Selenium Mass Balance in the Las Vegas Wash Using Field Data and Mathematical Modeling

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Background

- Selenium (Se) is an essential element at lower concentrations but potentially toxic at higher concentrations (Hamilton, 2004; Pilon-Smith and LeDuc, 2009).

- Benefits of using wetlands to remove a wide range of metal contaminants such as Se have long been recognized however very few studies have explored mass balance of Se in wetland ecosystems (Lin and Terry, 2003).

- With increasing ecosystem service improvements in the LVW over the last decade, there has also been a significant increase of wetland acreage and growing concern over bioaccumulation of Se and its possible impact in aquatic habitat.

Selenium Management Issues in Las Vegas Wash

- Naturally occurring geological hotspots, groundwater seeps on the southeast side of the valley
- LVS tributaries have exceeded 5 µg/L,
  - Duck creek (Whitney Drainage) - 40-62 µg/L in water
- The main LVW is typically < 4 µg/L,
  - Total selenium loading to Lake Mead exceed 1500 lbs/year
- Increased veg in the LVW have pros and cons in selenium management
  - More acreage of wetlands - growing concern of bioaccumulation and possible impact in aquatic habitat
  - Potential to remove using vegetation management

Objectives

Generate **Se database** for major components (Water, Sediment, and Plant) from LVW and tributaries.

Develop a **Se mass balance model** using the system dynamics approach that incorporates all undergoing processes between water, sediment, and plant.

Material and Methods

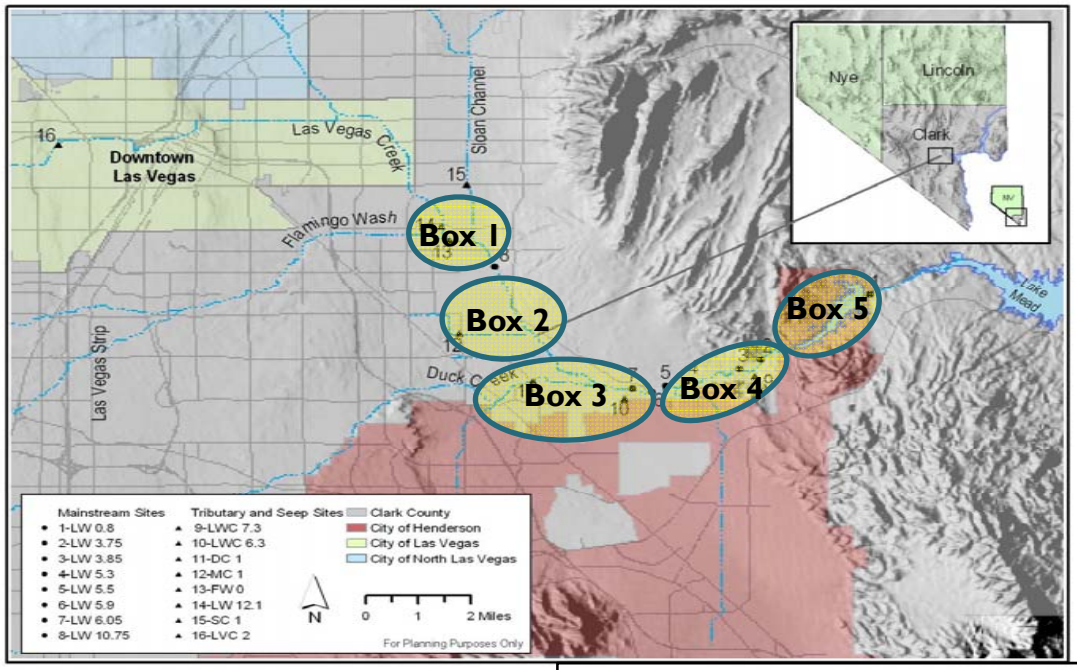
STEP 1
- Design model concept
- Define boundary area & develop a model framework

STEP 2
- Estimation of Se mass along major pathways, Develop Se database for modeling

STEP 3
- STELLA model run for five compartments
- Model calibration

STEP 4
- Model Results and Model simulation
- Final Report

Study Area (Wetland Compartments)

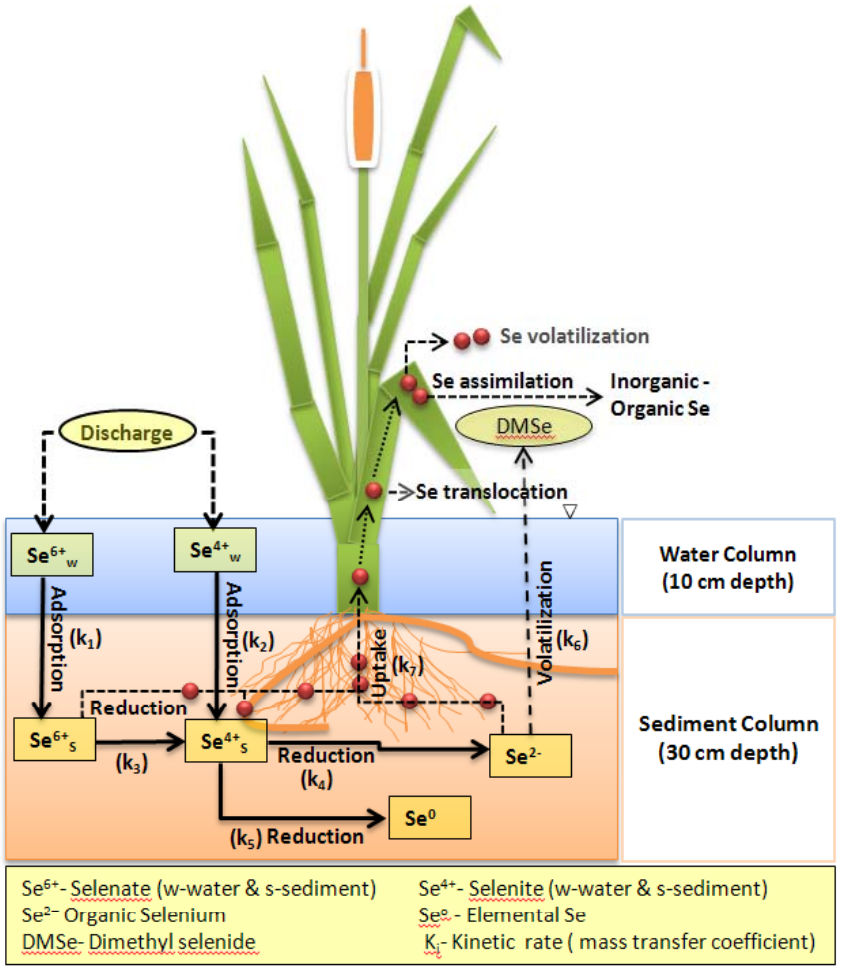


Source: LVWCC 2010

- Compartment 1: Tributary flow (Box-A)
- Compartment 2: Wastewater flow (Box-B)
- Compartment 3: Combine flow (Box-C)
- Compartment 4: Mainstream flow (Box-D)
- Compartment 5: Lake system flow (Box-E)

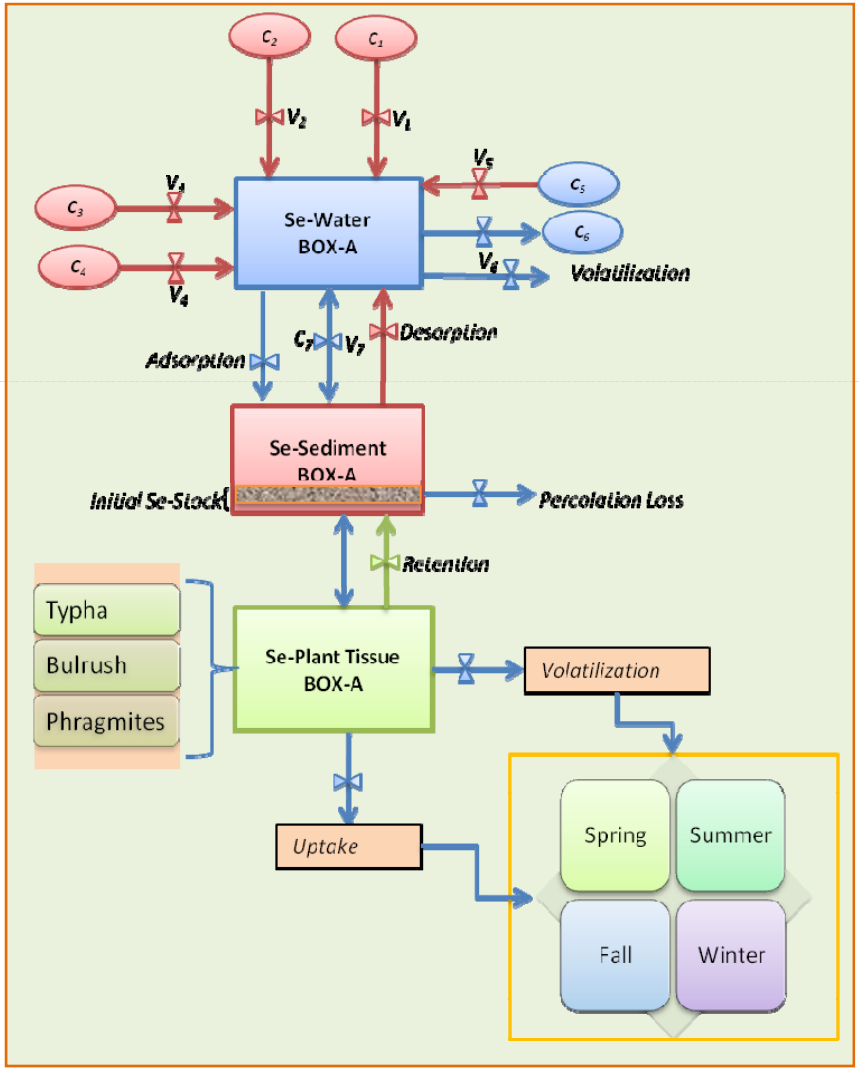
Model Concept

Selenium speciation and transport pathways in wetland ecosystem e.g. Plant Volatilization, which converts toxic inorganic Se to non toxic organic Se



