Selection of Critical Sources of Stormwater Pollutants

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1

Many types of runoff monitoring have been used to understand transport and fate, from small source areas to outfalls.

2

Other Source Area Sampling Methods

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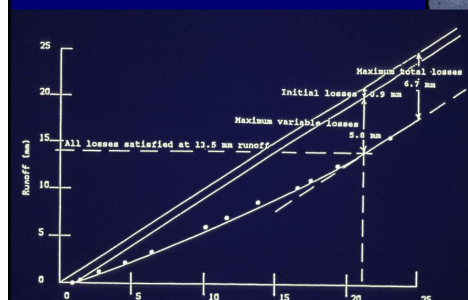
Controlled tests in small areas were used in conjunction with long-term rainfall/runoff monitoring at larger parking lot areas to develop actual hydrological relationships for paved areas, the most significant source of runoff for most urban areas during small to intermediate-sized rains.



Pitt 1987

This is an example of a rainfall-runoff plot from one of many controlled street washoff and runoff tests. About 1/3 of the rainfall is infiltrated through the street pavement for many of these events (up to 20 mm rains in this plot). No further infiltration was observed for larger events, resulting in classical pavement Rv values of 0.8 to 0.95 for large rains of interest for drainage design.

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Source Area Sampling in Drainage Area with Stormwater Control Testing
6/11/2003

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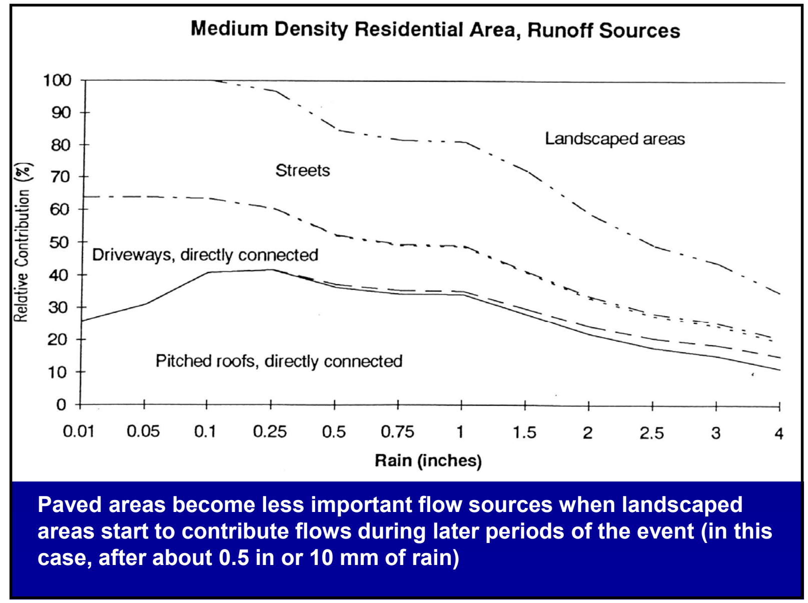
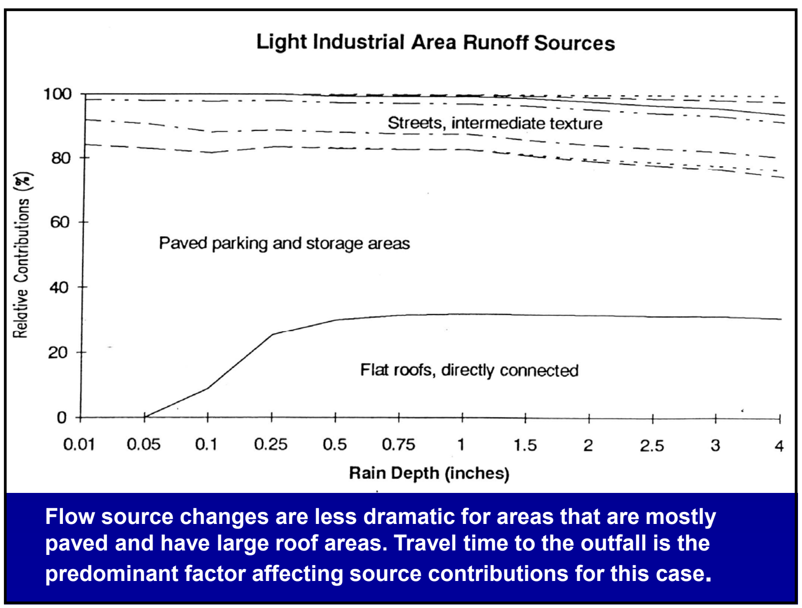

Medium Density Residential Area, Runoff Sources
Relative Contribution (%)
100
90
80
70
60
50
40
30
20
10
0
Landscaped areas
Streets
Driveways, directly connected
Pitched roofs, directly connected
0.01
0.05
0.1
0.25
0.5
0.75
1
1.5
2
2.5
3
4
Rain (inches)
Paved areas become less important flow sources when landscaped areas start to contribute flows during later periods of the event (in this case, after about 0.5 in or 10 mm of rain)

6


Light Industrial Area Runoff Sources
Relative Contributions (%)
100
80
60
40
20
0
Streets, intermediate texture
Paved parking and storage areas
Flat roofs, directly connected
0.01
0.05
0.1
0.25
0.5
0.75
1
1.5
2
2.5
3
4
Rain Depth (inches)
Flow source changes are less dramatic for areas that are mostly paved and have large roof areas. Travel time to the outfall is the predominant factor affecting source contributions for this case.

