlife population to drop below selfsustaining levels
- threaten to eliminate a plant or animal community
- reduce the number or restrict the range of a rare or endangered plant or animal



Regulatory Background

Endangered Species Act

Federal	
No effect	No consultation
Not likely to adversely affect	Letter of concurrence, no "take" coverage
Likely to adversely affect	Biological Opinion, "take" coverage
State	
Pursue, injure or harm to individuals, or attempt to	2081 Incidental Take Permit



Regulatory Background

Marine Mammal Protection Act

Federal	
Level A Harassment, "serious" injury or mortality	Letter of Authorization (federal rulemaking process)
Level B Harassment, non-serious injury and/or disturbance	Letter of concurrence, no "take" coverage
State	

Fish and Game Code, no permit process except for listed marine mammal species



Hydroacoustic Thresholds

• Fish

- − Peak pressure \geq 206 dB (re: 1µPa)
- SEL
 - > 2 grams = 187 dB (re: 1µPa2 sec)
 - < 2 grams = 183 dB (re: 1µPa2 sec)

Marine Mammals

- Level A Harassment (e.g., "Permanent Threshold Shift")
- Level B Harassment
- Temporary Threshold Shift



Hydroacoustic Thresholds



Model output:
distance at
which specific
decibel levels
are reached



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Hydroacoustic Impacts

Interpreting hydroacoustic effects modeling:

- "All models are wrong, some models are useful"
- At a distance of 1 foot from the sound source, all thresholds are exceeded in most (but not all) cases
- Decibel level dissipates over distance, fish and marine mammals can be thought of as mobile "sensitive receptors"
- CEQA assumptions for hydroacoustic models are usually wrong, and change, often substantially, as the project progresses toward final design



Factors and Uncertainties

- Context/environmental setting
- Pile size and type
- Number of piles per day
- Number of strikes per pile
- Frequency shift
- Other and unstudied sound sources
 - Different types of sound can affect aquatic resources in different ways
 - Pile driving is relatively well studied
- Gaps in scientific knowledge
- Modeling imperfections



Context/Environmental Setting







Moss Landing



Context/Environmental Setting

- Background noise
- Habituation
- Haul outs
- Migratory corridors
- Spawning and pupping
- Presence of ESA/CESA listed species





Factors Affecting Observed Hydroacoustics

- Sound source
- Physical dynamics of a site
- Background noise
- Type of piles
- Number of piles per day
- Number of strikes per pile
- Currents
- Soil/substrate type
- Distance of measurement
- Attenuation methods
- Type of pile driving equipment (down to model #)
- Other things we may not even be looking for...







Design Factors Affecting Pile Driving Assumptions and Models

- Anticipated use
- Structural load
- Geotechnical factors
- Skill of construction contractor
- Equipment availability
- Site access and maneuverability
- Physical conditions coefficients
- Unknown submerged objects





Factors and Uncertainties







Generalized Hierarchy of Pile Types



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Hydroacoustic Impacts Analysis

- Individuals' residence time within the affected area
- Incidental occurrence vs. core habitat
- Species' status
- Modeling uncertainties
- Background noise and habituation
- Speculative or discountable effects standards

- substantially reduce the habitat of a fish or wildlife species
- cause a fish or wildlife population to drop below self-sustaining levels
- threaten to eliminate a plant or animal community
- reduce the number or restrict the range of a rare or endangered plant or animal



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Mitigation Measures

- Very few cases where a technical solution can avoid all risk to individuals
- Minimization and avoidance
- Similar to many CEQA technical areas: noise, GHG, water quality, traffic





- Avoid deferral
- Avoid being overly prescriptive
 - Not every BMP is feasible for all construction conditions
- Allow for the regulatory process to run its course
- Do not assume that modeling assumptions will hold true for construction



- Implementation of some BMPs can extend the duration that resources are subject to disturbance
- Practicability of field biological monitoring and assigning source of stress or injury
- Consider the level of risk to the resource





- Consider use of an "if...then" framing
- Standard mitigation measures for developing a SWPPP may provide a good conceptual model
 - Develop a hydroacoustic effects analysis for review by NMFS
 - Include list of BMPs "such as..."
- Field measurement of underwater sound can be appropriate to refine and inform modeling results
 - Field hydroacoustic measurement is not a mitigation measure in and of itself
 - Consider the cost in relation to the resource risk
- Biological monitoring is typically effective for marine mammals, less so for fish
 - Site conditions influence efficacy of biological monitoring



Maintain flexibility

There is a physical universe that we cannot always control



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