Mixing Zones 101

Carl Reese,

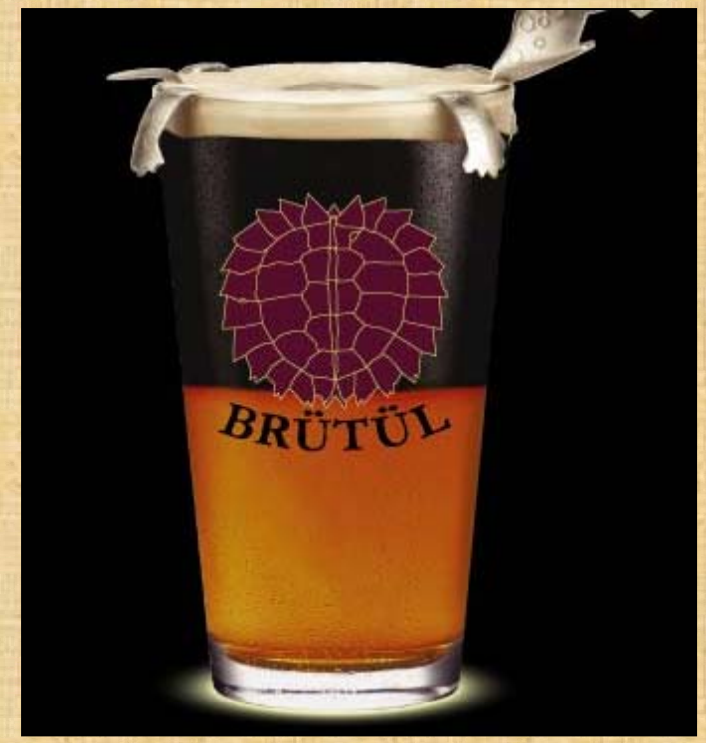
Kenwyn George, and Gerry Brown

Alaska Dept of Environmental Conservation

- **Many slides borrowed from:**
- Chelsea Morris
- Standards and Health Protection Division
- Office of Science and Technology

Complete Mixing: Chicago River & the White House

No Mix: Perfect Black and Tan



Mixing Demonstration: The Breakfast Experiment

What is a Mixing Zone?

- A mixing zone is:
  - A limited area or volume of water where initial dilution of a discharge takes place and where numeric water quality criteria can be exceeded (WQS Handbook, 1994)

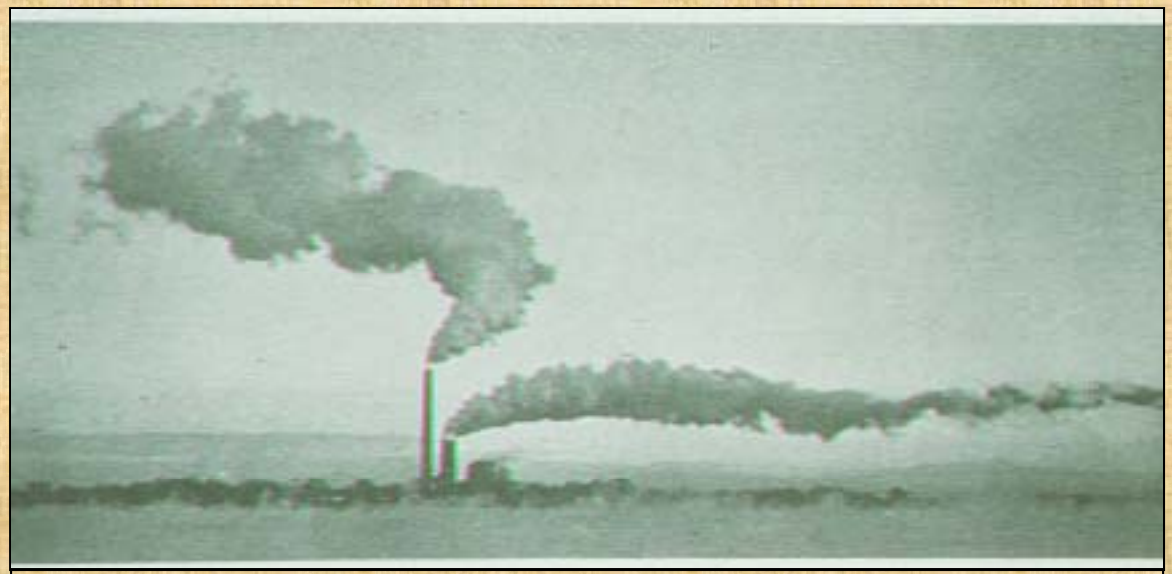
- Rationale: Sometimes organisms can be exposed to a magnitude above a criterion for a short duration without interfering with the designated use of a waterbody as a whole

What is a Mixing Zone?

- Two meanings:
  - *Regulatory mixing zone:* contained in the general policies section of a state's or tribe's WQS, at the state's or tribe's discretion
  - *Physical mixing zone*: calculated and implemented on a site-specific basis through a facility's NPDES permit

- A mixing zone is <u>not</u>:
  - A water quality criterion or a change to a water quality criterion
  - An area where water quality criteria do not apply

Mixing Zone Examples



Atmospheric example of turbulent buoyant jet mixing in a stratified shear flow.
Source: Ralph Turcotte, Beverly (Massachusetts) Times from www.cormix.info

Firebreather
Source: www.cormix.info

Mixing Zone Examples

Far-field plume mixing in River
Source: www.cormix.info

Wastewater outfall with boundary interaction
Source: I. Wood from www.cormix.info

Mixing Zone Authority

- 40 CFR 131.13: General Policies: States may, at their discretion, include in their State standards policies generally affecting their application and implementation, such as mixing zones, low flows and variances. Such policies are subject to EPA review and approval.

Mixing Zone Authority

- 40 CFR 122.44(d)(1)(ii): In determining whether a discharge causes, has the reasonable potential to cause, or contributes to an in-stream excursion above a narrative or numeric water quality standard, the permitting authority shall use procedures which account for…where appropriate, the dilution of the effluent in the receiving water.

