Foreword

Great Salt Lake is a large, shallow, terminal, hypersaline lake. The very shallow shoreline gradient and considerable tributary inflows provide for about 450,000 acres of vegetated and playa wetlands. About half of this acreage has been converted to complex systems of canals and impoundments that retain and control the flow of the three major tributaries, including the Bear, Weber and Jordan Rivers. These impoundments are carefully managed to optimize growth of sago pondweed to attract and support staging and migrating waterfowl. The uphill portion of these ponds and the uncontrolled fringe wetlands outside the impoundments also provide considerable nesting and rearing habitat for shorebirds as well as waterfowl. Together these two wetland types support substantial reproduction of several waterfowl and shorebird species and the annual migration of 5 to 7 million waterfowl and shorebirds. Recognition of vast acreages of these important habitats led to the inclusion of Great Salt Lake wetlands as a principle component of the Western Hemispheric Shorebird Reserve System – a recently recognized system of shorebird habitats that are essential to the successful continental and intercontinental production and migration of shorebirds in the Western Hemisphere.

Of growing concern to managers, scientists and stakeholders are the potential impacts associated with increased urbanization, and other anthropogenic activities, including water diversions, and the discharge of municipal and industrial wastewater that includes nutrients or toxics such as selenium or mercury. Our research group initially focused on nutrients and the potential linkage between elevated N and P concentrations and various response variables that indicate the trophic state and overall health of the wetlands, including both sheetflow and impounded wetland types (Miller and Hoven 2007). This included the seminal shorebird nesting and feeding study performed by Dr. John Cavitt of Weber State University (Cavitt 2007). Further, we provided an initial list of these indicators for their value in the development of a multi-metric index (MMI) or index of biological integrity (IBI).

Within the sheetflow wetlands, the plant and macroinvertebrate studies, the shorebird forage preference studies and documentation of nesting and hatching success, all indicate that the Farmington Bay sheetflow wetlands are fully supporting the designated beneficial uses of support for waterfowl and shorebirds and the necessary aquatic life in their food chain. For example, of the approximate 3500 nests that were marked and monitored by Dr Cavitt's crew (most of which occurred in Farmington Bay), more that 95% of the nests located in Farmington Bay successfully produced offspring. Similarly, 96% of the eggs that survived until time-of-hatching, successfully hatched. These values were similar to those found in Bear River National Migratory Bird Refuge and which are the highest success rates ever recorded in the nation. These high success rates, however, are partly attributed to the aggressive depredation program operated by the US Fish and Wildlife Service and Utah Division of Wildlife Resources. Notably, comparison of stomach contents with ambient macroinvertebrate sampling indicated that members of the macroinvertebrate families, Corixidae and Chironomidae (midges) were the most common prey

items. These were also the two most common taxa collected in sweep net samples throughout all of our study sites. In addition, the large flocks (often tens of thousands to hundreds of thousands of individuals), of numerous species of shorebirds observed to congregate and aggressively feed in the shallow sheetflows of Farmington Bay during fall staging adds further support for this conclusion. Characterization of juvenile habitat and forage preference was the final study performed which now provided a complete evaluation of the success of the each stage of the entire life history of resident shorebirds. This study, performed in 2007 and 2008 (Cavitt 2009) also indicated that the sheetflow wetlands were supporting the habitat and dietary needs of juvenile American avocets and black-necked stilts.

Throughout these studies and particularly since about 2004, a significant vegetative transition began to occur throughout the fringe wetlands surrounding the entire lake, including the shallow or "upstream" portions of the impoundments. It appears that as the water level receded and remained near historic low levels, exposure of lake sediments and flushing of the salts by rainwater or tributary runoff provided for a rapid successional change from the early colonization of more salt-resistant species, pickleweed (*Salicornia sp.*) and alkali bulrush (*Scirpus maritimus*), to the less salinity-tolerant and aggressively invasive *Phragmites australis*. Notably, the sparse pickleweed/alkali bulrush community comprises the most preferred nesting habitat for American avocets, black-necked stilts and other shorebirds and particularly when this plant community lies within about 20 m of freshwater flows. Yet, perhaps 100,000 acres or more of Great Salt Lake sheetflow and portions of impounded wetlands are now dominated by Phragmites and monicultural stands of this weed continue to invade sheetflow wetland areas. Replacement of these sparse stands of Salicornia and alkali bulrush, which includes shorebird rearing and fall staging areas, by Phragmites constitutes the single greatest risk to any of the Great Salt Lake ecosystems. In recent years intensive phragmites control programs, including herbicide spraying and controlled burning have begun in earnest by federal, state and private landowners and managers. Also, new studies have been initiated by the US Fish and Wildlife Service and others to understand the hydrologic, salinity and nutrient thresholds that allow phragmites invasion, the relative importance of seed germination vs rhizome growth in spreading and the rapid genetic and morphologic adaptations that are allowing the rapid spread of this weed. Toward this end, the Central Davis Sewer District has recently sponsored a project to understand the relationship between surface water flows across the sheetflow/mudflat areas, sediment and water column nutrient concentrations and other important sediment constituents such as heavy metals, salinity, total organic carbon and hydrogen sulfide. That study will begin providing insight into the potential for continued conversion from an alkali bulrush/Salicornia community to a Phragmites/cattail community and environmental factors that are contributing to this spread.

