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Dynamics of selenium species in a wetland system of Great Salt Lake, Utah, USA

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Abstract

The cumulative selenium in the Great Salt Lake via inflow can cause damage to fish and migratory birds at high concentration. One of the influx passages of selenium to the lake is through wetland systems which can be a natural method to reduce selenium concentration if favorable conditions are met. A series of nine integrated ponds was selected to study the lake selenium input and its behavior, receiving flow from the Jordan River through the Surplus Canal delivering to Farmington Bay at southeast of the lake. The variations of selenium species in diurnal cycle each in Spring, Summer, and Fall of 2006 were examined. Hourly values of dissolved oxygen (DO), redox potential (Eh), and pH of each pond were recorded for evaluating concentration of each of selenium species using the Eh-pH diagram. The accuracy of the diagram was cross checked by comparison to the hydride-generation atomic absorption spectrometry (HGAAS) which was found to be less than 2% error. Rising in the morning and dropping at night, the DO, Eh and pH fluctuated for the whole 24 hours resulting from biochemical effect. Hourly concentration for the selenium species was determined for all of the nine ponds during each season. The fluctuation patterns of total selenium were similar for all ponds, higher during 11 am to 5 pm, lower at night and lowest in the morning during 8 to 10 am. Of the four species, selenate and selenite dominated over elemental selenium and selenide for all three seasons. Selenate being higher during Spring but lower in Fall and dominated during Summer only at the upstream of the system whilst Selenite was the dominant species at the mid and downstream system. In total, the annual average results show total selenium concentration decreases towards the lake from 1.25 ppb at the first inlet pond to 0.50 ppb at the ninth pond. From this study we should ascertain the appropriate time to best release the water into the lake.

Keywords: Selenium, Speciation, Temporal variation, Selenium reduction

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1. Introduction

The Great Salt Lake enjoys the physical features of its size, its water levels and centrally located for migratory birds. It has extensive wetlands and nearby shallow ponds, water body and aquatic environments which attract multitude of flora and fauna including millions of migratory birds, their short term stay over place to breed and stage. Thus the lake is very important in ecological standpoint as more than 250 species of birds have been sighted many stopping at this long stretch of migration from North America to South America. In recent years it is believed that selenium and other contaminants are accumulating in the lake due to industrial wastes, irrigation drainage and other anthropological activities. Because selenium can be ingested to these varieties of birds through their diet and can cause malicious effect to them like reproductive deformities and others, it is high time for the Department of Environmental Quality to understand how selenium is affecting the water quality of this great lake, thus could develop water quality criterion for selenium.

Selenium is common in many geological formations in state of Utah in the USA. Although selenium is an essential trace element, it is toxic if taken in excess. Elemental selenium and most metalic selenides have relatively low toxicities due to their low bioavailability. By contrast, selenate and selenite are very toxic, and have modes of action similar to that of arsenic. Selenium also occurs in organic compounds such as dimethyl selenide, selenomethionine and selenocysteine, all of which have high bioavailability and are toxic in large doses.

The resulting diurnal dissolved oxygen concentration swings, especially during summer months of high daytime temperatures and long daylight hours, result in coincident changes in CO2 concentration, pH, and Eh. Irrigation return flows, waste discharge from industrial and mining facilities, and urban runoff contribute selenium into the Surplus and North Point Canals. Selenium that passes through the ADC wetlands ultimately flows into Farmington Bay, and eventually to the GSL. The temporally and spatially changing environments within the ponds influence selenium speciation and, consequently, its transport and ultimate fate. Thus, understanding selenium speciation within the wetland system is essential to quantifying the contribution of selenium to the GSL from the ADC wetlands.

The scope of this research is, thus, focused on understanding selenium cycling and speciation so as to elucidate fluxes of selenium species in GSL. The primary objective is to evaluate the selenium speciation in ADC wetlands pond under varied salinity and environmental conditions in a seasonal basis. The GSL system is seasonally dynamic due to change of runoff in the Jordan River which influences the ADC ponds flow. The variable wind events throughout the season mix the shallow ponds and thus oxidize the water to lessen anoxic zone.

2. Materials and methods

2.1 Research area and its hydrology

The Great Salt Lake (GSL) is considered as the saltiest lake in the Western Hemisphere and is fourth largest terminal lake. The lake is majorly fed by three rivers namely Jordan River, Weber River and Bear River. Though it is a terminal lake with very salty water, yet it is habitat of various species of birds, brine shrimp and other flora and fauna. The GLS whose surface area is about 8547 square kilometer is the prehistoric remains of Lake Bonneville. The water level of GSL averages about 366 meter above the sea level. The research area is ADC wetlands which has an area of about 10 square kilometer is located south end of GSL just north-west of Salt Lake City International Airport. The wetlands comprise of nine integrated ponds (see Figure 1). The surplus canal from Jordan River feeds the first Pond A and the flow thus gets distributed into eight other ponds. Part of the flow also goes to nearby Lake Front Duck Club. The interconnections of the ponds and flow direction can also be seen in Figure 2. Each pond is gate regulated so that flood might not occur in the pond and that required amount of water can be retained in the ponds and the rest of the flow can be released to Lake Front Duck Club and finally to Great Salt Lake via Pond I.