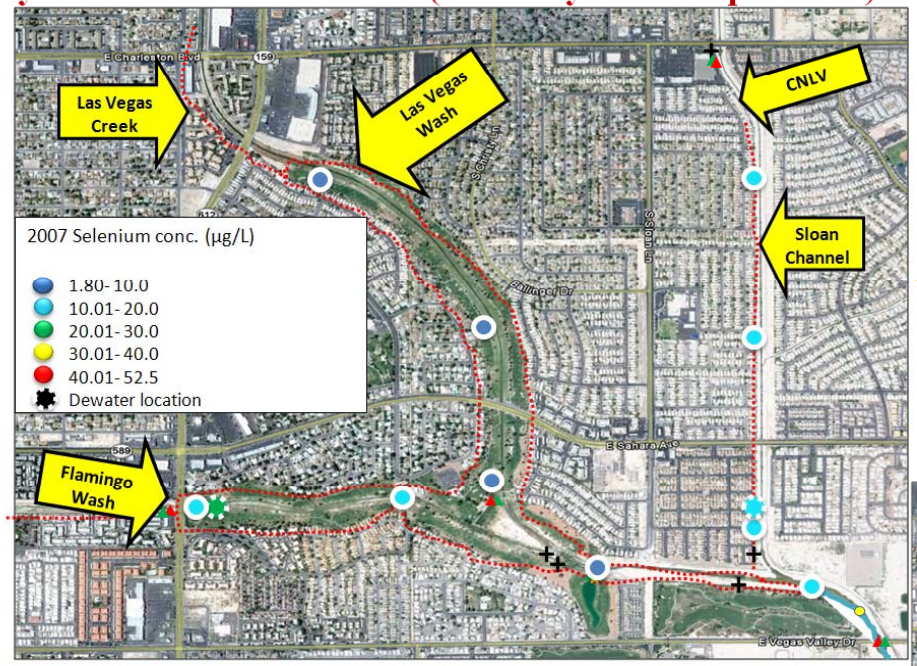
Model Framework

A conceptual framework for the study of Se dynamics in water, sediment and plant in wetland ecosystem



Model Boundaries and Se Sources

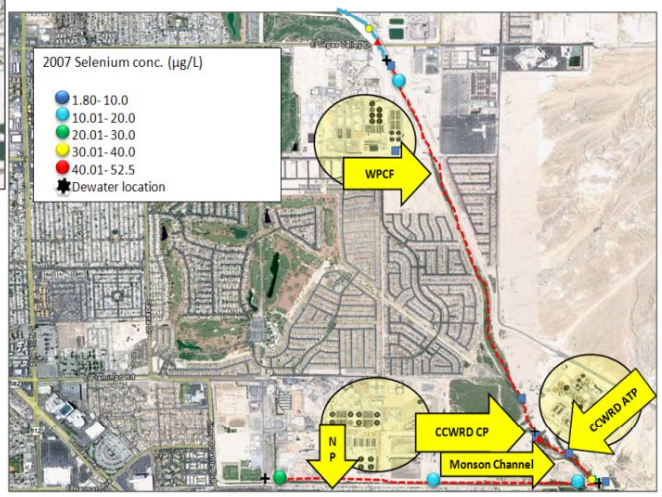
Physical Boundaries for Box 1 (Tributary flow compartment)



+ Proposed SNWA stream gage sites (monthly)
▲ SNWA Stream gage sites (monthly)
★ CCRFCD sampling locations (wet weather only)
■ Bureau of Reclamation sampling locations
Tributary inflows to wetland compartment 1

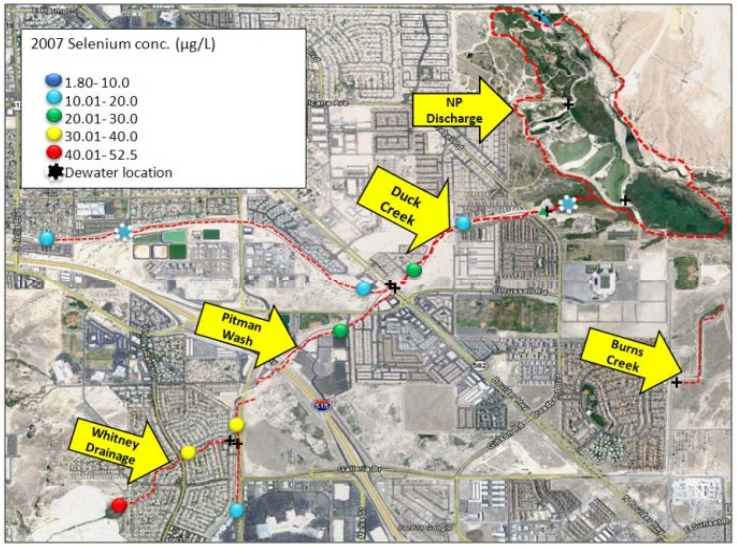
▲ Proposed SNWA stream gage sites (monthly)
▲ USGS stream gage stations (real time)
● City of Henderson sampling locations
Boundary for wetlands compartment 1(Tributary flow)
Outflow for wetland compartment 1

Physical Boundaries for Box 2 (Wastewater Effluents)

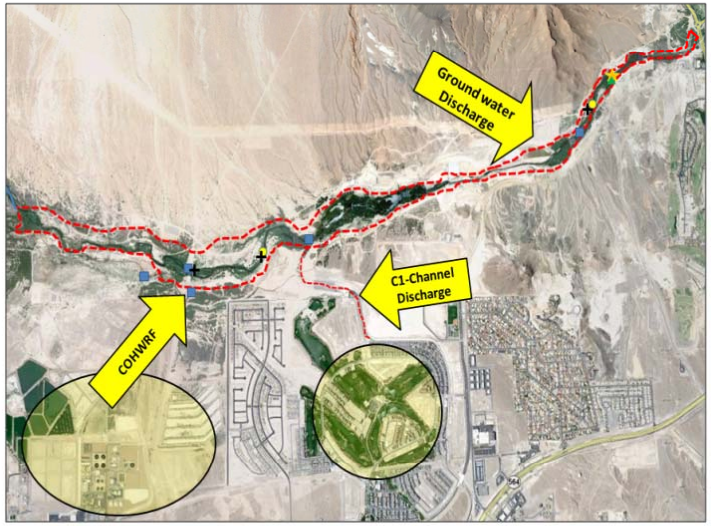


Model Boundaries and Se Sources

Physical Boundaries for Box 3 (Wastewater Effluents+ Trib. flow)



Physical Boundaries for Box 4 (Mainstream flow)



Physical Boundaries for Box 5 (Lake Las Vegas)

Model Development and Application

Se in Water: Discharge data for tributaries and mainstream LVW (USGS/SNWA)

Se conc. in water: For tributaries and mainstream flow (SNWA/NDEP)

$$\frac{\Delta V}{\Delta t} = Q_{in} + Q_{precip} - Q_{out} - Q_{et} - Q_{seep} \quad Eq \ldots (1)$$

Se in Sediment: Estimated using Se mass in seepage water; measured data used for reference condition.

Se in Plant: Channel polygons are measured using Arc GIS, field study (plant cover, frequency, density, and aboveground biomass) from selective polygons and extrapolate to the remaining.