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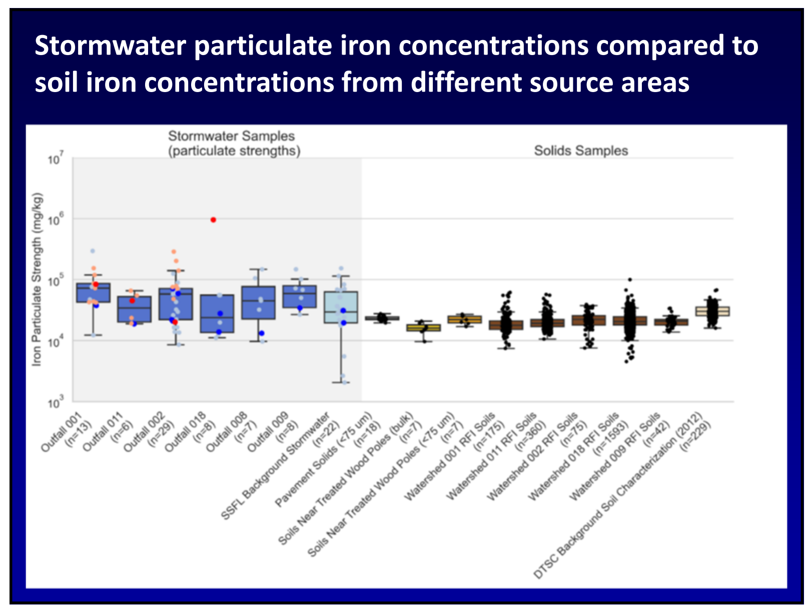
Stormwater particulate iron concentrations compared to soil iron concentrations from different source areas
Stormwater Samples (particulate strengths)
Solids Samples
Iron Particulate Strength (mg/kg)
10^7
10^6
10^5
10^4
10^3
Outfall 001 (n=13)
Outfall 011 (n=6)
Outfall 002 (n=29)
Outfall 018 (n=8)
Outfall 008 (n=7)
Outfall 009 (n=8)
SSFL Background Stormwater (n=22)
Pavement Solids (<75 um) (n=18)
Soils Near Treated Wood Poles (bulk) (n=7)
Soils Near Treated Wood Poles (<75 um) (n=7)
Watershed 001 RFI Soils (n=175)
Watershed 011 RFI Soils (n=360)
Watershed 002 RFI Soils (n=75)
Watershed 018 RFI Soils (n=1593)
Watershed 009 RFI Soils (n=42)
DTSC Background Soil Characterization (2012) (n=229)

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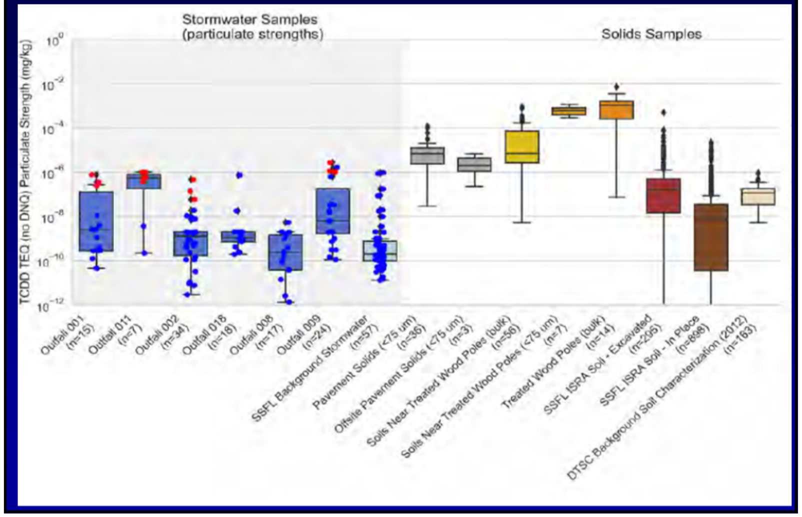
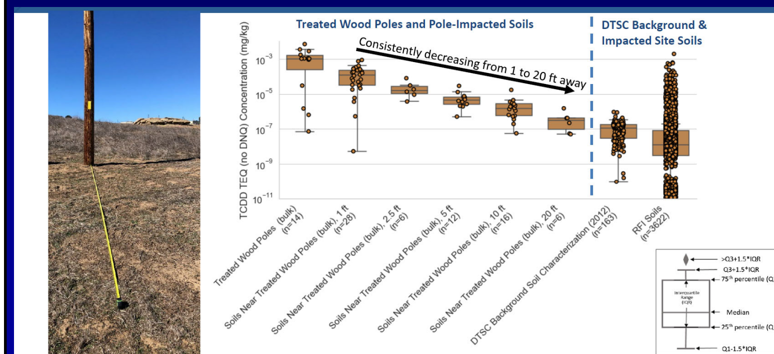
Similar plot comparing stormwater dioxin particulate concentrations with soils from different source areas



Follow-up Studies: Dioxin soil concentrations at different distances from treated wood utility poles compared to background soils and impacted soils



Subarea Ranking Methodology

- **Statistical methodology** (using binomial distribution) developed to rank the sites based on threshold comparisons while accounting for the number of usable data available at each site
- **"Weighting factors"** were calculated for each site for metals (cadmium, copper, and lead), dioxins (TCDD TEQ and 2,3,7,8-TCDD), and TSS.
  - **Multi-constituent "score"** was produced from metals and dioxin weighting factors to allow for relative ranking amongst potential stormwater control sites.

