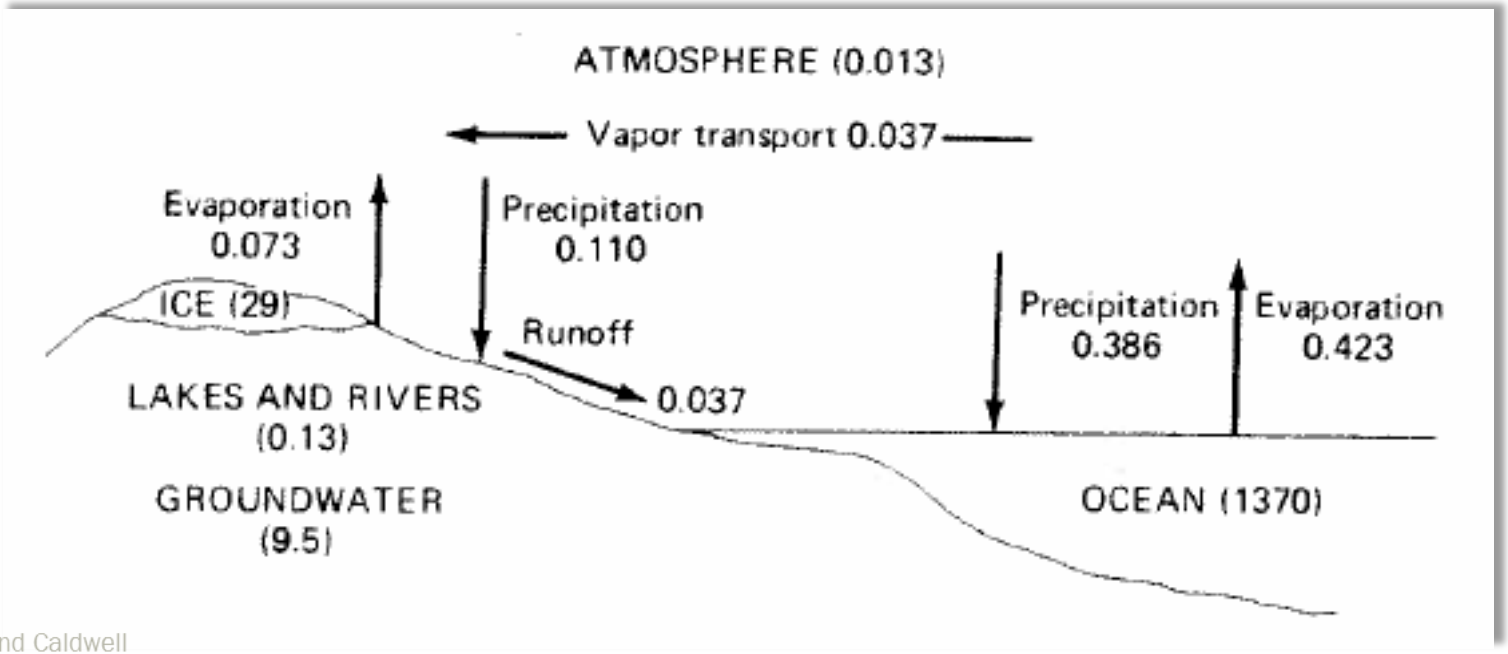
Stormwater Hydrology, Pollutant Sources, Loadings, Removal Mechanisms, and Monitoring

Jeff Herr, P.E., D.WRE

Brown AND Caldwell

Global Water Perspective

- Freshwater accounts for less than 3% of the total water on the earth
- Groundwater accounts for ~ 0.7% of the earth's freshwater
- < 0.1% of the freshwater on the earth is in surface waters



Water Resources

- SE states receive 34 to 57 inches of rainfall each year
- Rainfall volume is >>>> water demand
- Much of our rainfall becomes runoff and is lost to tide
- Stormwater runoff is naturally self-sustaining; pending major changes from climate change it will continue to rain

Hydrology: Most rainfall events are 1-inch or less

Manage common rain events for WQ improvement

Rainfall Event Range (inches)	Mean Rainfall Depth (inches)	Mean Rainfall Duration (hours)	Fraction of Annual Rain Events	Number of Annual Events in Range
0.00-0.10	0.041	1.203	0.427	56.683
0.11-0.20	0.152	2.393	0.142	18.866
0.21-0.30	0.252	3.073	0.080	10.590
0.31-0.40	0.353	3.371	0.055	7.312
0.41-0.50	0.456	3.702	0.048	6.325
0.51-1.00	**0.713**	**4.379**	**0.129**	**17.102 (117)**
1.01-1.50	1.221	5.758	0.051	6.733
1.51-2.0	1.726	7.852	0.024	3.145
2.01-2.50	2.271	8.090	0.011	1.470
2.51-3.00	**2.704**	**10.675**	**0.006**	**0.726**
3.01-3.50	3.246	9.978	0.003	0.391
3.51-4.00	3.667	13.362	0.002	0.260
4.01-4.50	4.216	15.638	0.001	0.149
4.51-5.00	4.796	17.482	0.000	0.056
5.01-6.00	5.454	23.303	0.001	0.167
6.01-7.00	6.470	40.500	0.000	0.019
7.01-8.00	7.900	31.500	0.000	0.019
8.01-9.00	8.190	3.500	0.000	0.019
>9.00	10.675	46.250	0.001	0.075

Minimal runoff from pervious areas and N-DCIA
Even in HSG 'D' soils – DCIA is the driver

Rainfall	Runoff depth for curve number of—												
	40	45	50	55	60	65	70	75	80	85	90	95	98
	inches												
1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.08	0.17	0.32	0.56	0.79
1.2	.00	.00	.00	.00	.00	.00	.03	.07	.15	.27	.46	.74	.99
1.4	.00	.00	.00	.00	.00	.02	.06	.13	.24	.39	.61	.92	1.18
1.6	.00	.00	.00	.00	.01	.05	.11	.20	.34	.52	.76	1.11	1.38
1.8	.00	.00	.00	.00	.03	.09	.17	.29	.44	.65	.93	1.29	1.58
2.0	.00	.00	.00	.02	.06	.14	.24	.38	.56	.80	1.09	1.48	1.77
2.5	.00	.00	.02	.08	.17	.30	.46	.65	.89	1.18	1.53	1.96	2.27
3.0	.00	.02	.09	.19	.33	.51	.71	.96	1.25	1.59	1.98	2.45	2.77

Which Pollutants? Which Forms?

