ASSESSING CONSTRUCTED WETLANDS FOR BENEFICIAL USE OF SALINE-SODIC WATER

by

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APPROVAL

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ABSTRACT

Changes in agricultural practices, and irrigation strategies combined with natural processes, have led to increased salinization of soil and water resources worldwide. Coal bed methane (CBM) development in the Powder River Basin of Montana and Wyoming results in the co-production of large volumes of modestly saline-sodic discharge water, and represents a potential source of salinization in areas of CBM development.

The objective of this study was to evaluate the potential of constructed wetlands as a tool for CBM product water management. This was accomplished by assessing seasonal water use andwater use efficiency (WUE) of three plant communities. Native species establish hydrologically distinct communities in former ephemeral channels now running with CBM product water, and nine species of those cataloged were selected and segregated into three communities. Closed-system wetland cells were constructed and each community was assigned to four of these cells, i.e., lysimeters. Chemistry of the supply water was a relatively low electrical conductivity (EC) and high sodium adsorption ratio (SAR) water (EC~ 3dS/m, SAR >25), typical of northern portions of the Powder River Basin.

All three communities had similar seasonal water use but WUE's differed significantly among the communities. This is likely due to overall differences in biomass production, as WUE is a relative value indicating consumptive water use as a function of biomass production. Evaporation from a Class A evaporation pan was observed to be significantly higher than evapotranspiration from the planted lysimeters. This suggests an open water surface has the potential to evaporate more CBM product water than a constructed wetland.

Species survivability was very good, with exception of American bulrush (*Scirpus americanus*) and Inland saltgrass (*Distichlis stricta*). It was evident American bulrush did not survive the winter while Inland saltgrass was likely out-competed by Creeping spikerush (*Eleocharis palustris*).

Results indicate that constructed wetlands planted with native, salt tolerant species have the potential to utilize substantial volumes of CBM product water while remaining viable and robust.

INTRODUCTION

Background

The Powder River Basin is a geologic basin located in northeast Wyoming and southeast Montana. Irrigators along the Tongue and Powder Rivers in Montana receive their irrigation waters from the Powder River Basin. Geologically, the basin is a source of salinity for in-channel water (Van Voast, 2003). Another potential source of salinity is waste water from oil and gas production, which may be high in sodium and may alter physical and chemical properties of soils (Robinson, 2002). Under specific circumstances sodium has the potential to induce surface crusting, inhibit germination and seedling establishment, reduce infiltration and hydraulic conductivity, and increase runoff and erosion (Miller and Donahue, 1990; Brady and Weil, 1999; Or et al., 2002). Discharge of water with increased salinity, especially sodium, in areas already high in geologically derived sodium, may cause a wide range of plant effects, from lower yields to plant mortality (Hanson et al., 1999). Technologies and best management practices for addressing the issue of large volumes of modestly saline and sodic water are in high demand and will be critical to sustainable compatibility of mineral extraction and traditional land and water resource uses in the basin.

Extensive coal deposits with significant storage of natural gas in Wyoming, Colorado, Utah, and Montana have stimulated coalbed methane (CBM) extraction and recovery in these states over the last ten years. Predictions point to the Powder River

Basin of Wyoming and Montana as the next significant area of development (Northern Plains Resource Council, 2001; De Bruin et al., 2002). The basin is, geographically, the largest of the producing basins in the western U.S. (Van Voast, 2003) (Figure 1).

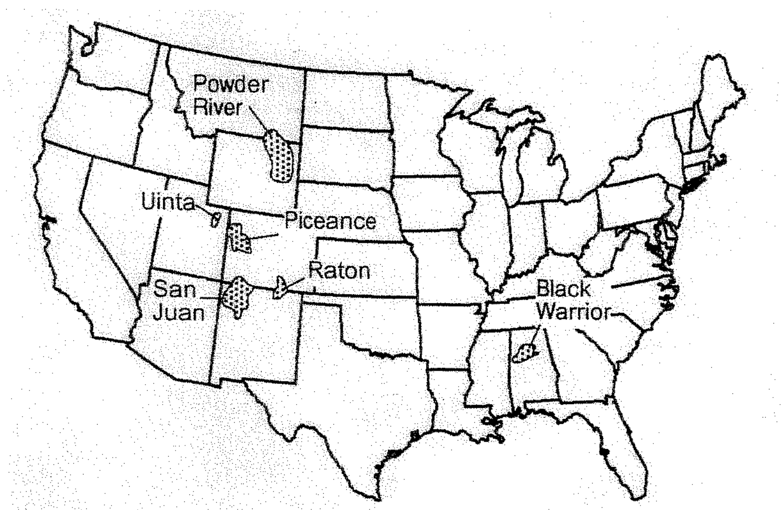

Figure 1. Principal CBM producing regions in the U.S. 2001. From Van Voast, 2003.

Coal deposits that contain methane gas in the Powder River Basin are at relatively shallow depths, making methane recovery economical. Shallow coal deposits are only one of the reasons CBM recovery is more economical than traditional extraction of coal and oil. Others include lower exploration costs and more cost-effective drilling (Robinson, 2001). Natural gas, when burned properly, is a cleaner fuel which emits, on average, half the carbon dioxide (CO_2) of coal, with fewer particulates (Flores, 1998; McMillion, 2000).

CBM is natural gas or methane (CH_4) formed when plant material is turned into coal by the geologic process of coalification. CBM is trapped and held within coal seams by hydrostatic pressure (Flores, 1998; De Bruin et al., 2002). There are three ways in which methane is trapped in coal seams. The first is adsorption on the molecular structure of the coal or other material surfaces. Methane can also be a free gas trapped within micropores and surface cracks of coal seams, or a dissolved gas within water.

Extraction of methane involves pumping water from coal seams to reduce hydrostatic pressure, which promotes desorption and frees methane for capture in a pipeline (Figure 2). As a result of this process, significant quantities of water containing dissolved solids, particularly sodium, are brought to the surface and must be managed.

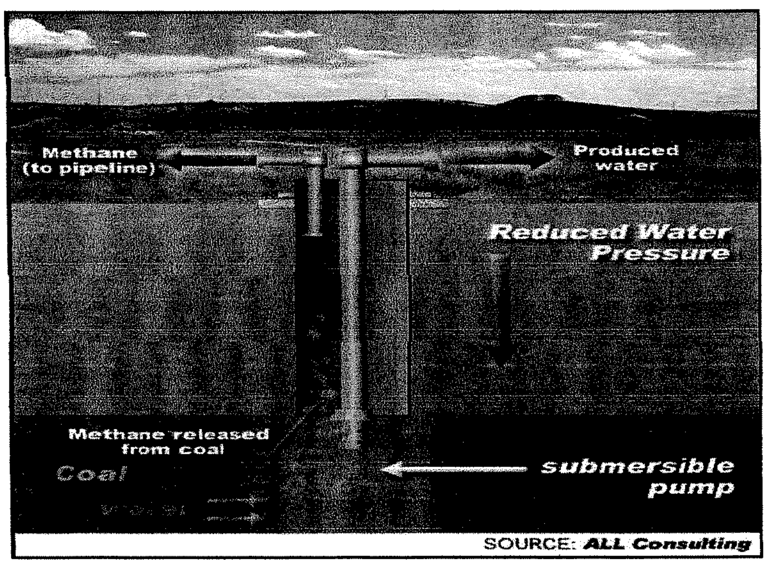

Figure 2. Methane Extraction Process.

In 2003, the Ninth Circuit Court of Appeals declared CBM product water, once brought to the surface, to be a pollutant under the 1972 Clean Water Act. This ruling has been taken to a higher court of appeals, and may be overturned yet again, but it serves to illustrate the point that this water and its potential impacts on soil, agriculture and water resources in eastern Montana and Wyoming is a principle concern among landowners and managers, agency representatives, and environmentalists.

CBM wells in the Powder River Basin may initially discharge large volumes of water (0.4 - 1.5 liters per second), which decrease to ~ 60% of the initial rate after about two years of production and continue to decrease for the life of the well (Rice et al., 2000, 2002; Robinson, 2001) (Figure 3).

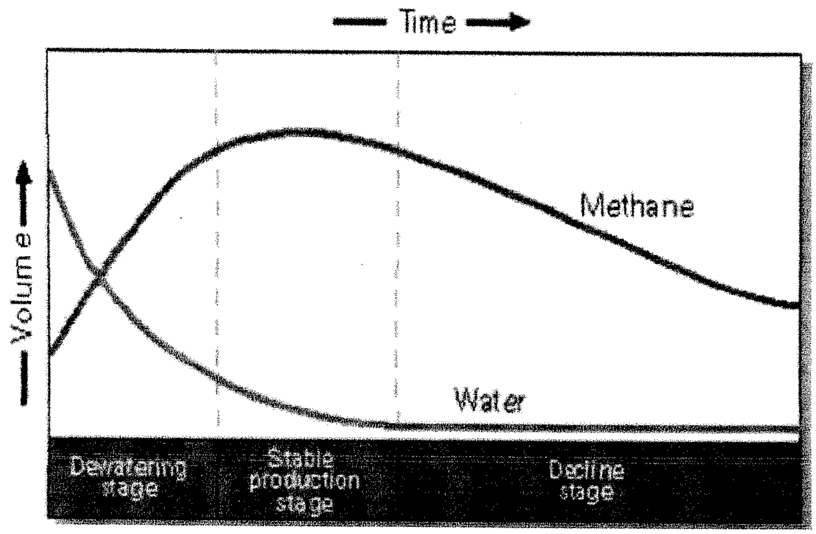

Figure 3. Typical water and gas production rates for a CBM well in the Powder River Basin. Time period is 15-20 years.

Projections for the next 10 - 15 years within the Powder River Basin call for the disposal and/or management of 308,118,700 m^3 (250,000 acre feet) of water annually from the Powder River Basin (Montana State University, 2004). At this point, economics preclude treatment of large volumes of CBM product water. Treatment becomes more economically viable as volumes are decreased and concentrations increased. Therefore, management techniques aimed at reducing CBM product water volumes may make treatment more feasible. Constructed wetlands have the potential to reduce volumes of CBM product water, resulting in less water with higher concentrations of salts and sodium through plant water consumptive use.

From the perspective of this study, there are two key issues of CBM product water management being considered. Is it possible for native, wetland plant communities to utilize substantial quantities of produced water, and is one community preferred over another for maximum water use potential?

Thesis Statement and Hypothesis

The purpose of this experiment was to assess constructed wetlands as a management option for saline-sodic water. Specifically, to compare seasonal water use and forage production of three wetland plant communities, each consisting of three unique species, irrigated with simulated CBM product water.

Native species establish hydrologically distinct communities in former ephemeral channels now running with CBM product water (Patz et al., 2002). Patz et al. (2002) identified native plant species in these channels and surrounding areas of CBM product water discharge. Negri et al. (1997) proposed that constructed wetlands could be used to reduce the amount of water co-produced by gas and oil wells. However, few assessments of the potential opportunities for wetland utilization of CBM product water have been presented.

The hypothesis was that constructed, lined, or closed basin wetland communities composed of native species would effectively reduce the volume of CBM product water requiring subsequent treatment and handling. This reduction would be accomplished through biological, chemical and physical processes occurring in the wetland ecosystem.

Objectives

The main approach of this project was to determine and compare seasonal water use of three wetland communities managed with on-demand supply of simulated CBM product water with a low EC, high SAR chemistry. Seasonal water use and community biomass production for each community were recorded and used to ascertain water use efficiency (WUE) for each community. Seasonal water use was used to define suitable community types for constructed wetlands. This information has potential for use by land managers and developers to determine best management practices for minimizing impacts from CBM production.

LITERATURE REVIEW

Climate, Soils, and CBM Product Water in the Powder River Basin, Montana

Warm, dry summers and periods of very cold weather in winter characterize the climatic conditions of the Powder River Basin in Montana. Average daily temperature for the Powder River Basin is 7.5° C. Winter snowfall is frequent, and total snowfall is 75-100 cm, but snow cover typically disappears during milder periods. Average annual precipitation is 25-33 cm, approximately 77% of which falls between April and September, with the heaviest rains falling during late spring and early summer (USDA, 1977, 1996).

Soils in the area are generally high in clays and may be salt or sodium affected themselves (USDA, 1977, 1996; Robinson, 2002; Warrence et al., 2002). A saline soil contains enough salts to adversely affect the growth of most plant species, and is defined as a soil with an EC > 4 dS/m (Miller and Donahue, 1990; Brady and Weil, 1999; California Plant Health Association, 2002). While decreased salinity leads to aggregate dispersion, elevated salinity increases osmotic stress in plants, often resulting in stunted vegetative growth and reduced yields (Miller and Donahue, 1990; Hanson et al., 1999). A sodic soil is defined as having an EC < 4 dS/m with an SAR > 13. Excess sodium may reduce permeability of soils to water and can have toxic effects on plant growth (Miller and Donahue, 1990; Brady and Weil, 1999; California Plant Health Association, 2002). A saline-sodic soil can have adverse effects on plant growth due to high salts, specifically sodium, and is defined as having an EC > 4 dS/m and SAR > 13 (Miller and Donahue, 1990; Brady and Weil 1999; California Plant Health Association, 2002).