Monitoring Locations

LEGEND

- Potential control subarea site
- Stormwater background site
- Outfall monitoring site

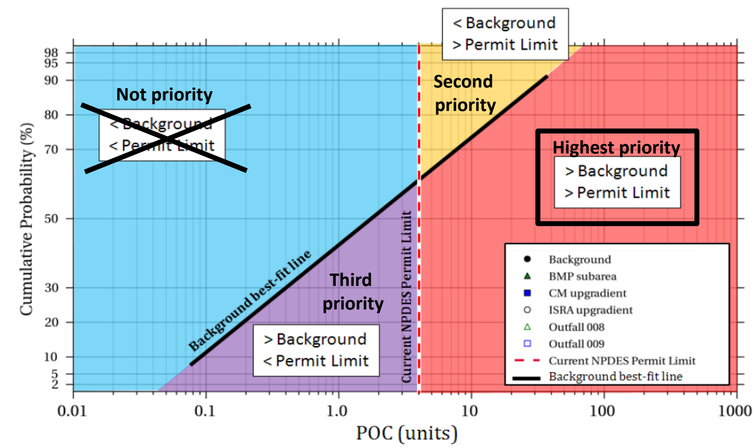
16 background sites and 68 potential stormwater treatment subareas monitored 2010 - 2012

800 400 0 800
Feet

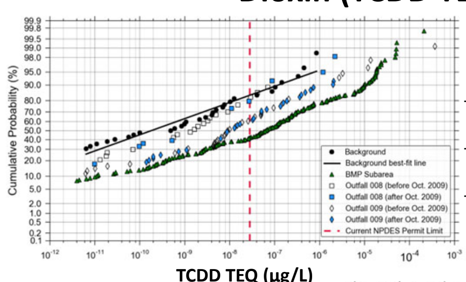
Stormwater Control Subarea Ranking Methodology

- Innovative, statistically rigorous approach
- Rank potential stormwater control subarea monitoring sites based on comparisons of:
  - Stormwater subarea concentrations with NPDES permit limits
  - Stormwater subarea particulate strengths with stormwater background particulate strengths
- Monitoring locations were scored based on number and percent of samples above NPDES permit limits and/or background
- Locations then ranked based on scores, and top locations identified
- Best professional judgment for stormwater control recommendations
- Process repeated annually through 2014

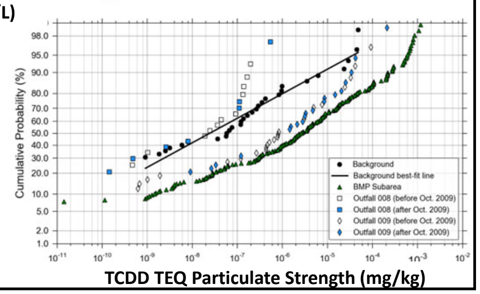
Basic Approach (example)



Dioxin (TCDD TEQ)



- Background subareas exceed NPDES Permit Limit
- Stormwater control subareas greater than Outfalls
- TSS/erosion is not always the issue



Example:

Site A: n = 10, m = 7 → $Weight_A$ = 0.83

Site B: n = 14, m = 2 → $Weight_B$ = 0.01

Based on weight alone, Site A would be prioritized over Site B.

Total Number of Observations (n)	Total Number of Critical Values in Data Set (m)													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	50													
2	50	[illegible]												
3	50	[illegible]	87											
4	31	[illegible]	69	94										
5	19	[illegible]	50	81	97									
6	11	[illegible]	50	66	89	98								
7	6	[illegible]	50	50	77	94	[illegible]							
8	4	[illegible]	36	50	64	86	[illegible]	99						
9	2	[illegible]	25	50	50	75	[illegible]	98	99					
10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	83	95	99	99				
11	1	[illegible]	11	27	50	50	73	89	97	99	99			
12	0	[illegible]	7	19	39	50	63	81	93	98	99	99		
13	0	[illegible]	5	13	29	50	50	71	87	95	99	99	99	
14	[illegible]	1	3	9	21	40	50	61	79	91	97	99	99	99
15	0	0	2	6	15	30	50	50	70	85	94	98	99	99