- Sediment
- Biochemical oxygen demand
- Pathogens
- Phosphorus: SRP, OP, TP
- Nitrogen: TKN = Org N + NH3; NOX = NO2 + NO3
  TN = TKN + NOX
  (Only some forms of nutrients are bioavailable)
- Metals
- Toxic compounds

The form matters for BMP selection:

Organic or inorganic, dissolved or particulate

Stormwater Pollutant Sources

POLLUTANT	PRIMARY SOURCES
Particulates	Soil erosion, sedimentation, pavement wear, atmosphere-fossil fuels, maintenance
Nutrients – N and P	Fossil fuels, fertilizer application, pets, septic tanks, sewer spills, wastewater reuse, soil erosion
Zinc	Tire wear, motor oil, grease
Copper	Metal plating, bearing and bushing wear, moving engine parts, brake lining wear, fungicides and insecticides
Cadmium	Tire wear, insecticides
Chromium	Metal plating, moving engine parts, brake linings
Nickel	Diesel fuel and gasoline, lubricating oils, metal plating, bushing wear, brake linings, asphalt
Petroleum	Spills, leaks or blow-by of motor lubricants, antifreeze and hydraulic fluids, asphalt
Pathogens	Birds, animal waste, septic tanks, sewer spills
Synthetic organics	Industrial processes, pesticides, insecticides, spills, asphalt

Some pollutants are visible and others are not.

Personal Pollution- Gross Pollutants, BOD

Organic Debris – TSS, N, P, BOD

Construction Erosion

Sediment, Turbidity, P

Combustion of Fossil Fuels
N, metals

Vehicles – particulates, metals, oils and greases

Sanitary Sewer Overflows
N, P, BOD, Pathogens

Wastewater Reuse
N, P, BOD

Natural Systems – Sediment release of N, P; Wildlife - Pathogens, N, P, BOD

In-Stream Erosion
TSS, Turbidity, P

Impacts of Stormwater Pollutants

- Gross solids (trash, debris, organic material)

  - aesthetics, reduces conveyance, nutrient source

- Sediments – reduces conveyance, contains other pollutants
- Oxygen demanding substances (BOD, COD)

  - reduces DO, impacts aquatic life, fish kills

- Nutrients (nitrogen and phosphorus)

  - eutrophication, oxygen demand

- Pathogens (bacteria and viruses)

  - impacts wildlife, aquatic life, human illnesses

- Heavy metals – toxic to wildlife, aquatic life, humans (lead, zinc, cadmium, chromium, copper, nickel)
- Oil & grease, hydrocarbons

  – toxic to wildlife, aquatic life, humans

Less Common Pollutants (all toxic)

- Insecticides/Pesticides
- Radioactive materials
- Solvents
- Other hazardous chemicals

SUMMARY OF LITERATURE-BASED RUNOFF CHARACTERIZATION DATA FOR GENERAL LAND USE CATEGORIES IN FLORIDA

LAND USE CATEGORY	TYPICAL RUNOFF CONCENTRATION (mg/l)						
	TOTAL N	TOTAL P	BOD	TSS	COPPER	LEAD	ZINC
Low-Density Residential[1]	1.61	0.191	4.7	23.0	0.008[4]	0.002[4]	0.031[4]
Single-Family	2.07	0.327	7.9	37.5	0.016	0.004	0.062
Multi-Family	2.32	0.520	11.3	77.8	0.009	0.006	0.086
Low-Intensity Commercial	1.18	0.179	7.7	57.5	0.018	0.005	0.094
High-Intensity Commercial	2.40	0.345	11.3	69.7	0.015	--	0.160
Light Industrial	1.20	0.260	7.6	60.0	0.003	0.002	0.057
Highway	1.64	0.220	5.2	37.3	0.032	0.011	0.126
Agricultural							
Pasture	3.47	0.616	5.1	94.3	--	--	--
Citrus	2.24	0.183	2.55	15.5	0.003	0.001	0.012
Row Crops	2.65	0.593	--	19.8	0.022	0.004	0.030
General Agriculture[2]	2.79	0.431	3.8	43.2	0.013	0.003	0.021
Undeveloped / Rangeland / Forest	1.15	0.055	1.4	8.4	--	--	--
Mining / Extractive	1.18	0.15	7.6[3]	60.0[3]	0.003[3]	0.002[3]	0.057[3]

1. Average of single-family and undeveloped loading rates
2. Mean of pasture, citrus, and row crop land uses
3. Runoff concentrations assumed equal to industrial values for these parameters
4. Value assumed to be equal to 50% of single-family concentration