Plant chemistry not in equilibrium with soil solution chemistry results in an osmotic difference between plant and soil. Plants may experience drought stress when a greater concentration of salts in soil solution than in plants causes water to move from plants to the soil solution. Non-halophytic plants may close their stomates in an attempt to avoid osmotic stress, but halophytes have other mechanisms by which they can compartmentalize, exclude, or excrete salts to prevent osmotic differences as salinity increases. For example, certain species have salt glands which maintain adequate osmotic potentials by extruding salts; others have mycorrhizal fungi on roots which are thought to enhance salt tolerance (Uchytil, 1990).

Typical upland soil types in areas of CBM development in the Montana portion of the Powder River Basin are fine family (<35% rock fragments), alluvial smectites of marine origin, high in montmorillonite clays (USDA, 1977, 1996). Three of the most common irrigable soils along the Powder River in Montana are from the Cherry, Marias, and Spinekop series (Fine-silty, mixed, frigid Typic Ustochrepts; Fine, smectitic, frigid Chromic Haplusterts; Fine-loamy, mixed, superactive, frigid Aridic Haplustepts, respectively). Textures of these soils are either silty clay loam or silty clay, and therefore, are at risk for dispersion by saline-sodic irrigation water (USDA, 1977, 1996; Robinson, 2002, 2003).

CBM product water quality is typically associated with elevated salinity and sodium hazards (Bureau of Land Management, 1999; Phelps and Bauder, 2001; Rice et al., 2002). Water quality in the coal beds of the Powder River Basin is not static across the whole basin. Total dissolved solids (TDS) of waters increases in a north/west direction through the basin, and this trend is paralleled by SAR values (Rice et al., 2000; USGS, 2000; Patz, 2002; Rice et al., 2002). TDS values range from 370 ppm to 1,940 ppm (Patz, 2002), and SAR values range from 5 - 69 (Rice et al., 2002). Sodium and bicarbonate are the major constituents in CBM production waters of the Powder River Basin (Van Voast, 2003), while sulfate is almost totally absent, and concentrations of calcium and magnesium vary.

On the eastern, recharge side of the basin, calcium and magnesium concentrations are higher and sodium lower, but, as one moves toward the northwest end of the basin (farthest from recharge) the sodium concentrations almost double while calcium and magnesium are substantially lower (Rice et al., 2002; Van Voast, 2003). Chemical conditions in coal beds favor the conversion of sulfate (SO_4) to sulfide, which is then removed as a gas or precipitate. Hence, CBM production waters in the Powder River Basin contain very little SO_4 (USGS, 2000).

Once brought to the surface, CBM product water undergoes fairly rapid chemical changes. Elevated concentrations of bicarbonates reduce calcium and magnesium solubility, and a change in the partial pressure of CO_2 causes bicarbonates to undergo a reaction producing sodium, carbonate, and elevated alkalinity. Free carbonate binds with calcium and magnesium in the water to form secondary carbonate materials such as limestone and dolomite. As the water moves downstream, EC values increase slightly (<10%), but significant increases in SAR values (~30%) occur because the more soluble sodium remains in the water while calcium and magnesium are precipitated (USGS, 2000; Patz, 2002; Sessoms and Bauder, 2002; Van Voast, 2003).

Constructed Wetlands in Watershed Management

Wetlands have long been considered nature's kidneys because of their ability to filter toxins and pollutants and absorb large amounts of nutrients (Kadlec and Knight, 1995; Anonymous, 1998; Gopal, 1999). With the exception of peat bogs, natural wetlands are very productive systems that support high biodiversity and perform a variety of ecological functions (Gopal, 1999). Constructed wetlands have been gaining acceptance as replacements of natural systems which have been lost or degraded and as treatment systems to improve water quality (Cunningham et al., 1995; Peterson and Teal, 1996; Tanner, 1996; Gopal, 1999) .

Use of constructed wetlands for treatment and reclamation has increased dramatically in the past twenty years. Due, in part, to this increase in use, the Army Corps of Engineers drafted section 404 of the Clean Water Act to define, preserve and maintain natural and constructed wetlands. Wetlands are simply defined as areas which are inundated for a sufficient amount of time to develop hydric soils and vegetation (Kadlec and Knight, 1995). Section 404 provides rules and regulations governing who may construct a wetland, how discharge of water and fill from wetlands is to be handled, and how to replace or rehabilitate natural systems. Once a wetland has been created, it must be maintained in perpetuity with the exception of treatment wetlands, artificial lakes/ponds for collecting water, or other systems designed specifically for water treatment (Environmental Protection Agency, 1977).

Wastewater Treatment

Constructed wetlands are being used to treat the wastewater from dairy and agricultural operations (von Oertzen and Finlayson, 1984; Bowman, 1992; DeBusk et al., 1995). Individual households are using constructed wetlands in place of traditional septic systems, and municipalities are using them as part of their wastewater treatment operations (Boyd, 1970; Cunningham et al., 1995; Peterson and Teal, 1996; Abissy and Mandi, 1999; Shutes, 2001). Abissy and Mandi (1999) studied the purification abilities of *Typha latifolia* and *Juncus subulatus* irrigated with raw urban wastewater under arid climates. Results revealed significant reductions in organic matter during all seasons. Nutrient removal was low but proved to be significantly higher in planted versus unplanted systems.

Constructed wetlands have been designed to treat storm water and urban surface runoff (Shutes, 2001), and are widely used in remediation of waters contaminated with heavy metals (Ernst, 1996; Mungur et al., 1997; Groudeva et al., 2001; Scholz and Xu, 2002). Cheng et al. (2002) assessed the capacity of the tropical species *Cyperus alternifolius* and the subtropical species *Villarsia exaltata* for removal of heavy metal contaminants in drinking water. Removal rates for the heavy metals were almost 100%, and remained stable over the five month operational period. Plant uptake was the main mechanism for removal, with the majority of heavy metals accumulating in below ground plant tissues (Cheng et al., 2002).

Management of Saline-Sodic Water

Although there is a large body of work reported in the scientific literature on constructed wetlands, limited research has been reported on their use in management and treatment of saline-sodic water, particularly product water from oil and gas wells.

In 1990 the Argonne National Laboratory began examining the possibility of using biological methods to optimize metal uptake and reduce the volume of water produced by oil and gas wells and which needed to be treated by mechanical means (Negri et al., 1997). The main purpose of the study was to examine effectiveness of a plant-based system in reducing the volume of water requiring treatment, effectively concentrating salts. Six species were evaluated for salinity tolerance at two salt concentrations (15,000 and 30,000 mg/L) with one non-saline control (0 mg/L). Mean evapotranspiration (ET) rates for all six species exceeded evaporation of open water up to a salt concentration of 20,000 mg/L, and several of the species maintained high ET rates in salt concentrations up to 60,000 mg/L. These results indicate that halophytic species have to potential to maintain high water use rates and remain viable under increasingly saline conditions.

Negri et al. (1997) selected two species for further study, based on results of laboratory screening. *Spartina alterniflora* (Saltwater cordgrass) was selected for its high salt tolerance, and *Scirpus validus* (common great bulrush) for its high ET rates. A model of plant dynamics which the researchers termed a 'bioreactor' was developed using approximately 40% of the ET rates of the *Spartina alterniflora* and *Scirpus validus*. The bioreactor was designed to treat 66.6 m^3 (~18,300 gallons) per day of product water using a surface area of 300 m^2 (~3300 ft^2), and predicted a 75% reduction in the volume of water in less than 8 days with the resulting water having a higher concentration of salts due to reduction in volume.

Argonne National Laboratory scientists, in cooperation with Devon Energy Corporation and the Gas Research Institute, established several on-site studies at an oil and gas lease in Oklahoma. Studies were conducted using the basic model developed in the laboratory to reduce product water volume (Negri et al., 1997; Settle et al., 1998). The constructed wetland consisted of two cattle watering troughs filled with pea gravel as a growth substrate and planted with *Scirpus validus* in the first trough to maximize ET and the more salt tolerant *Spartina alterniflora* in the second trough. The system was gravity operated, required no external power, and the only maintenance cost was fertilizer to maintain optimum growth of plants. Water volume in tanks was reduced by 75% in four days, and within seven days *Spartina* leaves were coated in salt crystals. Subsequently, a second site was constructed with a third trough containing no plants to compare the evaporation rate of open water to ET rates where plants were present. Troughs with plants reduced the volume of water 30% faster than open water troughs.

Several studies at Montana State University examined effects of CBM product water on plants and soils. Preliminary results of one study indicate some agricultural and forage species such as corn and barley, remain viable and vigorous under irrigation with saline-sodic water (Levy, personal communication[1]). Another study examined effects of CBM product water on soil chemistry and physical properties (Robinson, 2002). Results demonstrated that electrical conductivity (EC) and sodium adsorption ratio (SAR) of soil increased as EC and SAR of applied water increased, and with increased frequency of wetting and drying. However, SAR decreased only slightly with wetting to simulate rainfall while EC decreased substantially. Single wet/dry events with simulated CBM or Powder River water caused soils to have a slight increase in SAR and EC in association with the applied water. However, only about 1 in 25 of the soils sampled exceeded reported thresholds for salt injury and dispersion. With a five time wet/dry cycle of either water quality, solution SAR and EC values increased to nearly equal the applied water, and approximately 50% of the samples exceeded thresholds (Robinson, 2003). Results of this study indicate that, in general, the major issue with CBM water application to soils is when there are repeated wetting and drying cycles. In a constructed wetland system soils will remain saturated.

Shortcomings of Constructed Wetlands

Constructed wetlands have several general constraints on their usefulness. Wetlands require a large amount of land per unit volume of water. A sufficient supply of water is necessary to support the wetland. Source and quality of source water may necessitate pretreatment; in some agricultural and municipal cases wastewater must be

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[1] Fall, 2002. Personal communication with Allison Levy, undergraduate scholar at MSU Bozeman, currently working on the effects of salinity on germination and growth of agricultural and forage crops.

pre-treated before entering a treatment wetland (Gopal, 1999). A wetland limitation specific to cold climates is that primary functions may be minimal during winter months. Concerns for cold climate systems are low operating temperatures and ice formation on the surface. Both situations can alter hydraulic performance, lower reaction rates, harmfully impact dormant vegetation and freeze equipment (Maehlum et al., 1995).

In 1995 Maehlum et al., working with constructed wetlands in Norway, experimented with an aerobic pre-treatment stage in order to enhance nitrification and decrease biological oxygen demand (BOD), which reduces the possibility of the inlet channel becoming clogged by vegetation. Results were promising, (BOD reduction of 85-93% and N removal of 48-59%) but long-term impacts of a cold climate on performance were still unknown. Wittgren and Maehlum (1997), "review how cold weather conditions affect wetland processes and treatment results, and how the impacts can be handled in design and operation".

The main concern with constructed wetlands in cold climates is the formation of ice. Often in winter, water in natural swamps and marshes does not freeze due to an insulating layer of snow, which is trapped by standing dead vegetation. Freezing is strongly inhibited if snow accumulates before a significant ice layer forms. Presence of some ice on the surface of a constructed wetland may be beneficial in that an ice layer acts as insulation and slows cooling of underlying water. However, if vegetation is holding ice in place, the volume of water available for flow will be reduced as the ice layer thickens. This constriction of flow may lead to flooding, freezing and hydraulic failure. Raising the water level in the wetland prior to freezing may create space for air and water movement without contact with the overlying ice layer. This may be a way to avoid damaging ice formation while maintaining continued functioning of the rhizosphere, albeit at decreased rates (Wittgren and Maehlum, 1997).

Another method for avoiding damaging ice formation is to divert inflow water from a wetland in late fall and atomize it into the air during winter months. Fresh water freezes (some evaporates as well), while the remaining water, now more concentrated with respect to salts, remains liquid and can be removed from the system. Researchers in the southwestern United States are experimenting with this method and are seeing promising results. Montana and Wyoming have long, cold, and fairly dry winters which may increase practicality of using this method during winter months when wetland function and plant water use are low. One point of concern is that the process may not be as efficient with Powder River Basin product water. Product water from the southwestern U.S. has chemistries similar to sea water, while Powder River Basin product water is not nearly as saline so separation of saline and fresh water may be an issue in the Powder River Basin.

The Role of Plants in Phytoremediation

Phytoremediation, or bioremediation, is the concept of using plant-based systems and microbiological processes to counteract or eliminate contaminants in nature. These remediation techniques, which utilize specific planting arrangements, constructed wetlands, reed beds, floating-plant systems and numerous other configurations, have been common in the treatment of many types of wastewater, and lately, contaminated soils and atmospheric pollutants as well (Cunningham et al., 1995; Anonymous, 1998).

Advantages of phytoremediation are that systems are generally low-cost and low-tech with little maintenance expense, although there are some limitations. Remediation is best considered a long-term process since it is usually slower than chemical treatments; levels of parameters targeted must be within the tolerance limit of selected plants; and containment may be needed in the case of highly soluble contaminants which may leach out of the root zone (Cunningham et al., 1995).

Wetland Plants, Halophytes, Community Dynamics

Plants utilize one of three basic phytoremediation strategies; 1) phytoextraction/bioaccumulation: plants accumulate contaminants and are harvested in order to remove contaminants from the system; 2) phytodegradation: contaminants are converted into non-toxic materials by plants and associated microorganisms; 3) phytostabilization: contaminants are precipitated out of solution or absorbed/entrapped in the soil matrix or plant tissue (Cunningham et al., 1995).