Mixing Zone "Shoulds"

- Be no larger than necessary
- Protect the designated use of the waterbody as a whole
- Prevent lethality to passing organisms
- Prevent significant health risks

Mixing Zone "Should NOTs"

- Be used as a way to lower a designated use
- Be used as a way of revising criteria or developing site-specific criteria outside of the water quality standards process
- Overlap

Purpose of a Mixing Zone Policy

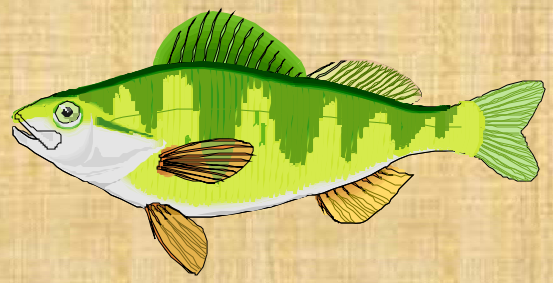
- Restrict areas where numeric criteria may be exceeded to known and controlled locations
- Reduce need for excessive wastewater treatment

Contents of a Mixing Zone Policy

- Statement specifying when and where mixing zones are allowed (if at all)
- Necessary information for defining mixing zone characteristics including:
  - Location
  - Size / shape (including flow)
  - Outfall design
  - In-zone water quality

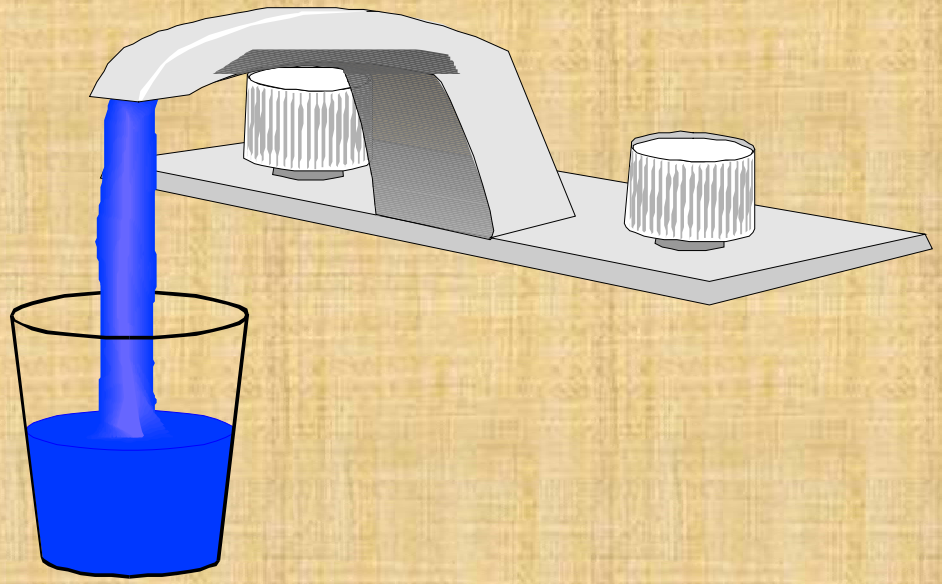
Mixing Zone Location: Aquatic Life

- Identify and protect biologically important and sensitive areas
  - Shellfish beds
  - Breeding and spawning areas
  - Habitat for endangered species
- Avoid locations that would block migrating organisms or create a zone of passage that is too narrow



Mixing Zone Location: Human Health

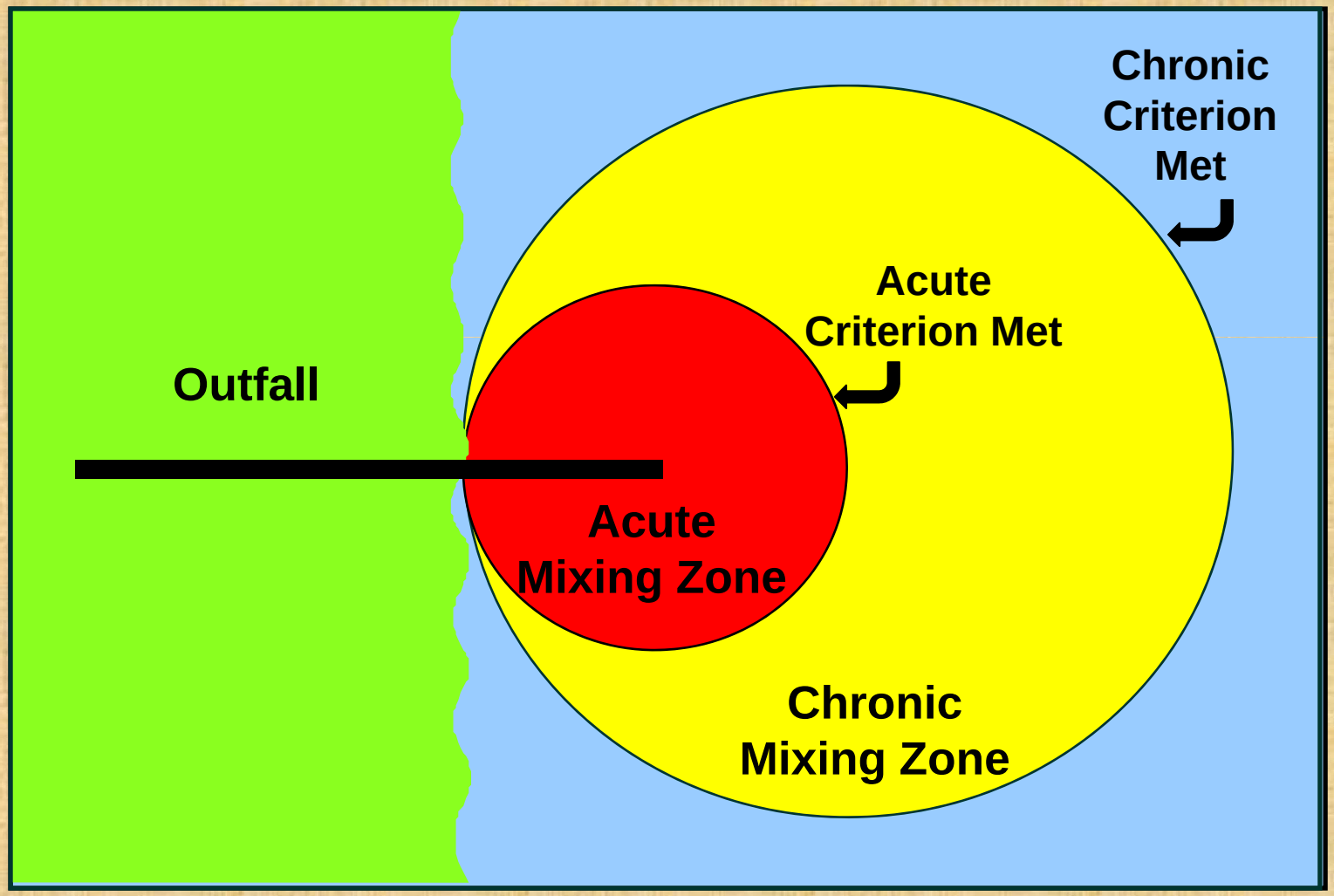
- Restrict mixing zones from areas that could pose significant human health risks