Source: Harper

SUMMARY OF CALCULATED AREAL POLLUTANT LOADING RATES FOR CENTRAL AND SOUTH FLORIDA

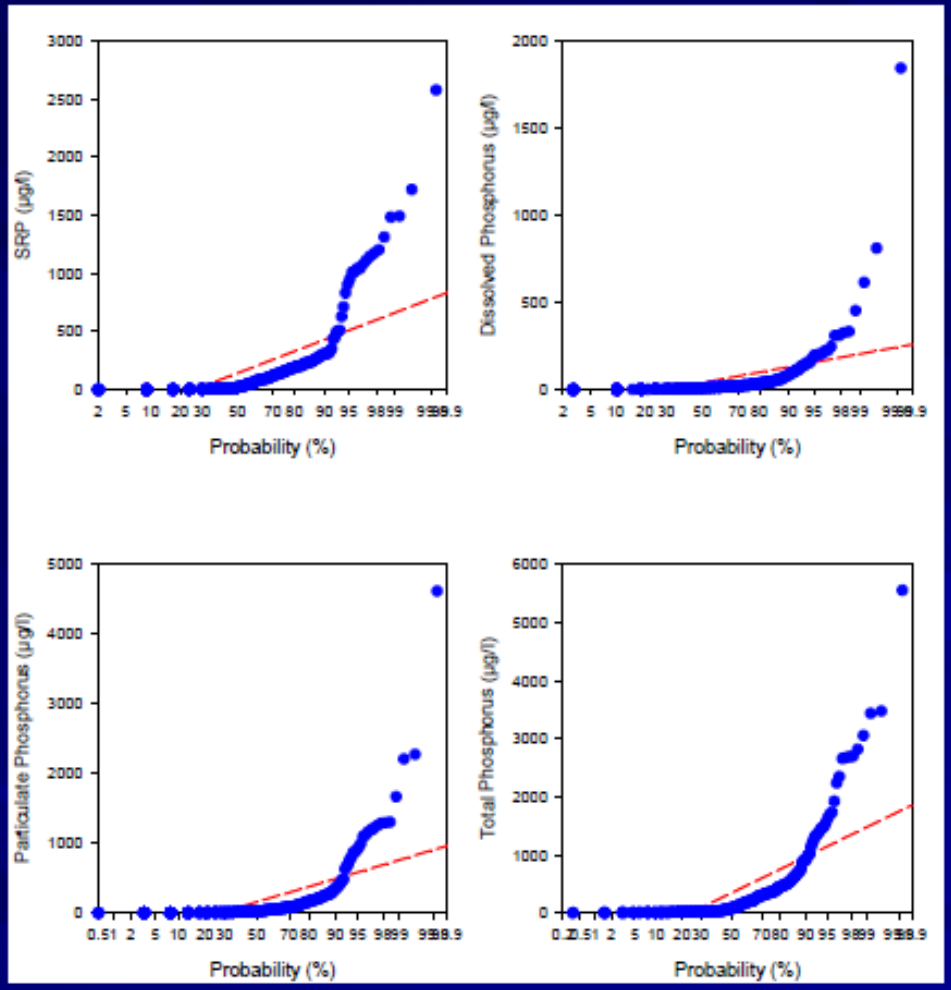
Development significantly increases pollutant loadings

LAND USE CATEGORY	AREAL LOADING RATE (kg/ac-yr)						
	TOTAL N	ORTHO-P	TOTAL P	BOD	TSS	TOTAL Zn	TOTAL Pb
Low Density Residential	2.88	0.169	0.320	7.63	31.9	0.06	0.052
Single-Family	4.68	0.335	0.594	14.3	56.1	0.122	0.083
Multi Family	8.51	0.924	1.72	38.4	256	0.188	0.299
Low-Intensity Commercial	5.18	0.157	0.650	36.1	343	0.511	0.635
High Intensity Commercial	13.0	1.52	1.96	79.3	435	0.782	0.985
Industrial	7.30	0.519	1.24	39.5	383	0.543	0.872
Highway	6.69	0.361	1.32	21.9	182	0.508	0.727
Ag – Pasture	4.54	0.732	0.876	7.99	126		
Ag - Citrus	2.91	0.123	0.197	3.60	21.9		
Ag - Row Crops	2.84	0.421	0.595				
General Ag	3.62	0.380	0.551	5.80	74.0		
Undeveloped	1.07	0.003	0.046	0.96	7.60	0.005	0.021
Mining	2.21	0.131	0.281	18.0	176	0.229	0.378
Wetland	1.81	0.204	0.222	4.96	11.2	0.009	0.039
Open Water	3.23	0.130	0.273	4.02	8.05	0.073	0.065

