Use of Constructed Wetlands to Remove Pesticides from Agricultural Tailwaters

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San Joaquin River Basin

- Essential waterway for California
- > 50% water in SJR return flow during summer months
- Pyrethroids and OPs in agricultural runoff in the SJR at toxic levels (Werner et al., 2004)
- Need to develop best management practices (BMPs) to reduce pesticide loads from agricultural return flows

Constructed Wetlands

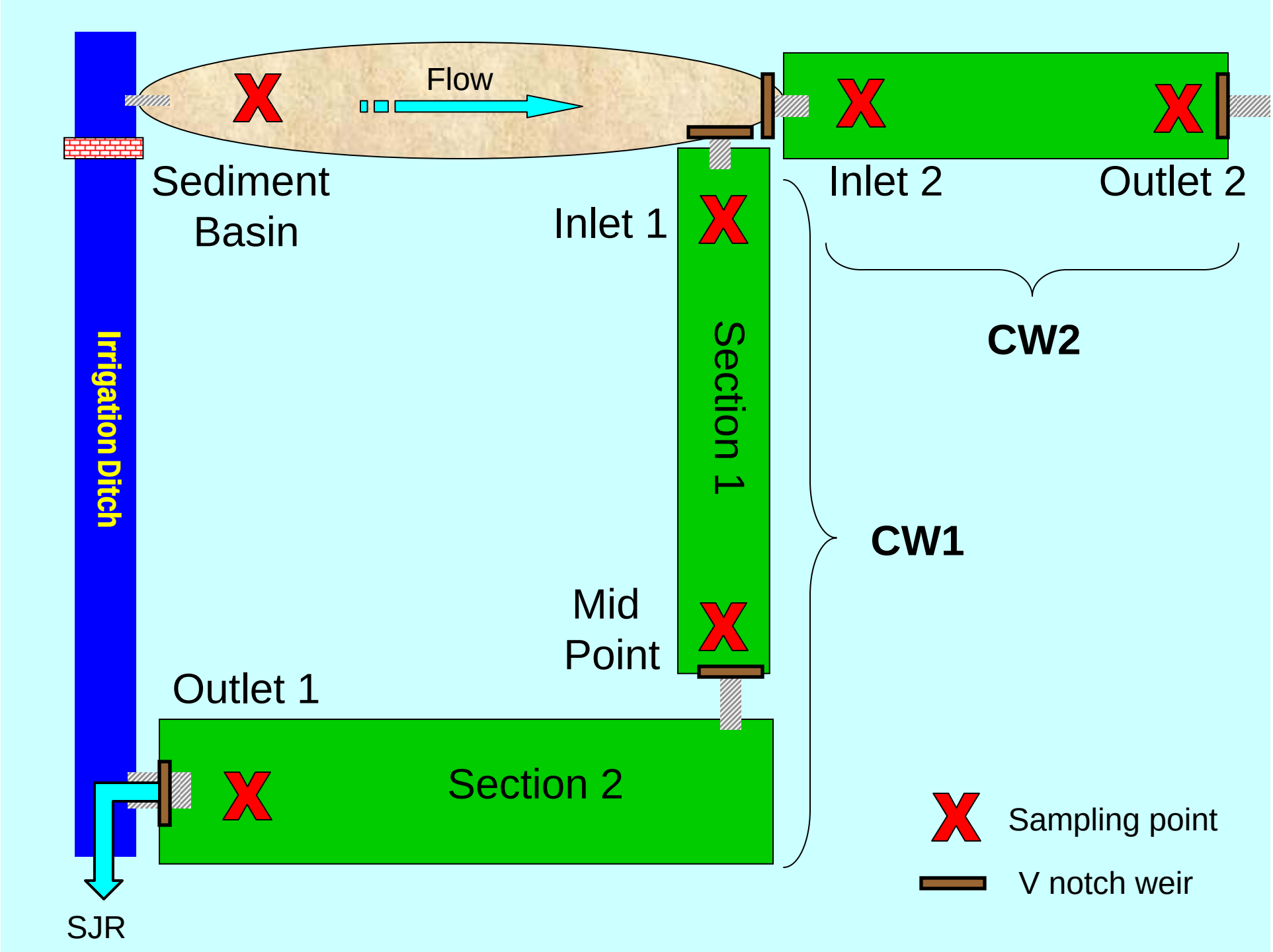
- CWs effective at removing OPs from agricultural return flows
  - Moore et al., 2002
  - Schulz et al., 2003
  - Rose et al., 2006
- Very few studies focused on pyrethroids