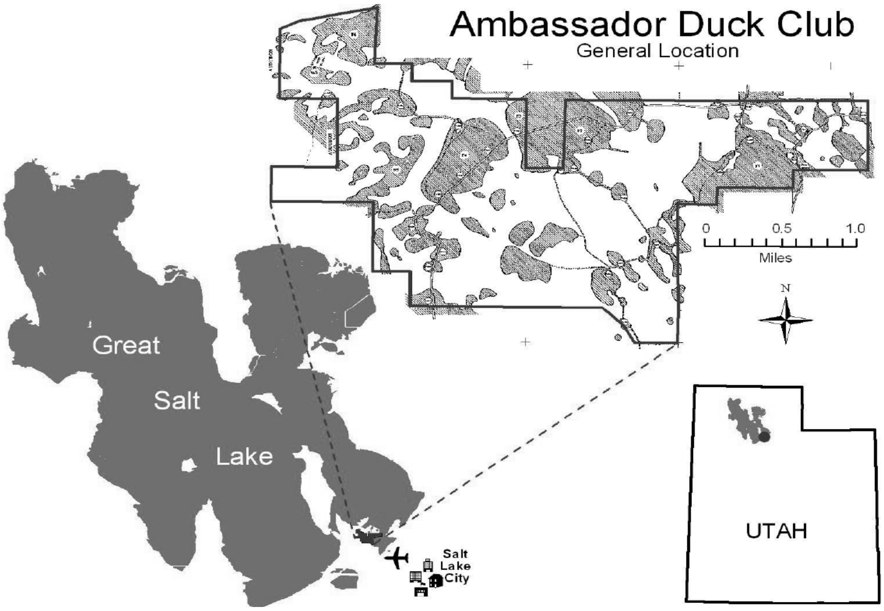

Figure 1 Location of the project area

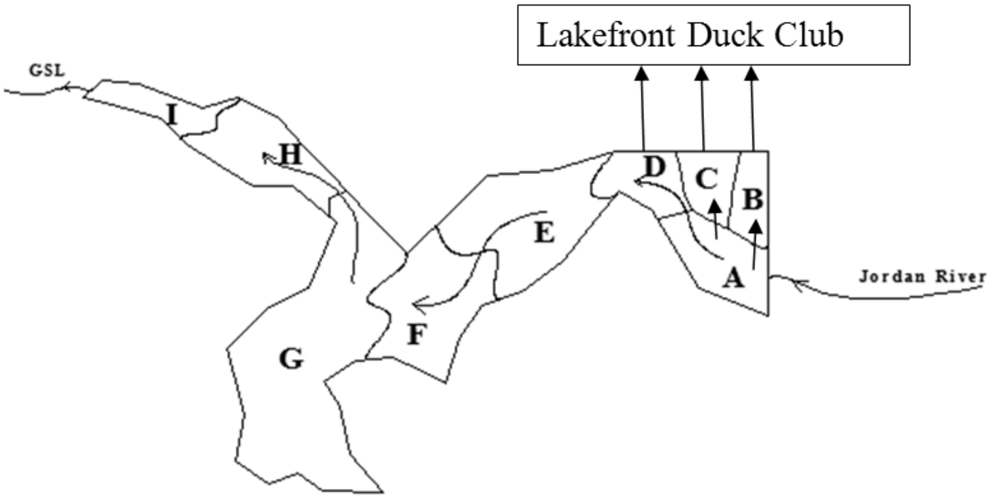

Figure 2 Nine integrated ponds in ADC wetlands

The average discharge measured in the calendar year of 2006 along with other relevant physical data is given in Table 1. Though the ponds are interlinked, the discharges at the ponds are different. The main reason is due to diversion of flow to the Lakefront Duck Club at various seasons by weir sluice gates. Though ground water is not investigated in this research studies but based upon the inlet and outlet discharge of the ponds, it can be speculated that there is some contribution from the ground water. The residence times of the water in the ponds are included in Table 2 in the Spring, Summer and Fall of 2006.

Table 1 Physical data for nine ponds of ADC in the calendar year 2006

Ponds	Average Area (sq. m)	Average Depth (m)	Average in Flow at gate (cubic m per sec)	Average out Flow at gate (cubic m per sec)
A	214296	1.500	1.2	0.6
B	22248	1.250	0.6	0.2
C	22995	0.750	0.2	0.2
D	81017	1.000	0.2	0.2
E	109297	0.750	0.2	0.8
F	1043692	0.500	0.8	0.6
G	2510754	0.750	0.6	0.4
H	553363	0.500	0.4	0.1
I	155900	0.300	0.1	0.1

Table 2 Residence time for nine ponds of ADC in the calendar year 2006

Ponds	Spring hr	Summer hr	Fall hr
A	27	26	23
B	25	22	23
C	18	19	19
D	21	22	21
E	25	21	21
F	20	20	20
G	18	21	18
H	22	22	23
I	18	19	18

The climate of the research area is typically same as mountainous regions of the Western United States. Because the area is close of Salt Lake City which is lower than mountains, it has moderate temperature but temperatures vary greatly between day and night during summer and winter seasons. The watershed receives majority of snowfall in winter months and during spring and summer months, the runoff in the river is high due to snow melt down from upper mountains. The annual precipitation ranges from 25 to 41 cm. The ponds have grasses all around the banks with Stuckenia pectinata as water plant species in the ponds. The average content of selenium come to the Pond A is estimated to be 1.5 ppb and average exiting through Pond I is 0.85 ppb. The difference of the concentrations is either absorbed in sediments, being consumed by birds and waterfowl or may get volatilize.