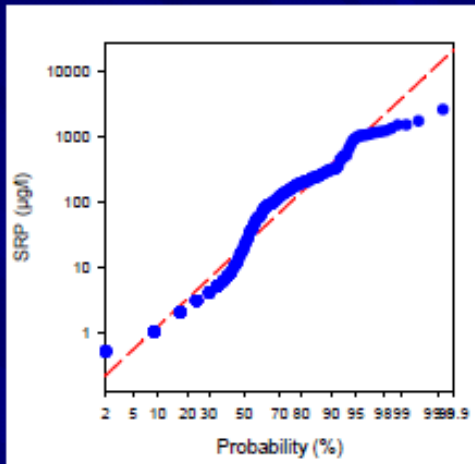
SOURCE: HARPER

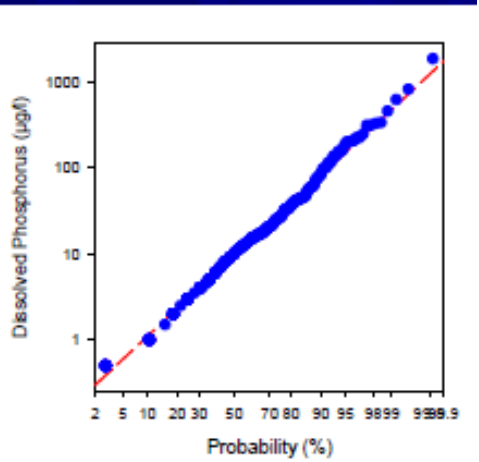
Statistical Evaluation of Data

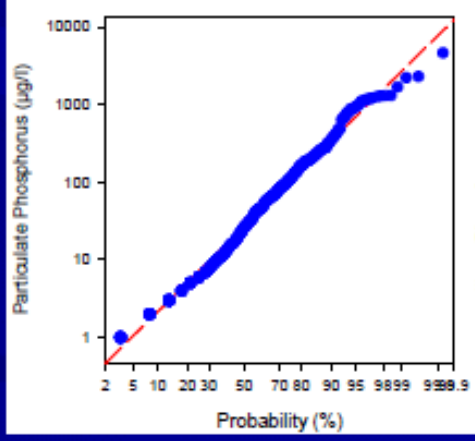
Probability Plots – Phosphorus Species

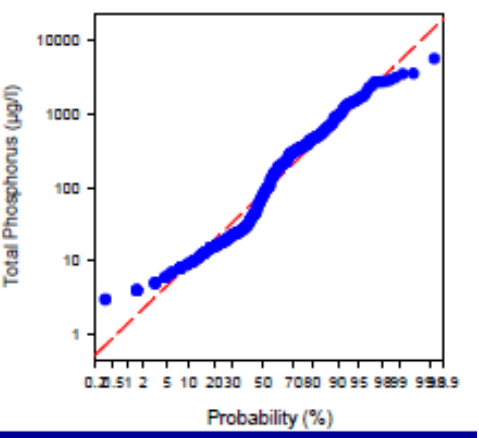


Normal Probability Distribution







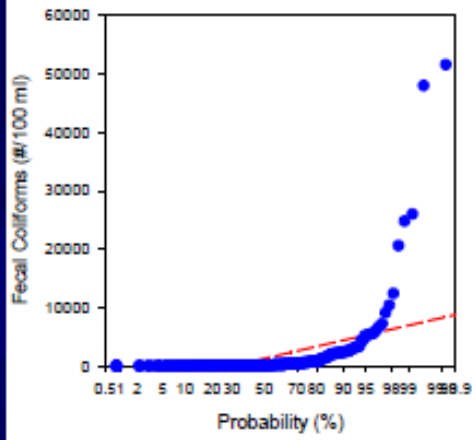


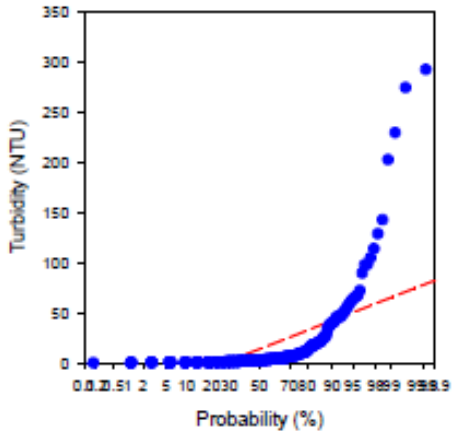
Log-Normal Probability Distribution

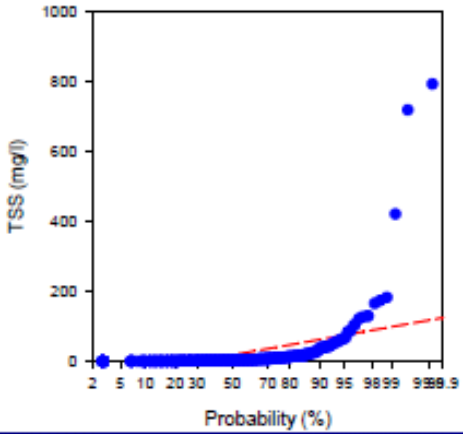
Source: Harper 2011

Statistical Evaluation of Data

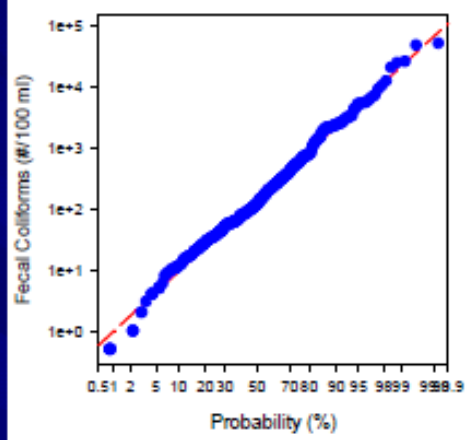
Probability Plots – Fecal, Turbidity & TSS