An example of a phytoextractor is *Spartina alterniflora*: salts are accumulated in plant leaves, and when harvested, accumulated salts are effectively removed from the system. There is an added cost-reduction benefit in that *Spartina alterniflora* can be used as forage for cattle. Plants are readily consumed and salt-covered leaves have not been seen to be harmful to cattle (Settle et al., 1998).

Rangeland of Wyoming/Montana contains many native and culturally significant species that could potentially be threatened by non-native species. *Spartina pectinata*

(Prairie cordgrass) is native to the area and may be a viable alternative in areas where *S. alterniflora* could be considered a potential weed. Cattails and rushes, while not all natives, may be useful because of salinity tolerance, high water use rates, and when the well has played out, the plants should absquatulate with the water and not become problematic.

Qadir et al. (2001) evaluated phytoremediation techniques on a calcareous saline-sodic soil (EC=24-32 dS/m, SAR=57-78 in top 0.15 m depth) planted with wheat (*Triticum aestivum L.*) in winter and rice (*Oryza sativa L.*) in summer, and irrigated with moderately saline-sodic water (EC=2.9-3.4 dS/m, SAR=12-19.4). It is not typical to have a calcareous saline-sodic soil but in this case the soils are classified as Calcic Haplosalids, likely due to the low solubility of $CaCO_3$ Original soil EC values were 24-32 dS/m at the surface 0.15 m depth, and decreased to ~ 7 dS/m at the lowest sampling depth (0.9 - 1.2 m). After one crop each of wheat and rice, the final surface EC values were about 10 +/-1 dS/m in all treatments. The SAR for the profile to 1.2 m depth was reduced from ~31 to ~15 in all treatments, indicating that a significant amount of the excess sodium in the soil was leached below the 1.2 m depth.

Plant Water Consumptive Use and Evapotranspiration (ET)

Idso (1981) reviewed a number of experiments addressing plant water use and evaporation to determine whether vegetation helped or hindered evaporation. Over the years, some researchers have found evaporation from open water to exceed ET of vegetated surfaces (Idso, 1981; Snyder and Boyd, 1987; Lafleur, 1990, Glenn et al., 1995;

Negri et al., 1997; Pauliukonis and Schneider, 2001), while others have concluded there is no difference (Idso, 1981; Lafleur, 1990). Some of this disagreement may be due to differences in experimental design, i.e. small, exposed lysimeters. There are also inherent differences in ET rates among plant species and communities and there is no standardized method for determining ET rates. Based on theoretical and experimental evidence, Idso concluded that evaporation from an extensive, open body of water would not significantly increase with the introduction of vegetation. In reality, the vegetation may in fact lower the evaporation rate. However, introduction of vegetation on a body of water of more limited extent may increase evaporation as long as the vegetation remains robust.

Pauliukonis and Schneider (2001) conducted a study along the southern shoreline of Oneida Lake, NY, USA. Results showed that *Typha latifolia L.*(broad-leaved cattail) had higher ET rates per unit leaf area (mm/mm^2 per day) than open water or bare soil and used an average of 5.75 +/- 1.34 mm of water per day. Researchers used the lysimeter method to determine daily ET rates in order to obtain consistent water use data across different substrates, plant forms and without interference of meteorological conditions. As the summer progressed, ET increased. Researchers suggest this was due to the ability of *T. latifolia L.* to increase the number of ramets from 5-8 at the beginning of summer to 8-20 at the end of the summer. Researchers also noted that *T. latifolia L.* did not show the typical midday drop in ET rates. They attributed this to claims by Leverenz (1981), Schulze et al. (1985), and Bernhoffer and Gay (1989) that plants with a constant supply of water do not need to regulate their stomata in order to conserve water in their leaves.

Studies by Snyder and Boyd (1987), Glenn et al. (1995), and Negri et al. (1997)

agree with the results obtained by Pauliukonis and Schneider that show ET from vegetated areas to exceed evaporation from open water.

Lafleur (1990) investigated ET of two sedge communities with contrasting surface moisture regimes (dry and wet) during vegetated and non-vegetated periods on southern James Bay in Ontario, Canada. While not definitive as to the influence of vegetation on ET, results suggest, in certain cases, vegetation can decrease open water evaporation. Lafleur proposed that physical and physiological differences in vegetation may be controlling factors in ET, while also explaining some of the conflicting results reported in the literature.

Water Use Efficiency

Most of the water use efficiency (WUE) research being conducted is concerned with improving WUE due to increasing concerns about water resources in both irrigated and non-irrigated agriculture (Hatfield et al., 2001; Howell, 2001; Pikul et al., 2004). Water use efficiency is a relative value used to assess and compare consumptive water use among species. Water use efficiency is also used to interpret how efficiently plants use water to produce biomass. WUE is defined as biomass or harvestable crop or commodity per unit of water use, typically expressed as grams of grain or dry matter divided by kilograms of water, and is calculated by dividing the total biomass produced by the total water used (Hatfield et al., 2001; Larcher, 2001; Pikul et al., 2004).

$$WUE = \frac{totalbiomass(g)}{totalwaterused(LorKg)} \qquad \text{[Eq. 1]}$$

The shortcomings of using WUE is that it is a ratio which is highly dependent on biomass. Biomass production is a function of plant physiology while water use is a function of plant maturity, stress, and environment.

A water use efficiency ratio brings data from physically and physiologically different plant species to a common scale for analysis. The problem with comparing WUE's of different crops or plants species, is that there are no standard metrics for computation.

It has been postulated that WUE is a nebulous term because plants loose water to the atmosphere rather than use it as raw material for biomass production. Researchers have used terms such as 'transpiration efficiency' or 'precipitation efficiency' interchangeably with WUE although they are not technically correct (Hatfield et al., 2001). WUE is based on evaporation and transpiration, and the term transpiration efficiency suggests evaporation is not considered. Precipitation efficiency is a measure of the dry matter produced per increment of precipitation. This is different from WUE in that WUE takes into account water from irrigation as well as precipitation.

Transpiration ratios are another method for assessing the efficiency of plant water use in biomass production. A transpiration ratio is the mass of water needed for a plant to produce a unit mass of dry plant material and is the inverse of WUE.

WUE depends on site-specific climatic conditions, and values for the same species will differ substantially over locations. WUE is impacted by evaporative demand which is driven by vapor pressure gradients between leaf and air. Evaporative demand can be influenced by temperatures and humidity, available water (precipitation and irrigation) and soil water storage capacity.

There are many ways of expressing plant consumptive water use, and one must be aware of how water use and crop production are expressed in order to properly evaluate responses. For this paper WUE is defined as grams of oven dry above ground biomass produced over the growing season divided by kilograms of water used over the growing season, because it is the best known and most widely used term today.

Thinking Outside the Well

Problems associated with management of saline-sodic soil and water are not solely related to the CBM industry. Irrigated regions of the world, particularly arid and semi-arid areas, have been contending with salinity issues since the beginning of recorded history (Hanson et al., 1999). Many portions of the world are struggling with saline-sodic soil and water issues and research into beneficial use and management could have global implications. In 1995 it was estimated that 25% of the worlds' irrigated land was damaged by salinity, and not a single continent was free of this impact (Batlle-Sales, 1995).

Anthropogenic salinization (secondary salinization) is as old as irrigation, but has been rapidly expanding since the 1950's. Development of large scale irrigation systems, clearing of land and replacement of trees and native deep-rooted vegetation with shallow rooted crops have been the major causes of secondary salinization since the end of WWII (Batlle-Sales, 1995; Ghassemi et al., 1995; Qadir et al., 2001; Barrett-Lennard, 2002; Turner and Ward, 2002). Agricultural water requirements already far exceed supplies in nearly 80 countries (Qadir et al., 2001).

The worlds increasing need for irrigable acreage is putting marginal land into agricultural use and using marginal waters for irrigation, resulting in adverse affects to soil and water resources. Many parts of the world experience natural or primary salinity due to geology, soil type, climate, and hydrology. Naturally occurring discharge of saline groundwater to surface water sources, compounded by agricultural and mining wastewater discharged into river systems, has led to a global increase in soil and water salinity and sodicity (Batlle-Sales, 1995; Ghassemi et al., 1995; Jayawardane et al., 2001).

In Australia, primary salinity is extensive but agricultural development has led to extreme stream salinization (Barrett-Lennard, 2002; Turner and Ward, 2002). Thirty-six percent of the divertable surface water of Australia is no longer potable and sixteen percent is of marginal quality (Ghassemi et al., 1995). Clearing of native vegetation for annual crops and pastures in Australia is a major cause of water logging and secondary salinity in many catchments, particularly southwestern Australia (Turner and Ward, 2002). Studies suggest that agricultural systems in Australia allow 20-100 mm of rainfall to infiltrate past the root zone, compared to estimates of 5 mm or less of deep drainage under pristine, native vegetation. Deep drainage to groundwater results in a rising water table, which causes water logging and secondary salinity.

Lack of adequate drainage and high water tables in Argentina are increasing salt concentrations in soils (Ghassemi et al., 1995). Irrigation with low quality water and inadequate drainage coupled with low rainfall and high evaporation rates are causal factors of salinity in Iran (Ghassemi et al., 1995). Nationally, South Africa has the problem under control, but over-irrigation on soils with poor drainage and discharge of industrial effluents exacerbated by excessive primary salinity is still a concern in some areas (Ghassemi et al., 1995). Egypt has fairly well-drained soils, but natural drainage cannot keep pace with increasing irrigation, so water tables are rising and salts accumulating (Helalia et al., 1992; Ghassemi et al., 1995). India and Pakistan are experiencing salinity problems associated with poor irrigation practices, and in northeast Thailand deforestation has led to increased salinity (Ghassemi et al., 1995). The heavy clay soils of coastal Thailand and China are naturally saline from seawater, and in the Commonwealth of Independent States (former USSR) natural factors are the main cause of salinity (Ghassemi et al., 1995). Irrigation and dryland farming, coupled with low rainfall and high evaporation rates in arid and semi-arid regions, are leading causes of secondary salinity in the western U.S. (Batlle-Sales, 1995; Ghassemi et al., 1995).

MATERIALS AND METHODS

System Design and Water Chemistry

Twelve closed-system wetland cells (i.e. lysimeters) were constructed using galvanized steel stock tanks, approximately 3 m long, 1 m wide, and 0.6 m deep, painted inside with marine grade paint/epoxy to prevent corrosion from the simulated product water. Pits were excavated and lysimeters placed with the top edge of each lysimeter approximately 5 cm above ground level to reduce non-uniform heating, cooling and ET due to positional effects from sun and wind (Figure 4).

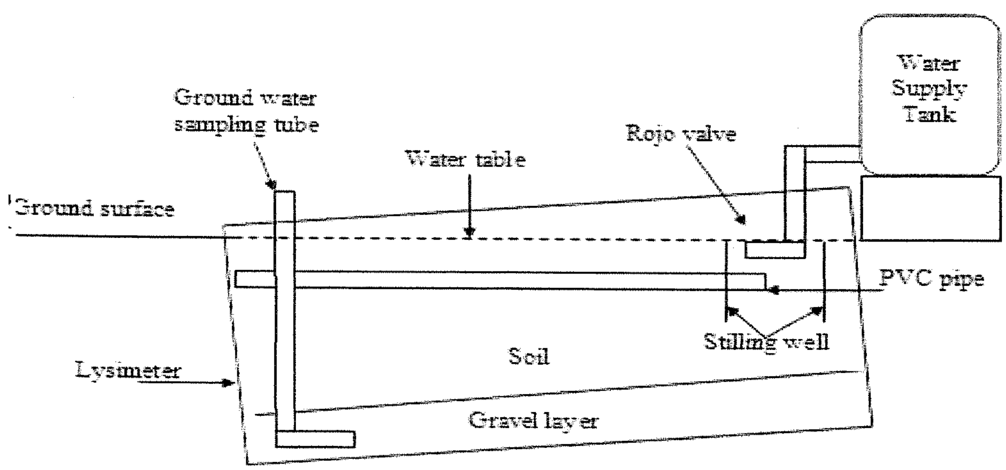

Figure 4. Schematic of lysimeter construction and installation.

Each lysimeter was set on a 2% grade to aid gravitational water flow. Lysimeters were filled to a depth of 15 cm with washed gravel (2 - 2.5 cm diameter) to maintain proper water movement and equipped with a sampling tube at the lowest point for water sampling. Weed barrier cloth was installed over the gravel and covered with 46 cm of soil. Perforated PVC pipe was installed on an even grade in conjunction with the desired water table height at the low end of each lysimeter (Figure 4). This facilitated horizontal water movement from upland to in-channel positions in each lysimeter. A stilling well was installed at high end of each lysimeter and PVC pipe set at the bottom of each well. Jobe Rojo™ float valves were attached to water delivery tanks and set in stilling wells (Figures 5 and 6). As evaporation and transpiration by plants caused a drop in the water table, float valves released water from supply tanks, thereby maintaining water table height at the soil surface of the low end of each lysimeter.