Mixing Zone Size

- Should be no larger than necessary
- Should not hinder movement within the waterbody or into tributaries

Mixing Zone Size Schematic



Mixing Zone Size and Low Flows

- Stream flow establishes how much dilution is available in the receiving water
- Low flow provides a "worst case scenario"
- EPA low flow recommendations:

Criteria	Hydrologically-based low flow	Biologically-based low flow
Acute aquatic life	1Q10	1B3
Chronic aquatic life	7Q10	4B3
Non-carcinogen human health	30Q5	
Carcinogen human health	Harmonic mean	

Mixing Zone Shape

- Consider the shape of the mixing zone
  - Shore-hugging plumes should be avoided

Wastewater outfall with boundary interaction
Source: I. Wood from www.cormix.info

Mixing Zone Outfall Design

- State should ensure best practicable engineering design
- Factors to consider:
  - Height of outfall
  - Distance to bank
  - Angle of discharge
  - Single or multi-port diffuser
- Modifying outfall design can avoid adverse impacts

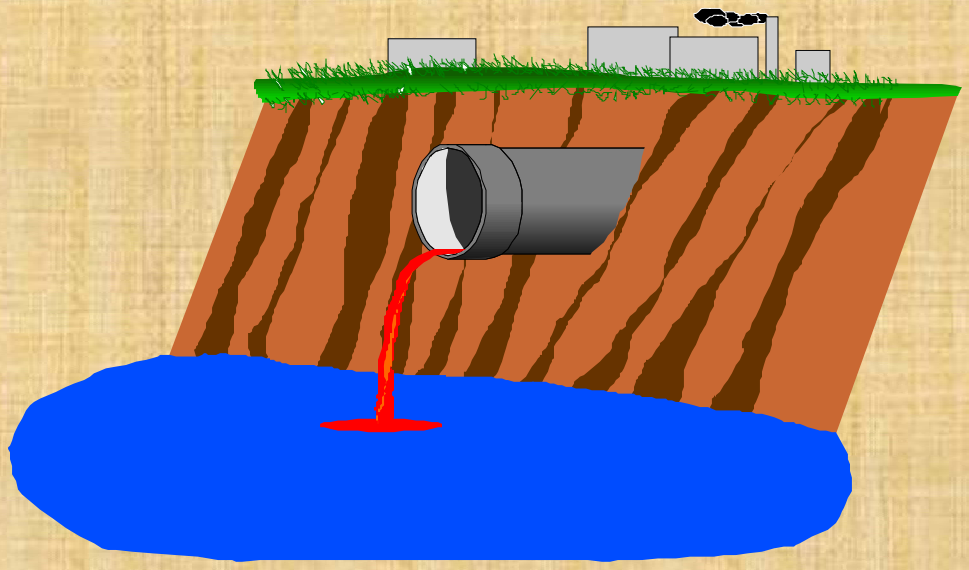
Mixing Zone Water Quality

- Mixing zones should be free from:
  - Concentrations causing acute toxicity
  - Concentrations forming objectionable deposits
  - Floating debris, oil, scum, and other nuisance materials
  - Substances producing objectionable color, odor, taste, or turbidity
  - Substances that result in a dominance of nuisance species

Other Mixing Zone Issues

Is the effluent attractive?

- States and tribes should consider whether a mixing zone may attract aquatic life.
  - For example, temperature can be attractive.



Other Mixing Zone Issues

Are there bioaccumulative chemicals?

- Mixing zones for bioaccumulative pollutants should be carefully considered.
  - Bioaccumulatives are more likely to affect the entire water body
  - Can pose significant human health risks
- May be appropriate to prohibit mixing zones for bioaccumulatives and/or restrict mixing zones where fish or shellfish harvesting takes place

Other Mixing Zone Issues

Is there rapid and complete mixing?

- Rapid and complete (R+C) mixing occurs when the lateral variation of in-stream concentration in the direct vicinity of the outfall is small (e.g., < 5%)
- Can occur when effluent flow > stream flow or when a diffuser is used
- If there is R+C mixing, use of up to 100% of the critical low flow may be acceptable
- If there is not R + C mixing, use of a fraction of the critical low flow may be appropriate

EPA Mixing Zone Guidance

- Water Quality Standards Handbook (1994)
  http://water.epa.gov/scitech/swguidance/standards/handbook/index.cfm
- Technical Support Document for Water Quality-based Toxics Control (1991)
  http://www.epa.gov/npdes/pubs/owm0264.pdf
- Compilation of EPA Mixing Zone Documents (2006)
  http://water.epa.gov/scitech/swguidance/standards/mixingzones/index.cfm

Alaska's Mixing Zone Regulations

- 18 AAC 240 (2003 Regulations)
- 18 AAC 240 – 270 (Adopted in 2006)

- 2006 Regulation were submitted to EPA in 2009 and are still under review.

Comparison of 2003 and 2006 Regulations

- **Anadromous Fish** – Prohibition for spawning areas changed from all anadromous fish to 5 Pacific salmon species.

- **Pre-existing authorizations** - Mixing zone may be reauthorized if evidence show no initial spawning area for salmon or other protected fish.

Comparison of 2003 and 2006 Regulations

- **Expanded Protected Waters** – Now includes lakes.
- **Spawning area definition** – time and location used in previous practices are now stated in regulation.
- **Consultation** – DEC is required to consult with ADF&G on spawning areas

Update on Changes

- Revised Regulations – State adopted in 2006
- New Guidance – nearly finalized
  - Covers general provisions for all mixing zones
  - How pre-existing permits can "grandfather" mixing zones
- Spawning Mitigation Plans
  - NOT allowed for Pacific salmon
  - Required for exception in other protected fish spawning areas

Mixing Zone Conditions

DEC must consider:

- the characteristics of the receiving water
- the characteristics of the effluent
- the effects, including cumulative effects, on the uses of the water
- **any measures that would mitigate potential adverse effects to aquatic resources**
- any other relevant factors

Mixing Zone Conditions

A mixing zone must:

- Use effluent that has been treated to remove, reduce and disperse the pollutants with the most effective, technologically and economically feasible methods
- Maintain and protect designated and existing uses of the waterbody as a whole
- Protect overall biological integrity
- Be as small as practicable

Mixing Zone Conditions

A mixing zone must NOT:

- **result in an acute or chronic toxic effect outside the mixing zone**
- create a public health hazard for water supply or contact recreation
- **preclude or limit established processing activities, commercial, sport, personal-use, or subsistence fish and shellfish harvesting**
- **reduce fish or shellfish populations**