Objectives

- Determine removal efficiency of pesticides at environmentally relevant concentrations in return flow

- Identify key environmental mechanisms

Study Site
80
780
Angel Island
San Francisco
Oakland
Hayward
580
680
880
Fremont
San Jose
5
Stockton
205
Wetlands
101
Wetlands
Google
lat 37.491283° lon -121.826451° elev 1046 ft
Eye alt 107.56 mi


Flow
Sediment Basin
Inlet 1
Inlet 2
Outlet 2
CW2
Irrigation Ditch
Section 1
CW1
Mid Point
Outlet 1
Section 2
SJR
Sampling point
V notch weir

Irrigation Ditch

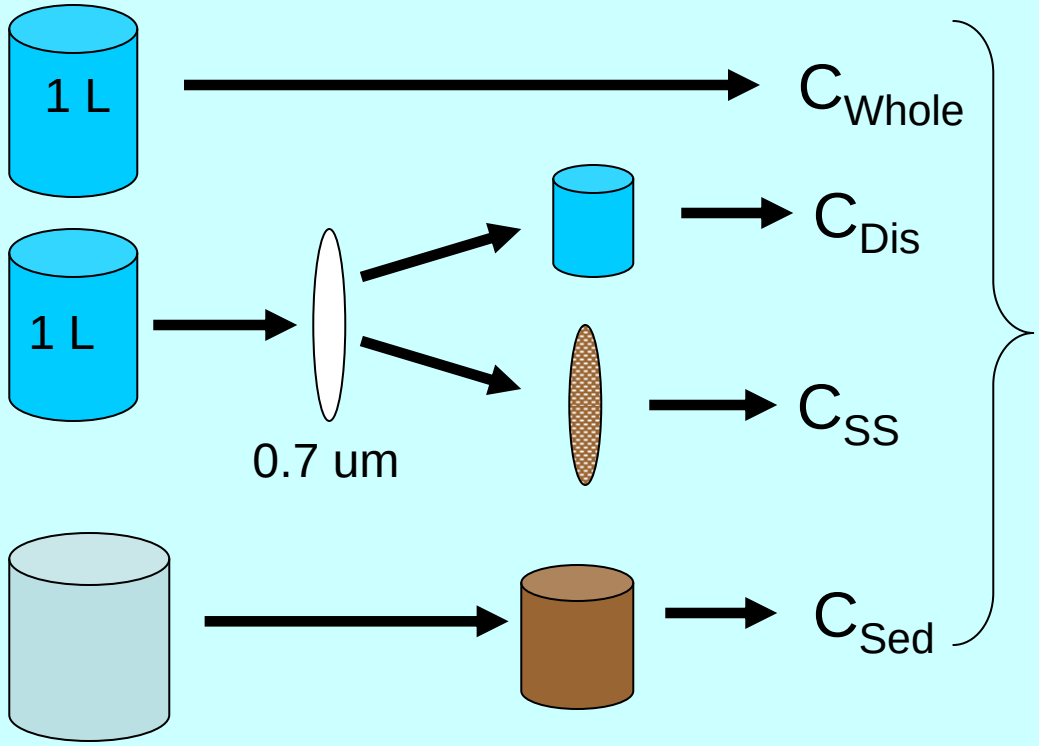
Wetland 2 (Outlet)

Wetland 1 (Section 1)

Wetland 1 (Section 2)

March 2007
May 2007
July 2008
Jul
ctober 2007

Methods - Monitoring



Analysis on GC:
Bifenthrin
λ-Cyhalothrin
Cypermethrin
Deltamethrin
Esfenvalerate
Fenpropathrin
Permethrin
Chlorpyrifos
Diazinon

Water – samples collected every two weeks

Sediment – passive depositional samples

Results

Wetland 1

Seasonal Water Concentrations (ng L^{-1})