Reliable coefficients are adopted for estimation of Se loss via volatilization

Selenium Database for Mass Balance

Selenium Datbase for Mass Balance

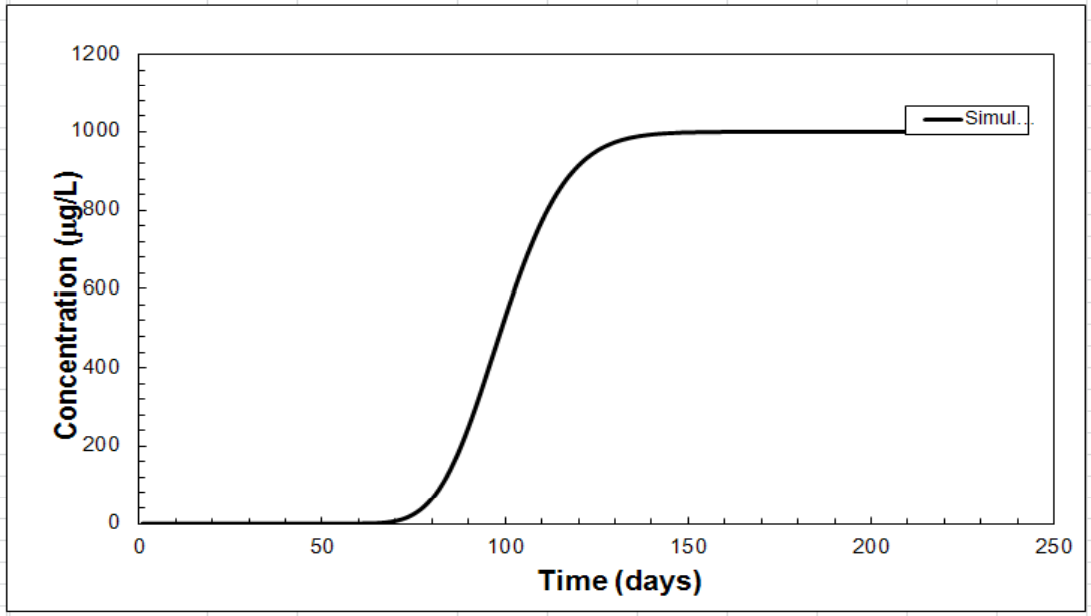
	Discharge				Se-Concentration			
Box 1	Inflows	Discharge Data	Outflow	Discharge Source	Inflows	Se-Data	Outflow	Se-Data
	FW-0	USGS	LW-10.75	SNWA	*FW-0	SNWA	LW-10.75	SNWA
	IW-12.01	USGS			*IW-12.01	SNWA		
	SC-1	SNWA			*SC-1	SNWA		
	* Se sampling locations were differenet from the discharge point							
Box 2	Inflows	Discharge Data	Outflow	Discharge Source	Inflows	Se-Data	Outflow	Se-Data
	LW-10.75	SNWA	LW-8.85	USGS	LW-10.75	SNWA	**LW-8.85	SNWA
	*WRTCP	UNLV			WRTCP	NDEP		
	*CLV	UNLV			CLV	NDEP		
	* Wastewater plants discharge data for 2009& 2010 were calculated taking mean from historical data							
	** Se data for 2008-2010 were different to the discharge point (taken from nearby locations)							
Box 3	Inflows	Discharge Data	Outflow	Discharge Source	Inflows	Se-Data	Outflow	Se-Data
	LW-8.85	USGS	LW-6.05	USGS	***LW-8.85	SNWA	***LW-6.05	SNWA
	*MC	SNWA/USGS			MC	SNWA		
	*DC	SNWA/USGS			DC	SNWA		
	**COH	UNLV			COH	NDEP		
	*2007-2010 discharge data for Monsson Creek (MC) &Duck Creek (DC) from SNWA and 2005-2006 from USGS							
	** Wastewater plants discharge data for 2009& 2010 were calculated taking mean from historical data							
	*** Se data for 2008-2010 were different to the discharge point (taken from nearby locations)							
Box 4	Inflows	Discharge Data	Outflow	Discharge Source	Inflows	Se-Data	Outflow	Se-Data
	LW-6.05	USGS	LW-3.4	USGS	*LW-6.05	SNWA	*LW-3.4	SNWA
	C1-Channel	USGS			C1-Channel	NA		
	*Se data for 2008-2010 were different to the discharge point (taken from nearby locations)							
	NA: Not Available							
Box 5	Inflows	Discharge Data	Outflow	Discharge Source	Inflows	Se-Data	Outflow	Se-Data
	LW-3.4	USGS	LW-0.05	USGS	*LW-3.4	SNWA	*LW-0.05	
	*Se data for 2008-2010 were different to the discharge point (taken from nearby locations)							

Analysis of Se Transport (Fetter Eqn.)

Variable	Value	Units
C_0	1000	mg/L
L	100	m
K	3	m/day
Grad	0.001	dimensionless
Effective Porosity	0.3	dimensionless
Velocity	1	m/day
α_L	1	m
Dispersion coefficient	1	m^2/day

$$C(x,t) = \frac{C_0}{2}\left[erfc\left[\frac{L - vt}{\sqrt{4D_L t}}\right] + \exp\left(\frac{vL}{D_L}\right) erfc\left(\frac{L + vt}{2\sqrt{D_L t}}\right)\right]$$

0.0047		
R =	1.16	
v =	4.3E-07	m/s
x = L =	1.2	m
α =	0.07918	
	0.00219	
	0.00182	m



C_0 = Initial Concentration at 0 distance
D_L = Dispersion coefficient
R = Retardation factor
V = average linear velocity
L = Length (Distance)
α = Dispersivity

Where, $R = 1+\rho_b K_d/\Theta$
ρ_b = bulk density
K_d = distribution coefficient
Θ = porosity
K_d for Se was taken using linear sorption curve (Literature value)

Based on the available field and literature data, Se in the sediment of our studied compartment was in equilibrium state (>1m Sed. depth is necessary to run Se transport simulation and quickly reached to the equilibrium)

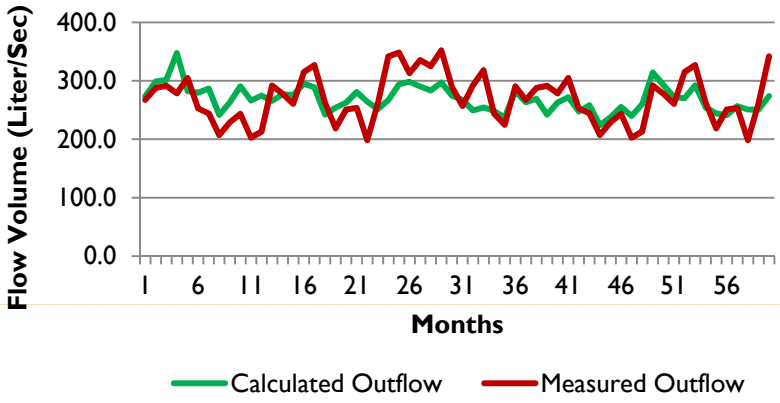
Model Calibration(2006-2008)

Box 1 Calibration

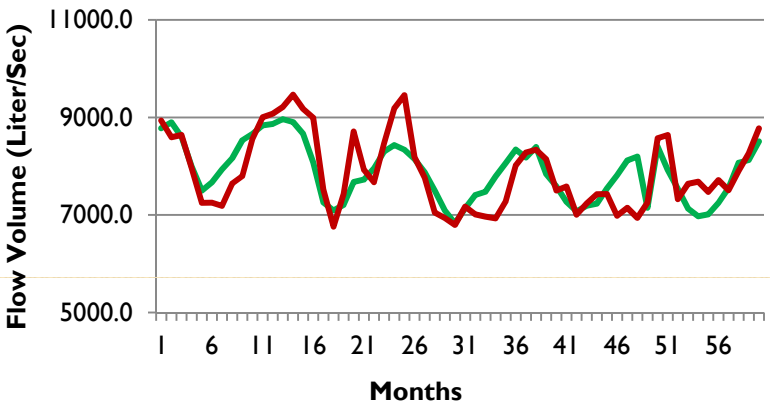
Months	Year	LVW-12.1	FW	SC	UF	PET	Outflow	Without Seepage	With Seepage	Calculated Outflow	Measured Outflow	Seepage %
1		49.3	237.4	15.03	109.6	3.67	267.33	411.0	328.7	**258.90**	**267.33**	0.650
2		110.2	302	20.72	109.6	5.85	287.92	541.9	433.4	**290.65**	**287.92**	0.531
3		124.6	288.5	17.29	109.6	12.27	291.25	538.8	430.8	**294.30**	**291.25**	0.541
4		200.7	254.3	21.23	109.6	19.68	278.44	583.9	466.7	**331.04**	**278.44**	0.477
5		104.9	198.7	21.65	109.6	28.9	304.79	432.0	345.0	**279.43**	**304.79**	0.706
6		80.5	197.7	14.51	109.6	34.55	252.44	398.9	318.4	**262.63**	**252.44**	0.633
7		82.8	196.4	17.74	109.6	39.73	244.17	402.6	321.3	**262.88**	**244.17**	0.607
8		55.3	182.5	13.97	109.6	32.46	207.01	358.1	285.9	**250.55**	**207.01**	0.578
9		80.8	177.6	17.85	109.6	26.09	228.92	383.2	306.1	**267.10**	**228.92**	0.597
10		78.1	181.9	26.93	109.6	15.02	243.54	395.0	315.7	**272.98**	**243.54**	0.617
11		70.8	176.4	18.7	109.6	6.18	202.55	374.9	299.8	**269.93**	**202.55**	0.540
12	2006	53.6	187.4	23.52	109.6	3.34	212.94	373.8	299.0	**263.98**	**212.94**	0.570
1		83.9	222.8	51.01	109.6	3.67	291.89	466.9	373.5	**288.28**	**291.89**	0.625
2		80.5	272.8	51.01	109.6	5.85	277.72	513.3	410.5	**285.78**	**277.72**	0.541
3		77.1	311.1	51.01	109.6	12.27	260.53	547.6	437.8	**281.65**	**260.53**	0.476
4		82.6	396.3	51.01	109.6	19.68	314.84	637.5	509.6	**281.67**	**314.84**	0.494
5		98.1	275.3	86.72	109.6	28.9	327.03	566.8	452.9	**297.75**	**327.03**	0.577
6		41.2	248.3	37.97	109.6	34.55	262.64	433.6	346.2	**250.71**	**262.64**	0.606
7		61.1	220.4	51.01	109.6	39.73	218.55	438.1	349.7	**263.07**	**218.55**	0.499
8		72.9	262.4	18.51	109.6	32.46	250.8	460.2	367.5	**260.98**	**250.8**	0.545
9		102.1	200.7	51.01	109.6	26.09	253.52	460.8	368.1	**288.88**	**253.52**	0.550
10		59.5	220	51.01	109.6	15.02	198.26	438.6	350.6	**271.68**	**198.26**	0.452
11		42.5	272.5	51.01	109.6	6.18	261.59	475.0	379.9	**266.54**	**261.59**	0.551
12	2007	31.2	216.1	51.01	109.6	3.34	341.65	407.6	326.0	**261.89**	**341.65**	0.838
1		116.1	184.2	17.09	109.6	3.67	348.2	426.6	341.2	**293.15**	**348.2**	0.816
2		153.6	183.1	11.62	109.6	5.85	313	457.3	365.8	**309.36**	**313**	0.684
3		87.1	167.1	21.79	109.6	12.27	335.5	384.4	307.2	**276.83**	**335.5**	0.873
4		85.4	171.3	20.06	109.6	19.68	325.2	384.4	307.1	**272.58**	**325.2**	0.846
5		136.1	181.2	13.29	109.6	28.9	352.1	437.3	349.3	**292.33**	**352.1**	0.805
6		85.4	152.3	20.12	109.6	34.55	289.6	364.0	290.5	**266.92**	**289.6**	0.796
7		75	191.5	18.31	109.6	39.73	256.9	390.4	311.6	**259.15**	**256.9**	0.658
8		49	199.2	19.78	109.6	32.46	292.5	374.3	298.8	**249.33**	**292.5**	0.781
9		54.9	204.2	21.69	109.6	26.09	318.1	387.8	309.7	**255.37**	**318.1**	0.820
10		49.6	181.5	13.1	109.6	15.02	243.5	352.3	281.5	**254.04**	**243.5**	0.691
11		38.1	185.2	11.34	109.6	6.18	224.7	343.6	274.8	**251.04**	**224.7**	0.654
12	2008	99.8	216.8	21.82	109.6	3.34	290.4	447.7	358.1	**286.67**	**290.4**	0.649
		0.39	0.12	0.08		-0.14		0.29	0.29	0.43	1	0.635