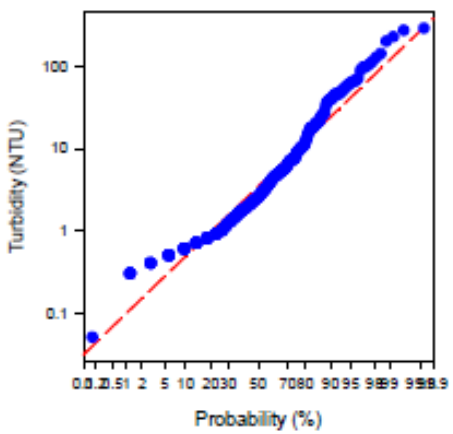


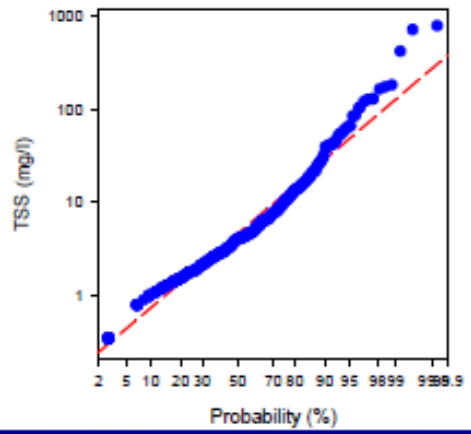




Normal Probability Distribution



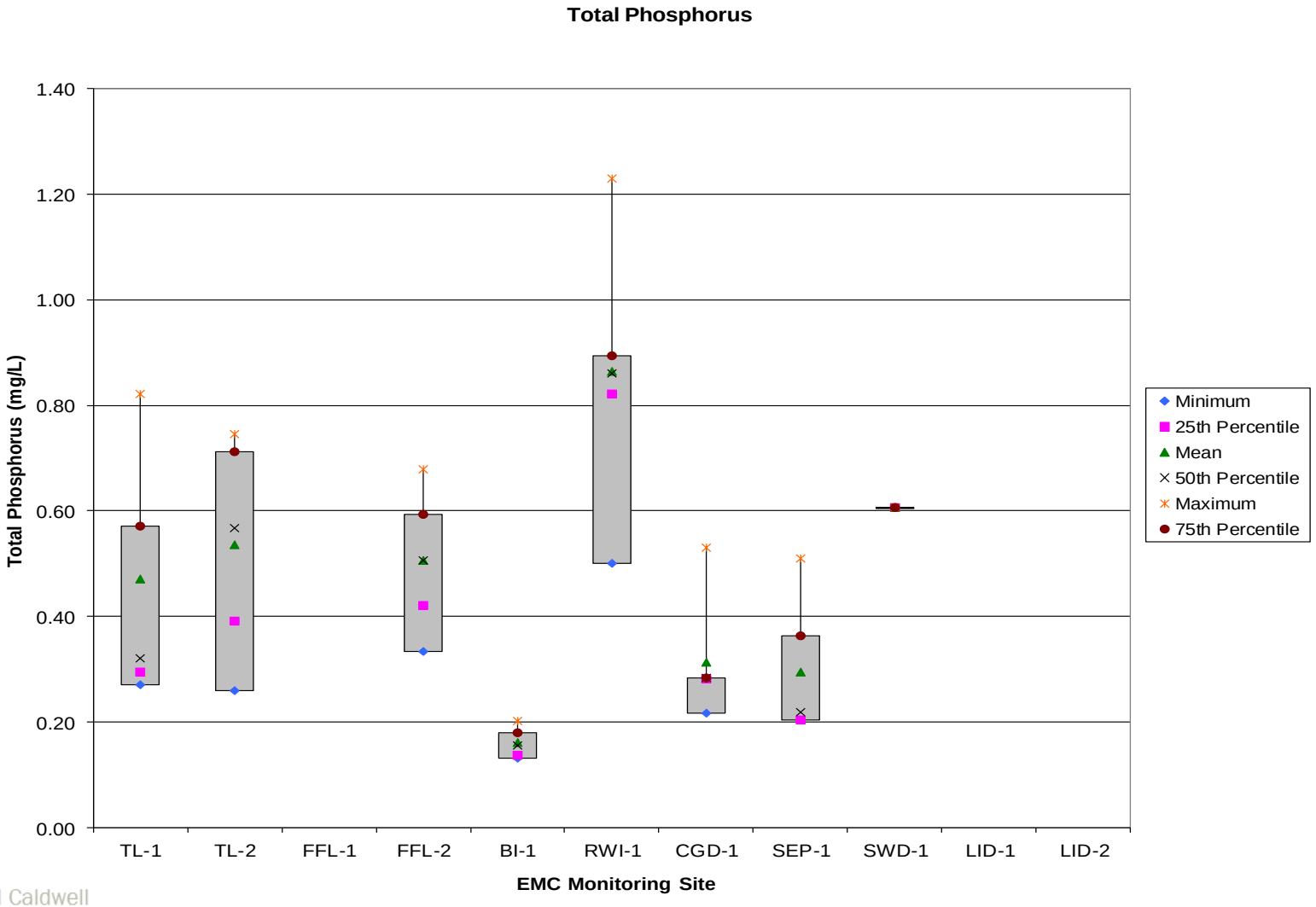




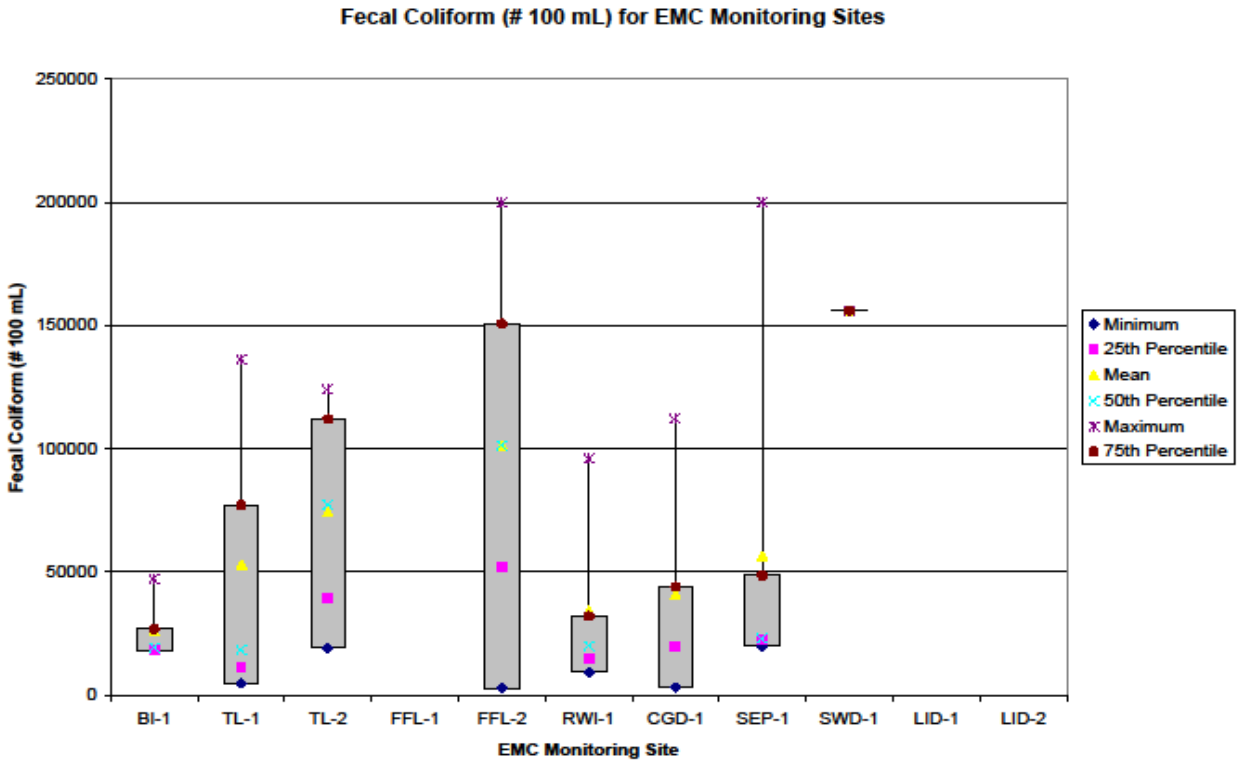