	2007		2008	
	Inlet	Outlet	Inlet	Outlet
Bifenthrin	2.0 (nd–9.0)	0.2 (nd–0.4)	0.8 (nd – 2.2)	nd
λ-Cyhalothrin	1.8 (nd – 5.9)	0.3 (nd–0.9)	0.2 (nd – 0.6)	nd
Cypermethrin	16.2 (1.7– 60)	4.3 (nd–12)	2.1 (nd – 8.4)	0.1 (nd –0.8)
Esfenvalerate	1.1 (nd-6.5)	0.04 (nd-0.2)	0.9 (nd – 4.5)	0.1 (nd – 1.0)
Permethrin	88 (13.8–337)	5.1 (nd–15)	12.3 (0.7 – 53)	0.1 (nd – 0.8)
Chlorpyrifos	3.9 (1.2–7.3)	1.6 (0.4–2.2)	51.0 (1.2 – 214)	2.5 (nd – 7.1)
Diazinon	8.2 (6.6–9.8)	16.0 (4.4–43)	nd	nd

Significantly lower at $p \leq 0.05$

Significantly lower at $p \leq 0.0005$ (pooled)

( ) Range of concentrations

Wetland 2

Seasonal Water Concentrations (ng L^{-1})

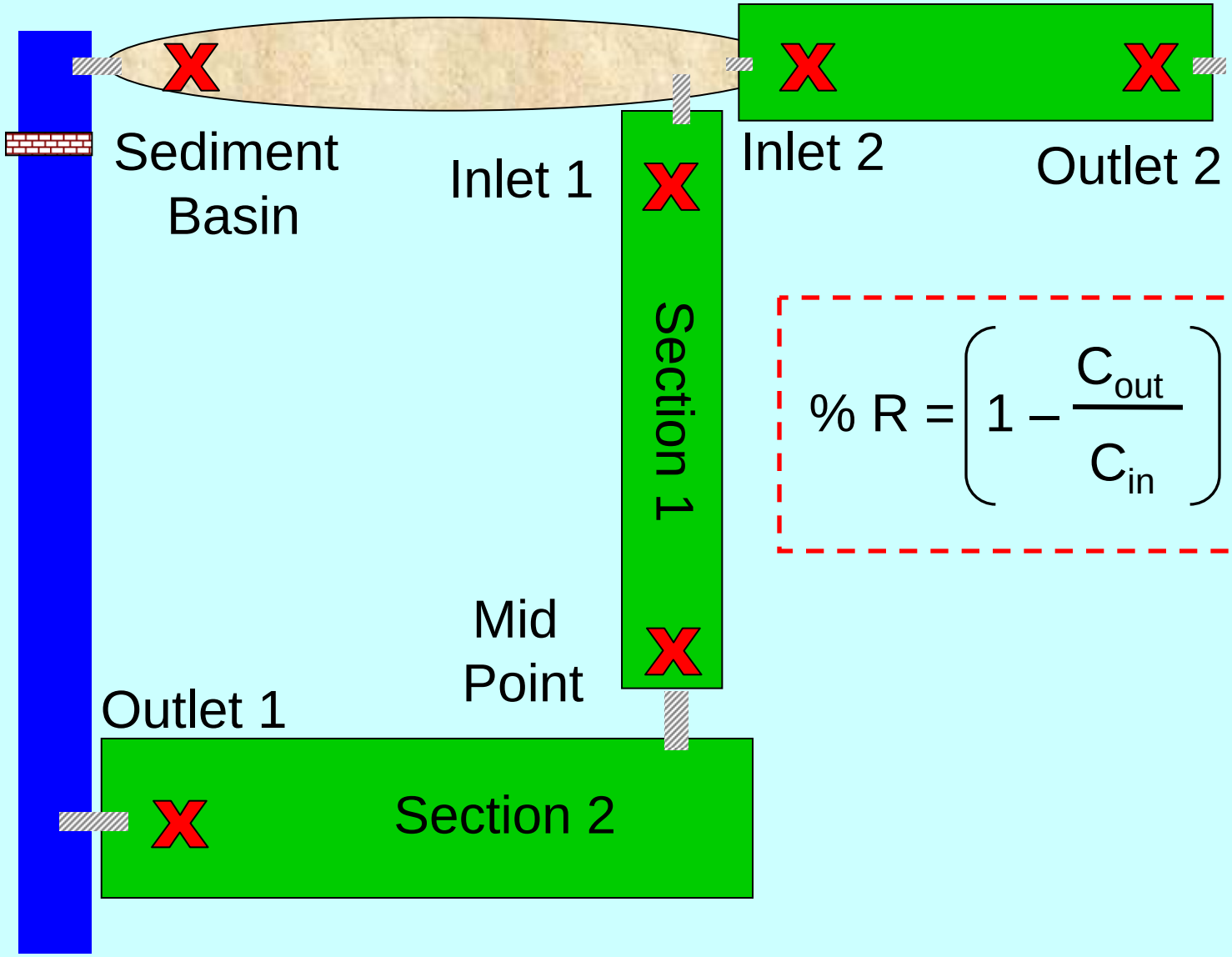
	2007		2008	
	Inlet	Outlet	Inlet	Outlet
Bifenthrin	2.6 (nd – 11.6)	0.2 (nd – 0.50)	0.8 (nd – 3.4)	0.4 (nd – 1.6)
λ-Cyhalothrin	3.3 (nd – 12.9)	0.2 (nd – 0.46)	nd	nd
Cypermethrin	20.5 (1.50 – 60)	3.6 (nd - 8.9)	8.7 (nd – 43)	nd
Esfenvalerate	0.89 (nd - 5.2)	0.03 (nd – 0.11)	0.3 (nd – 1.7)	nd
Permethrin	77 (14.2 – 121)	5.8 (nd - 15.9)	13.9 (1.5 – 40)	0.6 (nd – 3.3)
Chlorpyrifos	3.0 (1.26 – 4.5)	1.6 (0.6 – 4.6)	72.4 (2.5 – 222)	64.7 (1.8 – 429)
Diazinon	17.0 (nd – 34)	61.4 (nd – 235)	nd	nd