2011/2012 Ranking Results

Rank from Average Weights	Potential BMP Subarea (Co-location(s))	Watershed	Description	Approx. Upstream DA (ac)	Events Sampled	Multi-constituent Score	Rank from Max Metal Weight	Rank from Max Dioxin Weight	Rank from TSS Weight
1	**EVBMP0003 (A2SW0001)[ab]**	Outfall 009	ELV road runoff/CM-1 upstream west	11.8	14	0.94	1	1	32
2	**B1BMP0004 (B1SW0015)[a]**	Outfall 009	B-1 media filter inlet north	3.7	2	0.72	9	5	74
3	**ILBMP0001[b]**	Outfall 009	Lower parking lot 24" stormdrain	23	10	0.68	14	4	39.5
4	**EVBMP0001-A[b]**	Outfall 009	ELV culvert inlet (helipad road and ELV ditch, composite)	2.5	5	0.67	16.5	3	15
5.5	**EVBMP0002[b]**	Outfall 009	Helipad (pre-sandbag berms)	4.1	6	0.66	15	6	31
5.5	**ILBMP0002[a]**	Outfall 009	Road runoff to CM-9	2.5	7	0.66	3	12	15
7	**A1SW0009-A**	Outfall 009	CM-9 downstream-underdrain outlet (post-building 1324 parking lot asphalt removal, pre-filter fabric over weir boards)	16.4	1	0.63	2	19.5	74
8	**APBMP0001**	Outfall 009	Ashpile culvert inlet / road runoff	34	2	0.60	4	19.5	74
9	**LPBMP0001-A[b]**	Outfall 009	Lower Parking Lot sheetflow (post-gravel bag berms)	5.1	6	0.52	30	2	27
12.5	LPBMP0001[b]	Outfall 009	Lower Parking Lot sheetflow (pre-gravel bag berms)	5.1	2	0.50	9	19.5	15
15.5	**A2SW0002-A**	Outfall 009	CM1 effluent (post-filter fabric over weir boards)	52.8	4	0.43	18.5	19.5	28.5
15.5	A1SW0009-B	Outfall 009	CM-9 downstream-underdrain outlet (post-filter fabric over weir boards, post-building 1324 parking lot asphalt removal)	16.4	4	0.43	18.5	19.5	15
17	**B1BMP0003 (B1BMP0002)**	Outfall 009	B-1 parking lot / road runoff to culvert inlet	5.2	12	0.43	38	7	33
27	B1SW0014-B	Outfall 009	B-1 media filter effluent (post-media filter reconstruction)	4.7	4	0.27	32.5	19.5	74
28	LXBMP0004[b]	Outfall 009	LOX southwest downstream of sandbag berm	10.6	5	0.26	9	40.5	1
34	EVBMP0001[b]	Outfall 009	ELV culvert inlet (helipad road gutter)	1.8	3	0.11	25	31.5	15
36	EVBMP0002-A[ab]	Outfall 009	Helipad (post-sandbag berms)	4.1	5	0.09	40	29.5	74

Notes
1) Potential BMP subareas sorted by multi-constituent score, computed as described in Section 5.
2) ([a]) These potential BMP subarea monitoring subareas are upstream of existing stormwater quality treatment controls.
3) ([b])These potential BMP subarea monitoring subareas have new planned (i.e., designed and ready for construction) stormwater quality treatment controls.
4) (**) NPDES outfalls are included for comparison and method testing purposes only, stormwater controls are not being contemplated at these locations.
5) The rounding of weights may account for similar weights being ranked differently
6) Approximate drainage areas based on the cumulative drainage area of the SWMM catchment in which the monitoring location is located (Geosyntec, 2011). At locations where the monitoring point is upstream of the catchment outfall a "<" sign is used.
7) Bolded locations indicate that both the NPDES permit limit and 95[th] percentile background particulate strength threshold were exceeded for any one COC

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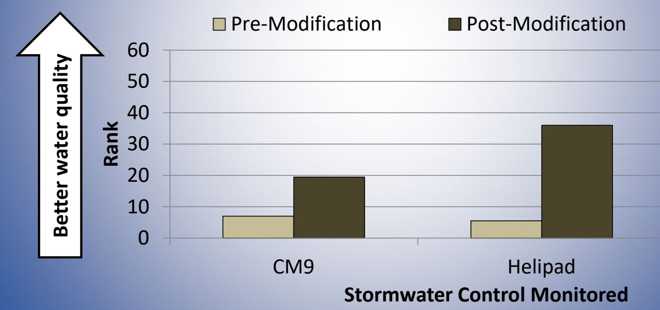
Water Quality Improvements

- Demonstrated by ranks, pre- and post-stormwater control modification (filter fabric added to CM weir boards; helipad sand bag berm constructed)
- Limited to sites with at least 2 samples



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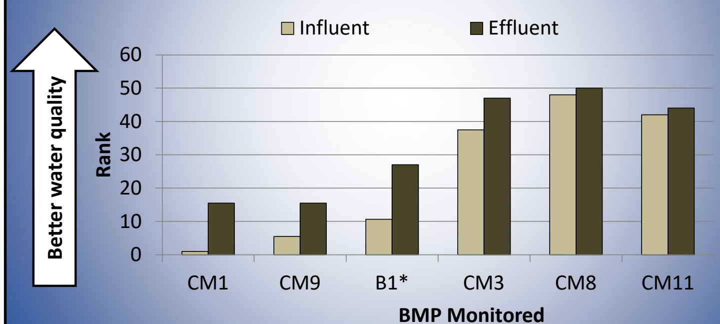
Water Quality Improvements

- Demonstrated by ranks, comparing influent and effluent.
- Limited to sites with at least 2 samples.