Mixing Zone Conditions

A mixing zone must NOT:

- **result in permanent or irreparable displacement of indigenous organisms**
- adversely affect threatened or endangered species except as authorized under the ESA
- **form a barrier to migratory species or fish passage**
- **contain pollutants that bioaccumulate, bioconcentrate, or persist above natural levels in sediments, water, or biota**

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Mixing Zone Conditions

A mixing zone must NOT:

- present an unacceptable risk to human health from carcinogenic, mutagenic, teratogenic, or other effects
- settle to form objectionable deposits
- produce floating debris, oil, scum and other material in concentrations that form nuisances
- **result in undesirable or nuisance aquatic life**

Mixing Zone Conditions

A mixing zone must NOT:

- produce objectionable color, taste, or odor in aquatic resources harvested
- cause lethality to passing organisms
- exceed acute aquatic life criteria beyond a smaller initial mixing zone surrounding the outfall

Review Question #1

- What is the primary purpose of a state/tribal mixing zone policy?
  a. Provide an effluent dilution function
  b. Create spatial variations in the effluent plume
  c. Create areas with less desirable water quality
  d. Restrict areas where numeric criteria can be exceeded and reduce the need for excessive wastewater treatment

Review Question #1

- What is the primary purpose of a state/tribal mixing zone policy?
  a. Provide an effluent dilution function
  b. Create spatial variations in the effluent plume
  c. Create areas with less desirable water quality
  d. Restrict areas where numeric criteria can be exceeded and reduce the need for excessive wastewater treatment

- Answer:

  d. The primary purpose of a mixing zone is to restrict areas where numeric criteria can be exceeded and limit the need for excessive wastewater treatment.

Review Question #2

- What is the primary reason for regulating the size of a mixing zone and its percentage of the total waterbody?
  a. To protect shellfish beds
  b. To protect human health
  c. To protect the designated use of the waterbody as a whole
  d. To protect drinking water resources

Review Question #2

- What is the primary reason for regulating the size of a mixing zone and its percentage of the total waterbody?
  a. To protect shellfish beds
  b. To protect human health
  c. To protect the designated use of the waterbody as a whole
  d. To protect drinking water resources

- Answer:
  c. Limiting the size of a mixing zone protects the designated use of the waterbody as a whole.

Review Question #3

- True or false? States and tribes are limited in the number and types of issues that may be addressed in their mixing zone policies.

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- Answer:
  - *False. States and tribes are encouraged to address as whatever is necessary to protect designated uses.*

Review Question #4

- True or false? At the zone of initial dilution, both acute and chronic aquatic life criteria can be exceeded in a mixing zone.

Review Question #4

- True or false? At the zone of initial dilution, both acute and chronic aquatic life criteria can be exceeded in a mixing zone.

- Answer:
  - *True. Although the area of a mixing zone where acute criteria may be exceeded is smaller, there still can be an area where both acute and chronic criteria are exceeded.*

Review Question #5

- Which of the following could preclude the establishment of a mixing zone?
  a. Area is used for recreational fishing
  b. Bioaccumulative pollutants in the discharge
  c. Proximity to drinking water intakes and sources
  d. Presence of shellfish beds
  e. All of the above
  f. None of the above

Review Question #5

- Which of the following could preclude the establishment of a mixing zone?
  a. Area is used for recreational fishing
  b. Bioaccumulative pollutants
  c. Proximity to drinking water sources
  d. Presence of shellfish beds
  e. All of the above
  f. None of the above

- Answer:
  e. All of these reasons could cause a state or tribe to preclude the establishment of a mixing zone.

ADEC mixing zones

Latest updates – and some comments

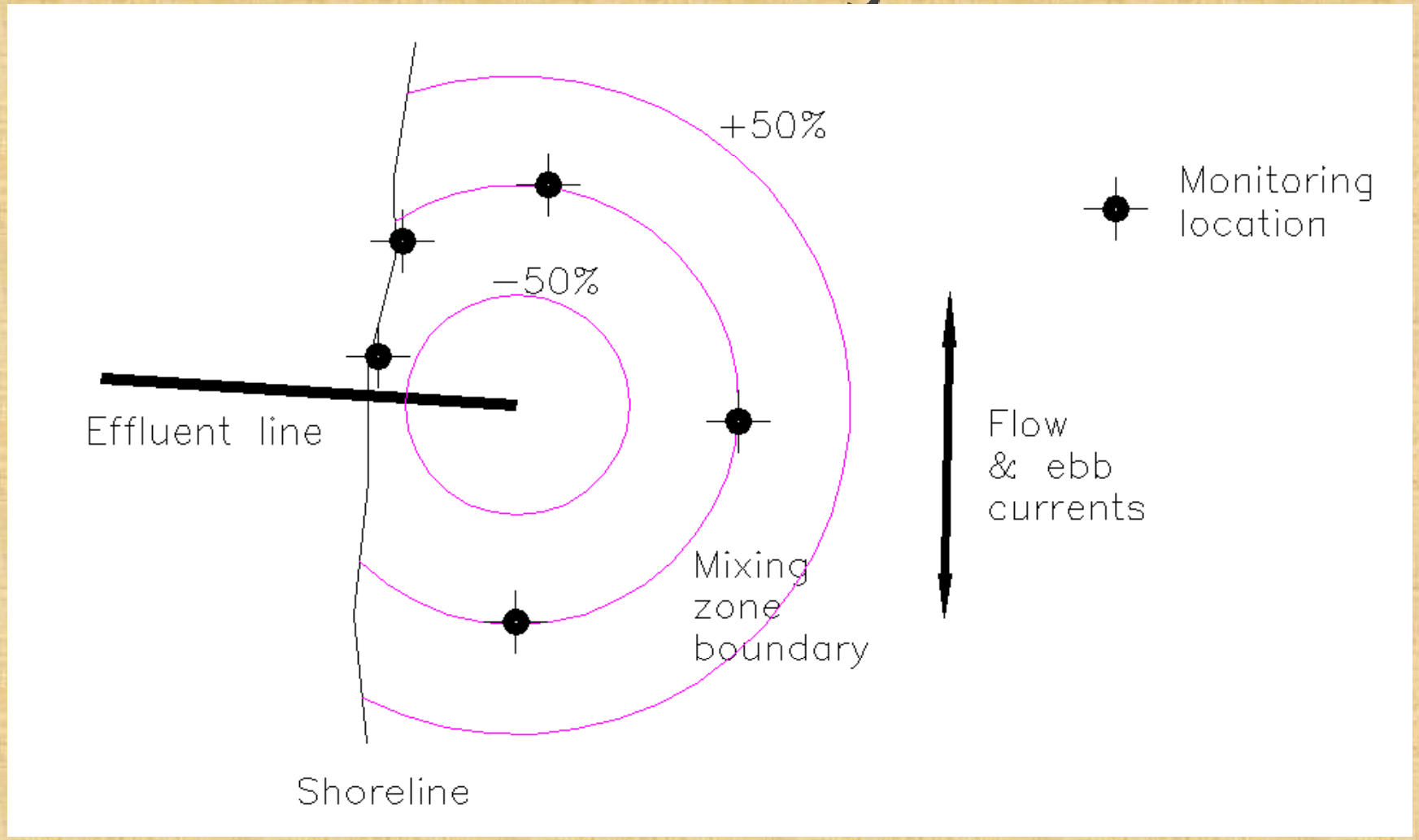
- Mixing zone modeling is NOT and exact science.
- With limited data and a multitude of variables mixing zone sizes are best estimates to +/- 50%

