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**BIOMASS PRODUCTION AND CHEMICAL CYCLING IN A
MAN-MADE GEOTHERMAL WETLAND**

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ABSTRACT

Biomass production and, to a lesser extent, chemical cycling have been evaluated in a man-made wetland created using geothermal water in southcentral Idaho. The wetland system consisted of a 0.25 ha area divided into two ponds. The upper pond contained submerged species (*Egeria*, pondweeds and coontail); the lower pond was planted with emergents (cattail, bulrush, and common reed).

Biomass production from emergent plants in the two-year-old system was promising and compared favorably with production values reported in the literature for natural wetlands. Chemical cycling of potassium (K) was evaluated through the lower pond system. Uptake of several other constituents (F and Na) of the geothermal water by the emergent plants was observed. However, there was little difference in elemental concentrations of the system's influent and effluent, probably due to evapotranspiration of water which effectively concentrates elements in the remaining water.

Twenty-one species of diatoms were identified in the geothermal wetland, and numerous species of insects were observed. The man-made wetland also created substantial habitat for wildlife. This type of system could be used as an alternative to injection of spent geothermal fluids from small-scale projects. Study results indicate that a wetland system can be developed to produce substantial quantities of biomass in a cold desert environment.

INTRODUCTION

For many years, wetlands were drained and filled for use in regional development. However, many scientists foresaw problems with such changes. Many recent studies have evaluated the role of wetlands as a resource (Melbrooks and Reed, 1981; Blumer, 1978). Results from these studies indicated that wetlands played a major role in nutrient cycling, biomass production, water purification and providing wildlife habitat. More recently, investigators have reviewed the mechanisms by which wetlands remove nutrients from wastewater and have synthesized data from the literature to model the relationship between nitrogen and phosphorus removal efficiencies at various application rates (Nichols, 1983). The potential for using wetlands in treating wastewater and creating wildlife habitat is attracting the attention of scientists, administrators and engineers (Tourbien and Pierson, 1976).

Spent geothermal fluids (hot water) could be used to create or enhance waterfowl wetlands (CH₂M Hill, 1981). However, there is a lack of directly applicable published information for defining effluent criteria and specific uses of wetlands for geothermal effluent disposal.

The disposal of spent geothermal water is a significant problem associated with commercialization of geothermal resources. In terms of general cost comparisons, subsurface injection would be favored over wetland disposal in cases of high effluent flows and/or zero discharge requirements (CH₂M Hill, 1981). If variances from the zero discharge

requirements could be secured, wetland construction could become economically attractive, especially in the arid west where large tracts of marginal land are available and water is a limited resource.

Initial research to evaluate the potential of using geothermal fluid to create wetlands was initiated in 1979. A literature review provided information on plant species which had the capability to thrive in slightly saline water and were known to bioaccumulate certain elements (Stanley, et al., 1980). Following the review, eighteen species of wetland macrophytes indigenous to the Great Basin were screened for their ability to adapt to geothermal water. Health and vigor of the species were observed. Results from the 1979 study showed that several species could thrive in geothermal water.

In 1980, the research program was expanded to include the best performers from the 1979 study and some species non-native to the Great Basin. Twenty-five species were examined. Chemical analysis provided information on peak concentrations of elements bioaccumulated by the plants (Breckenridge, Cahn, Thurow, 1981).

The results from the 1979 and 1980 studies were used in selecting species of plants that were established in a small-scale wetland constructed in 1981. This paper discusses establishment of the wetland and its biomass production potential. Selected elemental concentration data from water, soil, and plants are also reported. Chemical cycling data are discussed qualitatively due to difficulties in obtaining accurate

measurements. Additionally, the justification for conducting this study was to develop data that could be used by other scientists and administrators when evaluating wetland resources.

METHODOLOGY

Study Area

The wetland system was located on the Raft River Known Geothermal Resource Area (KGRA) in southcentral Idaho near the Idaho/Utah border. The Raft River valley is a cold desert environment with a mean annual temperature of 8°C. In the coldest months, December and January, the mean temperature is -3.1°C; in the warmest months, July and August, the mean temperature is 20°C. During the period of geothermal development at the Raft River KGRA, the yearly precipitation averaged 25.5 cm.