2.2 Laboratory analysis of selenium

Hydride-generation atomic absorption spectrometer, HGAAS was done for limited samples in five sampling stations to get clear picture and accuracy of Eh-pH diagram. HGAAS was used for the determining of trace elements in a variety of environmental samples because of the advantages of freedom from matrix interferences, and increased sensitivity (Zhang et al., 1999 and 2004). The basis of the analytical technique is the generation of hydride gas, hydrogen selenide (H2Se), from the different oxidation states of selenium. The hydride generation of H2Se consists of a standard Perkin-Elmer FIAS-100 flow injection system, which generates hydrogen selenide by mixing a reducing agent (NaBH4), and 10% HCl which produce excess of hydrogen which reduces the selenium in the sample.

Only selenite species (H2SeO3) under strong acidic conditions was reduced to hydrogen selenide. Therefore, before hydride generation occurred, all forms of selenium species was reduced to selenite. Once the gaseous hydrides are generated they are carried by hydrogen gas through a heat source (electric heating mantel) to dissociate the chemical compounds into free atoms. A known amount of light at a precise wavelength is then passed through the cloud of atoms generated by the process in the Perkin Elmer AANALYST 400. The amount of light absorbed by the clouds is proportional to the number of these atoms and is translated into Se concentration

(Beaty and Kerber 2002). A water sample contained selenate, selenite, and selenide (both organic and inorganic forms). Both oxidation and reduction were needed for selenite production and removal of interferences from reducing agent. Total and dissolved selenium were determined by digestion in HCl and potassium persulfate. The Se +4 and Se +6 were determined by rigorous digestion in HCl, in which Se+6 were reduced to Se+4. Subtraction yielded selenate (Se +6) and selenides and elemental selenium.

Calibration was performed before every sampling session. The system was checked to make sure; the hydrogen gas was on and at the recommended pressure. Spikes were prepared for each digestion and selenite determination. The spiked sample was analyzed every 10 samples to assure good Se recovery. A preparation blank was prepared with each digestion batch. This blank was used to monitor bias introduced by the digestion. The result was subtracted from samples in the batch .The most critical step of speciation was the accurate determination of selenite and total selenium.

2.3 Water quality data collection

Water samples collected in a weekly basis from March to November of 2006 were used to interpolate in diurnal basis. Samples were analyzed for total and dissolved selenium concentrations and selenium species including selenates, selenites; and elemental selenium plus selenides. DO, pH, specific conductance, oxidation reduction potential (ORP) (using an Ag/AgCl cell), and water temperature were measured using INSITU TROLLs 9000 and 9500 water probes. Filtered samples were taken with a peristaltic pump (geo-pump) with tygon tubing and rinsed between samples with deionized water. The filters used were sterile 0.45 micron diameter Millipore filters. These filtered samples were used by HGAAS to analyze the speciation of selenium. The speciation results from HGAAS were matched with Eh-pH diagram for the distribution of speciation. It was found that the margin of error was blow 2%.

After collection, the samples were put on ice and carried to the Utah State Department of Health laboratory and the University of Utah for analysis. Daily flow data were obtained from the Utah Division of Water Rights distribution system daily records collected at the Lower Jordan River Utah Club (site#5315). Also flow measurements at all inlets and outlets were performed by using a Marsh-McBirney Flo-Mate 20000 portable flow meter.

Hourly and seasonal water quality data were collected for the ADC wetlands during the year 2006. The water quality data included DO, pH, temperature in a month wise, which was interpolated to come up with the hourly basis. As can be seen in Table 3, the relevant water quality constituents are incorporated according to Spring, Summer and Fall of the calendar year 2006. There was variation of dissolved oxygen concentration during the diurnal cycle and so was the variation for pH concentration. Average dissolved oxygen variation took place in the range of 5.5 ppm. to 15 ppm and for pH, the variation took place in the range of 5.1 to 12.5. As can also be seen in the Table 3, the salinity of the ponds is in increasing trend from pond A to pond I ranging from 5 ppt to 7.5 ppt.

Table 3 Water quality constituents for nine ponds of ADC in the calendar year 2006

Ponds	Seasons	pH	DO (ppm)	Salinity (ppt)
A	Spring (March-May)	6.5-9.5	10.4-13.6	5.0-7.7
	Summer (June-August)	5.5-11.5	11.0-15.0	5.0-8.0
	Fall (September-November)	6.0-10.0	7.5-10.5	3.0-6.0
B	Spring (March-May)	6.5-9.5	9.5-12.0	5.5-8.1
	Summer (June-August)	5.1-11.3	10.5-14.0	6.0-7.5
	Fall (September-November)	5.8-12.0	8.5-10.5	4.5-5.5
C	Spring (March-May)	7.5-8.6	11.3-12.5	6.5-8.5
	Summer (June-August)	7.5-10.0	12.2-14.5	6.5-8.5
	Fall (September-November)	8.5-10.5	5.5-9.5	4.5-5.5
D	Spring (March-May)	8.5-10.5	11.5-13.5	5.4-7.5
	Summer (June-August)	7.5-12.5	10.5-14.5	5.6-7.9
	Fall (September-November)	8.5-11.5	9.5-11.5	4.6-6.9
E	Spring (March-May)	6.0-9.0	10.0-13.0	5.0-7.7
	Summer (June-August)	5.5-11.5	11.0-15.0	5.0-8.0
	Fall (September-November)	6.0-10.0	7.0-10.0	3.0-6.0
F	Spring (March-May)	6.5-9.5	9.5-12.0	5.5-8.1
	Summer (June-August)	5.1-11.3	10.5-14.0	6.0-7.5
	Fall (September-November)	5.8-11.0	8.6-10.5	4.5-5.5
G	Spring (March-May)	7.5-8.5	11.5-12.5	6.5-8.5
	Summer (June-August)	7.5-10.0	12.5-14.5	6.5-8.5
	Fall (September-November)	8.5-10.5	5.5-9.5	4.5-5.5
H	Spring (March-May)	8.5-10.5	11.5-13.5	5.4-7.5
	Summer (June-August)	7.5-12.5	10.5-14.5	5.6-7.9
	Fall (September-November)	8.5-11.5	9.5-11.5	4.6-6.9
I	Spring (March-May)	6.5-9.5	9.6-12.0	5.5-8.1
	Summer (June-August)	5.1-11.3	10.5-14.0	6.0-7.5
	Fall (September-November)	5.8-10.0	8.5-10.5	4.5-5.5