Model Calibration (2006-2010)

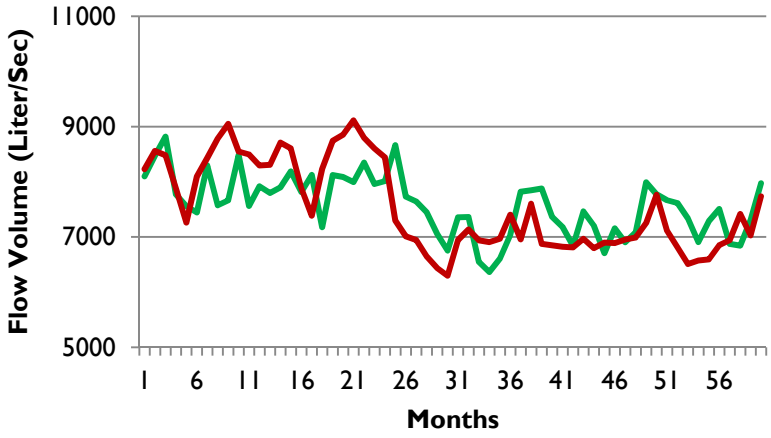
Box 1



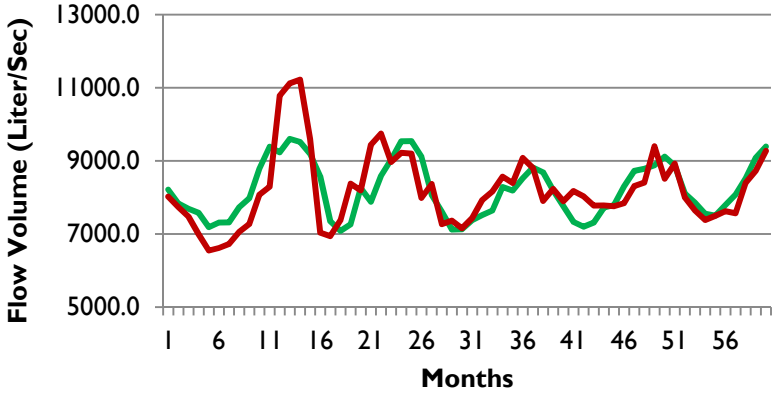
Box 3



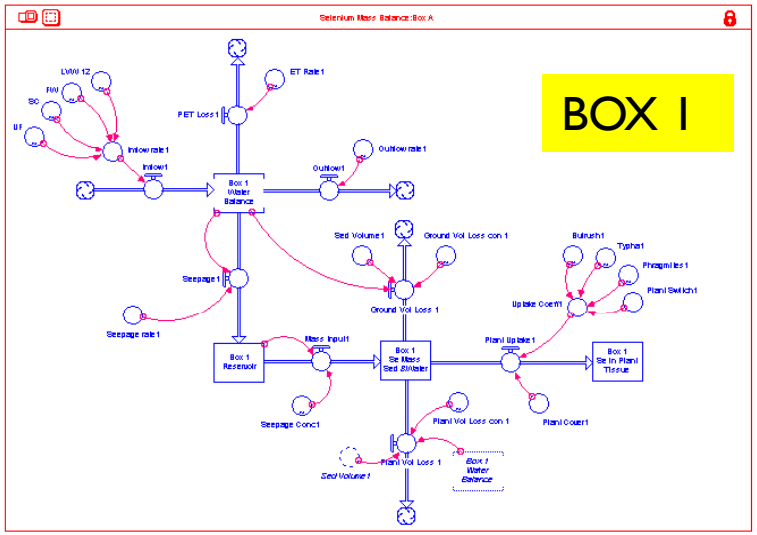
Box 2

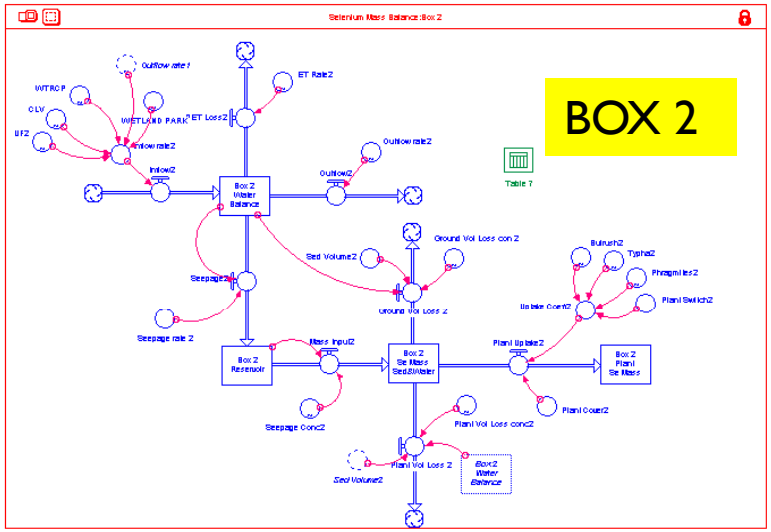


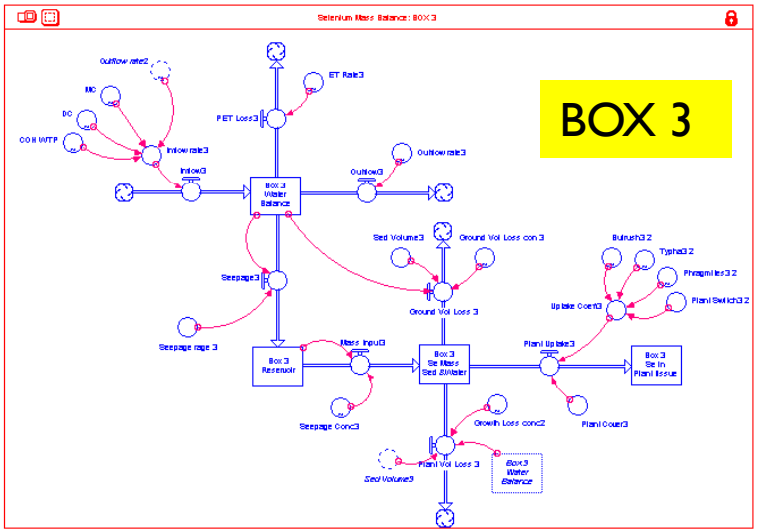
Box 4

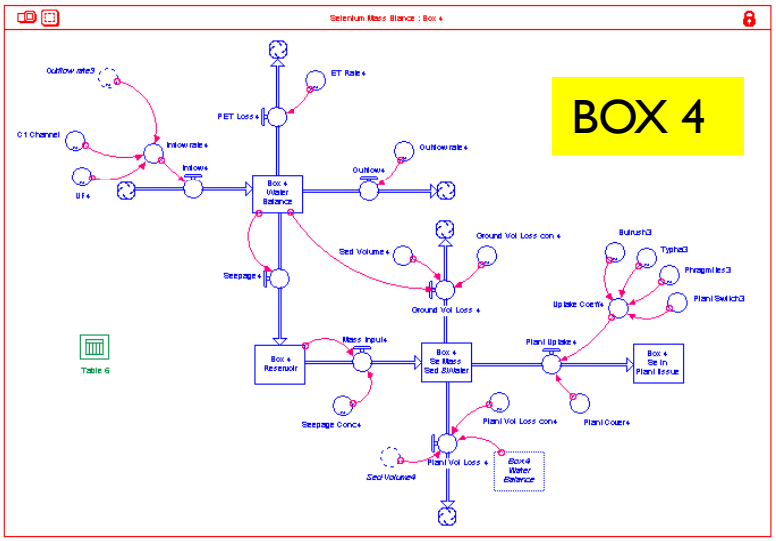


Model Results (2006-2008)