Log-Normal Probability Distribution

Source: Harper 2011

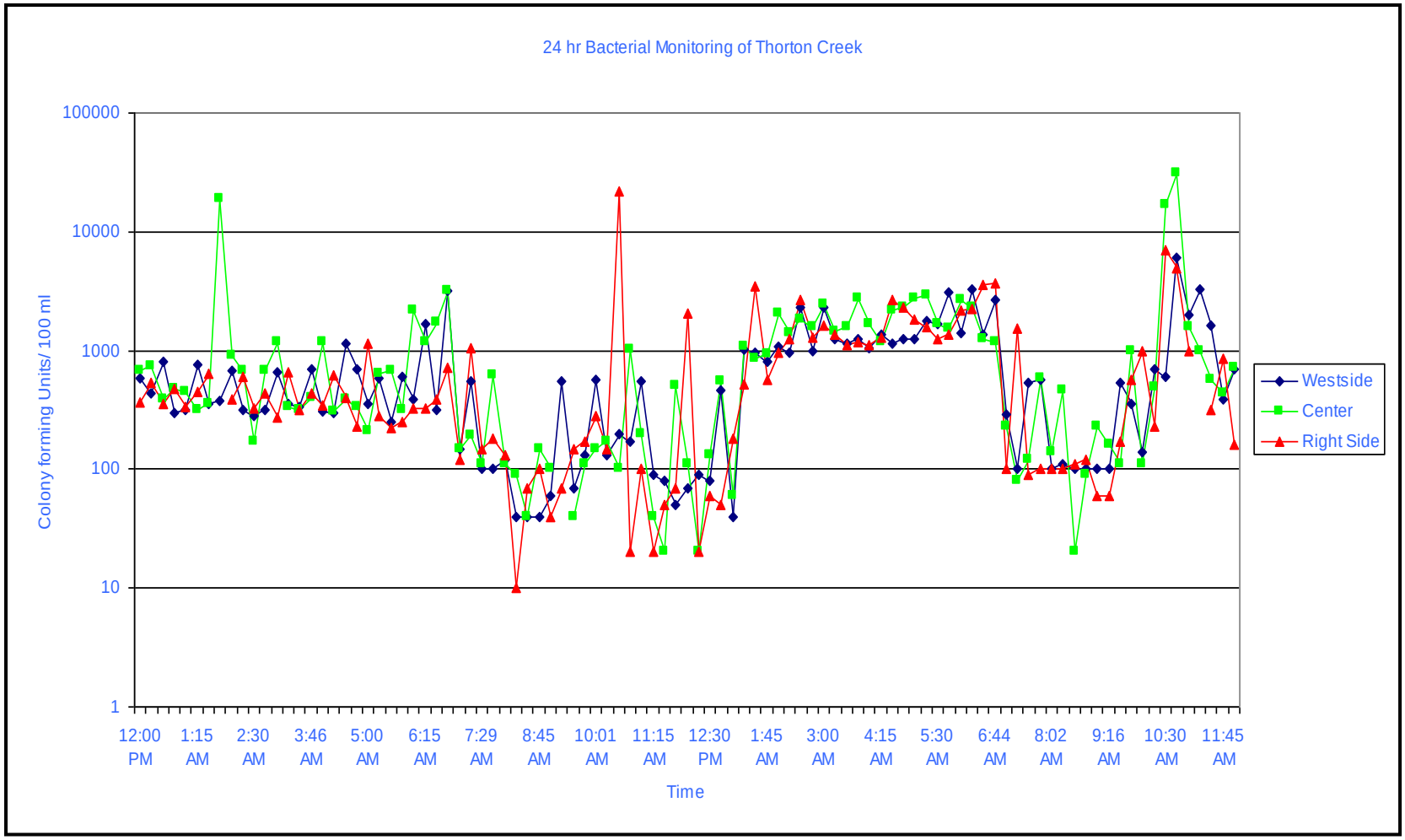
Stormwater pollutant concentrations are highly variable even at the same site