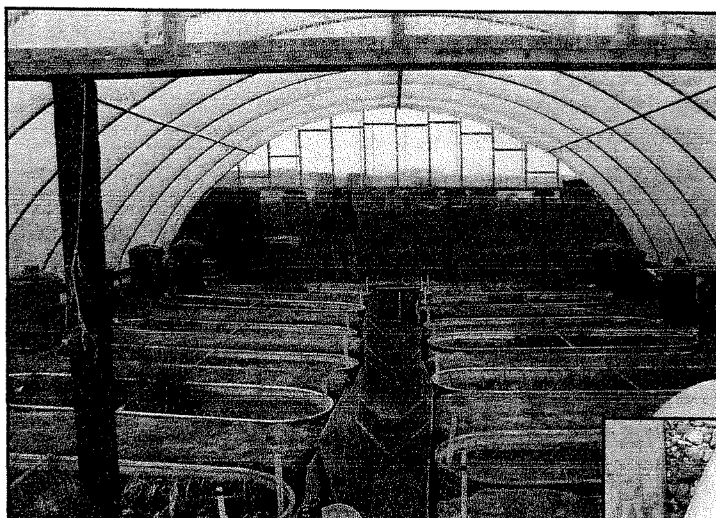

Figure 5. Installed and planted lysimeters.

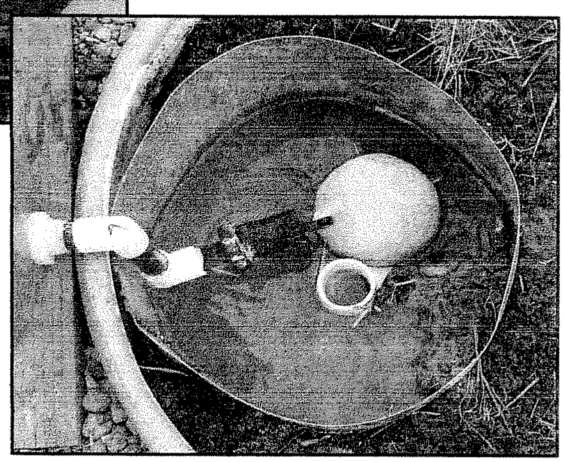

Figure 6. Rojo valve in stilling well.

The soil selection criteria for filling the lysimeters were based on information about soils in the Powder River Basin most likely to be adversely affected by CBM product water discharge. With the assistance of Tom Keck of the NRCS, soil types fitting our search criteria were identified, and Katie Alvin of the NRCS Bozeman offices constructed maps showing locations of selected soil types (Tom Keck, Katie Alvin, USDA-NRCS, personal communications[2]). Based on information from the assessment, the Patouza-Abor Complex near Three Forks, Montana was selected (USDA, 2002). This soil series is a fine, smectitic, frigid Torrertic Argiustoll (parent material is dominated by montmorillonite clays). It receives an average annual precipitation of 25 - 36 cm (Caprio et al., 2002). Particle size analysis of field samples was completed to evaluate clay content and soil texture, and followed protocol outlined in Gee and Bauder, 1986 (Appendix A).

Overburden soil (0-15 cm) was removed from the source location to minimize weed seed contamination and remove depositional material from upland erosion. On the basis of determination of texture and clay content (Appendix A), soil from a depth of 16 - 60 cm was bulked for use in the project, and samples analyzed for baseline soil chemistry. This soil material was used to fill each lysimeter.

To prevent introduction of potential weed species, plants native to Montana were selected for this study. Native plant species already found in areas of CBM product water discharge were selected for evaluation. Nine species among those catalogued by Patz et

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[2] Spring 1999. Personal communication with Katie Alvin of the Bozeman NRCS soil survey office. Personal communication and field work with Tom Keck, lead soil scientist for the Butte-Silverbow NRCS.

al. (2002) were selected and grouped into three communities (Table 1). Table 1 lists the species in each community and the abbreviations which will be used throughout the rest of this paper.

Table 1. Plant communities and abbreviations.

	Community 1	Community 2	Community 3
	Maritime/saltgrass/spikerush	**Cattail/cordgrass/wildrye**	**American/baltic/WG**
Wet	Maritime bulrush	Common cattail	American bulrush
Trans	Inland saltgrass	Prairie cordgrass	Baltic rush
Upland	Creeping spikerush	Canada wildrye	Streambank wheatgrass

Selection was based on: water use rates; salinity tolerance; mode of reproduction (rhizomes vs. seeds); forage quality; presence of dense, fibrous root systems to support an active rhizosphere and act as biolfilters; or some combination of these traits (Appendix B). Appendix C provides detailed descriptions of the nine species selected for this study. Based on national wetland indicator status and water requirements, each species within each community was segregated and positioned into one of three hydrological regions within the lysimeter (Table 2; Figure 7), with one species per region; 1) wet/in channel (OBL, FACW), 2) transitional (FAC), and 3) dry/upland (FACU, UPL). Once lysimeters were installed and filled with soil, each of the three plant communities was randomly assigned to four of the twelve lysimeters (Table 3).

Table 2: Wetland indicator status and lysimeter positions. Modified from The PLANTS Database. USDA-NRCS. 2004

CODE	DEFINITION	DESCRIPTION	POSITION
OBL	Obligate Wetland	99% Almost always occurs in wetlands	Wet/In-channel
FACW	Facultative Wetland	67-99% Usually occurs in wetlands but occasionally in non-wetlands	Wet/In-channel
FAC	Facultative	34-66% Equally likely in wetlands or non-wetlands	Transitional
FACU	Facultative Upland	67-99% Non-wetlands; 1-33% Wetlands	Upland
UPL	Obligate Upland	99% Almost always in non-wetlands under natural conditions, but may occur in wetlands in another region	Upland

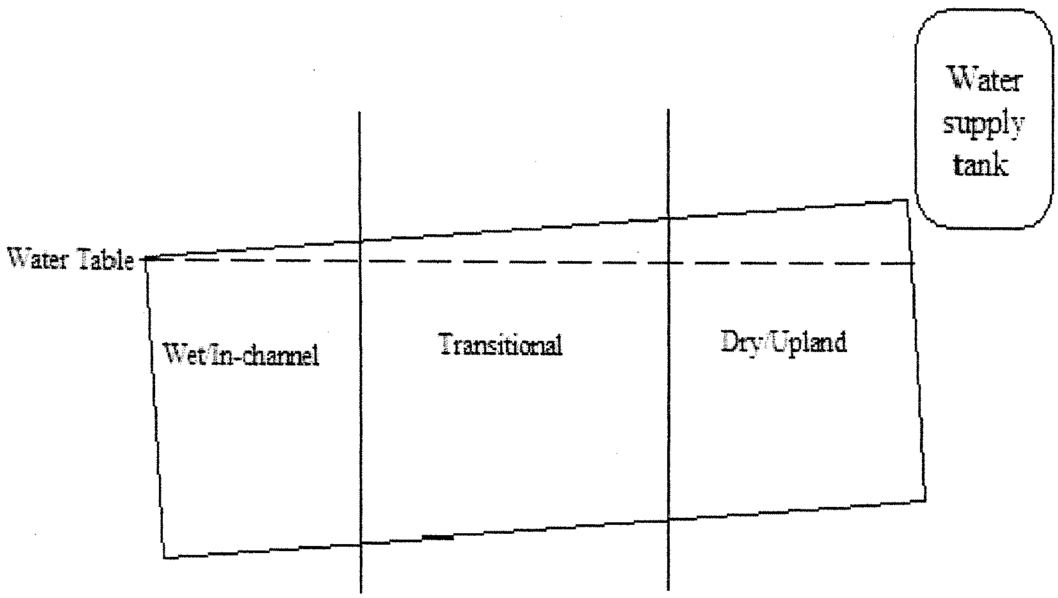

Figure 7. Designation of hydrologic regions for plant species.

Table 3. Assignment of communities to lysimeters.

Lysimeter Number	1	2	3	4	5	6	7	8	9	10	11	12
Community Number	3	2	1	1	3	2	1	2	3	1	3	2

Multiple runs of MINTEQA2 (Allison et al., 1991), a geochemical program for modeling groundwater chemistry, identified appropriate reagent combinations needed to synthesize treatment water qualities. Target treatment water chemistry simulated CBM product water of the Montana portion of the Powder River Basin and all twelve lysimeters received the same simulated water, it being EC ~ 3 dS/m and SAR ~ 25.

A greenhouse canopy was constructed over the study site to modify ambient air and soil temperatures and growing season length and to maintain precipitation inputs comparable to conditions within the Powder River Basin. The canopy also served to eliminate uncontrolled precipitation events (Figure 8).

Figure 8. Canopy over plots.

Operation and Sampling

This experiment was designed around a basic water balance equation which allows for the determination of ET as follows:

$$ET = P + I - DR - RO - \Delta W \quad \text{[Eq. 2]}$$

where ET = evapotranspiration, P = precipitation, I = irrigation, DR = drainage and deep percolation, RO = runoff and ΔW = soil water depletion (Or et al., 2002). In the present study, precipitation was excluded from the calculation of ET by the greenhouse canopy. Since each lysimeter was a closed system, deep drainage (DR) and runoff (RO) were non-existent, and all lysimeters were supplied water on the basis of evaporative demand, thereby negating soil water depletion (i.e. ΔW). The result was a simplified water balance equation,

$$ET = I \quad \text{[Eq. 3]}$$

where irrigation (water supply rate) was controlled and monitored. The water supply rate (I) was regulated by ET rates.

By assessing evapotranspiration, the potential role of these communities in managing volumes of water associated with CBM extraction in the Powder River Basin was characterized and quantified.

A single Class A evaporation pan was installed under the canopy and filled with the same water as the lysimeters received. Pan evaporation was determined manually on a weekly schedule. Water use was determined on a weekly schedule for each lysimeter with water supplied via calibrated supply tanks. Supply tanks were maintained and covered to minimize evaporative losses, and manual measurements of the amount of water depleted from supply tanks were conducted each week. At harvest, these water use amounts were converted to equivalent depths. This was done by first multiplying liters of water used by 1000 to get cm^3 of water used during the growing season.

$$WaterUse(cm^3) = WaterUse(L) * 1000 \qquad \text{[Eq. 4]}$$

Total water used (cm^3) was then divided by the surface area of each lysimeter (cm^2) resulting in equivalent depths of water used in centimeters.

$$EquivalentDepth(cm) = \frac{WaterUse(cm^3)}{SurfaceArea(cm^2)} \qquad \text{[Eq. 5]}$$

Diurnal and seasonal temperature fluctuations within the canopy were monitored with a Hanson AM400 data logger throughout the growing season.

Ground water samples were collected from the gravel substrate at the lowest end of each lysimeter monthly and analyzed to characterize changes in solution chemistry. Soil samples from each hydrological region of every lysimeter were collected at the end of the season to determine changes in soil chemistry, specifically the fate of salts. Community biomass production and cumulative water use rates (L) were determined at the end of the season and used to determine water use efficiency (WUE) for each community.

Statistical Analysis

All statistical analyses were conducted using R version 1.7.1 statistical software

(R Development Core Team, 2003). Single factor ANOVA's with community as a factor were conducted on seasonal water use, biomass and WUE. Significant differences at $P \leq 0.05$ were determined using a multiple comparison procedure for equal sample sizes. There are four basic assumptions for fixed factor level ANOVA models which were applied to these data; 1) for each factor level, the response variable is normally distributed; 2) homogeneity of variance; 3) for each factor level, the responses are random samples from the distribution associated with that level; 4) responses for each factor level are independent of the responses for any other level (Neter et al.,1996).

RESULTS

Statistical Analysis

ANOVA models are fairly robust against minor departures from model assumptions, but residual plots can be helpful in identifying serious departures and determining if the ANOVA model being used is appropriate. Diagnostic plots are shown for seasonal WUE only as seasonal water use and biomass production showed similar results with respect to model assumptions.

Figure 9 is a plot of the fitted values (or predictor variables) against the residuals for seasonal WUE of each lysimeter, with seasonal WUE in grams of biomass per kg water used on each axis. This plot is one of the most important plots in determining any major departures from ANOVA model assumptions. From this plot homogeneity of variance can be confirmed, outliers detected, and the appropriateness of a regression model determined. There are twelve dots, representing seasonal WUE for each lysimeter. Notice how all dots appear to fall within a horizontal band about 0 and the lack of any identifiable patterns in the way residuals depart from 0. This indicates the linear regression function is appropriate.

Homogeneity of variance can also be determined from this plot. Residual values that form patterns resembling a funnel, frown or have positive/negative slope indicate variances are not homogenous and transformations may be necessary. Data in Figure 9 form no such patterns, indicating error variances are homogeneous. One interesting thing to note about this plot is the locations of the community replications. Two communities are grouped just below 0.7 on the X axis while the third is above 1.1. This indicates that although variances are equal, mean seasonal WUE is different with respect to community. A fitted vs. residual plot is also helpful in identifying outliers, as they will affect distribution of plotted values, but they are more easily identified by a box plot.