Research on nutrient dynamics and their relationship to various measures of the plant, invertebrate and waterfowl community health in impounded wetlands have continued since

2004. The first comprehensive report (Miller and Hoven 2007) suggested several metrics that should be evaluated for their sensitivity to disturbance and their importance in reflecting the success of important ecological functions or for assessing designated beneficial use support. These included:

1. Macroinvertebrate species composition and density (during nesting season and fall migration season).
2. Percent of Ephemeroptera
3. Percent of Chironomidae
4. Percent Odonates or clingers
5. Percent exotic and/or invasive plants
6. Submerged aquatic vegetation above ground biomass
7. SAV percent coverage
8. C:N:P ratios in phytoplankton and macrophytes
9. Chlorophyll a / macrophyte fluorescence
10. turbidity/ light penetration
11. Presence/composition of floating vegetation
12. Summer mean diel DO
13. Diel minimum DO
14. Water column and sediment H_2S measurements

More recent studies have begun to elucidate these factors, methods of measurement and their importance to ecosystem function and waterfowl support and these studies have culminated in the present report. For example, (1) macroinvertebrate species composition, density and biomass were carefully measured during four consecutive months to include the spring nesting season through the fall migration and are described in the present report and Gray (2011) sampled macroinvertebrates in the fall of 2010. Both of these studies revealed the importance of submerged aquatic vegetation (SAV) as a habitat requirement and primary driver dictating the presence of most of the invertebrate taxa. Further, the dominant invertebrate taxa in the samples (midges, corixids) were found to dominate the springtime dietary composition of several common ducks (mallards, green wing teal, gadwall; Cavitt 2011). (2) In turn, the fall diet is primarily comprised of sago pondweed drupelets and tubers and bulrush seeds. These data illustrate the importance and functional health of the current macroinvertebrate and plant communities in these impoundments. Further, quantitative measures of overall SAV density and drupelet production and tuber density are essential metrics in the assessment of impounded wetland plant health and as preferred waterfowl food items. Clearly, the SAV (mostly sago pondweed) serves multiple essential functions for a healthy impoundment ecosystem – both ecologically and for designated beneficial use support. (3) The percent of the species composition as Ephemeroptera (mayflies) has been considered valuable an indicator of stream water quality. However, the two species found in Great Salt Lake wetlands (Calibeatis

sp. and Cienas sp.) are among the most tolerant of the mayflies and also among the very few mayfly taxa that inhabit quiet waters. More importantly, however, these mayflies are “clingers” on the SAV and occupy the guild of “scraper” – feeding on the epiphytes that colonize the leaves of SAV. Therefore, the greatest driver in mayfly presence is the presence of SAV, not water quality. Similarly, odonates (dragonflies and damselflies) are clingers, however, they are predators on other macroinvertebrate species. Therefore, their presence also indicates that various trophic levels are being occupied in a predictive/healthy fashion. (4) The SAV community is comprised of native, noninvasive species. Contrary to the emergent vegetative community, the submerged plant community appears to be much more resistant to invasive species – or these impoundments are fortunate that species such as Asian milfoil have not yet been introduced. (5) Carbon:nitrogen:phosphorus (C:N:P) ratios (the Redfield ratio) in phytoplankton or the water column of lakes have long been used to estimate the limiting nutrient for phytoplankton growth. Similar measurements in macrophyte leaves have not shown any relationship to water column nutrients – likely because rooted plants, including aquatic macrophytes obtain their nutrients from soils or sediments. Our current research into pore water chemistry, including soluble forms of N and P, may provide a more realistic understanding of nutrient dynamics in macrophyte communities and this remains an area of active research in our group. (6) Light penetration was also identified as a potentially important factor in dictating plant health. Recent measurements of light penetration through algal and duckweed surface mats, and the SAV canopy and subcanopy has shown that, except for circumstances where the canopy “self-shades” the underlying leaves and stems, light is not limiting to plant growth and this is probably due to the overall shallowness of these impoundments. Secondly, surface mats vary with respect to thickness, and particularly with the ephemeral nature of their presence on pond surfaces. For example, these surface mats are generally composed of either the filamentous alga, Chladophora, or the floating macrophyte, duckweed (*Lemna minor*). Both types are frequently blown off pond surfaces during summer thunderstorms. In addition, as a green alga or Chlorophyte, Chladophora is susceptible to bleaching and death due to excessive exposure to UV light at the pond surface. These factors reduce the effectiveness of surface mats as either a stressor on the pond ecosystem or as a potential metric for evaluating overall ecosystem health. For example, drupelet and tuber production are not related to the presence of surface mats or the timing of fall senescence. (7) Photosynthetic activity, measured by the fluorescence of chlorophyll a, may reflect plant health and continual research by Dr. Heidi Hoven is being performed to evaluate this phenomenon as a potential assessment metric and an early indicator of plant stress. (8) Numerous diel measurements of dissolved oxygen have demonstrated that all of the Great Salt Lake impounded wetlands studied thus far are subject to tremendous daily fluctuations in DO. Even the identified oligotrophic reference ponds in Public Shooting grounds WMA ranged from 0.0 to > 25 mg/L within a 24-hour cycle. That said, the more eutrophic impoundments in Farmington