The wetland system covered 0.25 ha (~50 x 56 m). It was divided into two ponds: an upper pond and a lower pond (with an adjacent algae pond) (Figure 1). The upper pond was about 1.2-m deep and was planted with submerged species: *Egeria* (*Egeria densa*), pondweeds (*Potamogeton nodosus*, *Potamogeton friesii*, *Potamogeton filiformis*), and coontail (*Ceratophyllum demersum*). The lower pond was about 15-cm deep and was planted with emergents: bulrush (*Scirpus acutus*), cattails (*Typha latifolia*) and common reed (*Phragmites communis*).

Cooled geothermal effluent flowed by gravity to the upper pond and was dispensed through a gated pipe. Five 10-cm Plastic (PVC) weirs controlled water flow between the upper and lower ponds (Figure 1). A collection system located at the east end of the lower pond made it possible to collect composite water samples as water flowed out of the wetland system. The water used in this study was obtained from a cooling pond which

maintained the water at about 30°C. Average concentrations of the dominant chemical constituents in the water are listed in Table 1. Flow rates were measured at the wiers between the upper and lower ponds. The average flow rate was 0.28 liters per second.

Soils at the wetland site are classified as an Ayses-Hiko Peak complex. This is a mixture of soils in alluvium from different sources and influenced by volcanic tuff. The ponds are lined with 4 cm of bentonite clay to reduce deep percolation. In the lower pond, a 4 to 8 cm layer of sand was applied over the bentonite as substrate for vegetation development.

Collection of Water, Sediment and Plants

Water, sediment, and plant samples were collected during the 1982 growing season on a biweekly basis. Composite water samples were collected at three locations: (a) upper pond inlet, (b) upper pond outlet, and (c) lower pond outlet.

Composite soil samples (from the upper 10 cm) were taken at the inlet and outlet of the upper and lower ponds.

Representative samples of all submerged vegetation from the upper pond were collected at random locations using a grab sampler. A grid system was used to identify sample locations for the lower pond.

Biomass Evaluation

Biomass data were collected for bulrush, cattails, and common reed. Initial densities for these species were established when the rhizomes were hand planted in rows approximately 15-cm apart. In order to obtain a good estimate of standing biomass, the sample area must be larger than the cluster size of the rhizomes. Cluster size dimensions have been determined by "cluster analysis" (Greig-Smith, 1964; Kershaw, 1964); from these data, the minimum total sampling area that would provide an accurate estimate of biomass for a stand was determined. The minimum areas are 0.8 x 1.6-m for cattails and 0.4 x 0.8-m for common reed. Values were not available for bulrush; however, the literature suggested that a sample area of 0.4 x 0.8-m would be sufficient to eliminate bias (Ondak, 1971; 1970). Sampling areas for the three species sampled during the 1982 growing season were greater than values reported in the literature (Greig-Smith, 1964; Kershaw, 1964). The areas were 2.5 x 5.0-m for cattail and bulrush, and 0.5 x 1.0-m for common reed.

The standing-permanent-quadrant technique (Good, et al., 1977) was used to evaluate biomass production. Eleven 0.5 x 1.0-m permanent quadrants were established in 1982: five cattails, five bulrush and one common reed. Only shoots outside the permanent plots were harvested. Biweekly, all shoots in each permanent plot were counted and this number was recorded as the average shoot density (N/area). On each sampling day, five locations for cattail and bulrush, and one location for common reed were randomly selected from the grid. Average shoot weight was determined for

the respective species by harvesting either 40 bulrush, 25 cattails or 25 common reed at the water surface. All shoots were oven dried for 24 h at 90°C to determine the average dried weight per shoot (W). Average shoot biomass values per unit were obtained by multiplying N/area by W.

Analytical Methods

Water samples were tested in the field for conductivity, pH, and temperature prior to being acidified with 2 ml of concentrated nitric acid. The samples were then tested for selected elements (Table 2).

Plant samples were dried, ground and homogenized. A nitric acid-perchloric digestion was used prior to determining the concentration of all elements except Cl^- ; chloride was extracted using a water leach method. Analytical methods and detection limits for specific elements are listed in Table 2.

Soil samples were dried, homogenized and sieved through a 2 mm sieve prior to being analyzed for selected elements (Table 3).

RESULTS AND DISCUSSION

Biomass Production

Biomass data were collected for emergents in the lower pond (Table 4). The three species reached peak biomass production at different times throughout the growing season (Figure 2). Common reed was the best biomass producer followed by cattail and bulrush. Their peak biomass production values were 1447, 760, and 580 dry g/m², respectively.