Stormwater pollutant concentrations are highly variable even at the same site



Fecal Coliform Variability



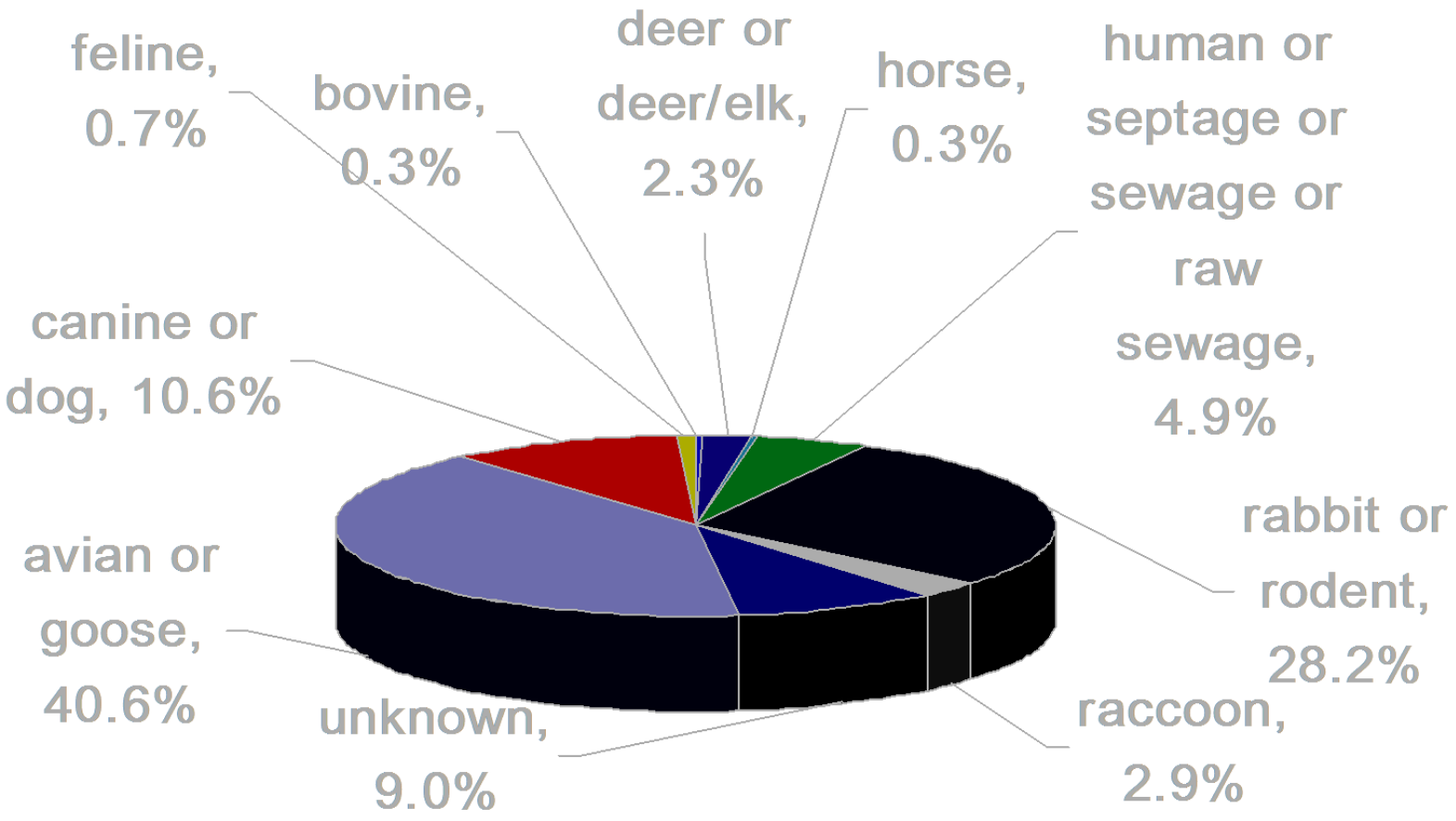
Fecal coliform ranged from 10 to >10,000 within 24-hour period. Source: BC 2007

Potential Pathogens in Stormwater

- Bacteria: campylobacter, salmonella, E. Coli, Shigella
- Viruses: cryptosporidia, giardia
- Parasites: cercarial dermatitis (swimmer's itch)