2.4 Selenium speciation

Selenium speciation in the wetland ponds is complex because of the influence of biological processes including bioaccumulation by microorganism, bioproduction of organoselenium and release of organoselenium (Presser and Luoma 2006). The main selenium compounds are selenate (SeO42-), selenite (SeO32-) and organic selenides (HSe-). Depending upon the variation of pH and dissolved oxygen including temperature during the diurnal cycle throughout the seasons, it was speculated that there is constant conversion of these species to one another within the ADC wetland environment. The simplified transformation reactions are:

$SeO42- + 2H+ \leftrightarrow SeO32- + H2O$

$HseO3-(aq) + 5H+ \leftrightarrow Se(s) + 3H2O$

$Se(s) + H+ \leftrightarrow HSe-$

Selenate and selenite have lower partitioning coefficients and can exist in significant dissolved concentrations. Traditional partitioning equations were used to estimate selenium partitioning. Masscheleyn et al., 1991 have done intensive studies of the distribution of selenium species based upon the change of pH and redox potential of water bodies. In other words, the selenium speciation conversions from selenate to selenite, selenite to elemental selenium, and from elemental selenium to selenide and reverse reactions are related to pH and redox potential. The above concept has been used in the ADC wetlands to quantify the conversion of selenium species in the diurnal and seasonal variation of pH and redox potential. These initial species concentrations serve as boundary conditions for the selenium transport model. Flows between ponds in the ponds were computed based upon the water balance model developed in GoldSim Software. Dye test was conducted to find the residence time of the ponds (see Table 2). The Eh-pH diagram shown in Figure 14 and 15 were modified from Masscheleyn and Patrick (1993) for the ADC ponds. Total selenium coming to the pond gets dissociated into four species of selenium due to change of pH and dissolved oxygen. The distribution of each of the species of selenium is based upon modified Eh-pH diagram as shown into Figures 14 and 15. The hourly change of Eh and pH gives an area in the Eh-pH diagram. The rectangular area is then converted to quantify each constituent species from the total selenium. For each of the nine ponds, the range of pH and redox potential (Eh) was hatched into the diagram and accordingly percentage distribution of each of the selenium species for each of the nine ponds were modeled with the continuous stirred-tank reactor (CSTR) transport model (not shown in this paper). The total selenium is segregated into four of its species and then modeled to find out what quantity remained in dissolved form ready to go to another pond after part of the selenium gets settled in the sediment or volatilized etc. The process repeats until the remaining selenium gets discharged into GSL.

It was seen from the model that part of the elemental selenium is removed from the system immediately by settling (about 60%) and remains dissolved in the water column (about 40%). Other species like selenate, selenite and selenide are subject to transport and various natural processes that influence ultimate fate. The model gives total selenium concentrations for each pond and that discharged to the GSL for each time step. Selenium concentrations were modeled as the initial discharge from the Jordan River Surplus Canal flowed through the nine primary ADC wetland ponds (see Figure 2) and into the Great Salt Lake.

3. Results and discussion

This research gives clear picture and knowhow to evaluate a range of scenarios to better understand the influences of complex natural processes occurring within the ADC wetlands. The results provide useful insight into short and long-term aspects of selenium transformation and distribution in the ADC wetland system. The important observations are synthesized in the discussions below.

3.1 Diurnal selenium speciation in ADC ponds

Hourly DO concentrations at the first pond changed dramatically during spring and summer in response to photosynthesis and respiration processes when biological activity was fully active. Cloud cover during storm events affected solar light energy and water temperature which dramatically lowered the photosynthetic production of DO (see Figure 3).