Productivity of the man-made wetland, when compared to values reported in the literature was high. Peak standing crop values reported in the literature for common reed range from 654 to 3999 with a mean of 1850 dry g/m²; these compare favorably with the Raft River value of 1447 dry g/m². Literature values for cattails ranged from 626 to 1668 with a mean of 1361 dry g/m²; the Raft River value was 760 dry g/m². Values from the literature for bulrush ranged from 193 to 802 with a mean of 606 dry g/m²; the Raft River value was 580 dry g/m². These values are impressive considering the system has only been established for two growing seasons. Based on this comparison, it is evident that reasonably high biomass values can be achieved by establishing reed, bulrush, and cattails in a man-made wetland.

Chemical Evaluation

Analyzing only elemental concentration data is not always sufficient to explain the movement of elements in a system such as this. For example, sodium (Na) concentrations in cattails (Table 8) appear relatively static throughout the growing season; however, the total mass of Na in the plant is dependent on both the concentration and the mass of the plant. The mass of the plant (Figure 2) and, thus, the mass of Na in the plant changes during the growing season. To determine the elemental mass within plant, soil, and water samples, several key assumptions must be made:

- o The total mass of soil and volume of water in the system remained constant throughout the growing season.
- o Since reasonably accurate data must be used in making mass determinations, only data for those elements in agreement with their quality assurance (QA) results are reported. Spiked replicate and standard values were included as part of the QA program for water, soil, and vegetation (Tables 5, 6, and 7, respectively). Data are reported for Na, F, and K (Tables 8, 9, and 10).

Although water purification potential was evaluated, it was considered a minor portion of this study for the following reasons:

- o Quality of the water entering the wetland varied with time, thus making it difficult to evaluate.
- o Because the densities of submerged plants in the upper pond were highly variable, the mass balance determination (on the upper pond) was considered to be non-conclusive.
- o Only a small portion of the lower pond was planted with common reed (4.3%). Thus, it was not considered in the mass determination.
- o Previous results from the wetland research (Breckenridge, Cahn and Thurow, 1982) indicated evaporation as having a major influence in water quality, especially from an open water source in the arid west. Thus, the high evaporation from the surface of the upper pond made evaluation of chemical cycling difficult. The effect of climatological conditions on variability in wetland systems has also been documented by Kadlec, (1976).

Based on previous assumptions and background information (Boyd, 1976, 1969, 1970; Mayes, et. al., 1977), chemical cycling of the lower pond system was evaluated. The simplified model used for this determination and many of the calculated values is as follows:

where:

- M_1 = mass of water = $7.69 \times 10^4 \text{kg}$
- M_2 = mass of soil = $1.2 \times 10^5 \text{kg}$
- M_3 = mass of bulrush
- M_4 = mass of cattail
- Q_1 = input from upper pond
- Q_2 = outlet from lower pond
- Q_3 = rainfall (negligible amount)
- Q_4 = uptake by plants
- Q_5 = sorption by soil
- Q_6 = transfer from soil
- Q_7 = transfer from plants.

Data regarding the total area of emergent species are required for mass determination. These areas for bulrush and cattail are 280.4 m^2 and 456.2 m^2 , respectively.

The following discussion will be limited to K, but a similar evaluation could be performed for the other data using the same procedure.

M_3 and M_4 can be calculated by multiplying the total area (m^2) by the biomass (g/m^2) for each of the sampling periods (Table 4). Using these values and the concentration values for K (Table 9), the mass determination for K in the lower pond over the growing season can be evaluated (Table 11).

The concentration of K in the water was observed to decrease slightly over the growing season (Figure 3). In conjunction with this decrease, an increase in mass of K in the plants and soil was observed. There appears to be a slight interaction between the plants and soil, especially during early and later portions of the growing season. During the early portion of the growing season, K is reduced in the soil while it is increasing in the plant. Toward the end of the growing season, the mass of K in the plants decreases and the mass of K in soil increases. This trend may have been a result of the plants discharging K to the soil. This type of effect was also noted by other researchers studying chemical cycling in aquatic plants (Mayes, et. al., 1977).