Significantly lower at $p \leq 0.05$

Significantly lower at $p \leq 0.0005$ (pooled)

( ) Range of concentrations

Removal Efficiency (%R)



$$\% R = \left(1 - \frac{C_{out}}{C_{in}}\right) \times 100$$

Removal Efficiency (%R)

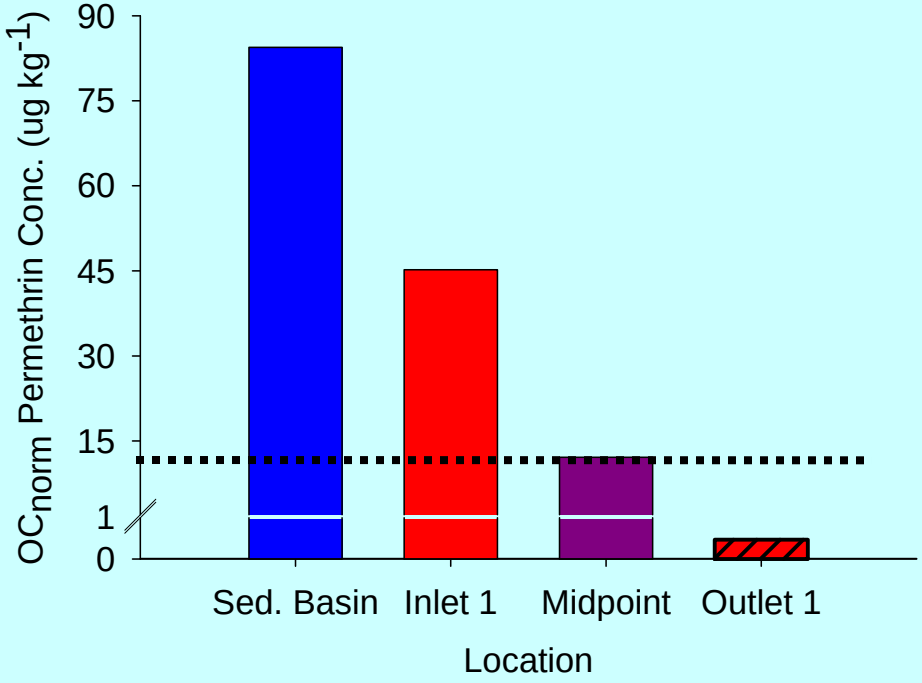
	Wetland 1		Wetland 2	
	2007	2008	2007	2008
Bifenthrin	**69**	**100**	**84**	**25**
λ-Cyhalothrin	**71**	**100**	**90**	**-**
Cypermethrin	**52**	**60**	**64**	**100**
Esfenvalerate	**87**	**100**	**77**	**100**
Permethrin	**90**	**97**	**94**	**80**
Chlorpyrifos	**61**	**75**	**52**	**-73**
Diazinon	**-168/22**	**-**	**-710/82**	**-**