Some variables that can affect the "perceived" mixing zone size if sampling conducted.

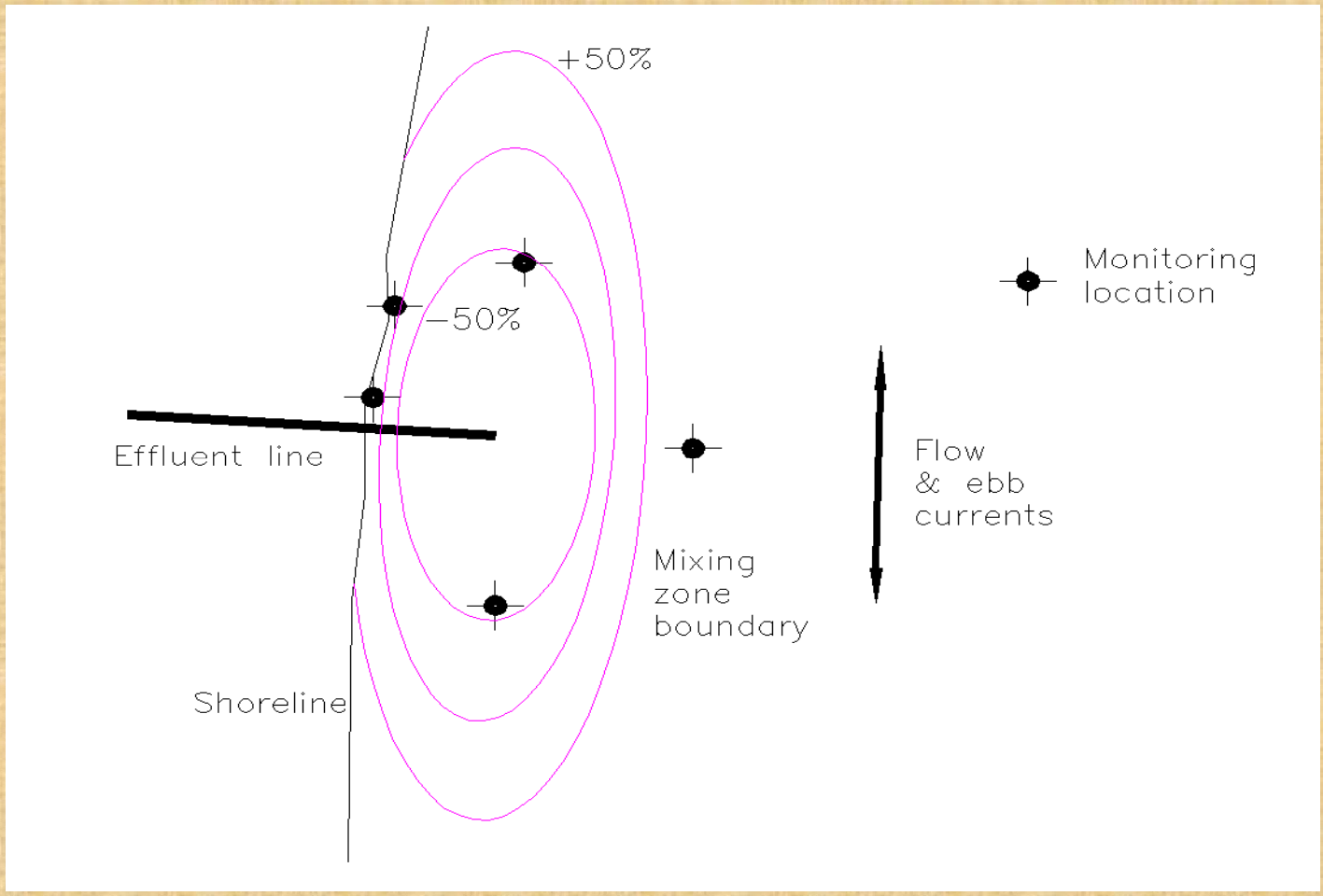
- Sampling location and collection date/season.
- Sampling location across a river. Pollutant concentration may vary at opposite banks / vary across a river.
- Current at time of sampling (90th% "estimate"?)
- "Pockets" of pollutants and clear water.
- Physical bathymetry.
- Effluent flow rate.
- Marine – stratification, depth of sample.
- "Estimates" of diffusion, bacterial die-off rates.