Habitat Development

The man-made wetland established habitat suitable for algae colonization and wildlife use. Twenty-one species of diatoms (a form of algae) were identified. Healthy populations of blue and blue-green algae were also noted. Additionally, the wetland provided forage and habitat for several species of birds. The most common species was the yellow-headed blackbird (Xanthocephalus xanthocephalus), of which nine pairs nested among the emergents of the lower pond. This density is equal to or greater than values reported for natural densities in the Northwest (Orians, 1980). One family each of blue wing teal (Anas discors), loggerhead shrikes (Lanius ludovicianus), and killdeer (Charadrius vociferus) fed from and nested around the area.

The upper pond was stocked with nile perch (Tilapia aurea) to control algae. These fish thrived and multiplied rapidly. Five to ten centimeter fish were introduced in early June; by September many of these fish were over 20-cm in length.

CONCLUSIONS

This research was conducted to evaluate the feasibility of developing a man-made wetland using spent geothermal water. Biomass production and, to a lesser extent, chemical cycling were investigated.

By the second season, a wetland established using geothermal water can produce quantities of biomass comparable to values in the literature for natural wetlands. A man-made wetland could be designed in a manner that would facilitate harvesting. Thus, biomass would be readily available and could be harvested during peak productivity periods. However, timing and methods employed in harvesting may be influenced by wildlife use and/or management techniques.

Results from the chemical cycling evaluation indicate that emergent plants (bulrush and cattails) can bioaccumulate selected elements during the growing season. However, water quality is not significantly improved as a result of this uptake. This is probably a result of concentration of elements in the water due to evapotranspiration and the system reaching equilibrium. Investigation of optimum flow rate, wetland size, and control of evapotranspiration could result in better treatment of geothermal water.

A man-made wetland can create wildlife habitat as evidenced by the relatively high density of yellow-headed blackbirds and use by other birds and amphibians. This type of system could provide habitat for wildlife near many energy development projects producing wastewater in the arid

west. The geothermal wetland produced an environment conducive to the growth of many species of algae. Although this research was conducted using geothermal effluent, other types of effluents (i.e., municipal wastewater, mining and drilling waters, etc.) could be used.

Future research should investigate the potential of combining wastewater streams (codisposal) to provide a system that would maximize nutrient and trace metal uptake and biomass production. These types of systems could produce large volumes of biomass that could be used as feedstocks in energy conversion processes.

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Figure 1. Geothermal Wetland constructed at the Raft River Facility.

TABLE 1. AVERAGE CONCENTRATIONS OF THE DOMINANT CHEMICAL CONSTITUENTS IN THE RAFT RIVER GEOTHERMAL WATER. DATA RECORDED IN mg/l; SPECIFIC CONDUCTANCE RECORDED IN μ mhos/cm.

Total N	0.8
PO ₄	0.2
F ⁻	8.7
B	0.3
Na	580
Mg	0.59
Si	90
Cl ⁻	920
K	40
Ca	55
SO ₄	40
Hardness (CaCO ₃)	160
HCO ₃	44
pH	7.3
TDS	1607
Alkalinity	34
Specific Conductance	2987

TABLE 2. ANALYTICAL METHODS AND RANGE OF DETECTION FOR ELEMENTS IN WATER AND PLANT SAMPLES

Parameter	Method	Range (mg/l)
Boron (B)	Carmine Method	0.1 to 10
Calcium (Ca)	Atomic Absorption	0.08 to 5
Chloride (Cl)	Specific Ion Electrode	1.8 to 35,500
Fluoride (F)	Specific Ion Electrode	0.02 to Saturation
Magnesium (Mg)	Atomic Absorption	0.007 to 1.0
Phosphorus (total)(P)	Vanado Molybdophosphoric Acid-Colorimetric	0.1 to 6.5
Potassium (K)	Atomic Absorption	0.04 to 2
Silica (Si)	Atomic Absorption	1.8 to 150
Sodium (Na)	Atomic Absorption	0.015 to 1

TABLE 3. ANALYTICAL TECHNIQUES AND DETECTION LIMITS FOR SOIL SAMPLES

Parameter	Method	Detection Limit (mg/l)
NH ₃	Colorimetric	1.0
NO ₃ -N	Nessler-Colorimetric Method	1.0
P	Phosphate-Molybdate Colorimetric Method	1.0
K	Atomic Absorption	5.0
B	Carmine Colorimetric Method	0.1
Cl	Mercuric Nitrate Titration	1.0
F	Specific Ion Electrode	0.5
Si	Atomic Absorption	1.0
Ca	Atomic Absorption	0.1
Mg	Atomic Absorption	0.1
Na	Atomic Absorption	0.1
pH	Probe	
Organic Matter (%)	Ferrous Ammonium-Sulfate Titration	