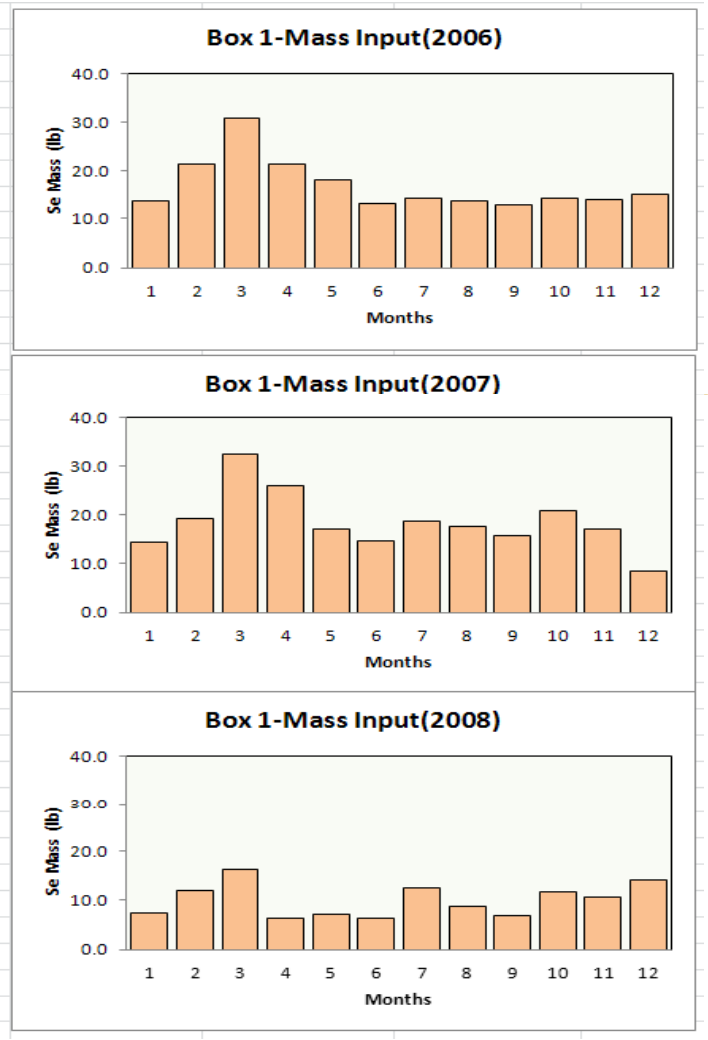


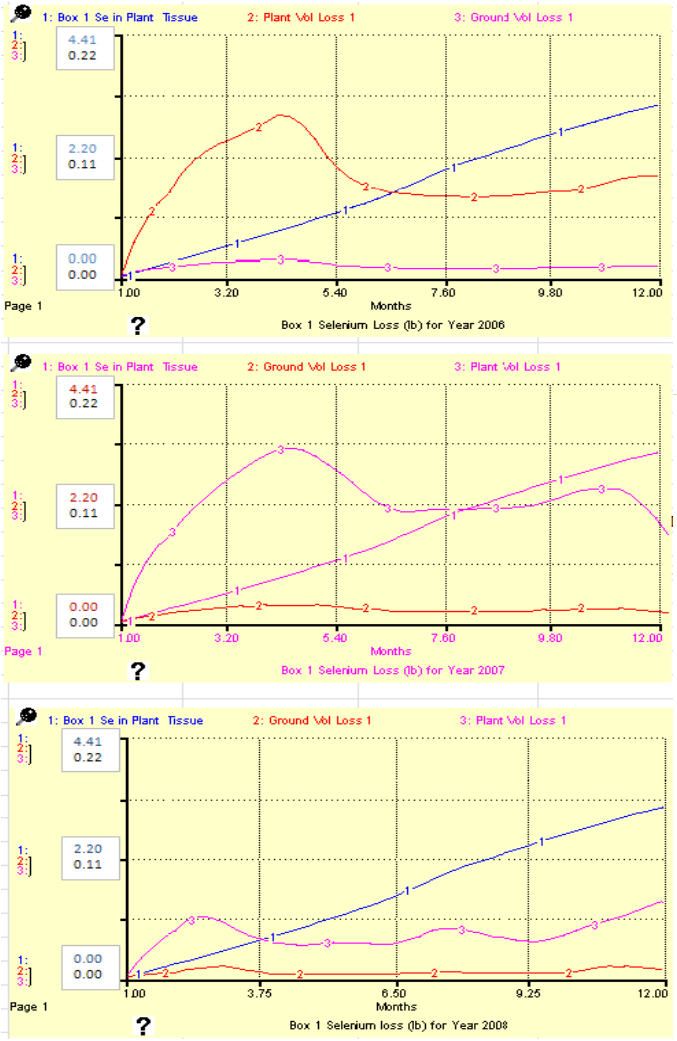






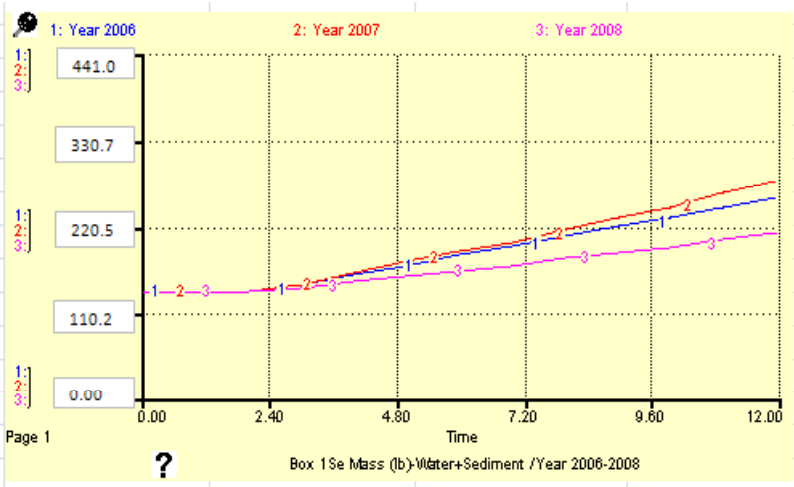
Selenium Mass and Distribution: Box 1

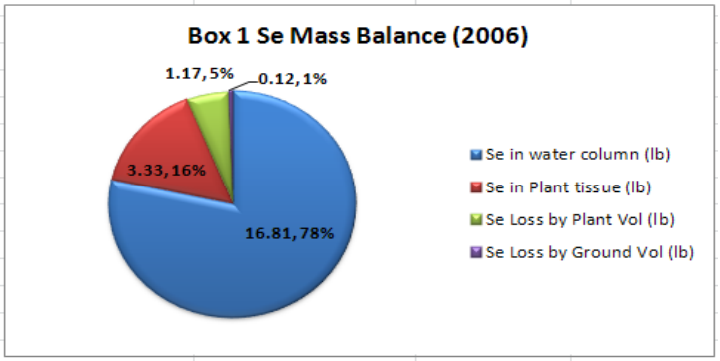


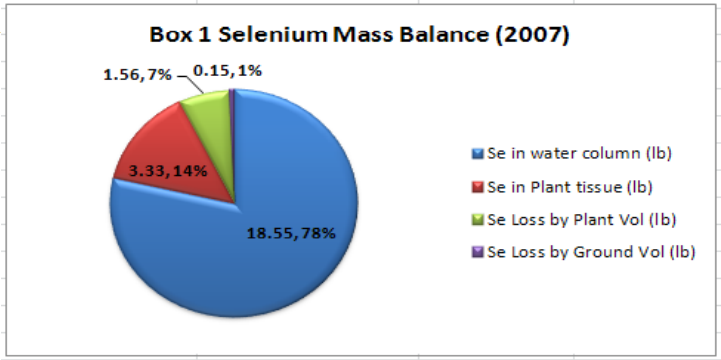


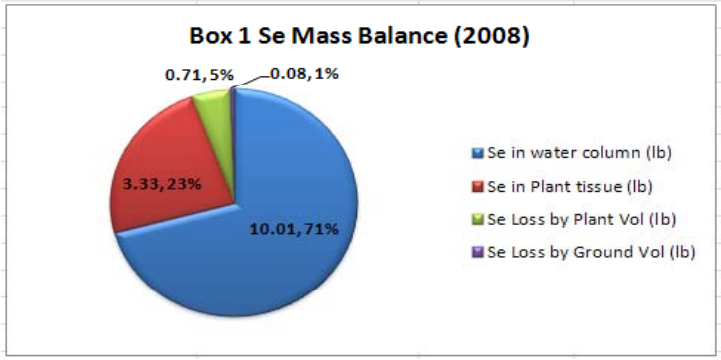
Mass added in box 1

Selenium Mass and Distribution: Box 1





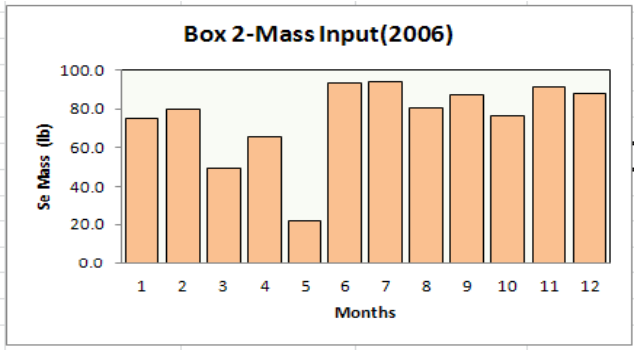


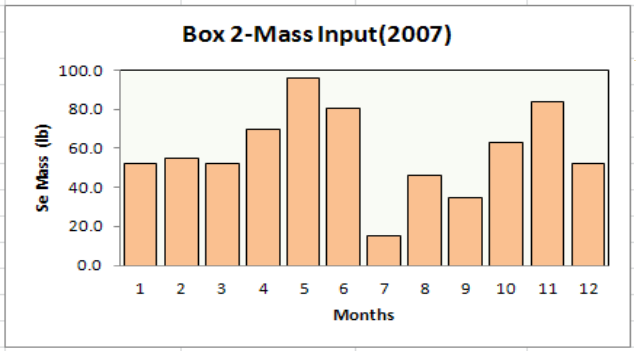


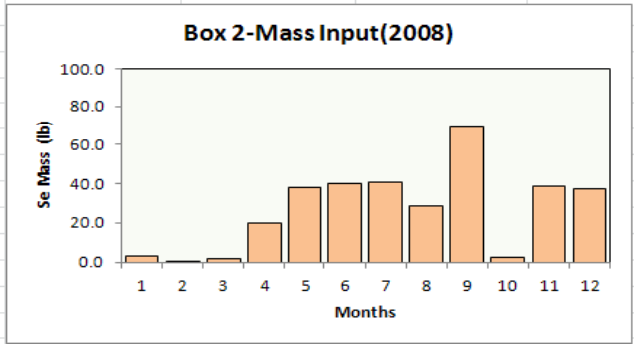
Based on 2006-2008 discharge and Se database, Plant tissue storage account approx. 15-20% of Se mass available in Box 1 compartment.