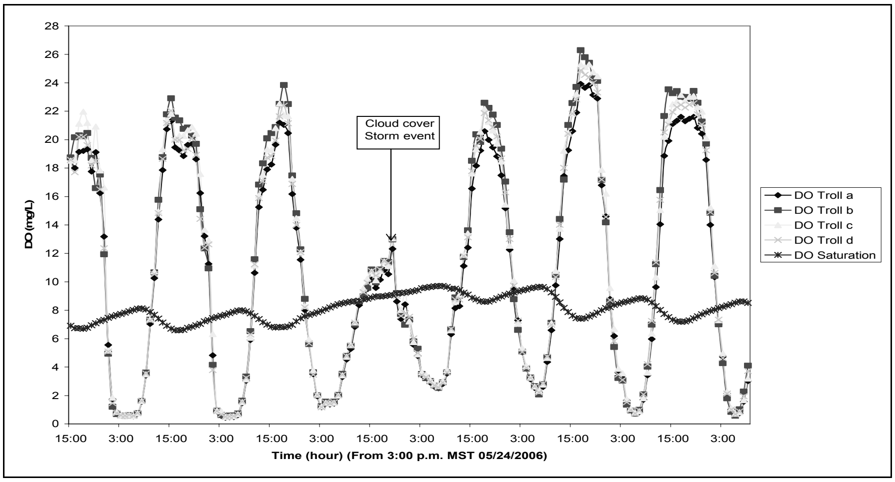

Figure 3 Do measurements at pond a during spring 2006 by troll 9000

The DO swings at pond A were significantly reduced during a period of cloud cover. The data suggest that the cloud cover decreased water temperatures and shortened the photoperiod, causing a decrease in biological activity. Anoxic or near anoxic conditions were present during night time in spring and summer for several hours (i.e., from about 1 a.m. to 6 a.m.). Also anoxic conditions caused denitrification or nitrates reduction to nitrogen gas (N2). Furthermore, the anoxic to anaerobic conditions likely result in methanogenesis. Selenide can be methylated by methanogenic bacteria forming dimethyl selenide. pH varied dramatically from 7.5 to 9.5 in a similar fashion for DO on a daily cycle in spring due to photosynthesis and respiration process. When photosynthesis was predominant during the day time, CO2 was consumed by aquatic plants, algae and photosynthetic organisms, lowering the acidity of the water and increasing the pH. By converse, when respiration was predominant (at nighttime) CO2 was "pumped" back into the system increasing acidity and decreasing the pH of the water. These "biological pumps" repeated the same process on a daily cycle.

Diurnal variations in DO, pH, and redox cause the distribution of selenium species to vary over the course of a day. Figures 4 to 12 show the diurnal distribution in the different ponds, each at a distinct time of the year – March 15, July 15, or October 15. These three different dates have been chosen to represent a day for each season based upon the similarity of distribution of selenium species in the ponds. March 15 is the representative date for spring 2006, July 15 for summer 2006 and October 15 for fall 2006. Based upon the location of the ponds in the ADC wetland and other parameters such as flow through the ponds and their shape and size, the ponds A, E and H illustrate distribution of selenium species in the rest of the ponds. In other words, selenium species distributions are similar in ponds A, B, C and D; pond E shows a similar distribution with Ponds F and G. Finally, ponds H and I also demonstrated similar distributions.

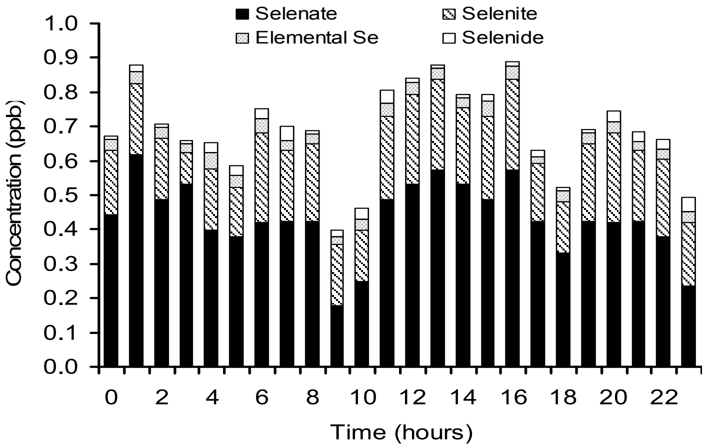

Figure 4 Diurnal selenium species distribution in spring 2006 (March 15) in pond A (Representative of ponds A, B, C and D)

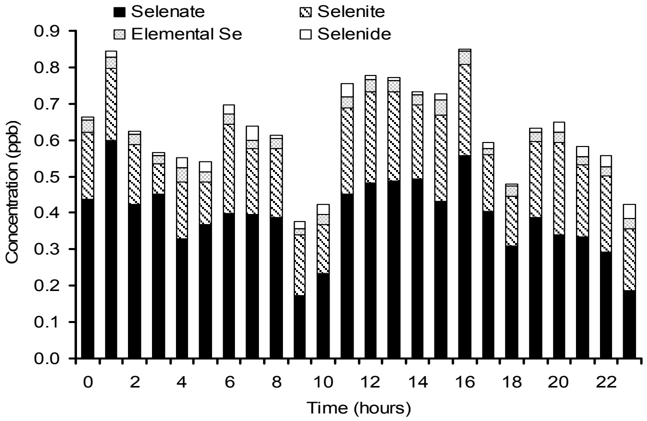

Figure 5 Diurnal selenium species distribution in spring 2006 (March 15) in pond E (Representative of ponds E, F and G)

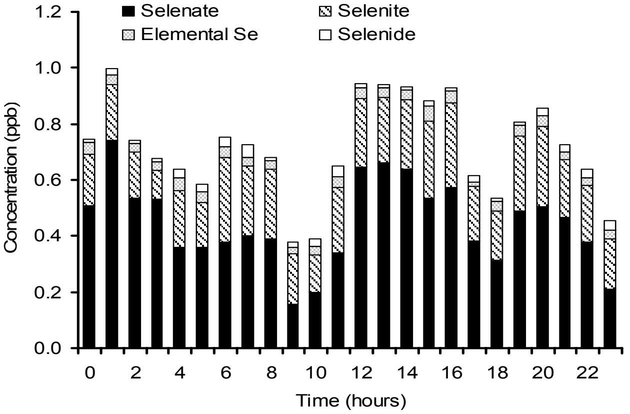

Figure 6 Diurnal selenium species distribution in spring 2006 (March 15) in pond H (Representative of ponds H and I)