TABLE 4. BIOMASS PRODUCTION RESULTS FROM 1982 FOR EMERGENT SPECIES IN A MAN-MADE GEOTHERMAL WETLAND

Sampling Dates (1982)	Mean and Standard Deviations of Biomass Production (dry grams/meter ²) for Emergent Species		
	Bulrush	Cattail	Common Reed ^a
4-28	67 ± 17	38 ± 8	--
5-12	151 ± 29	190 ± 37	52
5-26	394 ± 72	270 ± 54	189
6-9	550 ± 100	457 ± 103	293
6-23	356 ± 57	639 ± 135	468
7-7	548 ± 84	760 ± 151	744
7-23	580 ± 82	739 ± 130	1067
8-4	568 ± 81	532 ± 79	1101
8-18	410 ± 48	564 ± 119	1447
9-1	388 ± 25	689 ± 104	1402

a. Only one permanent plot was established for common reed due to the small area planted with this species.

Figure 2. Biomass production of emergent species during the 1982 growing season.

TABLE 5. QUALITY ASSURANCE RESULTS FOR THE WATER DATA

<u>Element</u>	<u>Spiked Sample Analytical Results (ppm)</u>	<u>Known QA Value (ppm)</u>
B	0.25	0.27
Ca	10.5	52.9
Cl	927.0	713.7
F	6.0	6.1
K	50.0	35.5
Na	450.0	447.8

TABLE 6. QUALITY ASSURANCE RESULTS FOR THE SOIL DATA

<u>Test Parameter</u>	<u>Replicate Results^a</u>			
	<u>A</u>	<u>B</u>	<u>C</u>	<u>D</u>
NH ₃	1	2	12	8
NO ₃	1	1	6	3
P	15	12	12	9
K	169	169	156	164
B	0.3	0.3	0.4	0.3
Cl	5856	83	20	20
F	3.0	3.1	3.0	2.6
Si	13	1.0	14	8
Ca	7209	8047	8178	7644
Mg	272	282	438	384
Na	30	30	29	25
pH	8.1	8.0	8.1	8.0
Organic matter	1.3%	1.3%	1.1%	1.1%

a. All values reported as ppm unless otherwise noted.

TABLE 7. QUALITY ASSURANCE RESULTS FOR VEGETATIVE DATA

(Units)	Replicate Results						Tomato Leaf Standard Values
	A	B	C	D	E	Mean	
Na (%)	0.20	0.19	0.19	0.23	0.21	0.20 ± 0.2	--
K (%)	4.43	4.44	4.38	4.45	3.55	4.25 ± 0.39	4.46 ± 0.03 ^a
F (ppm)	26.0	25.5	28.0	26.0	31.0	27.3 ± 2.28	--
Cl (%)	1.44	1.44	1.48	1.39	1.37	1.41 ± 0.07	--
B (ppm)	30.5	28.5	90.0	90.0	13.0	50.4 ± 36.78	30.0 ^b
P (%)	0.30	0.33	0.35	0.33	0.30	0.32 ± 0.02	0.34 ± 0.02 ^a
Ca (%)	2.94	3.09	3.14	2.95	2.79	2.98 ± 0.14	3.00 ± 0.03 ^a
Mg (%)	0.61	0.60	0.60	0.61	0.59	0.60 ± 0.01	--

a. Certified values.

b. Non-certified values.

TABLE 8. SODIUM (Na) CONCENTRATION IN SAMPLES FROM THE GEOTHERMAL WETLAND DURING 1982

Sample and Location	Unit	Sample Dates									
		April 28	May 12	May 26	June 9	June 23	July 7	July 24	August 4	August 18	September 1
Water	ppm										
Inlet		560	590	610	590	490	420	450	445	470	500
Upper pond		600	580	620	610	560	500	460	470	460	480
Lower pond		590	590	660	640	580	510	475	470	470	500
Soil	ppm										
Upper pond		2,135	1,819	1,119	1,577	1,560	1,531	1,618	1,738	902	311
Lower pond		795	510	747	1,189	1,098	1,518	1,267	1,235	960	216
Vegetation	Percent ^a										
Upper pond											
Egeria		1.63	1.39	1.76	1.65	1.60	1.15	2.64	--	1.21	--
Pond weed		1.32	2.19	1.98	1.68	2.55	1.93	1.44	1.23	1.71	1.69
Lower pond											
Bulrush		0.93	1.10	0.99	0.91	0.90	0.68	0.85	0.72	0.87	0.79
Cattail		1.16	1.01	1.06	0.97	0.93	0.91	0.94	1.05	1.24	1.04
Common Reed		--	1.80	0.32	0.21	0.30	0.41	0.46	0.35	0.41	0.30

a. 1% = 10,000 ppm.

