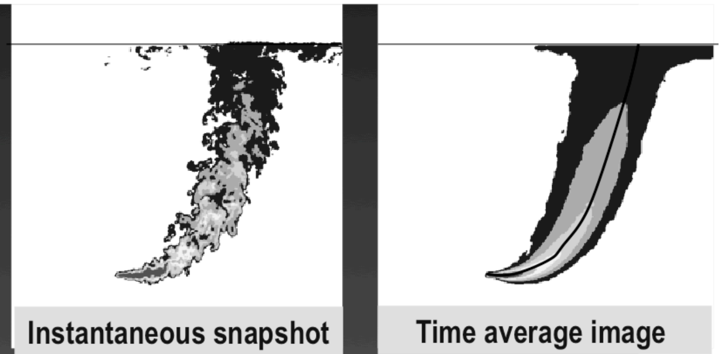
What to look for when reviewing a Mixing Zone Study in WA

EPA Mixing Zone Webinar Workshop Series
January 22-24, 2013



Based on: Phil Roberts, Georgia Tech, 2003

Anise Ahmed, Ph.D., P.E.

How dilution is defined in WA?

- Volumetric Dilution factor:

$$DF = \frac{V_a + V_e}{V_e}$$

~~$$= \frac{V_a}{V_e}$$~~

- Concentration based dilution factor:

$$DF = \frac{Ce - Ca}{Cp - Ca} \longrightarrow DF = \frac{Ce}{Cp}$$

Mixing Zones in WA (WAC-173-201A-400)

- Apply AKART prior to mixing zone authorization
- Maximum size of mixing zone
- Minimize mixing zones
- Must prove no environmental harm
- Consider critical conditions

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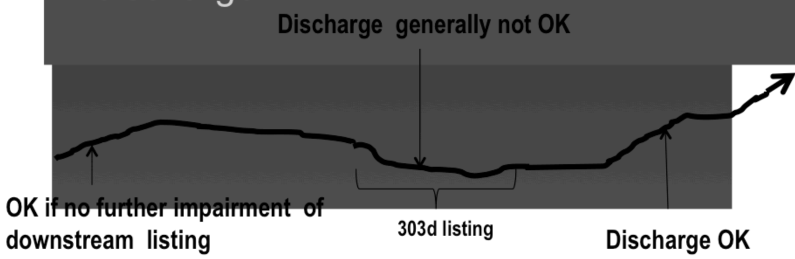
Other Mixing zone regulations

- Overlapping mixing zones
- Extended mixing zones
- Mixing zones for stormwater
- Mixing zones for CSOs

Mixing zones and 303(d) listing

- Cannot authorize discharge that contributes to an impairment
- Mixing zone may be authorized if no impairment is found at the point of discharge



Mixing Zone Models used in WA

- Theoretical Models
  - Visual PLUMES (UM3, VSW, etc.)
  - RIVPLUME
  - CFD (being reviewed)
- Empirical Models
  - RSB (NRFIELD)
- Semi-Empirical
  - CORMIX

Farfield Predictions

Method of Brooks

$$\varepsilon = \alpha L^n$$

ε = *lateral dispersion characteristics,* $m^2 s^{-1}$

L = *length scale, m*

α = *dispersion coefficient for Brooks algorithm (units dependent on n)*

n = *Brook's law exponent*

= *4/3 (Oceans)*

= *1 (Coastal and estuarine areas)*

= *0 (rivers)*

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Spreadsheet for estimating far-field dilution : http://www.ecy.wa.gov/programs/eap/pwspread/pwspread.html

FARFIELD.XLS: Far-field dilution of initially diluted effluent plumes using the linear diffusivity Brooks model
as presented by Grace (R.A. Grace. Marine outfall systems: planning, design, and construction. Prentice-Hall, Inc.)