Pockets of pollutants

+/- 50% accuracy with the modeling



More likely shape



Marine

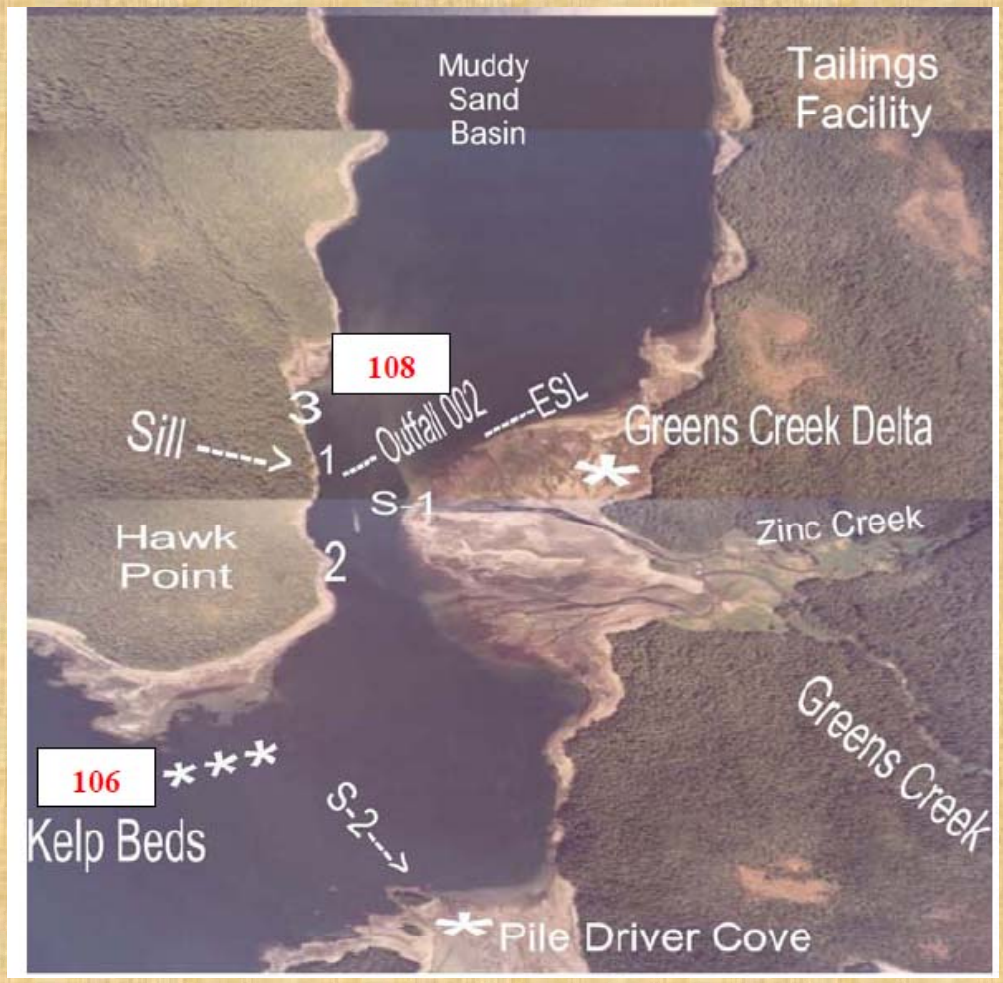
- Greens Creek Mine
- Red Dog Port

Greens Creek Mine

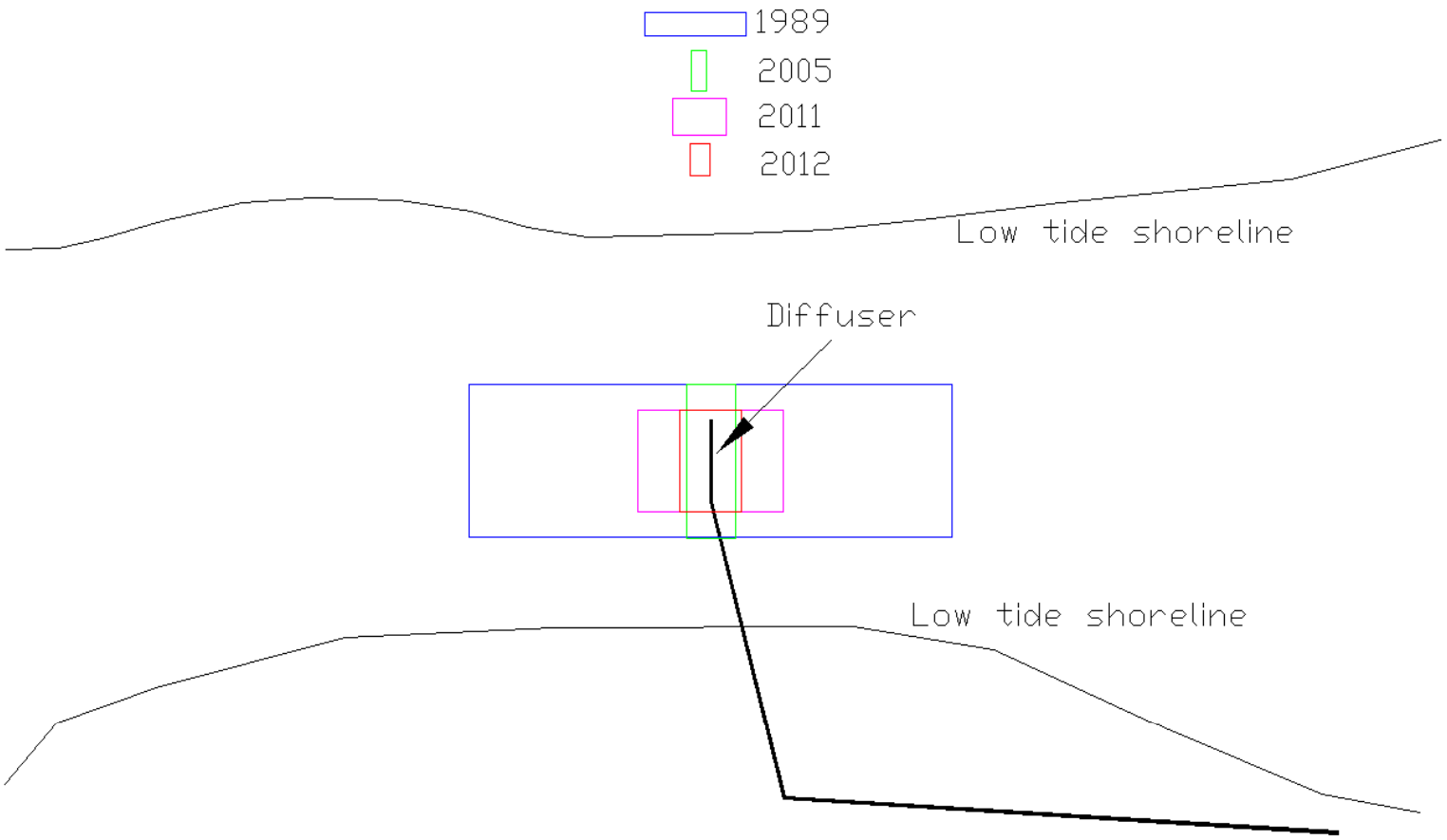
- The size has varied over the years

Year	Flow (gpm)	Metal	Dilution Factor	Mixing zone Size W x L	Basis
1989			265	300' x 1000'	Dye study
1998	1145	Copper	81		Plumes / TBEL
2005	2500	Copper	81	300' x 100'	Plumes / TBEL
2011	3200	Copper	81	200' x 300'	CORMIX / TBEL
2012	3200	Lead	36	200' x 130'	CORMIX /Performance