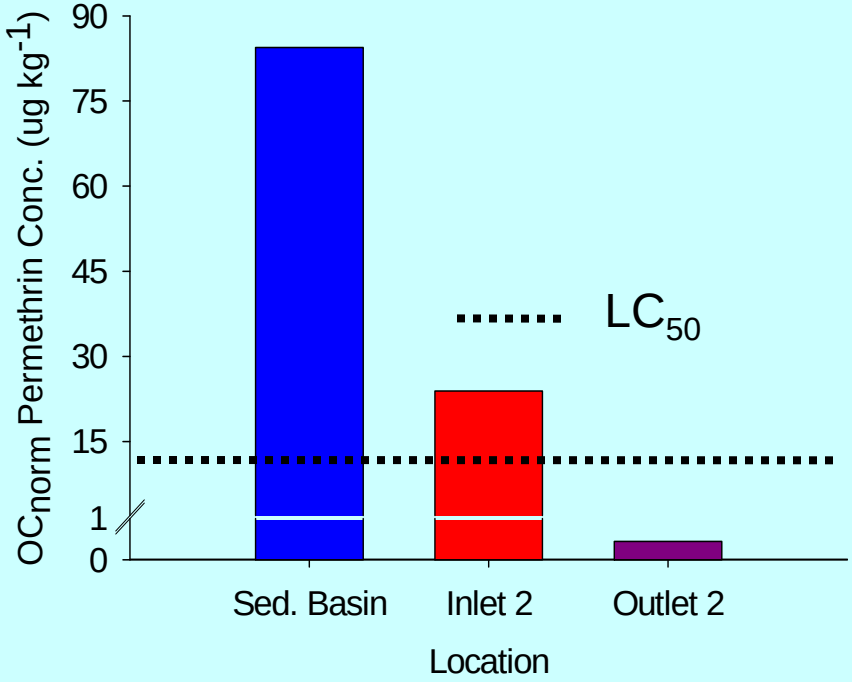
2007 Load Estimates (mg)

Daily Flow x Concentration

	Inlet 1	Outlet 1	W1 % R	Inlet 2	Outlet 2	W2 % R
Bifenthrin	633	12	**98**	159	8	**95**
λ- Cyhalothrin	1155	18	**98**	582	5	**99**
Cypermethrin	12291	318	**97**	3252	152	**95**
Esfenvalerate	1046	3	**100**	185	2	**99**
Permethrin	91596	308	**100**	12415	148	**99**
Chlorpyrifos	1828	34	**98**	322	23	**93**
Diazinon	2865	242	**92**	1442	458	**68**

Sediment Toxicity (*H. azteca*)





<u>Estimated OC normalized Toxicity*</u>

λ-cyhalothrin	0.45
Bifenthrin	0.52
Cypermethrin	1.08
Esfenvalerate	1.54
Permethrin	10.83

* Weston 2005

Mechanisms

What are the important environmental parameters influencing removal?

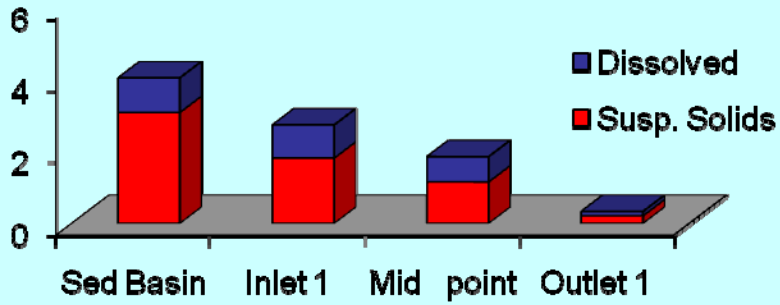
- Phase partitioning of water samples
- Sediment data
- Midpoint comparisons
- Effective lengths