*Average of impacted B1 influent streams

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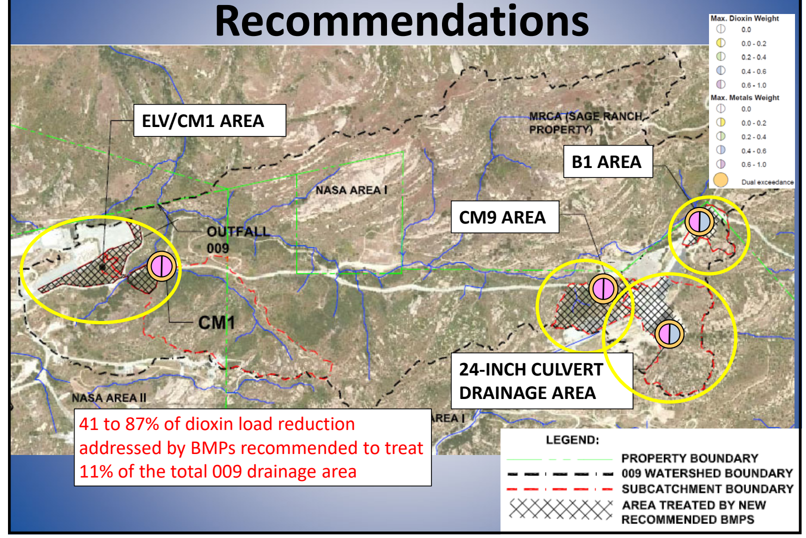
New Stormwater Control Recommendations



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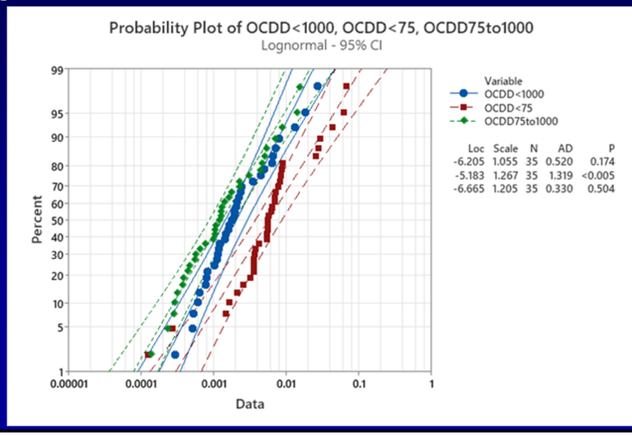
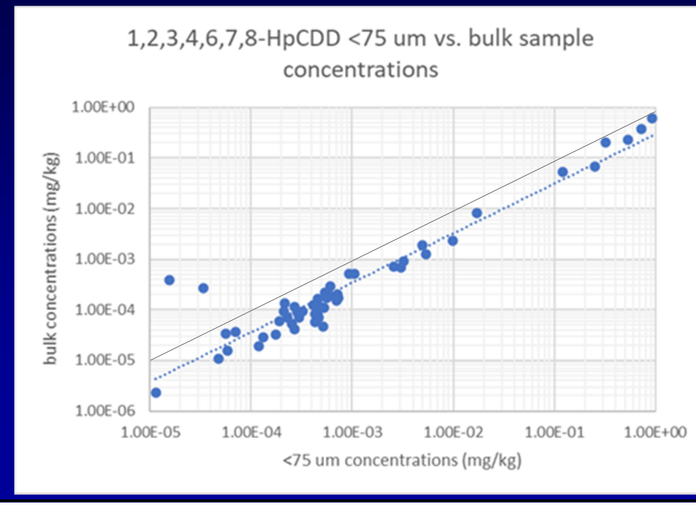
Another special studies component examined particulate strength by particle size.

Pavement solids particulate strengths for different particle ranges:



Example scatterplot comparing <75 µm particle range dioxin congener data to bulk sample particulate strength data.

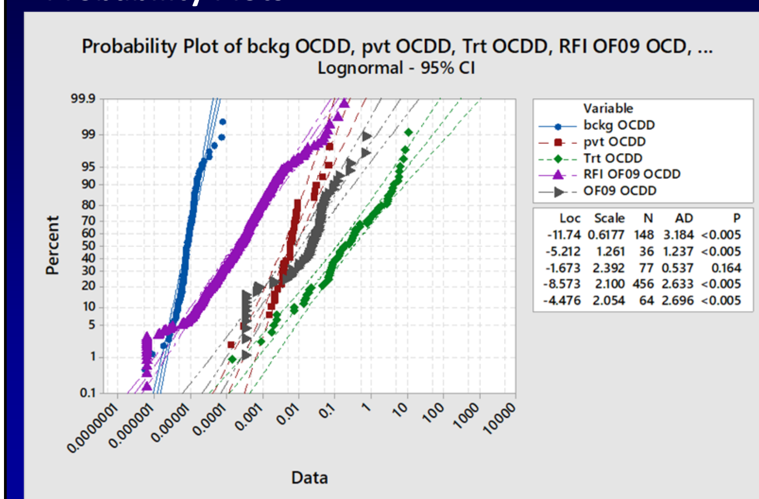


Identifying Dioxin Sources using Congener "Fingerprinting" Techniques

The sources used in the calculations were the same for each outfall set:

- Outfall stormwater (separately for OF001, 002, 003, 008, 009, 011, and 018)
- RFI soil for the same watersheds as the outfall, <75 µm
- Pavement solids <75 µm
- Atmospheric deposition
- Background stormwater
- Paved area sheetflow near treated wood

Example Dioxin Congener (OCDD) Source Area Probability Plots



Rankings of Median Particulate Strengths of OCDD Congener Compared to Outfalls (1 lowest)

	Background soil	RFI soil	Pavement soil	Pavement soil near treated wood	Outfall
OF001	1	2	3.5 close tie	5	3.5 close tie
OF002	1	2	4	5	3
OF003	1	2	3.5 close tie	5	3.5 close tie
OF008	1	2.5 close tie	4	5	2.5 close tie
OF009	1	2	3	5	4
OF011	1	2	3.5 close tie	5	3.5 close tie
OF018	1	2	3	5	4

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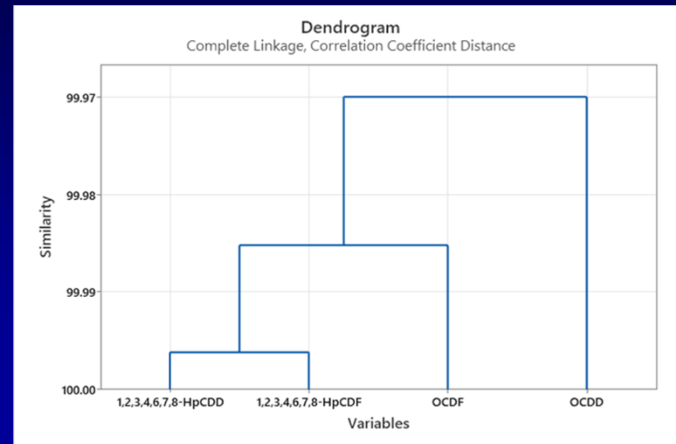
Dioxin Congener Relationships using Cluster Analyses; Outfall 009 example:



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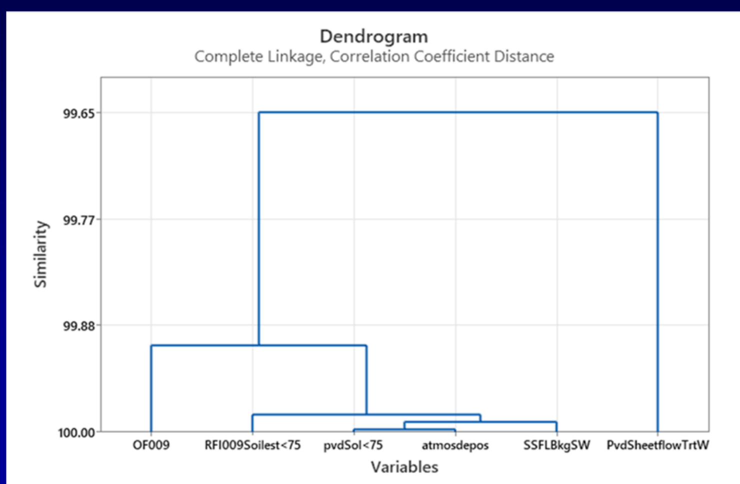
Dioxin Congener Sources in Outfall 009 Watershed using Cluster Analyses (using four congeners found in all sources)



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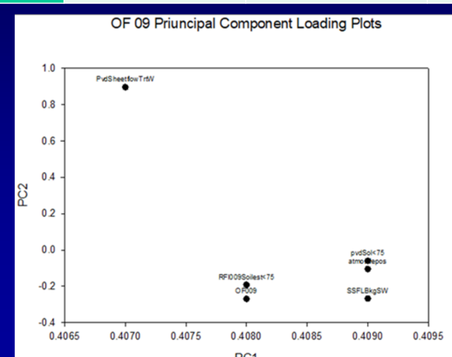
Principal Component Analyses of Dioxin Congener Sources

Variable	PC1	PC2	PC3
OF009	0.408	-0.269	-0.78
RFI009Soilest<75	0.408	-0.192	0.579
pvdSol<75	0.409	-0.06	0.215
PvdSheetflowTrtW	0.407	0.897	-0.076
SSFLBkgSW	0.409	-0.268	0.07
atmosdepos	0.409	-0.105	-0.008



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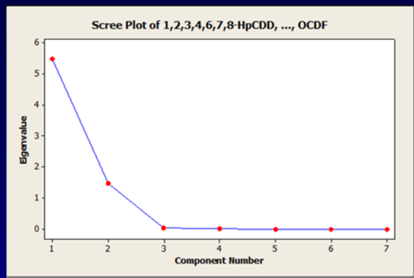


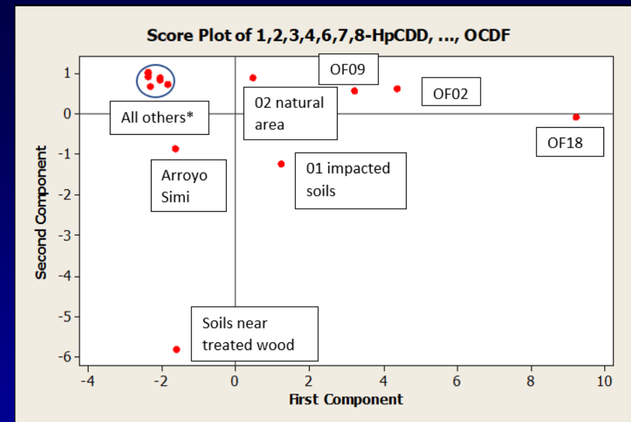
Principal Component Analysis: 1,2,3,4,6,7,, 1,2,3,4,6,7,, 1,2,3,4,7,8-, 1,2,3,6