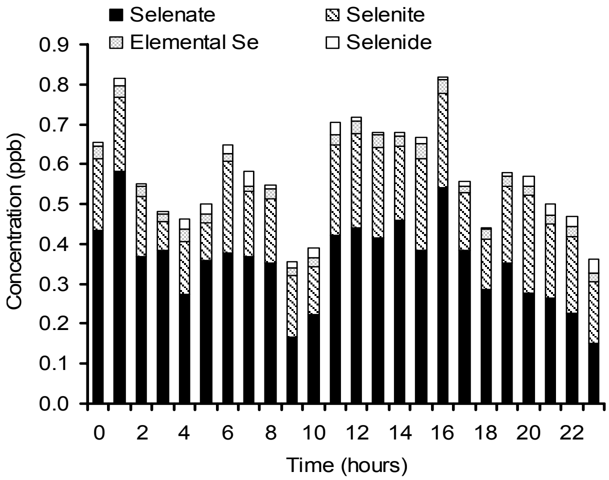

Figure 7 Diurnal selenium species distribution in summer 2006 (July 15) in pond A (Representative of ponds A, B, C and D)

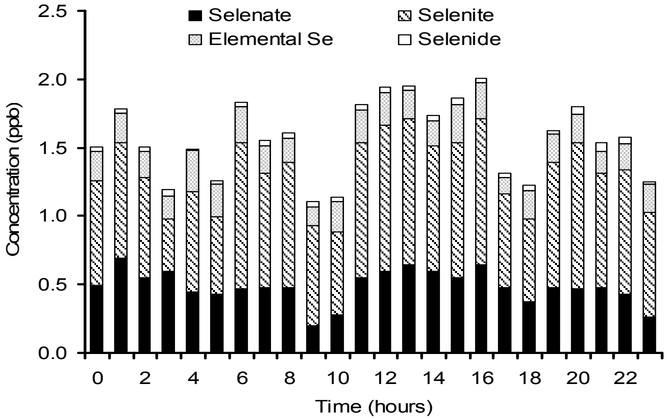

Figure 8 Diurnal selenium species distribution in summer 2006 (July 15) in pond E (Representative of ponds E, F and G)

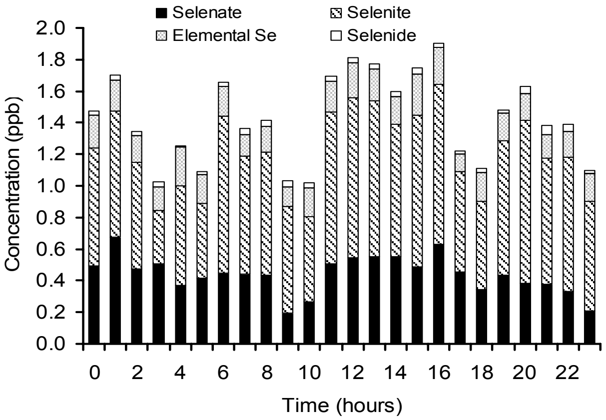

Figure 9 Diurnal selenium species distribution in summer 2006 (July 15) in pond H (Representative of ponds H and I)

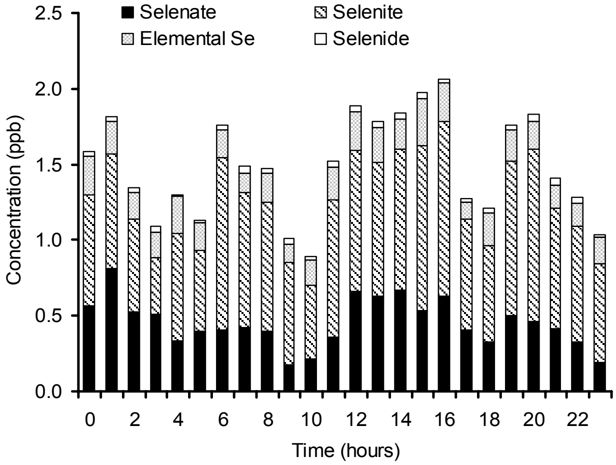

Figure 10 Diurnal selenium species distribution in fall 2006 (October 15) in pond A (Representative of ponds A, B, C and D)

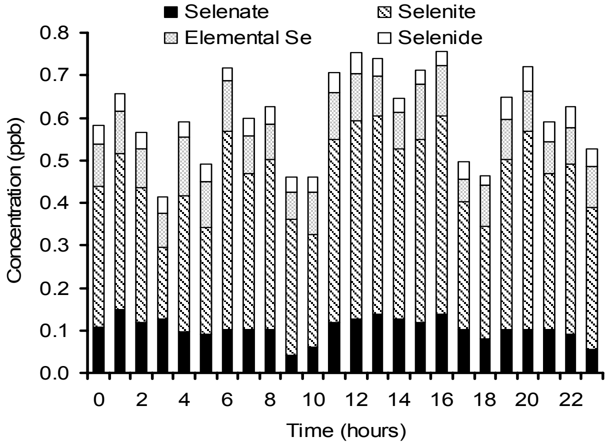

Figure 11 Diurnal selenium species distribution in fall 2006 (October 15) in pond E (Representative of ponds E, F and G)