INPUT

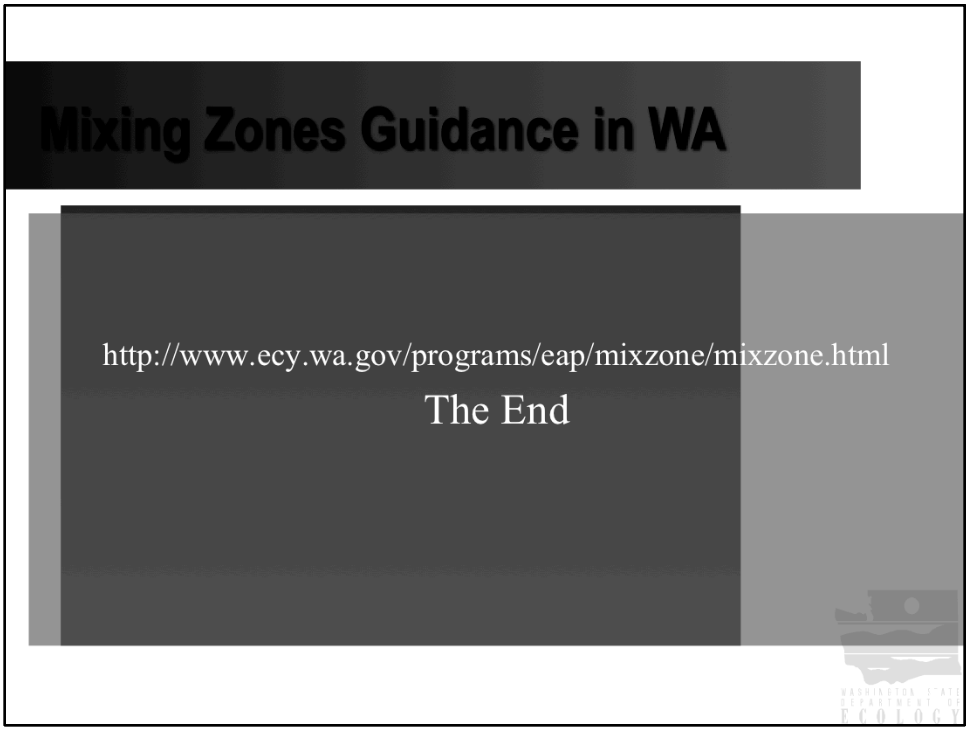
Linear Eddy Diffusivity
Eo=(alpha)(width)
(Grace/Brooks equation 7-65)

1. Plume and diffuser characteristics at start of far-field mixing
   - Flux-average dilution factor after initial dilution — 19.56
     (*e.g.* dilution at end of computations with UDKHDEN)
   - Estimated initial width (B) of plume after initial dilution (meters) — 12.07 meters
     (*e.g.* eqn 70 of EPA/600/R-94/086 for diffuser length and plume diameter)
   - Travel distance of plume after initial dilution (meters) — 5.47 meters
     (*e.g.* "Y" from UDKHDEN or horizontal distance from PLUMES output)
2. Distance from outfall to mixing zone boundary (meters) — 65.5 meters
   (*e.g.* distance to the chronic mixing zone boundary)
3. Diffusion parameter "alpha" per equations 7-62 of Grace, where Eo=(alpha)(width)
   (This sheet differs from the PLUMES approach by assuming different units for alpha depending on the far-field algorithm. Initial diffusion coefficients (Eo in m^2/sec) are calculated as follows on this sheet: 4/3 power law: Eo = (alpha)(width)^(4/3); linear eddy diffusivity: Eo = (alpha)(width); constant eddy diffusivity: Eo = (alpha).) — 6.88E-04 m/sec
4. Horizontal current speed (m/sec) — 0.05 m/sec
   (*e.g.* same value specified for UDKHDEN or PLUMES)
5. Pollutant initial concentration and decay (optional)
   (these inputs do not affect calculated farfield dilution factors)
   - Pollutant concentration after initial dilution (any units) — 5.11E-02 any units
     (*e.g.* effluent volume fraction = 1/initial dilution)
   - Pollutant first-order decay rate constant (day^-1) — 0.00E+00 day^-1
     (*e.g.* enter 0 for conservative pollutants)

OUTPUT

Eo = 8.3061E-03 m^2/s
Beta = 1.6516E-01 unitless

	Far-field Travel Time (hours)	Far-field Travel Distance (m)	Total Travel Distance (m)	Effluent Dilution	Pollutant conc-entration
Dilution along plume trajectory:	2.63E-02	4.73E+00	10.20	1.96E+01	5.11E-02
	5.25E-02	9.45E+00	14.92	1.96E+01	5.11E-02