TABLE 9. POTASSIUM (K) CONCENTRATIONS IN THE MEDIA SAMPLED FROM THE GEOTHERMAL WETLAND DURING 1982

Sample Media and Location	Unit	Sample Dates									
		April 28	May 12	May 26	June 9	June 23	July 7	July 24	August 4	August 18	September 1
Water	ppm										
Inlet		50	47	46	45	45	41	45	44	45	46
Upper pond		48	47	48	47	47	44	44	43	45	46
Lower pond		47	46	53	47	46	45	44	47	47	47
Soil	ppm										
Upper pond		1,081	1,261	1,454	1,079	974	1,004	940	986	981	685
Lower pond		646	325	643	840	800	841	698	913	802	502
Vegetation	Percent ^a										
Upper pond											
Egeria		3.76	3.12	3.66	3.89	3.39	3.01	2.85	--	2.49	--
Pond weed		2.09	4.27	4.91	3.10	4.65	4.26	3.22	2.82	3.38	2.80
Lower pond											
Bulrush		3.04	3.44	2.90	2.60	1.92	1.86	1.37	1.48	1.36	0.78
Cattail		3.29	3.34	3.08	2.36	2.48	1.76	1.50	1.33	1.58	1.25
Common reed		--	4.51	3.84	3.43	3.22	2.23	1.75	1.37	1.54	1.19

a. 1% = 10,000 ppm.

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TABLE 10. FLORIDE (F) CONCENTRATIONS IN THE MEDIA SAMPLED FROM THE GEOTHERMAL WETLAND DURING 1982
(ALL VALUES IN ppm)

Sample Media and Location	April 28	May 12	May 26	June 9	June 23	July 7	July 24	August 4	August 18	September 1
Water										
Inlet	7.7	7.4	7.6	8.0	8.4	10.3	10.2	10.7	10.2	10.4
Upper pond	8.1	7.6	8.0	8.4	8.6	9.8	10.8	10.9	10.8	10.5
Lower pond	7.7	7.4	4.0	8.2	7.9	9.8	11.2	9.1	10.4	10.6
Soil										
Upper pond	14.5	12.8	12.2	7.4	6.0	6.6	7.4	11.8	12.6	12.4
Lower pond	9.3	7.6	6.8	6.2	3.9	8.7	9.5	8.7	10.2	9.8
Vegetation										
Upper pond										
Egeria	32.0	23.5	21.5	45.0	43.0	33.0	30.0	--	35.0	49.0
Pond weed	18.5	21.5	24.0	20.0	45.0	31.0	28.0	46.0	38.0	55.0
Lower pond										
Bulrush	24.2	14.5	27.0	49.2	38.7	28.3	23.0	35.0	24.0	41.0
Cattail	38.0	38.0	22.0	40.0	44.0	35.0	35.0	33.0	28.0	40.0
Common reed	--	56.0	34.0	57.0	35.0	28.0	27.0	44.0	43.0	50.0

TABLE 11. MASS DETERMINATION VALUES CALCULATED FOR WATER, SOIL AND VEGETATION FROM THE LOWER POND OF THE GEOTHERMAL WETLAND

Media	Mass of K (Kg) Calculated for Ten Sampling Periods									
	S ₁	S ₂	S ₃	S ₄	S ₅	S ₆	S ₇	S ₈	S ₉	S ₁₀
Water	3.65	3.58	3.88	3.61	3.58	3.42	3.38	3.46	3.56	3.58
Soil	77.5	39.1	77.2	100.1	96.1	100.9	83.8	115.7	99.0	66.3
Bulrush	0.58	1.46	3.20	4.00	3.67 (1.89) ^a	4.01	2.70	2.40	1.51	0.65
Cattail	0.57	2.90	3.82	5.01	7.78	4.28	5.11	3.16	4.04	4.07

a. Calculated value based on projected biomass value.

Figure 3. Chemical cycling of K through the soil, water and vegetation of the geothermal wetland.