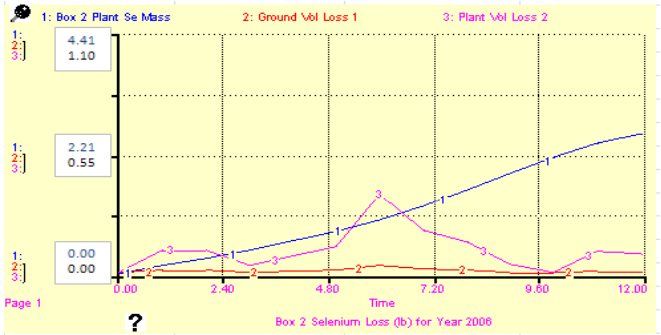
Contribution of Se loss via plant volatilization and ground vol. contribute approx. 6-8% of Se mass

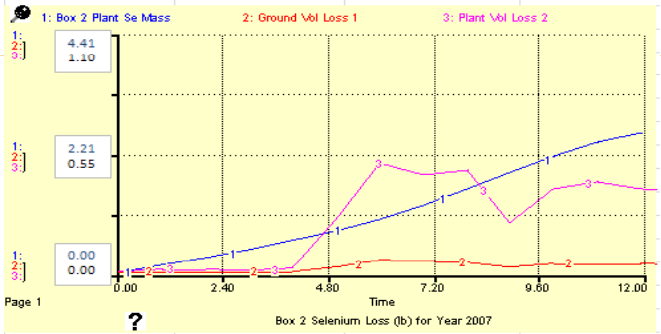
Selenium Mass and Distribution: Box 2

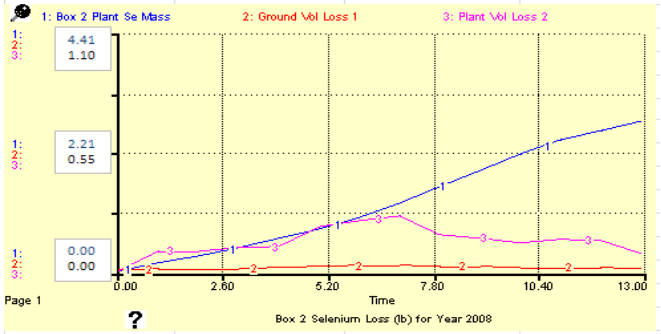






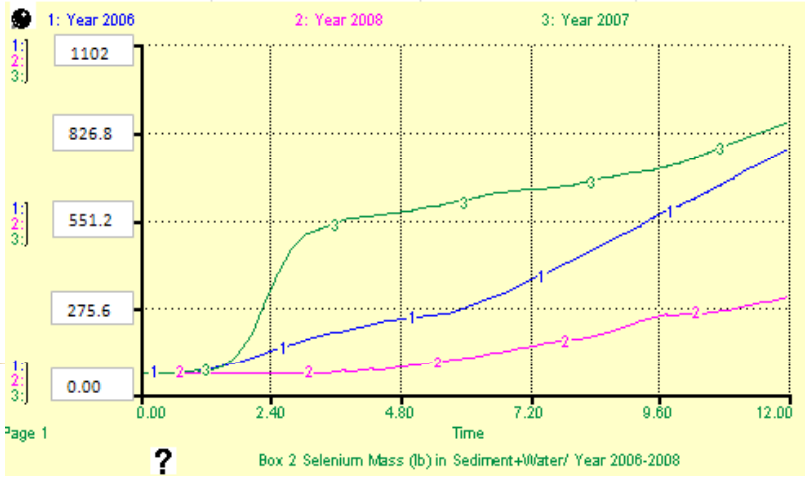


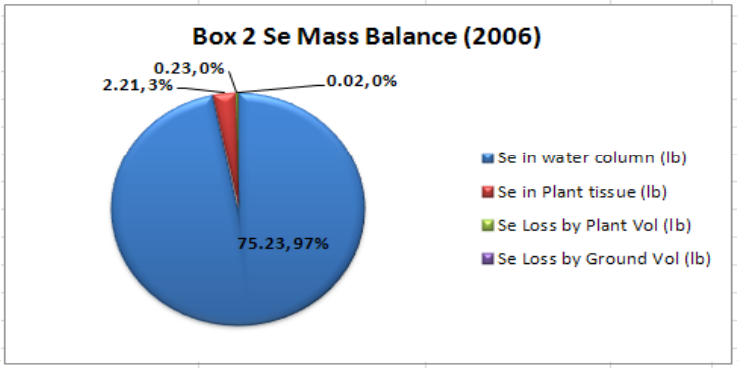


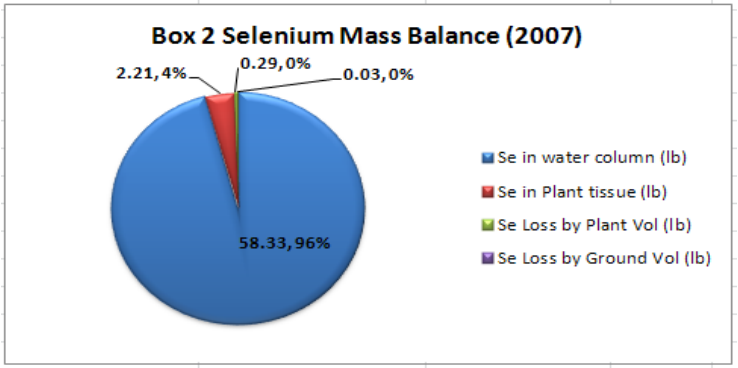


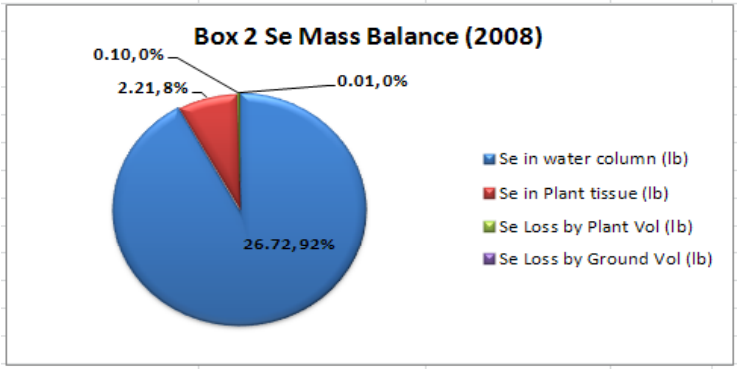
Mass input during months of Year 2008, results based on somewhat unreliable flow data at station LW 8.85 (USGS-9419679)

Selenium Mass and Distribution: Box 2





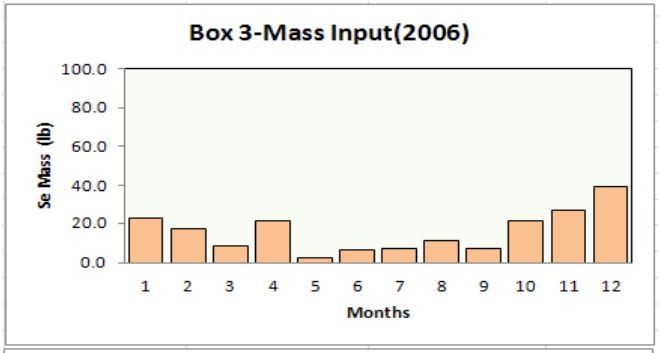


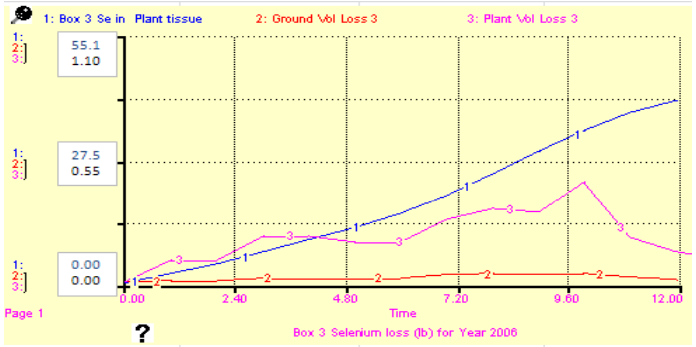


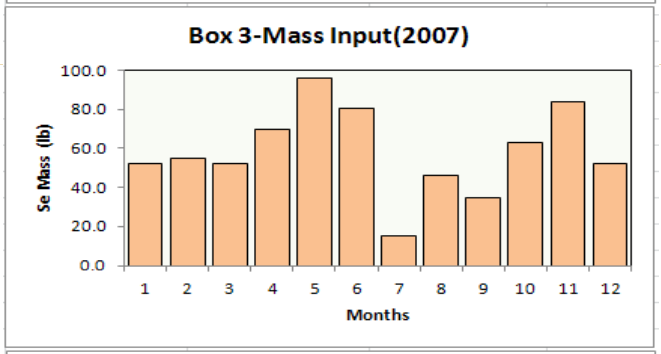
Based on 2006-2008 discharge and Se database, Plant tissue storage accounts only 3-8 % of Se mass available in Box 2 compartment.