MST Results – All Stations, All Rounds Combined

Total = 687 Isolates

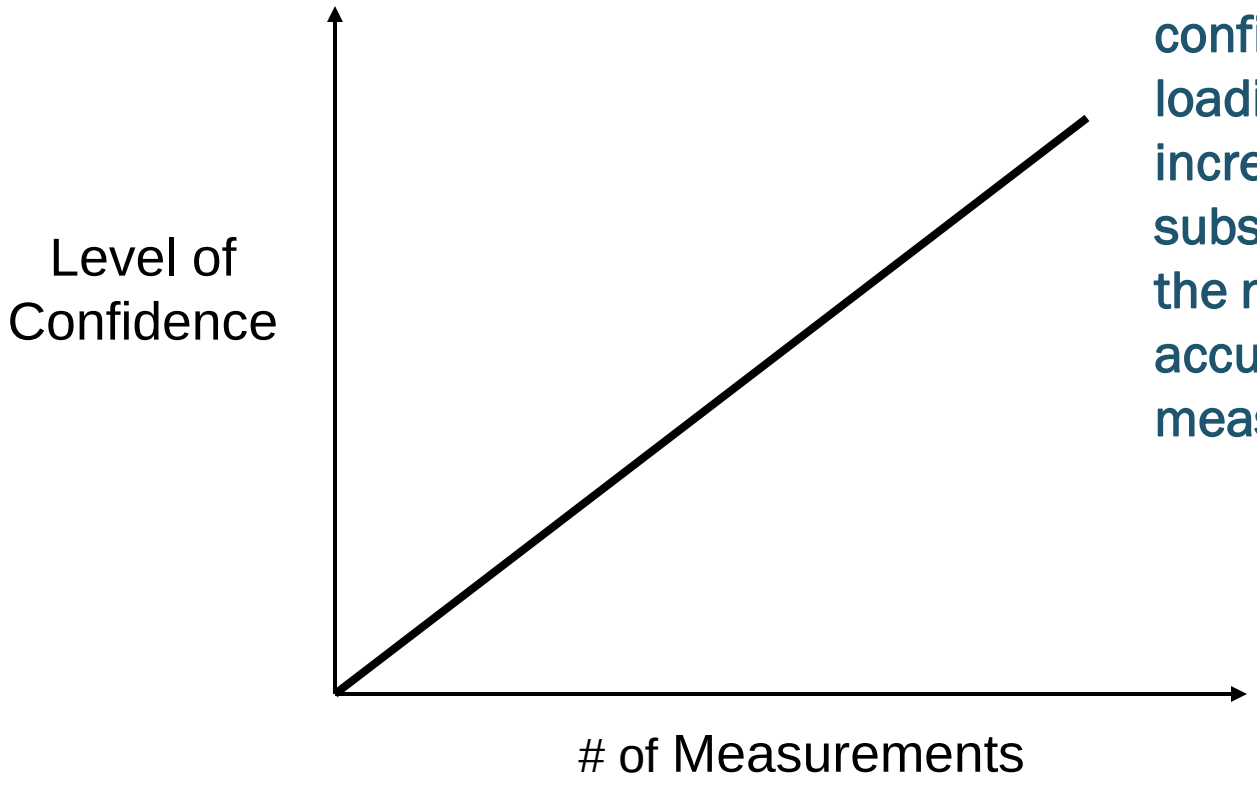


Stormwater Pollutant Removal Mechanisms

MECHANISM	POLLUTANTS AFFECTED
Sedimentation	Solids, BOD, COD, P, N, metals pathogens, synthetic organics
Filtration	Same as sedimentation
Soil incorporation	All
Chemical ppt.	Particulates, P, Dissolved P, metals, pathogens
Adsorption	Dissolved P, metals, syn. organics
Ion Exchange	Dissolved metals
Oxidation	COD, BOD, petroleum hydrocarbons (PHs), synthetic organics, pathogens
Photolysis	Same as oxidation
Volatilization	Volatile PHs, syn. organics
Microbial Decomposition	BOD, COD, PHs, syn. organics
Plant uptake	N, P, metals
Natural die-off	Pathogens
Nitrification	NH_3-N, organic N
Denitrification	NO_3 + NO_2

How Do We Estimate Pollutant Loadings?

1. Perform Measurements
2. Estimate Using Models



Our level of confidence in loading estimates increases substantially with the number of accurate measurements.

Flow and Concentration Monitoring is Essential

Sources of Pollutants in a Watershed

Point Sources

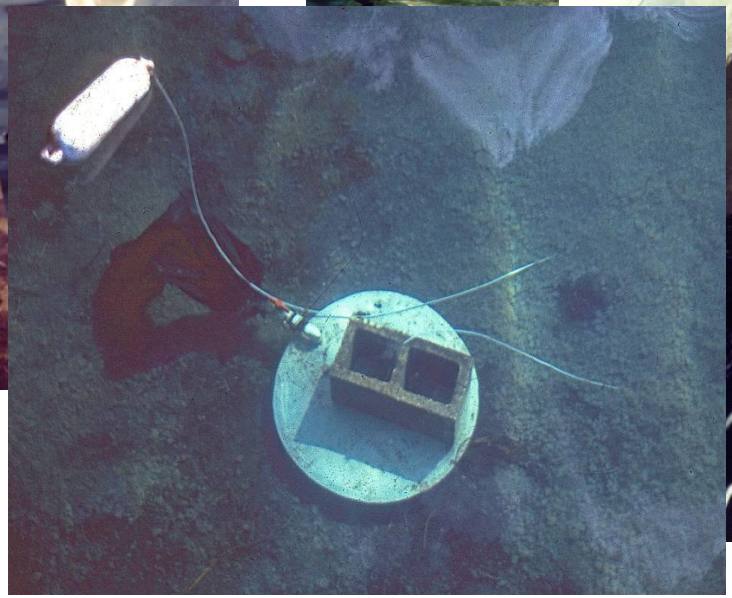
- Wastewater discharges
- Industrial discharges
- Combined wet weather discharges
- Sanitary sewer overflows
- Agricultural discharges Major source but rarely regulated.

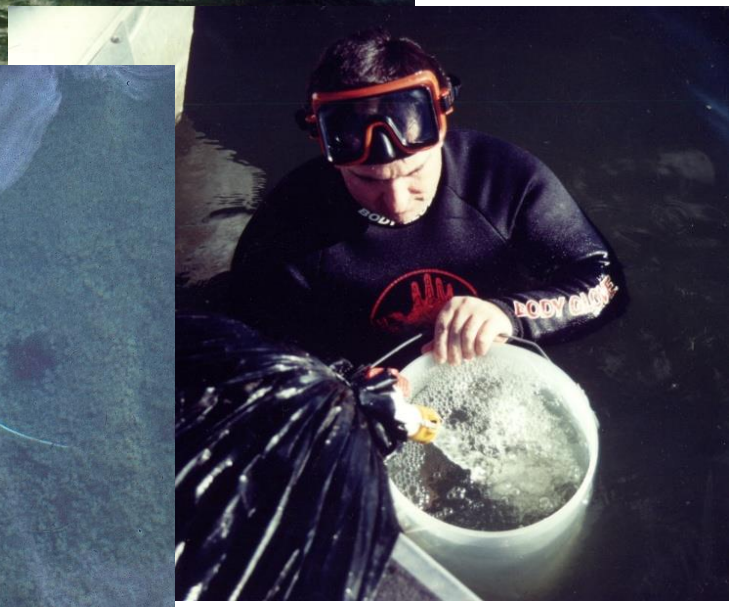
Non - Point Sources

- Stormwater discharges
- Septic systems
- Groundwater seepage
- Atmospheric deposition (primarily N)
- Bird, pet, wildlife waste
- Fertilizer
- Internal nutrient recycling from water bottom sediments

Non-point sources are typically a much larger pollutant source than point sources in a watershed. Some sources are very difficult to quantify.

Sediment and Groundwater Seepage Testing Critical for Lakes (streams)





Thank you!

Brown AND Caldwell

essential ingredients®