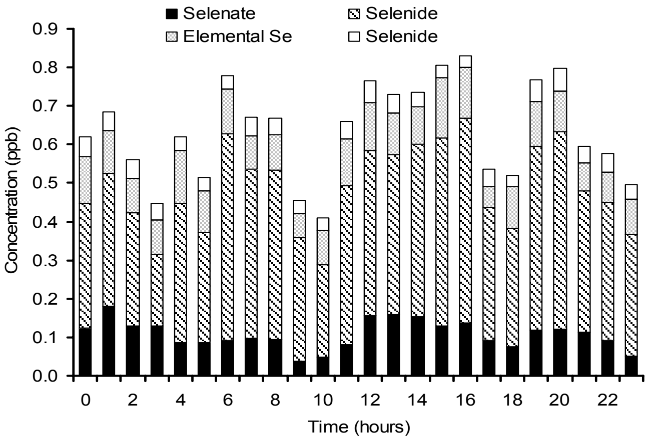

Figure 12 Diurnal selenium species distribution in fall 2006 (October 15) in pond H (Representative of ponds H and I)

The similar water depths of ponds A, B, C, and D (average of about 1 m) results in similar wind-induced mixing and dissolved oxygen concentrations. The distribution of selenium species shows similarity in three groups of ponds in the ADC wetland. As for example, the ponds A, B, C and D show similar distribution. The main reason of it is due to their low depth in nature and wind-induced mixing phenomenon influencing the oxygen content in an analogous way. The ponds A, B, C and D show very much close distribution; similarly E, F and G lie in one group and ponds H and I are the last set of close group where selenium species is seen in close distribution. Thus pond A represents characteristics of ponds A, B, C and D; Pond E represents ponds E, F and G; pond I represent ponds H and I.

Ponds H and I are shallow and wide, with average depths of 0.5 m and 0.3 m. Thus, turnover of the ponds due to wind directly influences the oxygen content and results in similar selenium species. Pond A shows selenate being the most dominant species, followed by selenite in Spring and Summer of 2006 but in the Fall of 2006, selenite dominates selenate. Selenium and selenide concentrations remain similar during the entire diurnal distribution. Selenate and selenite are the predominant species due to the predominant Eh and pH within the pond. In pond A, pH ranges from 6.5 to 11.5 while the redox potential ranges from 0.4 volts to 0.9 volts, the situation thus makes selenate dominating on other selenium species.

The concentration of selenium species in Pond E is comparatively higher than in preceding ponds B, C and D since it receives flows from pond A and ponds B, C and D. The selenium species distribution in ponds A, B, C and D are different due to widely varying Eh and pH values during the diurnal cycle over the year. Unlike Ponds A, B, C and D, there is a prominent increase in the concentration of elemental selenium and selenide in pond E. The main reason is due to its redox potential being low in most of the seasons. The low value of Eh is close to 0.25 volts, which accelerates the reduction process of selenium species. When the dissolved oxygen decreases the reduction process takes place and so selenate and selenite get converted to elemental selenium and selenides. Part of the elemental selenium settles down and selenides gets attached to organic particles which remain suspended or settles down. This phenomenon changes the total concentration of selenium in the ADC wetlands.

Variation of species in Ponds F, G, H and I are generally the same. Ponds G and H show a different type of selenium species distribution than the ponds A, B, C, D, E and F due to their shallow nature and increased salinity. Selenite is the dominant selenium species in ponds G and H, but both selenate and elemental selenium exist at significant and similar concentrations. The main reason is the oxidation of selenite to selenate due to the high redox potential (Eh) and the reduction of selenate and selenite to elemental selenium during the night time hours when DO level is low.

The seasonal variations in these ponds show a similar pattern of selenium speciation. Ponds C, E, F and G show the dominance of selenite and prominent occurrence of elemental selenium and selenide. The seasonal distribution show that these ponds have comparatively lower redox potential than ponds A, B and D. Due to lower DO concentrations, selenate reduction is accelerated especially at night when further reduction leads to elemental selenium and selenide. In Summer 2006, however, selenate was more prevalent than selenite. This is because the increased sunlight to raise the level of dissolved oxygen during summer, thereby accelerating the oxidation process. During the spring and fall, redox potential decreases, increasing selenium reduction.

Selenite dominates in ponds C, F and I as these ponds had Eh values close to 0.25V and pH varies from 6 to 11 for most of the time during the spring season but for pond A, there is domination of selenate during Spring as Eh is around 0.75 volts ranging its pH values from 6.5 to 11 (see Figure 14 and 15). Ponds A, B, D, E and F were dominated by selenite as Eh of these ponds remained close to 0.75V ranging their pH from 6.5 to 11 during the fall season. Also, yearly average value of the selenium species from for each of the pond can be seen in Figure 13.