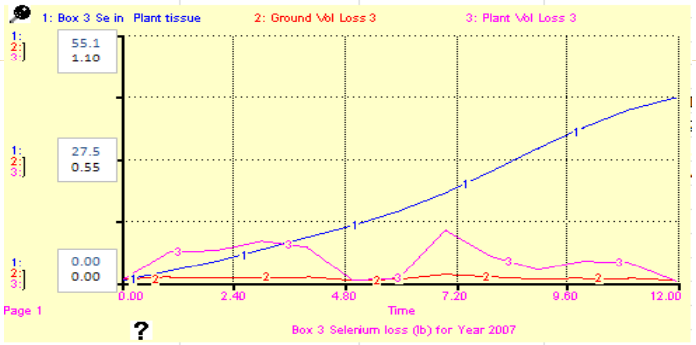
It is due to less wetlands acreages and higher frequency of wastewater treatment plant

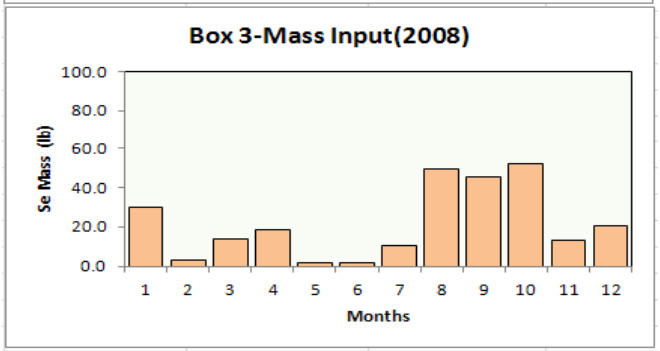
Selenium Mass and Distribution: Box 3

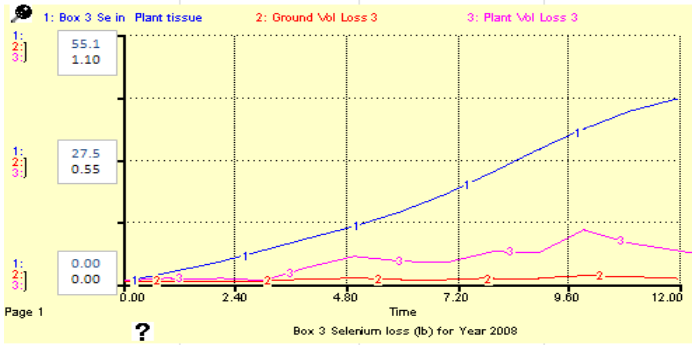






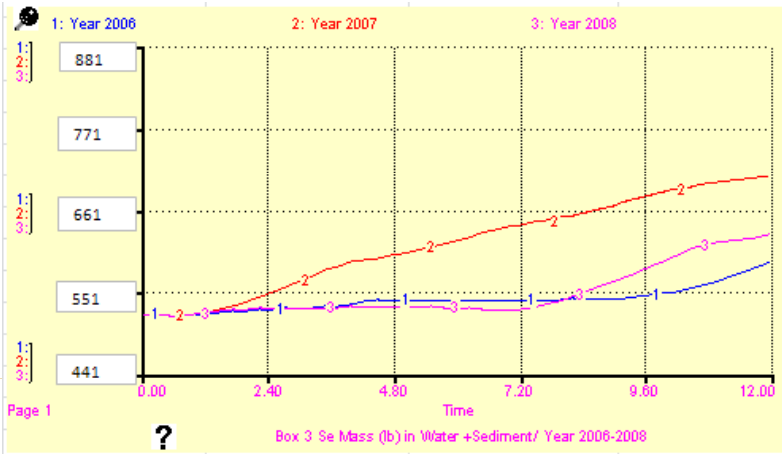


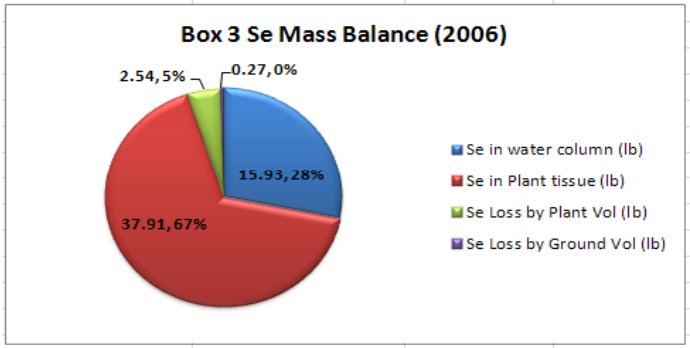


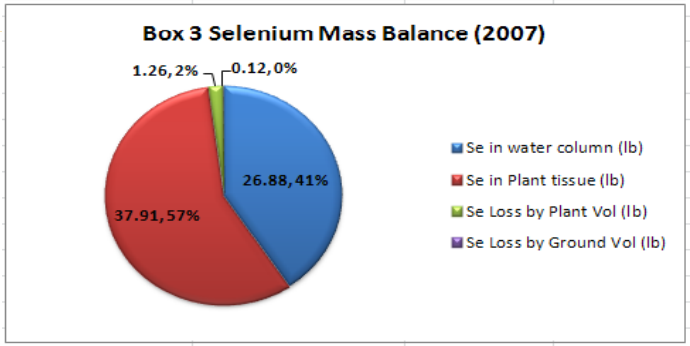


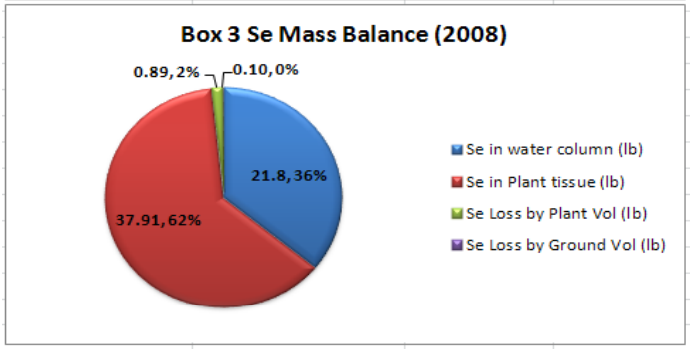
Se Mass input was significantly higher during the Year 2007 for most of the months in comparison to 2006 and 2008

Selenium Mass and Distribution: Box 3





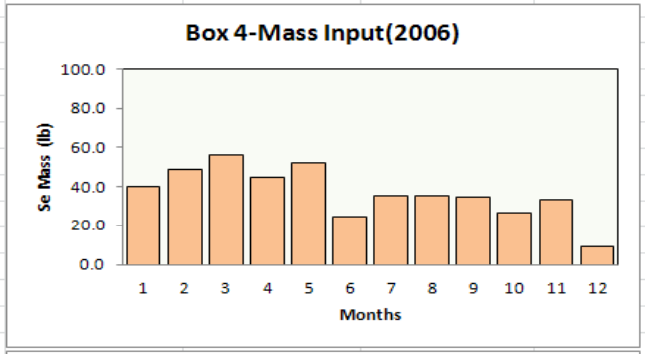


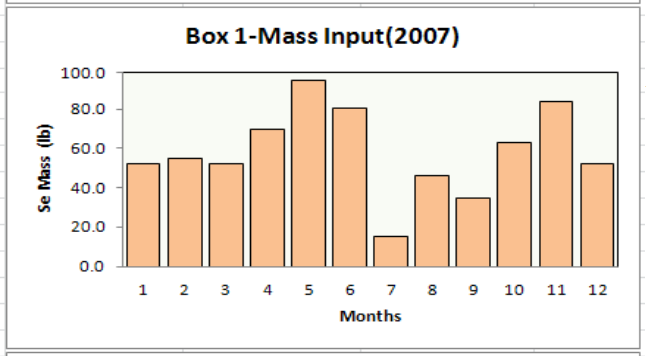


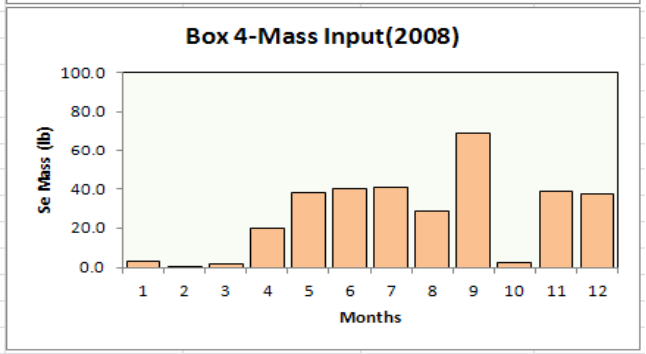
Due to dense vegetation cover and wetlands acreage, Se mass storage in plant tissue (57-67%) simply exceeded the total mass available through seepage.