Mixing Zones Guidance in WA
http://www.ecy.wa.gov/programs/eap/mixzone/mixzone.html
The End

AKART

- All known, available, and reasonable treatment
- Similar to BAT but more restrictive, i.e. requires current reasonable technology
- Dilution only allowed after AKART

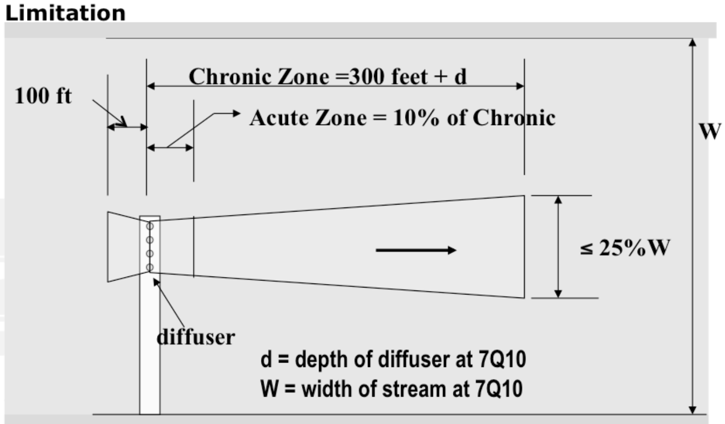
Maximum Size: Streams

Hydraulic Limitation

Can use only max stream flow of 25% 7Q10

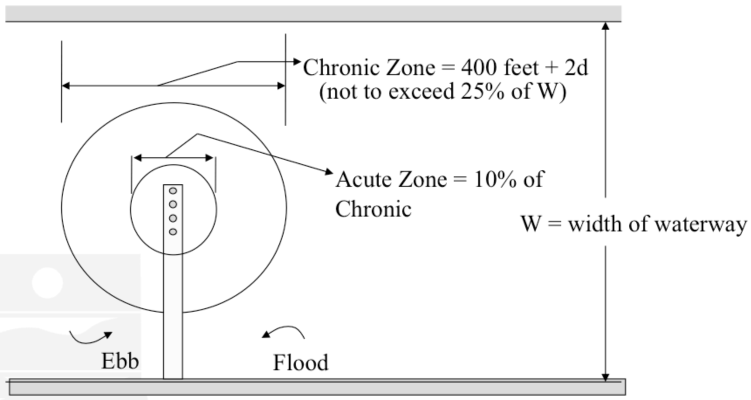
$$DF_{max} = \frac{Q_{NPDES} + 0.25 * 7Q10}{Q_{NPDES}}$$

Distance Limitation



Maximum Size: Estuaries

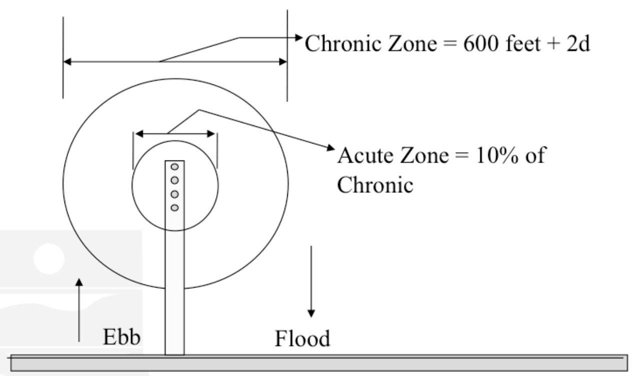
- **Distance Limitations**



d = depth of diffuser at MLLW
W = width of waterway at MLLW

Maximum Size: Oceans

- **Distance Limitations**



d = depth of diffuser at MLLW

Maximum Size: Lakes/Reservoirs (>15 days detention)