Bay generally spent more time at or near zero mg/L and low dissolved oxygen continues to be monitored for its potential as a potential driver of the macroinvertebrate community composition. However, the recent work of Dr. Gray (2011) and this present study indicates that the presence and overall plant density of the SAV in providing macroinvertebrate habitat is a primary factor in providing for a diverse macroinvertebrate community that represents the several guilds or trophic levels that are indicative of a healthy community. (9) The present study provides considerable evidence that several sediment-derived toxic metals and hydrogen sulfide are responsible for reduction or loss of several ecologically important macroinvertebrate species and measures of plant productivity, reproductive potential and waterfowl food production. These results are presented in several graphs and tables throughout the following reports that display negative correlations between metals and sulfides and various plant and macroinvertebrate metrics and measures.

This discovery begins to elucidate the apparent contradiction between management goals and environmental consequences, where lush production of SAV, and particularly sago pondweed and its associated production of drupelets and tubers are paramount to the attraction and support for waterfowl. Yet, natural fall senescence and accumulation of this organic material in the sediments has been occurring for many decades. Decomposition of this organic material has created very high sediment oxygen demand. In turn, this leads to sediment and water column hypoxia and subsequent mineralization and re-release of dissolved nutrients, metals and hydrogen sulfide into the sediment pore water and then into the water column. For example, water column P concentrations in the “upstream” Farmington Bay impoundments are consistently 1.5 to 3 times higher than Jordan River concentrations and impoundment ammonia concentrations are consistently nearly an order of magnitude higher than those in the Jordan River. Results presented in the following reports indicate that these sediment biogeochemical processes can cause significant adverse impacts to plant and invertebrate productivity and community structure. As such development of potential management strategies for controlling sediment toxics release should remain as a top priority in future research for these important wetland resources. As one example, periodic pond draining and drying appears to reverse the progression toward excessive anoxia and nutrient release by expediting the oxidation of organic matter and increasing the oxidation state and thereby reduce the solubility of toxic metals and sulfides.

These observations provide direction and priority in future research. We suggest the following studies for their ability to provide additional insight into important ecological functions as well as meaningful indicators of beneficial use support:

1. Continue research to gain a better understanding of the conditions which allow the spread of Phragmites. These include:

a. Sediment moisture, nutrient, salinity and organic carbon concentrations and how these influence the spread of phragmites with respect to rhizome vs seed germination. Of particular interest is whether sediment nutrient, concentrations already exceed thresholds for phragmites proliferation and other ecosystem regime change points. This understanding will facilitate the pursuit of other potential strategies for phragmites control.
b. Perform genetic studies to understand the role that genetic mutations play in developing local genotypes and phenotypes that improve phragmites survival and spread. These studies may assist in developing future treatment for phragmites control.
c. Continue sediment physical and chemical analysis in the impoundments to better understand the link between pore water TDS, nutrient, metal and hydrogen sulfide and various indicators of plant health and drupelet and tuber production.
    i. Secondly, we need a better understanding of the relative importance of these sediment characteristics and fluxes between their influence on plant abundance and health (i.e. habitat quality) – as a predictor of macroinvertebrate community health verses the direct stress of these toxics on the invertebrate community. Although this may appear as a subtle point, it is vastly important to understand the importance of these potential covariables in developing future metrics that accurately reflect ecosystem function and beneficial use.
d. Finally, as we gain a better understanding of the dietary needs of waterfowl and shorebirds and the seasonal changes in their dietary habits, it is imperative that we continue intensive monitoring in order to ensure the long-term presence and quality of food items, understand seasonal and annual variability of these items, and as a long-term monitoring tool that will help in predicting changes that may influence ecosystem function and potential impacts to the waterfowl and shorebirds that depend on these resources.