Sedimentation

Partitioning in Water Column

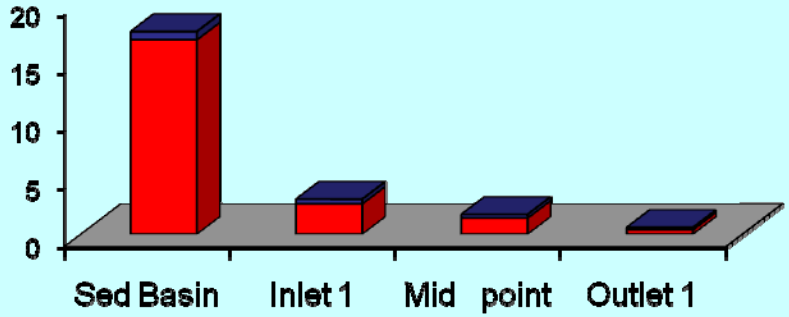
Bifenthrin

SS = 61%



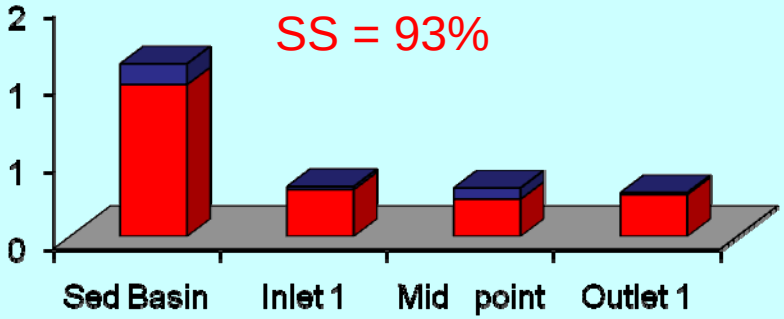
λ-Cyhalothrin

SS = 79%



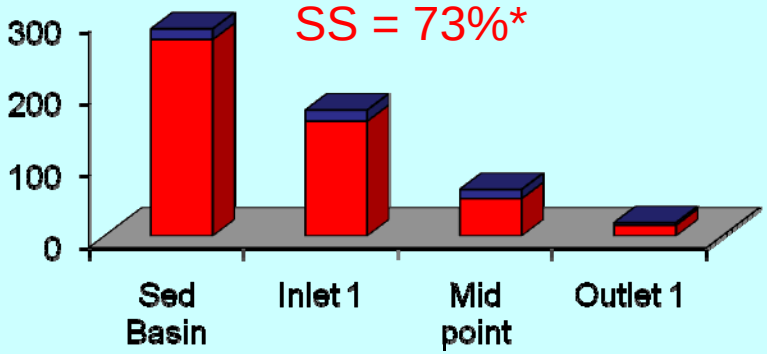
Esfenvalerate

SS = 93%



Permethrin

SS = 73%*



SS = % associated with suspended solids

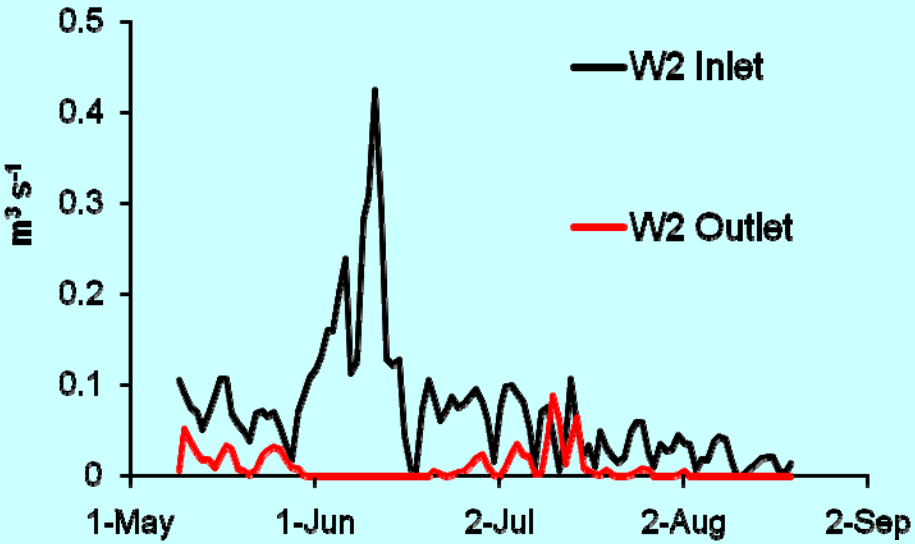
2007 Average Sediment Concentrations (ug/kg)

	Bifenthrin	λ-Cyhalothrin	Cypermethrin	Esfenvalerate	Permethrin
Sed Basin	4	15	105	2	892
Inlet 1	38	24	33	3	687
Midpoint	12	5	22	10	195
Outlet 1	2	0.1	nd	0.7	8
W1 % Removal	**86**	**99**	**100**	**60**	**98**
Inlet 2	67	30	52	5	542
Outlet 2	0.7	0.2	1	nd	12
W2 % Removal	**96**	**99**	**97**	**83**	**98**