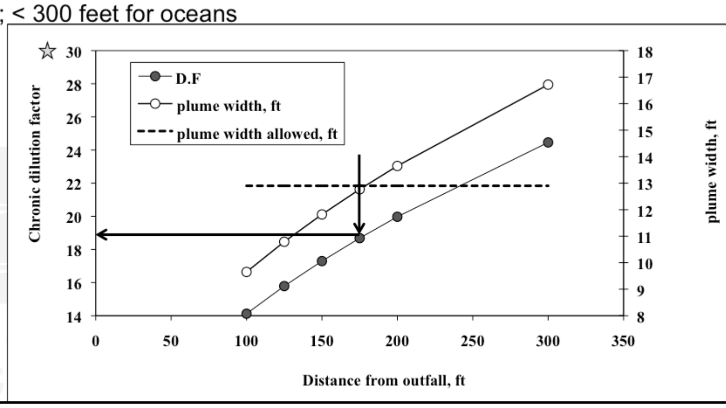
- **Mixing zones not allowed unless**:
  - All other options are exhausted
  - Overriding public interest
  - Advanced waste treatment is provided

- **If Allowed**:
  - Cannot use more than 10% of waterbody volume
  - Cannot use more than 10% of surface area
  - Cannot use more than 15% of width of waterbody.

Minimize Mixing Zones

Where possible

- Use less than 25% 7Q10 ambient flow
- Use less than 25% stream width
- Use smaller mixing zones: < 300 feet for streams; < 200 feet for estuaries; < 300 feet for oceans



No environmental harm

- No loss of sensitive or important habitat,
- No interference with existing or characteristic uses of the waterbody
- No resulting damage to the ecosystem
- No adverse public health affect

Critical Conditions

- Flow and Concentration
  - Ambient flow
  - Effluent flow
  - Ambient/Effluent concentrations
- Depth
- Stratification
- Dilution type

Ambient Flow

- Freshwater
  - Acute and Chronic …… 7Q10
  - Carcinogen ……………… Harmonic Flow
  - Non-Carcinogen ……… 7Q10
- Saltwater
  - Acute …… 10th % or 90th % current velocity*
  - Chronic/ Carcinogen/ Non-Carcinogen ……………… 50th % current velocity*

* Evaluated over a spring and neap tide

Effluent Flow

- Acute … highest daily Q_{max} in last 3 years
- Chronic/Non-Carcinogens … highest monthly Q_{avg} in last 3 years
- Carcinogens … Annual Average Flow
- Stormwater (Western WA):
  - Acute …… 1-hour peak flow from 2-yr 6-hr storm event
  - Chronic ..... Average flow from 2-yr 72-hr storm event
- Intermittent flow:
  - Estimate DF using Q_{max}
  - Increase DF by ($Q_{1\text{-hr avg}}/Q_{max}$) for acute
  - Increase DF by ($Q_{4\text{-day avg}}/Q_{max}$) for chronic

For Estimating Volumetric Dilution Factor

- Ambient Concentration:
  - Assume zero when no reflux
  - If reflux is present use reflux as ambient
- Effluent Concentration:
  - Assume 100% or 100 ppm

For Reasonable Potential Calculation

$$C_p = \frac{C_e}{DF} + (1 - \frac{1}{DF}) * C_a$$

- Ambient concentration (Ca)
  - Acute/Chronic …. 90th percentile
  - Carcinogen/Non-Carcinogen…Geometric Mean
- Effluent concentration (Ce)
  - (Acute/Chronic): Cmax x F*
  - (Carcinogen/Non-Carcinogen): 50th percentile

* uncertainty factor => based on number of samples, CV, and confidence interval (EPA, TSD, Table 3-1, 3-2)

Depth

- Freshwater
  - Acute and Chronic …… at 7Q10
  - Carcinogen ……………… at Harmonic Flow
  - Non-Carcinogen ……… at 7Q10
- Tidally influenced Freshwater
  - Same as above but at MLLW
- Marine waters
  - At MLLW

Stratification

- Use density profile that gives the least mixing
- Evaluate both:
  - maxium stratification (largest differential in sigma-t values)
  - minimum stratification (smallest differential in sigma-t values)
- Human Health
  - Use average of maximum and minimum

Dilution Type

- **Unidirectional flow:**
  - Acute and Chronic …… Centerline
  - Human Health …… flux average
- **Marine and rotating flows:**
  - Acute and Chronic/ …… Flux average
    Human Health

Overlapping Mixing Zones

Allowed where:

- Combined size meets the maximum mixing zone size limitations
- No barrier to migration of indigenous organisms with potential for ecosystem damage

EXTENDED MIXING ZONES

May be considered for:

- Discharges existing prior to 1992
- Where altering the size increases protection
- Where volume of effluent is more beneficial than removing the discharge.
- Necessary for social or economic development in the area.