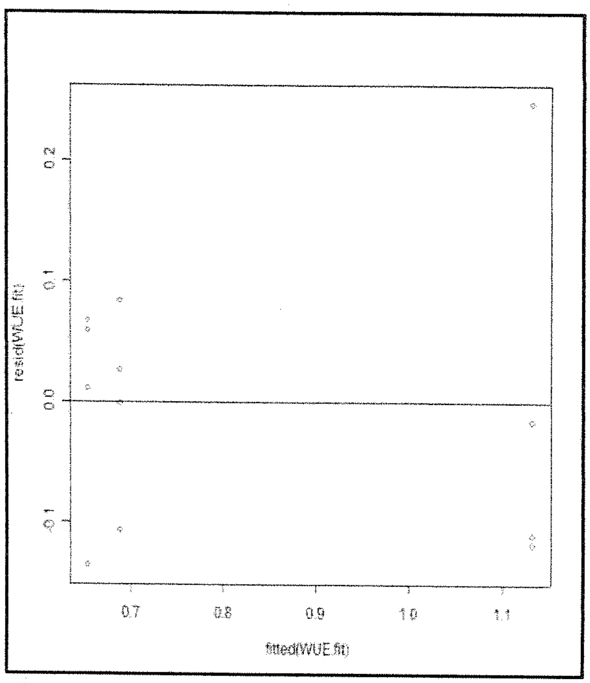

Figure 9. Plot of fitted vs. residual seasonal WUE's for each lysimeter. Seasonal WUE is in g/kg on both axis.

Figure 10 is a boxplot showing median, 1st and 3rd quartiles and maximum/minimum seasonal WUE for each community. Seasonal WUE in grams of biomass per kg water used is on the Y axis with each community along the X axis. Median seasonal WUE is represented by the line through each box while minimum and maximum WUE values are shown by the lines extending above and below each box.

Boxplots show summary information about the symmetry of the residuals and possible outliers, and are used to determine departures from the assumptions of normality and equal variance. Figure 10 confirms there are no outliers in the data set as outliers are identified by open circles above or below boxes. Communities 1 and 2 appear to be slightly skewed, most values are below the median for community 1 and above the median for community 2, but overall there are no serious departures from normality. There also appear to be no major departures from the assumption of equal variance because the data have similar spreads, that is, the boxes and tails have similar ranges in values. Notice how all three boxes are in different locations along the Y axis. This confirms what was seen in Figure 9, that although variances are equal, there is a difference in mean seasonal WUE with respect to community.

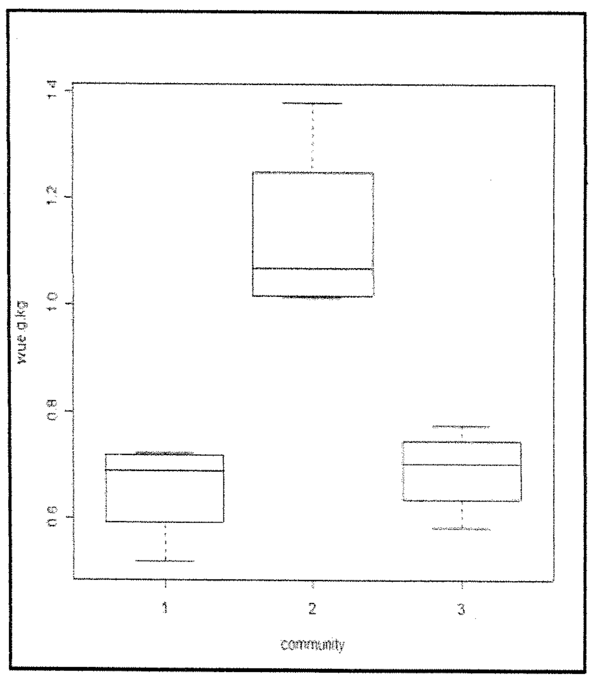

Figure 10. Boxplot showing median WUE, 1st and 3rd quartiles, variance and the presence of outliers for each community along the X axis. Seasonal WUE is in g/kg on the Y axis.

Figure 11 is a normal probability plot of residuals against expected values under normality. If residuals are distributed normally, a linear pattern is seen about the regression line. The pattern seen in Figure 11 indicates the error terms are normally distributed.

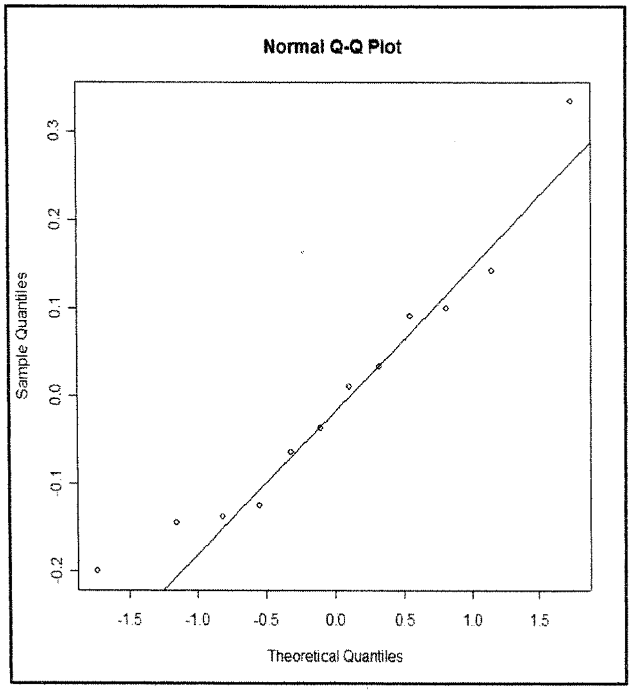

Figure 11. Normal probability plot showing data along a regression line. Seasonal WUE is in g/kg on both axis.

Plant Performance and Water Use

ANOVA results indicated there was no statistically significant difference in mean water use over the growing season with respect to community type ($P = 0.05$), even though differences were observed (Table 4, Figure 12). Maritime/saltgrass/spikerush and Cattail/cordgrass/wildrye communities had seasonal water use rates within 16 liters of each other (1100 and 1116 L, respectively), while the American/baltic/WG community used 950 liters. Graphically, this may seem like a large difference, but statistically it is not significant.

Table 4. ANOVA tables for seasonal WUE, total biomass, and seasonal water use.

Analysis of Variance Table

Response: wue (g/kg)

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
community	2	0.56749	0.28375	19.155	0.0005713 ***
Residuals	9	0.13332	0.01481		

Response: BIOMASS

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
community	2	846163	423081	21.779	0.0003558 ***
Residuals	9	174833	19426		

Response: H2O

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
community	2	23797	11899 1.7417	0.2294	
Residuals	9	61484	6832		

*** Significant at ∝ = 0.05

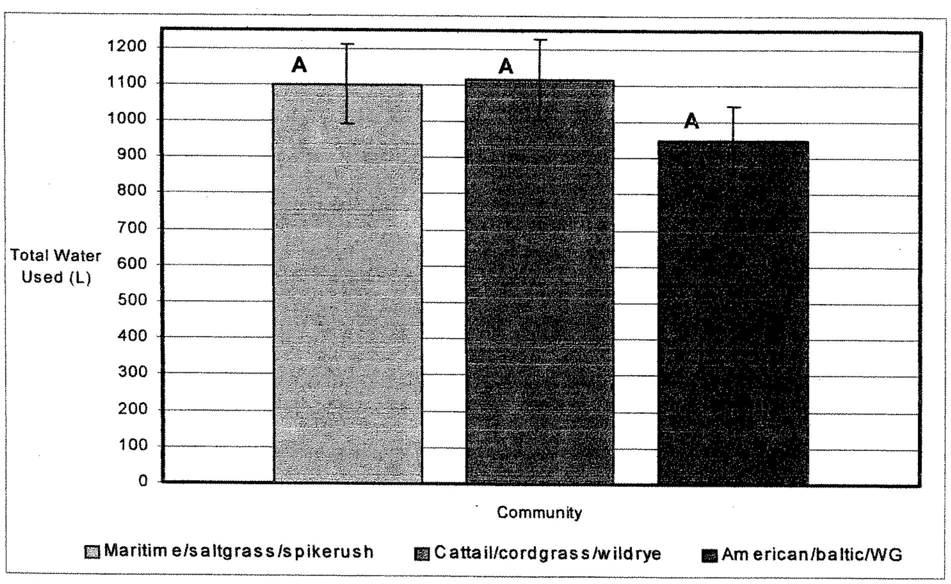

Figure 12. Seasonal water use rates for all three communities. Letters indicate statistically similar water use. Error bars indicate 10% of the data.

ANOVA confirmed that mean biomass and WUE's differed significantly with respect to community type (P = 0.05) (Table 4). Recall that WUE is dependent on biomass, so significant differences in biomass production will be reflected in WUE. Recall also that WUE is a ratio of biomass produced per unit water used, and a lesser ratio indicates less efficient use of water compared to a greater ratio. WUE's for the Maritime/saltgrass/spikerush and American/baltic/WG communities are less than the WUE of the Cattail/cordgrass/wildrye (Figure 13). That is, less biomass was produced per unit of water used in the Maritime/saltgrass/spikerush and American/baltic/WG communities.

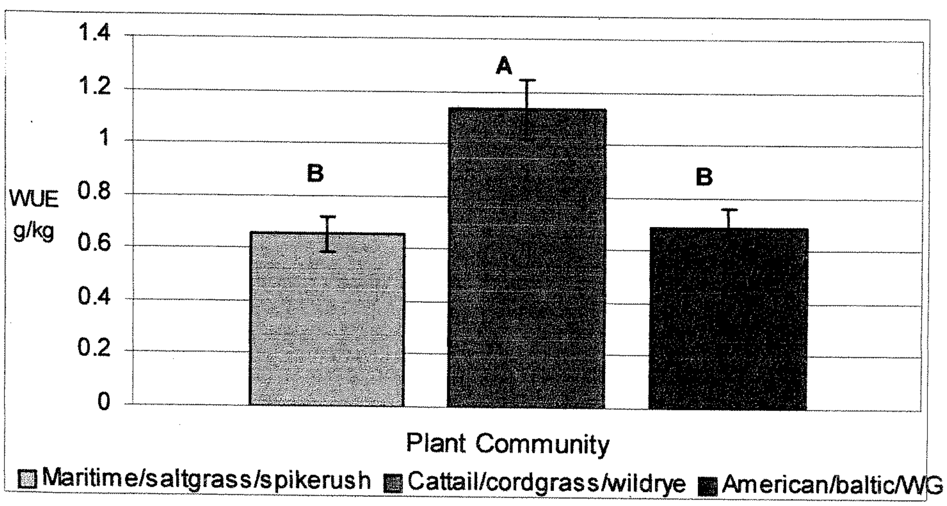

Figure 13. Average seasonal WUE for each community. Letters indicate statistically similar values for average seasonal WUE. Error bars indicate 10% of the data.

Results of mean separations indicate mean WUE for the Cattail/cordgrass/wildrye community was significantly different from mean WUE's of the Maritime/saltgrass/spikerush or the American/baltic/WG communities, and that the

Maritime/saltgrass/spikerush community was statistically similar to the American/baltic/WG community, as is illustrated by identical letters in Figure 13.

Class A pan evaporation exceeded that of each community during the growing season (Figure 14). This situation may have resulted from the pans location. It was placed on the open, southern edge of the canopy. Shade cloth was installed, but evaporation may have been impacted by edge effect due to fluctuations in solar radiation, ambient temperature and wind.

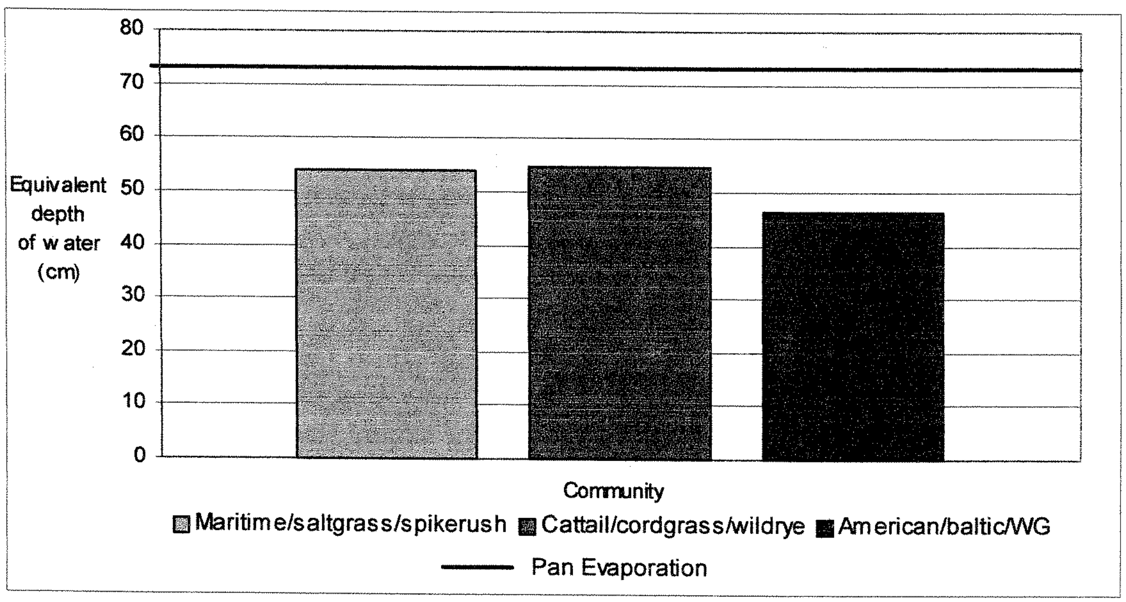

Figure 14. Average equivalent depth of water used for each community and Class A pan evaporation for the 2004 growing season.