Eigenanalysis of the Correlation Matrix

Eigenvalue	5.4719	1.4759	0.0445	0.0061	0.0014	0.0003	0.0001
Proportion	0.782	0.211	0.006	0.001	0.000	0.000	0.000
Cumulative	0.782	0.993	0.999	1.000	1.000	1.000	1.000

Variable	PC1	PC2	PC3	PC4	PC5	PC6	PC7
1,2,3,4,6,7,8-HpCDD	0.406	0.257	-0.140	-0.177	-0.271	-0.802	-0.043
1,2,3,4,6,7,8-HpCDF	0.398	0.289	-0.490	-0.435	0.011	0.488	-0.301
1,2,3,4,7,8-HxCDF	0.198	-0.728	0.113	-0.560	-0.219	0.032	0.234
1,2,3,6,7,8-HxCDD	0.423	0.018	0.668	-0.084	0.460	-0.012	-0.394
1,2,3,7,8,9-HxCDD	0.405	0.252	0.369	0.272	-0.587	0.342	0.318
OCDD	0.426	-0.035	-0.247	0.196	0.553	-0.017	0.641
OCDF	0.336	-0.505	-0.290	0.588	-0.130	-0.004	-0.431

The calculated eigenvalues indicate how the different variables (the congeners here) contribute to explaining the variability in the data set. The first principal component accounts for most of the variability, while the others contribute less amounts. The loading for each variable indicates the relative significance for each variable per principal component. The scree plot shows the relative contributions for each component. Usually, the first two or three principal components contribute most of the total explanation of the variability, as indicated by the additional components contributing very little. The score plot is a scatter plot of the loadings for the first two principal components and indicates how the outfall and sources are related.



***all others include: OF01, OF08, 002subarea impacted soils, pavement fines, SSFL background soils, ISRA excavated soil, and ISRA soil in place**

The chemical mass balance equation is written in a matrix form as follows:

$$\begin{bmatrix} x_{11} & x_{12} & x_{13} & \cdots & x_{1n} & \mu \\ x_{21} & x_{22} & x_{23} & \cdots & x_{2n} & \mu \\ x_{31} & x_{32} & x_{33} & \cdots & x_{3n} & \mu \\ \vdots & \vdots & \vdots & \cdots & \vdots & \vdots \\ x_{n1} & x_{n2} & x_{n3} & \cdots & x_{nn} & \mu \\ 1 & 1 & 1 & \cdots & 1 & 0 \end{bmatrix} \begin{bmatrix} m_1 \\ m_2 \\ m_3 \\ \vdots \\ m_n \\ 1 \end{bmatrix} = \begin{bmatrix} C_1 \\ C_2 \\ C_3 \\ \vdots \\ C_n \\ 1 \end{bmatrix}$$

X A B

The chemical mass balance equation which is the basis for this model is as follows:

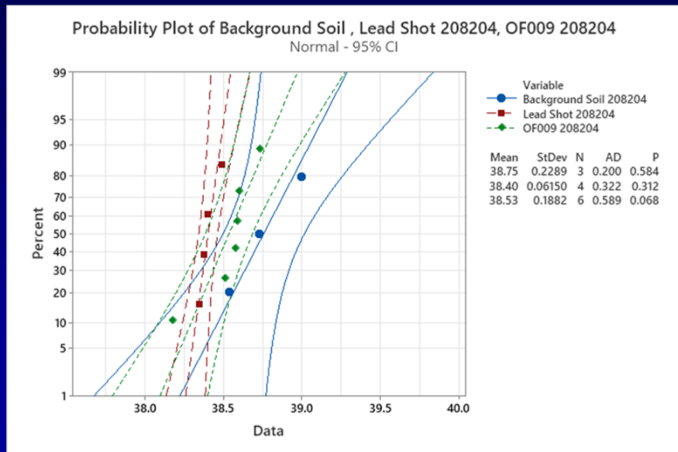
$\Sigma n\ (mn)\ (xpn) + \mu = Cp$

mn = the fraction of material from source type n
xpn = the concentration of tracer p in source type n
Cp = the concentration of tracer p at the outfall
µ = error term associated with tracer p

The chemical mass balance model was used to calculate the likely contributions of the different TCDD congener sources affecting the outfall stormwater.

outfall	RFI soil	background soil	pavement	atmospheric deposition	Pavement runoff near treated wood	Reliability (based on sums)
OF 001	0.56	0.35	0.08	0.01	<0.01	good
OF 002	0.58	0.34	0.07	<0.01	<0.01	fair
OF 003	0.64	0.24	0.10	0.02	<0.01	fair
OF 008	0.77	0.15	0.06	0.01	<0.01	poor
OF 009	0.54	0.40	0.07	<0.01	<0.01	fair
OF 011	0.64	0.26	0.09	0.02	<0.01	fair
OF 018	0.42	0.45	0.11	0.02	<0.01	fair