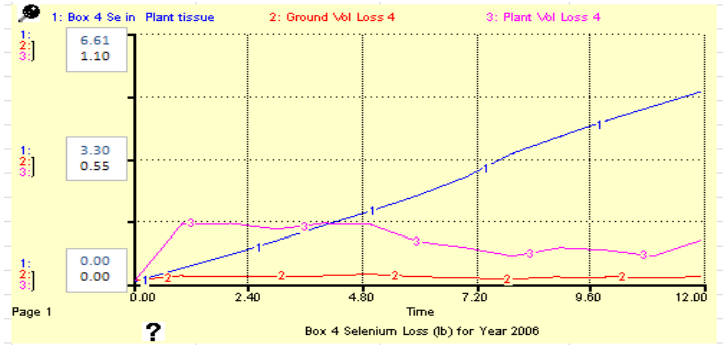
However, seepage accounts for approx. 10% of the total flow volume, there is a possibility of excess Se mass removal through vegetation management in compartment 3

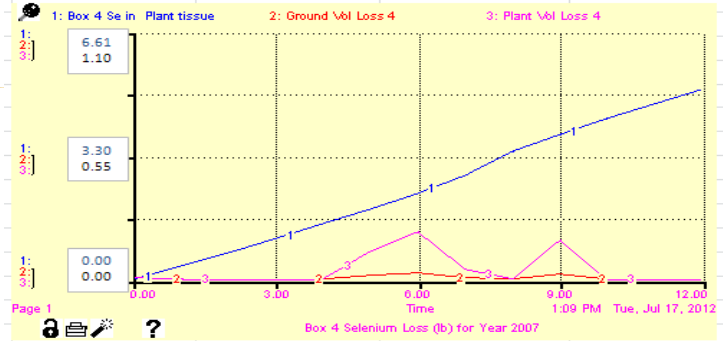
Selenium Mass and Distribution: Box 4

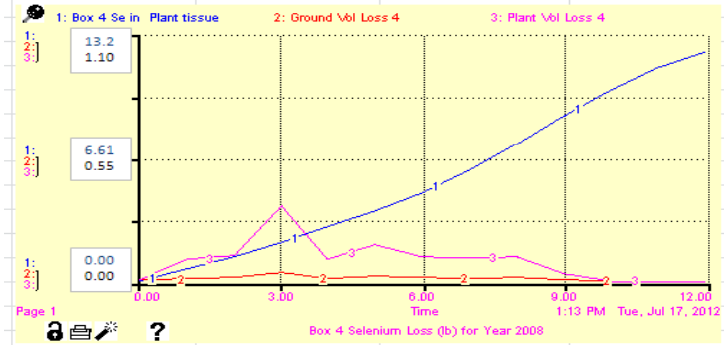






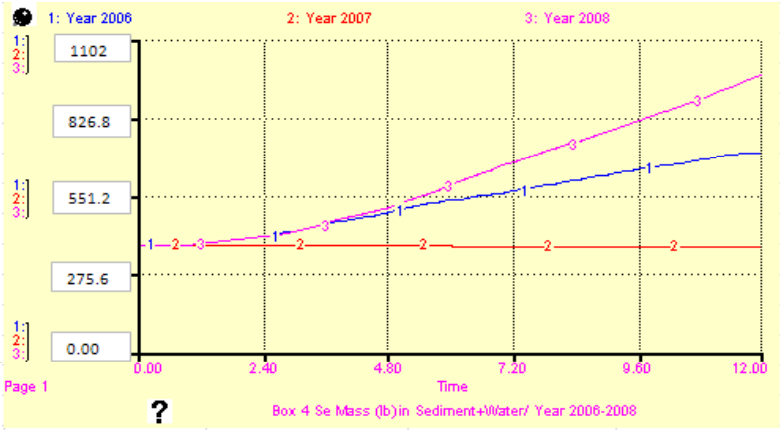


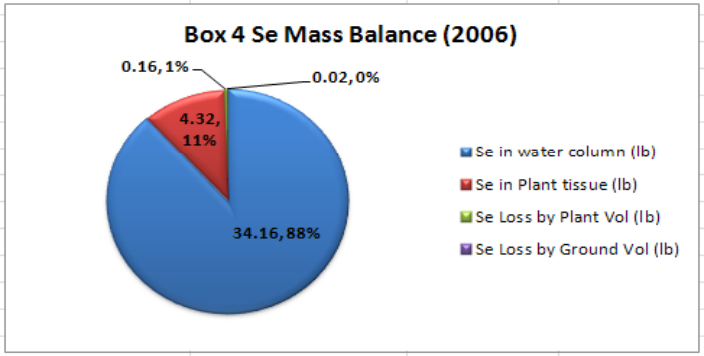


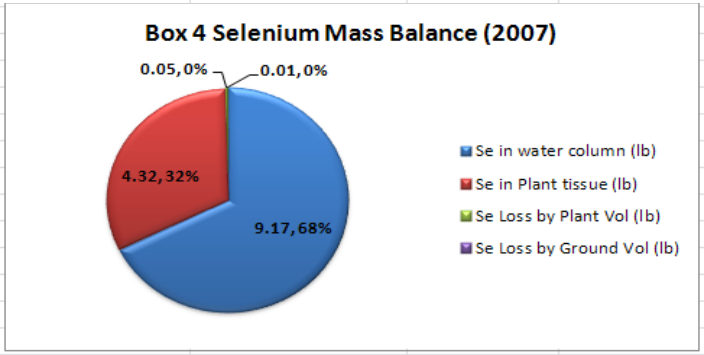


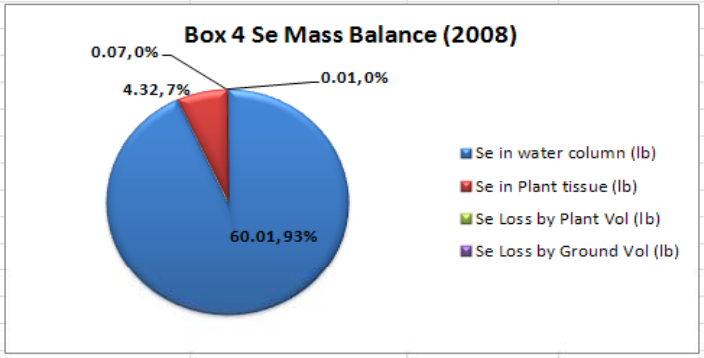
Few months during the Year 2006-2008 were functioning as Se source rather than sink i.e. Se mass from inlet < Se mass in outlet

Selenium Mass and Distribution: Box 4





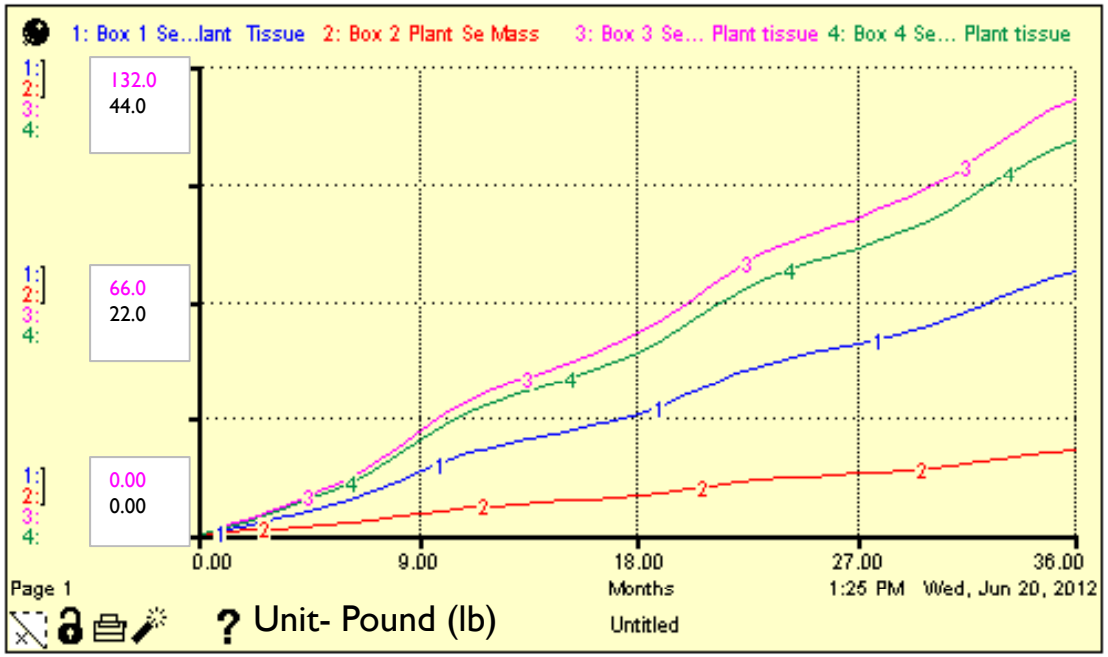




Based on 2006-2008 discharge and Se database, Plant tissue storage accounts approx. 11-32% of Se mass available in Box 4 compartment.

Groundwater seepage contributed significant amount of Se mass in the system since the compartment functions as Se source for some occasions.

Present scenario of Selenium storage by different plants: Box 1-4



Proposed scenarios (2035 and 2050)

- Scenarios will be developed assuming variable flow and selenium conc. from existing sources for all compartments.

- Scenarios based on ongoing and future management activities, For e.g. Wetlands area increase/decreased after completion of wetlands park, bank stabilization activities and associated revegetation plan.

THANK YOU!!!