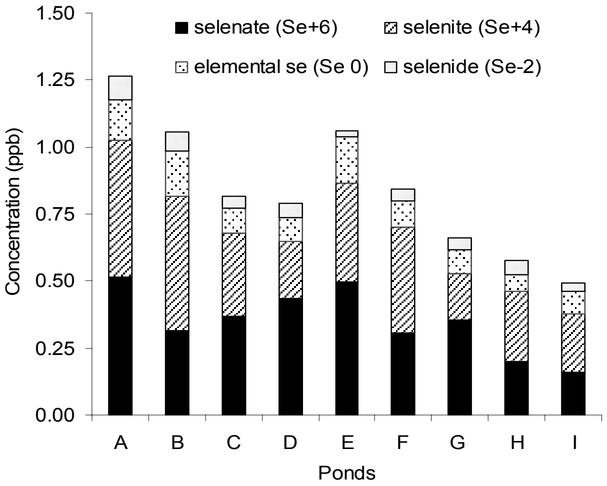

Figure 13 Model estimates of average annual selenium species concentrations in ADC ponds for 2006

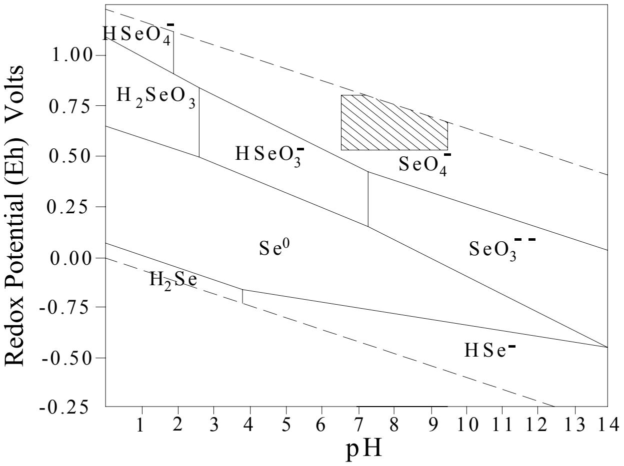

Figure 14 Selenate species in majority when E_h was at higher range in ADC wetland (Hatched box shows the distribution of Se^{+6})

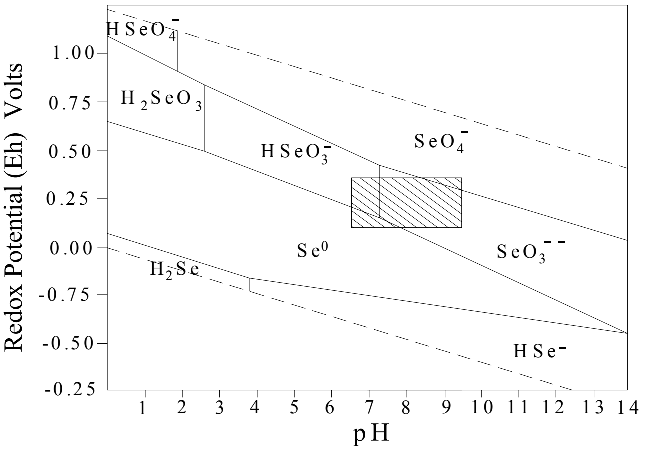

Figure 15 Selenite species in majority when E_h was at lower range in ADC wetland (Hatched box shows the distribution of Se^{+6}, Se^{+4} and Se^0)

Measured Eh values for the ponds throughout the year are sufficiently low for Mn (IV) reduction to occur (occurs at a redox level, pe, of 7.5) but too high for Fe (III) reduction (occurs at pe <-1) (Drever, 1997). In general, the distribution of selenium species in the ponds, as indicated by the Fe, Mn, and Eh data, are consistent with distribution that would be predicted by the oxic conditions at ADC wetland ponds.

The decrease in selenates concentration in Pond E and H during Summer and Fall suggests that pH related sorption along with Fe (III) or Mn (IV) reduction processes may exert important controls on dissolved selenates concentration in this region of the ADC wetlands. Because selenates is more strongly adsorbed for pH $\leq$ 6.0 (Dzombak and Morel, 1990; Drever, 1997), as pH decreases toward 6.0, selenates would be expected to strongly adsorbed to mineral surface. Microbes that reduce selenates to selenites have been reported from aqueous environment (Liu and Narasimhan, 1994; Stolz and Oremland, 1999; Ike et al., 2000). It should be noted that selenates reduction is entirely responsible for the increase in selenites concentration in ponds C and H. The model analysis clearly shows that selenite increases from spring to summer but on the other hand selenate decreases.

The increase in selenites concentration is consistent with its continued release from on- going reductive dissolution of Fe (III)/ Mn (IV) oxides/ oxyhydroxides. It should be noted that the increase in dissolved selenides concentration in the pond may also reflect release of selenides sorbed to Fe-Mn oxides/oxyhydroxides during reductive dissolution of these oxides/oxyhydroxides.

4. Conclusions

The research that served as the basis of this study supports the following conclusions:

(1) Vegetation growth in the ponds cause diurnal changes in selenium speciation in response to corresponding changes in DO concentration, redox potential, and pH. All ponds showed a dampening of vegetation growth and associated pH swings as the photoperiod and temperatures decrease during the fall. Similar responses,

although short term, were observed to result from temporary decreases light intensity from cloud cover.

(2) The biochemical transformations resulted in higher concentrations of selenite and organic selenium as compared to the predominantly selenate that exists in Jordan River Surplus Canal water. The extent of these transformations varied from pond to pond. The main controlling factors were Eh, pH, salinity, and residence time of the ponds. The higher residence time with increasing salinity in the pond increases the speciation dynamics.

(3) The data collected for Eh in the ADC ponds show that redox potential decreases as water flows toward the GSL. This situation results in reduction of selenates to selenites and elemental selenium and subsequent adsorption or incorporation to the solid phase, thereby immobilizing Se from water columns and reducing Se ecotoxic risks to some extent.

5. References

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