Soil and Water Chemistry

Figure 15 illustrates how plant water consumption affected ground water EC (dS/m) of each lysimeter. Notice how similar groundwater EC is at the beginning of the growing season (Sample date 1), and how much variability is seen by the end. Figure 16 is average EC of the four replications for each community, and the same trend is observed. This is likely a function of evapoconcentration through plant consumptive use.

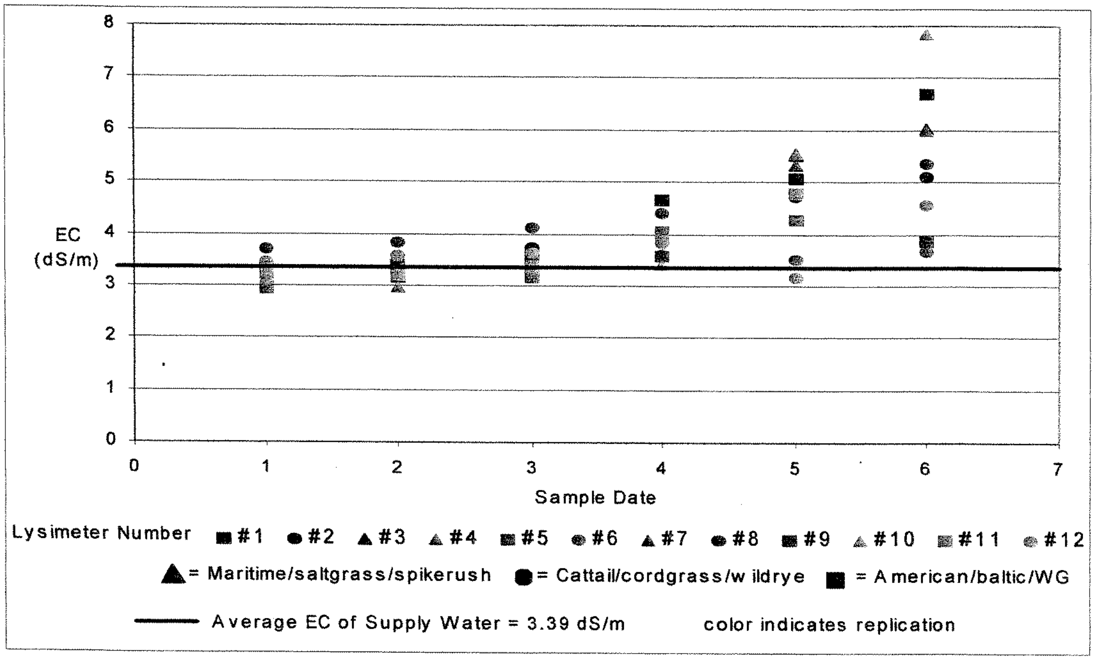

Figure 15. Groundwater EC (dS/m) for each lysimeter during the 2004 growing season.

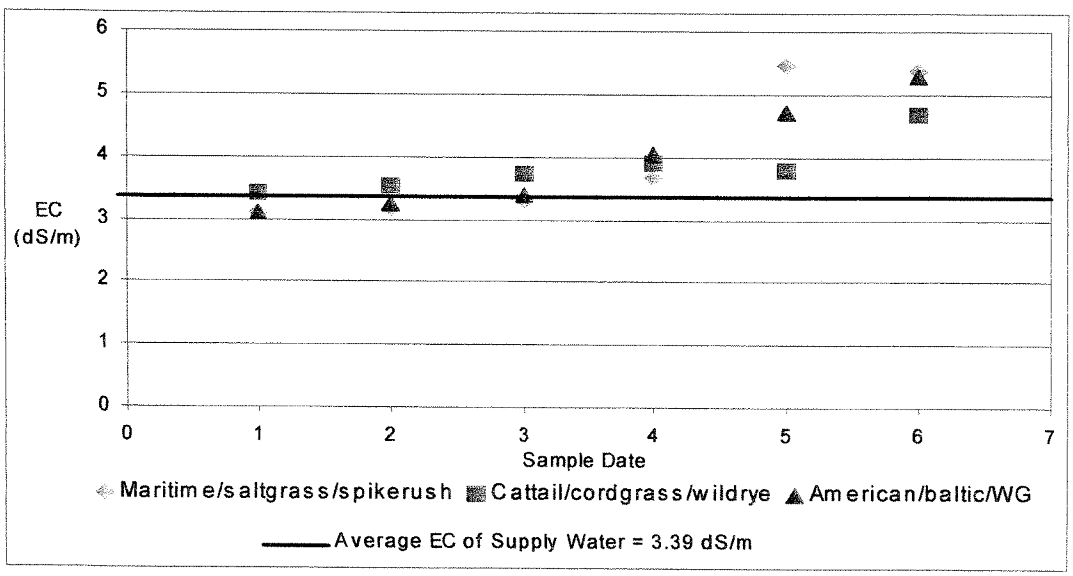

Figure 16. Average groundwater EC (dS/m) for each community during the 2004 growing season.

Some of the salts in the applied water will be bound by the soil matrix, and this is illustrated in Figures 17 and 18. Figure 17 shows average saturated paste EC for each hydrologic region of each community at the end of the growing season. The solid black line represents baseline saturated paste EC of 0.93 dS/m.

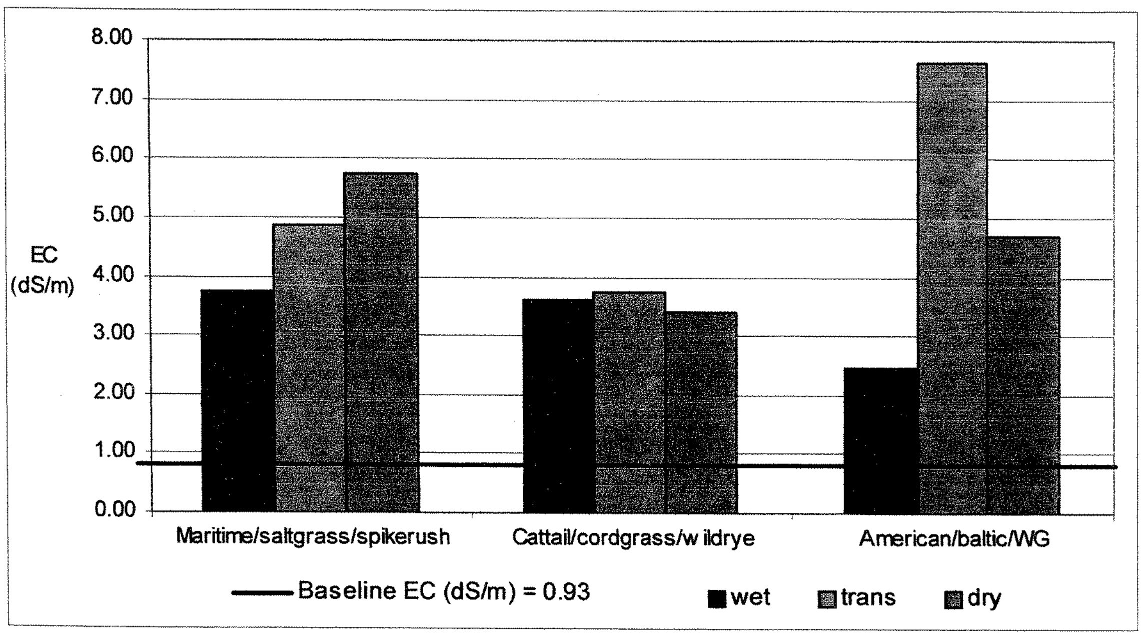

Figure 17. Average saturated paste EC (dS/m) for each hydrologic region (wet, transitional, dry) of each community at the end of the 2004 growing season. Baseline saturated paste EC is represented by the solid line.

Figure 18 is a graph of average saturated paste SAR determined from extractable cation concentrations for each hydrologic region of each community at the end of the growing season. The solid black line represents baseline saturated paste SAR of 1.31.

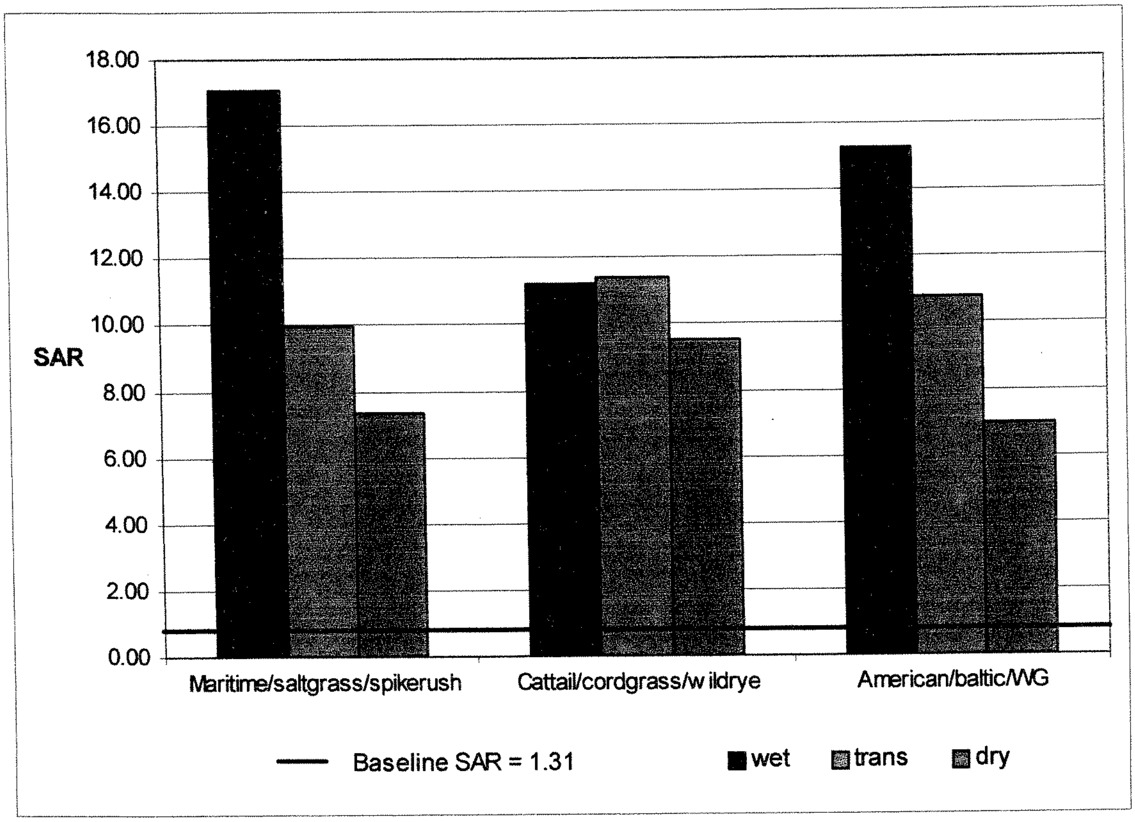

Figure 18. Average saturated paste SAR for each hydrologic region (wet, transitional, dry) of each community at the end of the 2004 growing season. Baseline saturated paste SAR is represented by the solid line.

DISCUSSION AND CONCLUSIONS

Discussion

Lack of significant differences in seasonal water use among communities was unexpected. Results of plant community water use in this study are contrary to what have been documented for agricultural crops (USDI-BOR, 2004). For purposes of discussion, water use was expressed in terms of equivalent depth of water used. Overall, crop water use for this study was at the lower range of reported values for the Bozeman Agrimet station. Crop water use rates for the 2004 season at the Bozeman Agrimet station were as low as 43.4 cm for spring grain, and as high as 80.5 cm for hay alfalfa (USDI-BOR, 2004). Crop water use rates for this study ranged from 46.4 cm to 54.6 cm, a range of 9 centimeters compared to a reported range in crop water use of almost 40 centimeters at the Bozeman Agrimet station.

A variety of reasons can be advanced to help explain differences in water use between wetland communities of this study and agricultural crops.

★ This study calculated water use rates of a community of multiple species while Agrimet stations report water use rate of individual species.

★ There was not a significant magnitude of stress placed on plants to allow for species to perform at capacity.

★ In this study, water was never a limiting factor.

★ An artificial season length was imposed and plant communities not allowed to senesce under natural conditions.

★ Lysimeters were planted in the fall of 2003 so plant communities were still establishing during the 2004 growing season.

★ Some plant communities did not have full vegetative canopies.

Plant Performance

Although differences in water use were not statistically significant, a comparison of mean values offers some insight to community performance. Survivability and plant physiology may be factors in lower seasonal water use rates among communities in this study compared to agricultural crops.

The American/baltic/WG community had the least crop water use, while the Maritime/saltgrass/spikerush and Cattail/cordgrass/wildrye communities showed similar crop water use. Differences between the former and two latter communities can be explained by the fact that approximately 1/3 of the American/baltic/WG community was bare soil, plants had low growth forms and did not colonize the lysimeter. Hence there was less overall vegetation in the American/baltic/WG community to evapotranspire water. Had the American bulrush survived and flourished, crop water use rates would likely have been significantly higher.