Location of outfall



Graphical depiction of the mixing zones



Modeled as a diffuser or as a single port

Comparison of outputs - CORMIX vs PLUMES					
Dilution for chronic WQS= 36			Port spacing 11.4 ft (~3.5m)		
90th percentile current (1.4 m/s)			Port diameter 3.5" (0.088m)		
	Dist. To boundary (m)	Dist. To boundary (ft)	Plume diameter at boundary (in)	Plume area at boundary (in2)	Dilution
Diffuser (CMX)	95.5	313	17.5	241	36.5
Diffuser (PLM)	2.5	8	27	572	59.5
Single port (CMX)	20	66	Not in the output		
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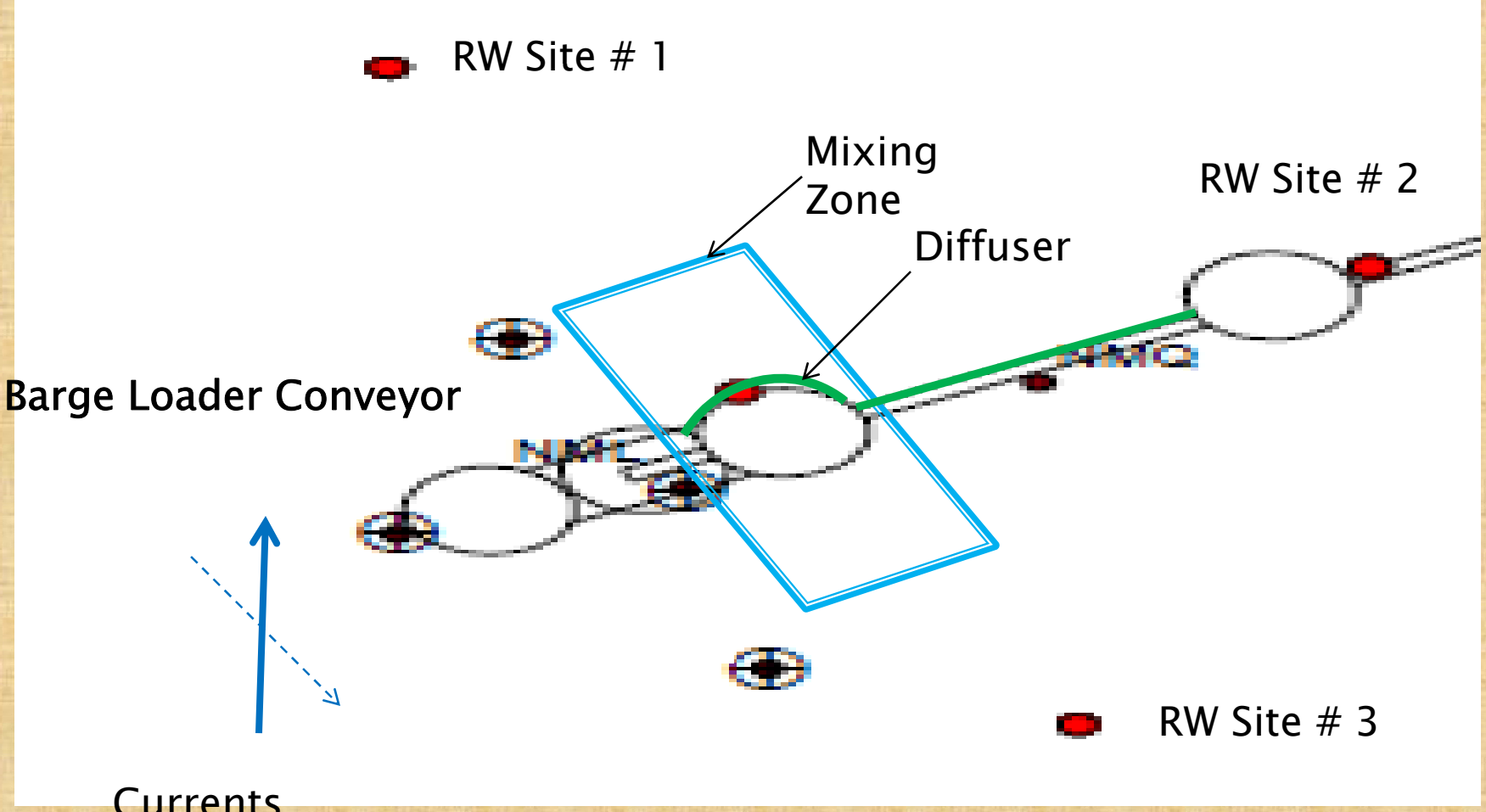
TBEL vs Performance based

Comparison - 2005 TBEL-based limits vs. Performance based limits							
	2005 TBEL Permit Maximum Daily Limit (MDL)	Perf. Based Maximum Daily Limit (MDL)	MDL Decrease		2005 TBEL-based Permit Average Monthly Limit (AML)	Perf. Based Average Monthly Limit (AML)	AML Decrease
Cd	100.00	14.74	-85%		50.00	7.18	-86%
Cu	300.00	63.44	-79%		150.00	24.14	-84%
Pb	600.00	558.79	-7%		300.00	219.16	-27%
Hg	2.00	2.30	15%		1.00	1.03	3%
Zn	1000.00	414.48	-59%		500.00	185.90	-63%

Red Dog Port

Location of diffuser



Diffuser details

Distance of Nearest Discharge Port From Shoreline at M.L.L.W.: ***160 meters***

Diameter and Length of Diffuser: ***20 meters long*** *Depth at M.L.L.W.:* ***6.7 meters***

Orientation of Diffuser to Shoreline: ***Perpendicular*** *No. Of ports* ***3***

Height of ports above diffuser ***1 meter*** *Orientation to diffuser:* ***Perpendicular***

Port size: ***0.1143 meters*** *Spacing* ***10 meters between ports***

Current Direction relative to diffuser and Average/Maximum velocities Perpendicular, 0.517/0.772 meters/second flowing in a northerly direction.

Design considerations

- 5’ of ice in the winter
- Variations in summer & winter flow
- Variations in pollutant concentrations in the summer and winter.
- Assumptions: Ignore the caisson that the diffuser is attached to.
- Historic impacts to receiving water from fugitive dust.