MIDPOINT OBSERVATIONS

%R in Sediment Concentrations

	Bifenthrin	Cypermethrin	Esfenvalerate	Permethrin
2007 Season	32	15	-171	65
June 25	-21	-70	-40	51



Midpoint % Removal Efficiency

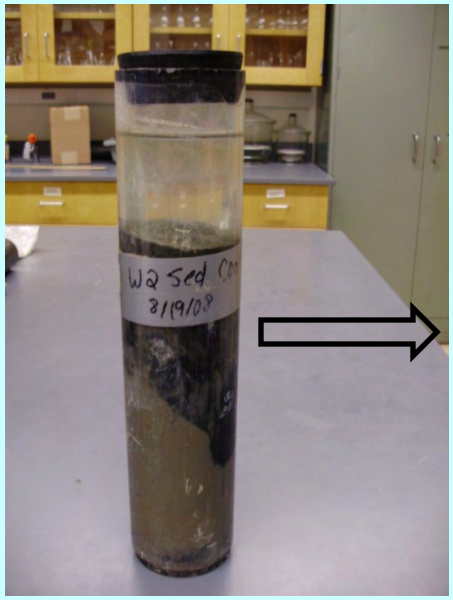
(Water Samples)

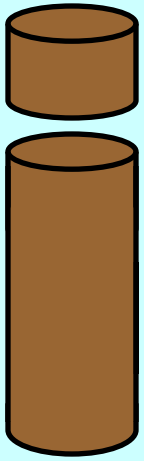
	2007	2008
Bifenthrin	4	50
λ-Cyhalothrin	0.4	100
Cypermethrin	18	48
Esfenvalerate	-3	92
Permethrin	25	70
Chlorpyrifos	15	36
Flow (m^3 s^{-1})		
Mean	0.07	0.03
Max	0.43	0.16

March 2008

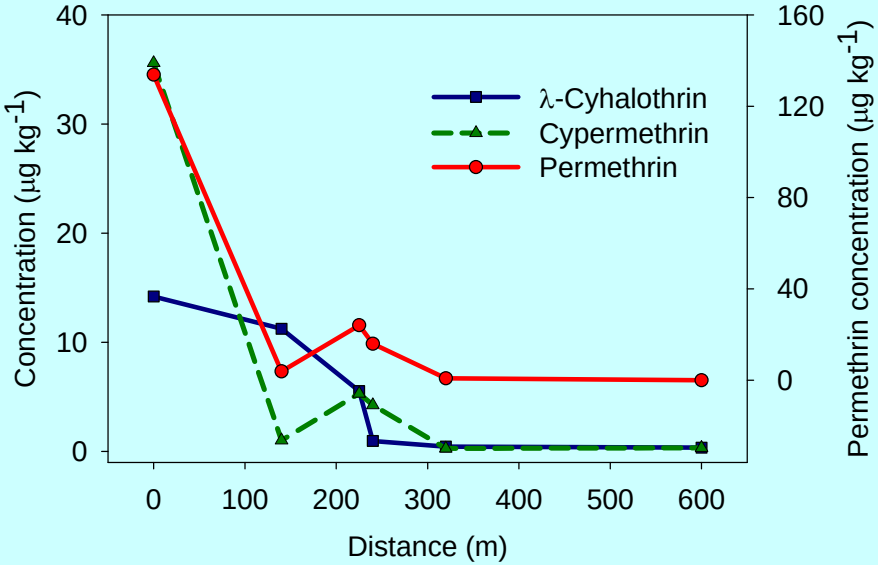
•Vegetation and Flow very important in wetland performance

Effective Length [L_{50}](m)





0 – 5 cm



	2007	2008
λ-Cyhalothrin	267	100
Cypermethrin	100	76
Permethrin	178	80
Average	182	85

58% Reduction in Ave Flow ⟹ ~ 53% shorter L_{50}

Conclusions

- Wetlands efficient at removing pesticides from water column:
  - Concentrations reduced 52-94% for pyrethroids, 52-61% for chlorpyrifos
  - Loads out reduced > 95% for pyrethroids, 68 – 98% for organophosphates
  - Potential sediment toxicity reduced to below LC50 values

Conclusions

- Sedimentation in conjunction with infiltration primary mechanisms of removal
- Vegetation and flow rate important considerations in design
- Potential for persistence and accumulation of pesticides between seasons

  [Data not shown]

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