In the Maritime/saltgrass/spikerush community, saltgrass, which has slow growth rates, did not overwinter well and was replaced by the more adaptive and aggressive spikerush in every replication. By the end of the growing season Creeping spikerush had colonized the length of the lysimeter (~3meters), effectively eliminating the saltgrass. Slow spring regrowth of Cattails left patches of bare soil in the Cattail/cordgrass/wildrye community, but this community had the highest seasonal water use even though the

Maritime/saltgrass/spikerush community had the most ground cover. Cattails and Canada wildrye grow taller than other species in this study and wildrye had the earliest spring growth. These two traits likely increased the ability of this community to use water.

Creeping spikerush only grows 15 to 20 cm high while Wildrye and Cattails can attain mature heights over 1 meter. Large plants produce more biomass than smaller plants, thereby increasing plant water consumptive use. In this study, taller plants such as cattails and wildrye had more vegetation above the overall plant canopy, where it was exposed to atmosphere. This can lead to higher evapotranspiration rates due to differences in solar radiation, wind and relative humidity above and below the vegetative canopy.

Canada wildrye was the first of all species to initiate spring growth. As soon as vegetative growth begins in the spring, plant water consumptive use commences, so species with early spring growth are able to utilize available water earlier. In the American/baltic/WG community only one or two American bulrush plants in each replication survived the winter, and bare ground was not colonized by Baltic rush or streambank wheatgrass. This resulted in less vegetation, hence less water use. Creeping spikerush has higher rates of vegetative spread and earlier spring regrowth than Inland saltgrass. These two characteristics are possible reasons for the ability of Creeping spikerush to out compete Inland saltgrass.

Evaporation from a single Class A evaporation pan was compared to actual ET of the three plant communities. In all three plant communities, pan evaporation exceeded community ET (Figure 14). Actual pan water use and the ratio of pan to community ET is consistent with data from Agrimet that shows reference ETr (pan evaporation) to be higher than crop ET (USDI-BOR, 2004). Comparing Agrimet Etr data of 96.7 cm to ETr of 72 cm for the present study, pan data appears reasonably approximate to Agrimet data.

Biomass

Significant differences in biomass production (Table 4) are consistent with data reported by the National Agricultural Statistics Service (NASS) (USDA, 2004). Yields of all three communities in this study were lower than values reported for hay alfalfa in Gallatin county or counties in the Powder River Basin. With the exception of the Cattail/cordgrass/wildrye community, reported yields for other types of hay in the same counties were also higher than yields for this study. It is likely that species survivability and colonization were major factors in lower yields and lack of variability in yields for the American/baltic/WG and Maritime/saltgrass/spikerush communities.

The American/baltic/WG community had the lowest dry weight of the three communities (1.42 tons/acre). This is a consequence of lack of colonization by the other species in this community when American bulrush did not survive the winter. Inland saltgrass was crowded out by Creeping spikerush which colonized all available open space in the lysimeter. Although this improved percent cover, dry weights were still low (1.57 tons/acre). Rushes are known for hollow, pithy stems which, when combined with the short stature of spikerush, could have resulted in lower dry weights (NEED REFERENCE). Even with low spring regrowth of the Cattails, the Cattail/cordgrass/wildrye community had the highest biomass production (2.72 tons/acre).

Again, this is likely a outcome of plant physiology and survivability as discussed previously.

Water Use Efficiency

The WUE metric is dependent on the units selected for computation. In this study, WUE is defined as grams of dry matter produced per lysimeter, divided by kilograms of water used within the same lysimeter over the growing season, strictly for comparison among the communities of this study. Due to lack of significant differences in water use among the communities, calculated WUE merely reflects biomass divided by a constant (or non-significantly different value) for each community. Hence, the community with the least WUE is a reflection of the community with the least biomass, while the community with the highest WUE produced the most biomass (Figure 13). Any discussion about differences in WUE would merely reiterate the discussion pertaining to biomass production.

Soil and Water Chemistry

For purposes of initial planting and soil sampling determinations, hydrologic regions were defined by dividing lysimeters lengthwise into three equal parts (~1.1m) (Figure 7). Soil samples were collected from random positions within each hydrologic region of each lysimeter. The intent of soil sampling was to look for general trends in each lysimeter with respect to solution EC and SAR.

For this experiment, groundwater was represented by water which percolated through the soil to the gravel layer where it could be sampled. Over the course of the growing season, soil solution and groundwater chemistry changed with respect to EC and SAR (Figures 15, 16, 17 and 18), and all twelve replications showed a general increase in EC and SAR as the growing season progressed (Figures 15 and 16).

As water is applied to upper elevations, it percolates vertically through the soil profile and laterally along elevational gradients. This resulted in more available water in the lower elevations of each lysimeter in this study. Salts remain in solution and are transported with water, so lower elevations of each lysimeter received more salts as well.

In solution, salts either bind to soil particles and concentrate in the soil profile or remain in solution where they are transported to lower depths in the soil as leaching and drainage occur. Lysimeters were designed to be closed systems so there was no dilution from groundwater, and water that percolated through soil profiles had higher concentrations of salts than applied water. Areas with water tables at or near the surface tend to experience higher rates of evaporation of available water. More water will be evaporated from soils with water tables at the soil surface than soils with water tables farther below the soil surface. More energy is required to evaporate water which is adsorbed to soil particles, so water at or near the surface will be evaporated faster than water deeper in the soil profile.

Soil solution EC increased from the beginning to the end of the growing season in all three communities regardless of hydrologic position (Figure 17). In the field, increasing soil solution EC is a function of evapoconcentration and soil texture. In this study, soil texture was consistent in all lysimeters so differences in soil solution EC were likely a consequence of evapoconcentration, water table position and leaching gradient, but there is no consistent pattern among communities with respect to hydrologic region and changes in soil solution EC (Figure 17).

SAR also increased from the beginning to the end of the season, with the greatest increase measured in transitional and wet regions of two of the three communities (Figure 18). SAR increases disproportionately as a consequence of how SAR is calculated. SAR is calculated by dividing the amount of sodium present by the square root of calcium plus magnesium divided by 2.

$$SAR = \frac{Na^{2+}(meq / L)}{\sqrt{(Ca^{2+}(meq / L) + Mg^{2+}(meq / L)) / 2}} \qquad \text{Eq.6}$$

More water, hence more sodium, was available in wet and transitional regions of each lysimeter. Evapotranspiration causes an increase in soil solution concentrations by removing water but not salts, resulting in an increase in SAR. Once CBM product water is exposed to the atmosphere, calcium and magnesium form carbonate precipitates with available CO_3, thereby increasing SAR as well.

Conclusions

Constructed wetlands composed of native halophytic or salt tolerant plant species have potential to utilize saline-sodic water while remaining viable. For example, a 1 acre constructed wetland with seasonal ET rates of 59 cm could evapotranspire 1.77 acre feet of water during a single growing season.

Maritime bulrush, Baltic rush, Creeping spikerush and Canada wildrye appeared to be the most likely candidates for use in a constructed wetland designed for beneficial use of saline-sodic water. Constructed wetlands have the added benefit of providing food and habitat for wildlife, and some plant species have potential to be used as forage. Constructed wetlands have potential to be visually appealing while increasing recreation opportunities such as hunting and fishing.

Evapoconcentration of salts in a constructed wetland could lead to adverse soil salinity and sodicity conditions with respect to long-term impoundment, viability and reclamation. Over time, increasing salinity and sodicity may have detrimental effects on plant propagation, seedling emergence, establishment and yields as well as increasing plant mortality. Native range plants of the Powder River Basin have some tolerance to salinity due to the nature of soils in the area, but may not be able to re-establish constructed wetland sites with significantly elevated salinity and sodicity. In such cases, this may lead to the area becoming a sacrifice site, where the wetland is filled in and no attempts at reclamation made.

APPENDICES

APPENDIX A

Particle Size Analysis

Appendix A: Summary of particle size analysis of soil samples for 0-15cm and 16-60cm, collected from six soil pits excavated on site from which study soil was obtained. Soil used to fill wetland cells was collected from 16-60cm depth in proximity to and surrounding pits 2 and 3 (highlighted in red). Soil from 0-15cm depth was stockpiled and used for revegetation of excavation site.

SAMPLE #	Pit/sample depth	corrected 40sec[3]	corrected 24hr[1]	SAND g/100g[4]	CLAY g/100g[2]
1	Pit 1 0-15cm	24.5	14.5	50	29
2	Pit 1 16-60cm	22	13	56	26
3	Pit 2 0-15cm	25	14.5	50	29
4	Pit 2 16-60cm	30.5	21	39	50
5	Pit 3 0-15cm	29	17.5	42	35
6	Pit 3 16-60cm	32.5	20.5	35	41
7	Pit 4 0-15cm	28	16	44	32
8	Pit 4 16-60cm	31	18	38	36
9	Pit 5 0-15cm	28.5	15.5	43	31
10	Pit 5 16-60cm	32	19	36	38
11	Pit 6 0-15cm	25.5	12	49	24
12	Pit 6 16-60cm	28.5	18	43	36

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3 Corrected values are actual readings minus the hydrometer reading of a blank solution (Gee and Bauder, 1986).

4 Sand defined as >0.05mm diameter; clay defined as <0.002mm diameter (Gee and Bauder, 1986).

APPENDIX B

Plant Characteristics Table

Appendix B: Categorization of selected native species suitability for constructed wetlands - a comprehensive review.

Common Name	Scientific name	Growth habit / Duration	Active growth period	Growth Rate	Propagation Method	pH Range
Alkalai (Maritime) bulrush	*Scirpus maritimus*	Graminoid / Perennial	Spring, Summer	Slow	Rhizomes/Seed	4 - 7
American bulrush	*Scirpus americanus*	Graminoid / Perennial	Summer	Moderate	Rhizomes/Seed	3.7 - 7.5
Common cattail	*Typha latifolia*	Forb-herb / Perennial	Spring, Summer	Rapid	Rhizomes	5.5 - 7.5
Inland saltgrass	*Distichlis spicata*	Graminoid / Perennial	Spring, Summer, Fall	Slow	Rhizomes	6.4 - 10.5
Baltic rush	*Juncus balticus*	Graminoid / Perennial	Spring, Summer	Rapid	Rhizomes/Seed	6 - 9
Prairie cordgrass	*Spartina pectinata*	Graminoid / Perennial	Spring, Summer	Rapid	Rhizomes/Seed	6 - 8.5
Creeping spikerush	*Eleocharis palustris*	Graminoid / Perennial	Spring	Moderate	Rhizomes/Seed	4 -8
Streambank wheatgrass	*Pascopyrum smithii*	Graminoid / Perennial	Spring, Summer, Fall	Moderate to Rapid	Rhizomes/Seed	4.5 - 9
Canada wildrye	*Elymus canadensis*	Graminoid / Perennial	Spring, Summer, Fall	Rapid	Tillers/Seed	5 - 7.9

Table References:

Uchytil, 1990; Snyder, 1992a; Snyder, 1992b; Uchytil, 1992a; Uchytil, 1992b; Hoag, 1998a; Hoag,1998b; Hoag, 1998c; Hoag, 1998d; Simonin, 2000; Hoag et al., 2001; USDA-NRCS, 2004; Prairie Seeds, 2004.

Appendix B (Cont): Categorization of selected native species suitability for constructed wetlands - a comprehensive review.

Common Name	Hydrologic Regime	Wetland Indicator Status [A]	Pioneer	Competitive	Nitrogen Fixer	C:N Ratio [B]	Root Depth	Root Matrix
Alkalai (Maritime) bulrush	Wet / In channel	OBL	Yes	No	No	High	12"	Yes
American bulrush	Wet / In channel	FAC, FACW	Yes	Yes	No	Med	14"	Yes
Common cattail	Wet / In channel	OBL	Yes	Very	No	High	14"	Yes
Inland saltgrass	Moderate / transitional	FAC, FACW	Yes	No	No	High	2"	Yes
Baltic rush	Moderate / transitional	FACW, OBL	Yes	No	Yes	Med	20"	Yes
Prairie cordgrass	Moderate / transitional	FACW, OBL	Yes	No	No	High	18"	N/A
Creeping spikerush	Upland / transitional	OBL	Yes	No	Yes	High	14"	Yes
Streambank wheatgrass	Upland / transitional	N/A	Yes	No	No	Med	20"	Yes
Canada wildrye	Upland / transitional	FACU, FAC	Yes	No	No	Med	16"	No

Explanation of symbols used in this table:

A - Wetland Indicator Status - See Table 2. USDA-NRCS. 2004.

B - Carbon to nitrogen ratio. USDA-NRCS. 2004. C:N >12 slow decomposition and accumulation. C:N <12 rapid decomposition and accumulation.

Appendix B (Cont): Categorization of selected native species suitability for constructed wetlands - a comprehensive review.