Effluent vs. Water Quality Criteria

Parameter	WQS (metals TR)		MEC (TR)
	Acute	Chronic	
OUTFALL 001			
Cadmium	40.2	8.85	5.52
Copper	5.8	3.7	273
Lead	221	8.5	504
Zinc	95.1	85.6	766
FC (#/100 mL)	43	14	1375
OUTFALL 005			
Cadmium	40.2	8.85	14
Copper	5.8	3.7	5.8
Lead	221	8.5	227
Mercury	2.1	1.06	0.56
Zinc	95.1	85.6	1733

Flow Variations

- Domestic WW – design flow 12,000 gpd
  - 25 gpm instantaneous
- IX /Storm Water – Max 450 to 750 gpm
  - 750 gpm based on 10-year/24-hour Event
- Annual Contribution of Metals – Mass Basis
  - IX approximately 4 to 5 times more than domestic for Cd, Pb, Zn.
  - Domestic 60 percent more than IX for Cu.
  - Hg not sampled on Domestic….Yet!

Background vs. Ambient RWC

	Background (~ 1km away)	Old Ambient RWC (Near outfall)
Cd	0.068 ug/L	1.09 ug/L
Cu	1.3 ug/L	Unknown
Hg	0.000675 ug/L	0.17 ug/L
Pb	0.038 ug/L	4.04 ug/L
Zn	0.36 ug/L	56.8 ug/L

DF = (MEC – RWC) / (WQS – RWC) = (MEC – WQS) / (WQS – RWC) + 1

Impacts of RWC on Dilution

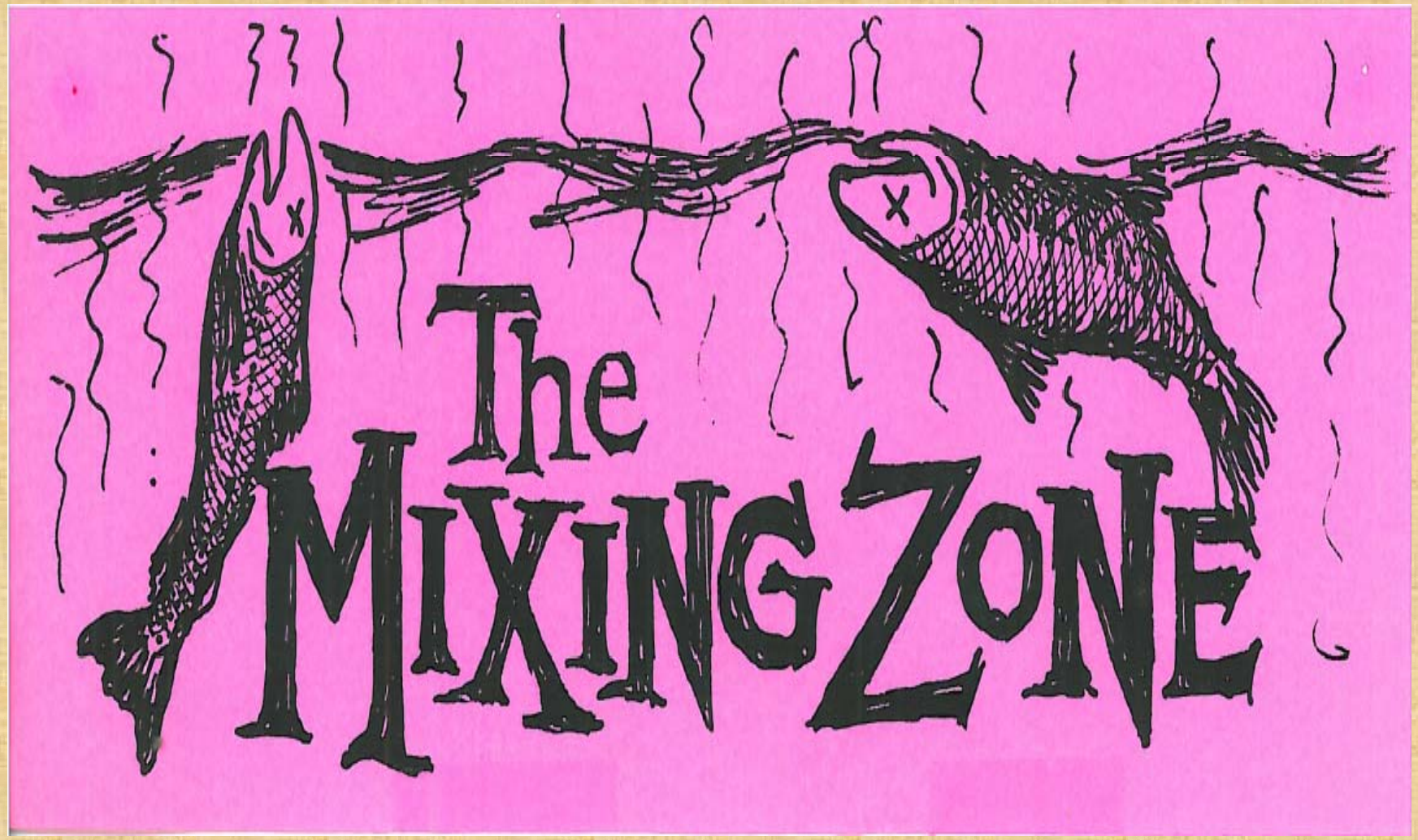
Parameter	Ambient Conc.		Dilutions - Bkgrd		Dilution - RWC		Percent Increase	
	Bkgrd	RWC	DFa	DFc	DFa	DFc	DFa	DFc
OUTFALL 001								
Cadmium	0.068	1.09	0.17	0.79	0.15	0.77	-11.8%	-2.5%
Copper	1.3	1.3	60.7	111.7	60.7	111.7	0.0%	0.0%
Lead	0.038	**4.04**	2.28	59.5	2.31	111.7	1.2%	**87.7%**
Zinc	0.360	**56.8**	8.7	9.7	19.9	26.6	**128.7%**	**174.2%**
FC (#/100 mL)	0	0	32.0	98	32	98	0.0%	0.0%
OUTFALL 005								
Cadmium	0.068	1.09	0.35	1.6	0.33	1.68	-5.7%	5.0%
Copper	1.3	1.3	1.36	2.50	1.36	2.50	0.0%	0.0%
Lead	0.038	4.0	1.03	26.75	1.03	49.8	0.0%	86.0%
Mercury	0.00068	0.17	0.30	0.57	0.24	0.49	-20.0%	-14.0%
Zinc	0.360	56.8	18.3	20.3	44.6	59.8	**143.7%**	**194.6%**

Red Dog Take-Home Points

- Effects on dilution may not be obvious. Depends on effluent, WQS, and RWC.
- Location, location, location…
- Specify RW sites upfront as much as possible.
- Without representative RWC data you cannot accurately predict MZ sizes.


Hey! Where are all the Fish?
JUL 9 2002

- What the mixing zone is NOT……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