Multivariate Analyses to Identify Sources of Stormwater Lead using Isotope Ratios



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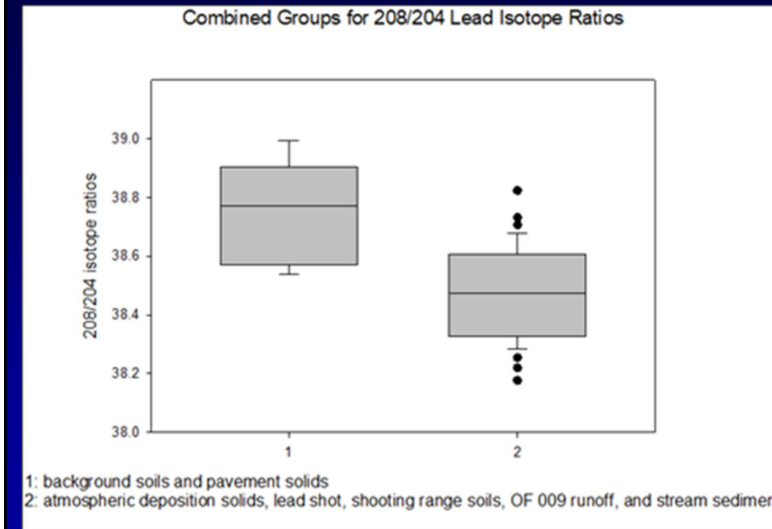
Kruskal-Wallis One Way Analysis of Variance on Ranks, p = 0.006



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Pearson Correlation Matrix Showing Correlation Coefficients and p Values (significant differences high-lighted)

	Pb208/204	Pb207/204	Pb206/204	Pb208/206	Pb207/206
Pb208/204		0.605	0.8	-0.421	-0.651
		1.36E-05	7.05E-11	0.00443	0.00000175
Pb207/204			0.132	0.283	0.118
			0.394	0.0627	0.447
Pb206/204				-0.881	-0.969
				3.32E-15	5.08E-27
Pb208/206					0.953
					2.08E-23

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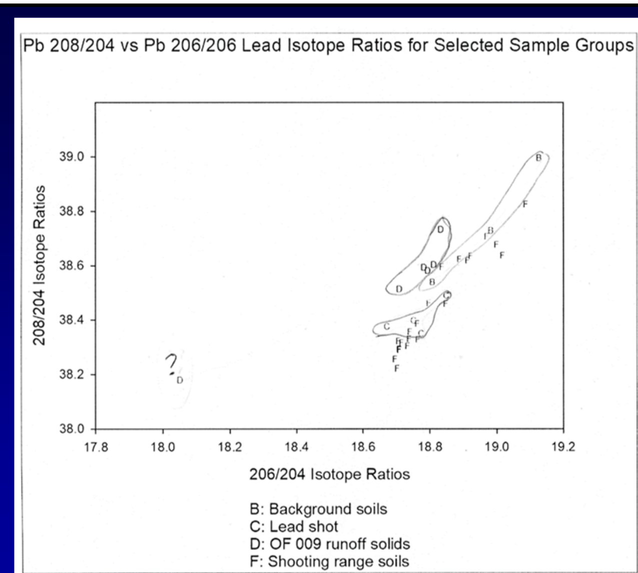

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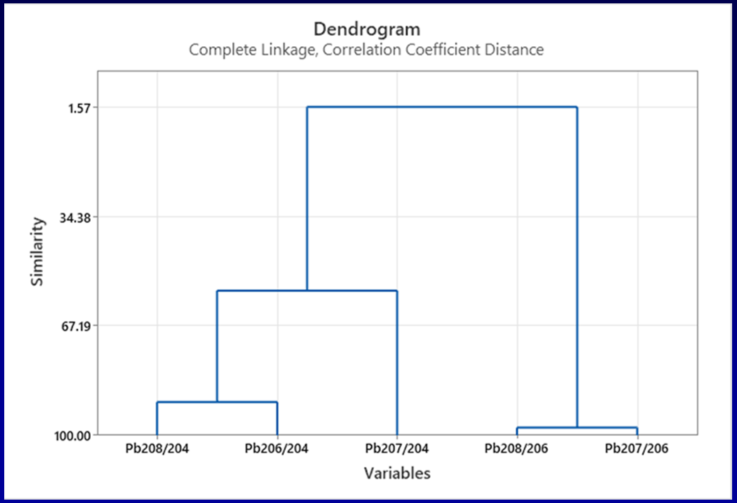
Cluster Analysis Dendogram showing Relationships and Similarities between Lead Isotopes



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Further cluster analyses found that most of the lead shot and shooting range soil ratio data are in one cluster group (1), while most of the OF 009 runoff ratio data are in another cluster group (2).

percentage in each similarity category	cluster group 1	cluster group 2	cluster group 3	cluster group 4	total
Background Soil	0	33	33	33	100
Lead Shot	75	25	0	0	100
OF009 Stormwater	0	80	20	0	100
Pavement Solids	0	0	67	33	100
Shooting Range Soil	52	14	29	5	100
Stream Sediment	17	50	33	0	100
average	24	34	30	12	100

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