Common Name	Salinity Tolerance [C]	Anaerobic Tolerance [D]	Drought Tolerance [E]	Moisture Use	Soil adaptation fine/med/coarse	Sustainability Fresh/saline/brackish
Alkalai (Maritime) bulrush	High 77 dS/m*	High	Low	Moderate	ALL	Fresh/saline/brackish
American bulrush	High 42.5 dS/m*	High	Mod-high	Moderate	Fine/Medium	Fresh/saline/brackish
Common cattail	Low-High 17.5 dS/m*	High	None	High	ALL	Fresh/slightly brackish
Inland saltgrass	High 70 dS/m*	High	Moderate	Moderate	Fine/Medium	Fresh/saline/brackish
Baltic rush	High	High	Low	High	ALL	Fresh/slightly saline
Creeping spikerush	Low	High	Low	High	Medium/Coarse	Fresh/slightly saline
Prairie cordgrass	None	High	Low	High	Fine/Coarse	Fresh/slightly saline
Streambank wheatgrass	High 34 dS/m*	Moderate	Moderate to high	Moderate	Medium/Coarse	Fresh/slightly saline
Canada wildrye	Moderate	None	Moderate	Moderate	ALL	Fresh/slightly saline

Explanation of symbols used in this table:

C - Salinity tolerance - Low < 4 dS/m, Mod 4 - 9 dS/m, High > 9 dS/m (Brady and Weil, 1999). USDA-NRCS, 2004. *From Aronson, 1989.

D - Anaerobic tolerance - USDA-NRCS. 2004.

E - Drought tolerance - USDA-NRCS. 2004.

Appendix B (Cont): Categorization of selected native species suitability for constructed wetlands - a comprehensive review.

Common Name	Forage Quality [F]	Grazing Preference	Resistance to grazing/trampling	Conservation Uses
Alkalai (Maritime) bulrush	Low	Livestock will consume young plants	N/A	Erosion control, wastewater treatment, creation/restoration of wetlands, bank stabilization
American bulrush	Low	Livestock, wildlife - early season	Yes	Erosion control, wastewater treatment, creation/restoration of wetlands, bank stabilization
Common cattail	Low	Waterfowl, muskrats	Will tolerate moderate grazing	Highly invasive-not used for conservation
Inland saltgrass	Fair	Livestock, wildlife	Yes	Good for reclamation of saline sites
Baltic rush	Low to very good	Hay crop for cattle. Forage for livestock and elk	Will increase with heavy grazing	Erosion control, wastewater treatment, creation/restoration of wetlands, bank stabilization
Creeping spikerush	Med-high in Spring	Livestock, big game, ducks, geese	Yes	Erosion control, creation/restoration of wetlands, bank stabilization, sediment trap
Prairie cordgrass	Low	Muskrats, livestock waterfowl	Will tolerate moderate trampling	Erosion control, creation/restoration of wetlands, stabilization, species diversity
Streambank wheatgrass	High in spring	Livestock, big game	Moderate sod formation	Erosion control, reclamation, stabilization
Canada wildrye	Med	Livestock, wildlife	Yes, but short-lived	Restoration, erosion control - plants only live 2-4 yrs

Explanation of symbols used in this table:

F - Forage quality - Based on crude protein content. USDA-NRCS. 2004.

APPENDIX C

Selected Plant Species Descriptions

Appendix C: Selected Plant Species Descriptions

Alkali bulrush (*Scirpus maritimus*) is a heavily rhizomatous, native perennial wetland plant found in areas with saturated soils or standing water up to 1 meter deep (Hoag, 1998b; Hoag et al., 2001; USDA-NRCS, 2004). It propagates best when the water table is within 10 cm of the surface (Hoag, 1998b; USDA-NRCS, 2004). Alkali bulrush typically occurs on freshwater sites, but will also form large, dense stands in either alkaline or saline sites, preferring a pH range of four to seven but tolerating values up to nine (Hoag, 1998b; USDA-NRCS, 2004). It is a pioneering species and is usually replaced by other species under good soil and water conditions (Hoag et al., 2001). Mandel and Koch (1992) reported that the large carbon reserves of Alkali bulrush maintain carbohydrate levels through metabolic conservation, and are not affected when under anoxia stress. Alkali bulrush is an excellent choice for wastewater treatment as the rhizomes form a matrix for beneficial bacteria (Mandel and Koch, 1992; USDA-NRCS, 2004). When alkali bulrush is grown at or above the water surface it produces fewer seeds, but has better shoot survivorship, and produces a greater number of tillers, thereby increasing production of underground biomass (Mandel and Koch, 1992; Kantrud, 1996). If it is grown in deeper water it produces a greater number of seeds, but less underground biomass, tillers, and total biomass (Mandel and Koch, 1992). Seeds and rhizomes are food for waterfowl, game birds and songbirds as well as muskrat and beaver (Hoag, 1998b; Hoag et al., 2001; USDA-NRCS, 2004). Reports on use by grazers vary; Kantrud (1996) states that cattle and horses readily graze the young plants while others say grazers rarely use this species (Hoag, 1998b; Hoag et al., 2001; USDA-NRCS, 2004).

Inland saltgrass (*Distichlis stricta*) is a highly salt tolerant, native perennial common in sloping and flood channel bank configurations in drainage systems of Wyoming and the western United States (Uchytil, 1990; USDA-NRCS, 2004). Growth is rapid with plants spreading via a well-developed system of deep underground rhizomes (Uchytil, 1990; USDA-NRCS, 2004). Inland saltgrass has moderate water use rates, and water tables are often at or near the surface (Uchytil, 1990; USDA-NRCS, 2004). Inland saltgrass can withstand anaerobic conditions, and rhizomes will sprout even when covered by 30cm of sediment (Uchytil, 1990). The lacunae tissue of the roots is apparently continuous with the rhizome and leaf sheath which allows for gas exchange under partial inundation and in heavy soils (Uchytil, 1990). It tolerates slightly acidic to highly alkaline pH values (6.4 - 10.5), (USDA-NRCS, 2004). Inland saltgrass is highly salt tolerant, persisting in EC values up to 70 dS/m (56,000 ppm) (Ungar, 1974). Salt glands are active in the extrusion of salt, which helps maintain adequate osmotic potentials (Uchytil, 1990). Vesicular-abuscular mycorrhizal fungi have been observed on inland saltgrass roots and are thought to further enhance salt tolerance (Uchytil, 1990). It is a pioneer species, colonizing barren, saline soils with the aid of sharp, pointed rhizomes which are well adapted to piercing heavy clays and shales, effectively loosening hard packed soil. The ability of Inland saltgrass to loosen hard packed soil may help other plants become established (Uchytil, 1990; USDA-NRCS, 2004). Inland saltgrass provides fair forage for cattle and horses because it remains green during periods of drought when most other grasses are dry; ducks are reported to occasionally eat the dried seeds and burning provides tender forage for wild geese (Uchytil, 1990; USDA-NRCS, 2004).

Creeping spikerush (*Eleocharis palustris*) is a native perennial hemicryptophyte that grows along marshes, ditches and streambanks, and in lakeshores, river bottoms, wet meadows and flood areas (Snyder, 1992a; Hoag, 1998d; Hoag et al., 2001; USDA-NRCS, 2004). Reproduction is rhizomatous with rapid vegetative spread, and rhizomes will spread into areas too deep for seedling establishment (Snyder, 1992a; Hoag, 1998d). Creeping spikerush develops a thick root mass that can extend 40+ cm in the soil profile, giving it the ability to resist erosion and compaction, and survive in areas where the water table drops to below 30cm of the surface (USDA-NRCS, 2004). It has high water use rates and will tolerate standing water up to 15 cm deep and three to four months of flooding (Hoag et al., 2001; USDA-NRCS, 2004). Creeping spikerush has a low salinity tolerance, and the optimum pH range is 4 - 8 (USDA-NRCS, 2004). It is a nitrogen fixer, and through recycling, makes nitrogen available to other plants in the wetland (Snyder, 1992a; Hoag et al., 2001). The seeds and rhizomes are food for ducks and geese while rabbits, muskrats, big game and other grazers utilize it for its high spring protein content (Hoag, 1998d; Hoag et al., 2001; USDA-NRCS, 2004).

Common cattail (*Typha latifolia*) is a native perennial that reproduces by seed dispersal and rapid vegetative propagation from rhizomes (Lorenzen et al., 2000; USDA-NRCS, 2004). Preferred habitats are marshes and pond edges with season-long saturated soils, and/or standing or slow moving water up to 30 cm deep (Uchytil, 1992b; Hoag et al., 2001; USDA-NRCS, 2004). Reports on salinity tolerance vary widely (Uchytil, 1992b; Hoag et al., 2001; USDA-NRCS, 2004) but, in general, cattails have moderate to high salinity tolerance. Cattails have high water use rates, and can withstand perennial flooding and reduced soil conditions (Hoag et al., 2001). At the appropriate stage of growth, all parts of the cattail are edible, but forage quality is only high in early spring for livestock and big game and by summer it is a poor protein and energy source (Uchytil, 1992b; USDA-NRCS, 2004).

Prairie cordgrass (*Spartina pectinata*) is a native, rhizomatous species found in a variety of habitats from low-lying roadsides, marshes, streams and flood plains to seasonally dry sites (Hoag et al., 2001; USDA-NRCS, 2004). Two very noticeable features of prairie cordgrass are the presence of aggressive rhizomes, which have the ability to grow 2.5 - 3.5 meters per year and a dense, deep root system with root biomasses up to 3000 g/m^2 (USDA-NRCS, 2004). Although it is typically a freshwater species, it will tolerate moderate salinity and alkaline conditions (Hoag et al., 2001; USDA-NRCS, 2004). It has high water use rates, can grow streamside in 0.3 m of water, and will tolerate extensive temporary flooding, high water tables and occasional drought (Walkup, 1991). The seeds and rhizomes are food for small mammals, and waterfowl (Hoag et al., 2001). Reports on forage quality are contradictory; Hoag et al. (2001) states that the plants provide high quality forage for muskrats, geese, livestock and other grazers, while the USDA-NRCS (2004) states that it is not a forage resource.

Canada wildrye (*Elymus canadensis*) is a native cool-season bunchgrass inhabiting disturbed sites from riparian areas to wetlands (Simonin, 2000; Prairie Seeds, 2004; USDA-NRCS, 2004). It is typically found along incised channel banks of ephemeral streams in north-central Wyoming, and along the Missouri River flood plain in

Montana (Simonin, 2000). Canada wildrye tolerates a range of hydrological regimes, showing fair to good flood tolerance and moderate water use rates (Prairie Seeds, 2004; USDA-NRCS, 2004). It is a quick starter, and can be prolific from seeds or tillers (Simonin, 2000). It has been noted to be fairly salt tolerant and prefers neutral to alkaline pH (Simonin, 2000; USDA-NRCS, 2004). Canada wildrye provides good early season forage, and good fall regrowth for late-fall and spring forage, but once mature is generally considered inferior (Prairie Seeds, 2004; USDA-NRCS, 2004).

American bulrush (*Schoenoplectus americanus*) is a native perennial, commonly found in backwater areas of streams, lakes, ponds, swamps, wet woods and roadside ditches (Mandel and Koch, 1992; Hoag, 1998a; Hoag et al., 2001; USDA-NRCS, 2004). It has a robust root system, with medium to rapid rates of rhizomatous spread. American bulrush is an obligatory wetland plant which tolerates freshwater, alkaline and saline conditions, and is reported as surviving in brackish waters with EC values of 42.5 dS m-1 (Uchytil, 1992a). Although it prefers a neutral pH, it can tolerate pH values in the range of 6.7 - 8.9 (Mandel and Koch, 1992). American bulrush will endure long periods of drought or water levels 5 - 10 cm above the surface for 3 - 4 weeks but growth is inhibited in greater than 60 cm of water (USDA-NRCS, 2004). Seeds and rhizomes of the plant provide food for muskrats, geese and other waterfowl, and grazers will use it for forage in early growth stages but palatability and production are low (Uchytil, 1992a).

Baltic rush (*Juncus balticus*) is the most common and widespread rush in the dry Intermountain and Great Basin regions (Snyder, 1992b; Hoag, 1998c; Hoag et al., 2001). It is a rhizomatous, native perennial found from low elevations to subalpine and alpine sites (Snyder, 1992b; Hoag, 1998c; Hoag et al., 2001; USDA-NRCS, 2004). Typical habitats are wet depressions, marshes, springs and pond or stream edges. Favored environmental conditions are areas which are flooded in spring and dry out in the fall (Hoag, 1998c). *Juncus* species can tolerate a wide range of hydrologic conditions, from severe drought with water tables 3 m or more below soil surface to extreme flooding (Hoag et al., 2001). Baltic rush is found in a wide range of soil types as well, from acidic to neutral, alkaline or sodic (Hoag, 1998c). Baltic rush is an important part of the nutrient dynamics of wetland plants communities because of its ability to fix nitrogen (Hoag, 1998c). It is resistant to erosion and trampling because of dense root systems (Snyder, 1992b), which also form a matrix for beneficial bacteria (USDA-NRCS, 2004). Baltic rush is an important forage species for livestock and elk, and is used as hay for cattle, although palatability decreases as the season progresses (Snyder, 1992b; Hoag et al., 2001). Seeds and rhizomes are food for small mammals, waterfowl and upland game birds, while the plants provide important cover (Hoag et al., 2001).

Streambank wheatgrass (*Elymus lanceolatus*) is a native perennial sod-forming grass (USDA-NRCS, 2004). It has an extensive rhizomatous root system, and vegetative propagation occurs primarily by rhizomes (USDA-NRCS, 2004). Streambank wheatgrass is found in slightly acidic to moderately saline conditions. It will tolerate moderate flooding and has high drought tolerance, but prefers seasonally saturated upland or terrace soils (USDA-NRCS, 2004). Streambank wheatgrass provides good early season forage for livestock and wildlife until fall when the plant dries out and becomes coarse (USDA-NRCS, 2004).

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