Mixing zones for Stormwater

Maybe granted exemption from size limitations if:

- All BMP'S have been applied
- No potential threat to
  - Sensitive habitat and ecosystem
  - Public health
  - Beneficial uses
- No barrier to migration of indigenous organisms with potential for ecosystem damage

Mixing zones for CSO's

- Must comply with all mixing zone requirements
- But, exempt from size criteria once a year provided "no environmental harm" clause is fulfilled

UM3

- Simulates 3D plume trajectory
- Predicts centerline based on 3/2 power (~gaussian) profile and top-hat (average) concentrations
- Multiport plume merging simulated with reflection technique
- Does not directly resolve lateral or bottom boundary constraints

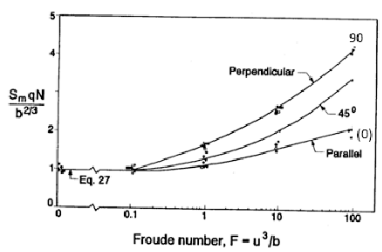
VSW

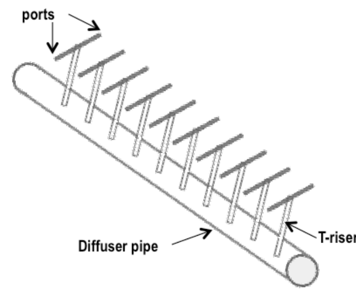
- Same as UM3 but applied to very shallow waters
- Resolves bottom constraint (bottom hit) by reflection technique

RSB…."range of experiment"

- Straight diffuser, uniformly spaced round ports on T-risers, horizontal ports in marine waters with plumes merging rapidly with length scale ratios:

$$0.31 < \frac{s}{l_b} < 1.92 \quad 0.078 < \frac{l_m}{l_b} < 0.5$$





S = port spacing;
lb = relates buoyancy per unit diffuser length to brunt Vaisala density frequency;
lm = relates momentum to density per unit length

CORMIX

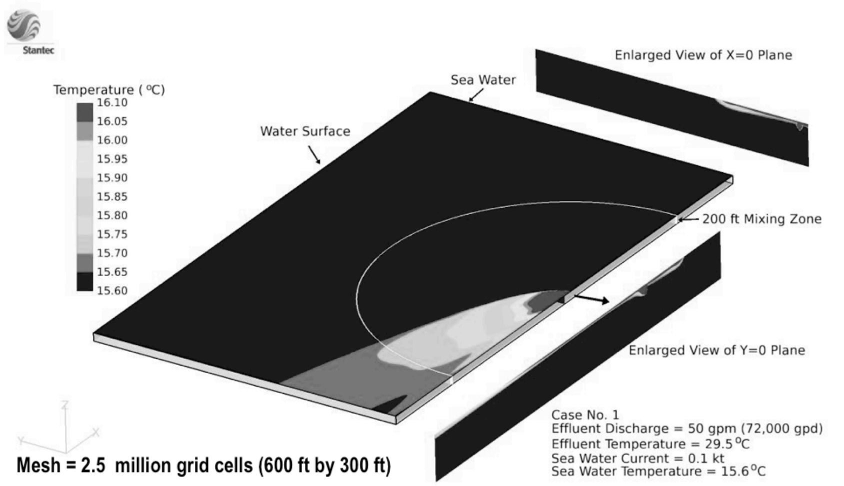
- CORMIX 1 single port positive/neutral buoyant discharges
- CORMIX 2 multiport positive/neutral buoyant discharges
  - Uses "equivalent slot diffuser"
  - May need CORMIX1 if plume details near each port are desired
- CORMIX 3 buoyant surface discharge

RIVPLUME (based on Fischer et al. 1979)

- Single port, short diffuser, or bank discharge
- Plume completely and rapidly vertically mixed within the acute zone. So a 2-D model
- Uses mean cross-sectional velocity
- It incorporates boundary effects of shoreline through superposition
- Cannot model ambient density stratification, dense plumes or tidal buildup
- Available at the following site:

http://www.ecy.wa.gov/programs/eap/pwspread/pwspread.html

CFD (Computational Fluid Dynamics)



Courtesy: Dr. Lin Fangbiao, Stantec Corporation