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WETLAND MODELING AND INFORMATION NEEDS AT STILLWATER NATIONAL WILDLIFE REFUGE

by

David B. Hamilton
Gregor T. Auble

U.S. Fish and Wildlife Service
National Ecology Research Center
4512 McMurry Avenue
Fort Collins, CO 80525-3400

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INTRODUCTION

Workshop Objectives and Approach

The marshes in and around Stillwater National Wildlife Refuge (the Refuge) are extremely dynamic; expanding and contracting in size both seasonally, due to runoff and subsequent evapotranspiration, and over longer periods, due to climatic variation. The dynamic nature of these marshes results in a diversity of wetland habitats, which support a variety of migratory birds. To maintain this wetland diversity and control the loss of migratory bird habitat in the Lahontan Valley, the Refuge was established and currently manages a complex of marsh units. However, changes in the hydrology, and changes that will occur as a result of the Fallon Paiute-Shoshone and Truckee-Carson-Pyramid Lake Water Rights Settlement Act (Public Law 101-618, 104 Stat. 3389), greatly affect the Refuge's wetland management capability. In light of these changes, and the legal requirements associated with environmental impact assessments, the Refuge convened a workshop to discuss several aspects of wetland management in the Lahontan Valley. The workshop, described in this report, had three primary objectives:

1. discuss the types and relative proportions of primary wetland habitats that should be provided as described in the settlement act;
2. discuss wetland management models that might be developed to help manage these marshes under hydrologic regimes likely in the future; and
3. discuss future information and monitoring needs, including proposals for valley-wide biodiversity surveys, which would be helpful when considering withdrawn Bureau of Reclamation (BR) lands for possible incorporation into the Refuge.

Several presentations at the beginning of the workshop provided a common basis for discussing these objectives. Refuge staff provided background on the history and past management. The Nature Conservancy discussed their role in the settlement act, proposals for valley-wide biodiversity surveys, and results of a literature review for Stillwater Marsh and the Lahontan Valley (Nachlinger 1993). Kay Fowler provided an historical context of changes in vegetation and waterbird use of the marshes based on her ethnography of the local Paiute Indians (Fowler 1993). Finally, Bob Elston discussed a model that predicts archaeological sites based on environmental variables (Raven and Elston 1989).

The workshop was organized by staff from the Refuge and facilitated by the authors of this report. Participants included Ron Anglin, Bill Henry, Anne Janik, Cliff Creger, Fred Paveglio, and Mary Jo Elpers of the U.S. Fish and Wildlife Service (the Service); Jeff Baumgartner, Jan Nachlinger, Hope Humphries, and Graham Chisholm of The Nature Conservancy; David Yardas of the Environmental Defense Fund; David Robertson of Robertson Software, Inc.; Norm Saake, Terry Retterer, and Larry Neel of the Nevada Department of Wildlife; Lew Oring and Kay Fowler of the University of Nevada; and Robert Elston of Intermountain Research.

Background

The marshes in the Lahontan Valley of Nevada are terminal wetlands at the end of the Carson River (Figure 1). Much of the following background information on these wetlands has been summarized from Anglin and Shellhorn (1992). The marshes expand in size in the spring because of runoff from the adjacent mountains and contract through the summer due to evaporation and transpiration, often leaving alkaline flats. They also expand and contract as a result of longer-term climatic conditions. For example, the marshes extended over approximately 215,000 acres during the 1984-85 flood but are almost completely dry currently due to drought conditions since then. It is this dynamic nature of the water regime, both within and among years, that maintains these marshes. When they are wet, these marshes are among the most productive wetlands in the world. This productivity and the diversity of wetland habitats support a variety of migratory birds, including ducks, geese, pelicans, marsh birds, and shorebirds, as well as indigenous mammals, reptiles, and amphibians. As the marshes dry out, concentrations of salts and trace elements may increase to toxic levels, killing fish and other species unable to migrate. When the wetlands are dry, sediments are consolidated and aerated, salts encrusted on the surface are blown away, and plant succession is set back.

Terminal wetlands of the Great Basin in general, and marsh units at the Refuge in particular, are composed of a series of ponds or management units whose progressive expansion and contraction explains the diversity of wetland habitats. For explanatory purposes, consider the four ponds shown in Figure 2. In early spring, fresh water (i.e., 200-400 μmhos/cm) from snow melt initially fills pond A. As the runoff continues, the down-gradient ponds B, C, and D are progressively filled. As water enters each pond, it dilutes (freshens) any residual water from the previous year. However, mixing

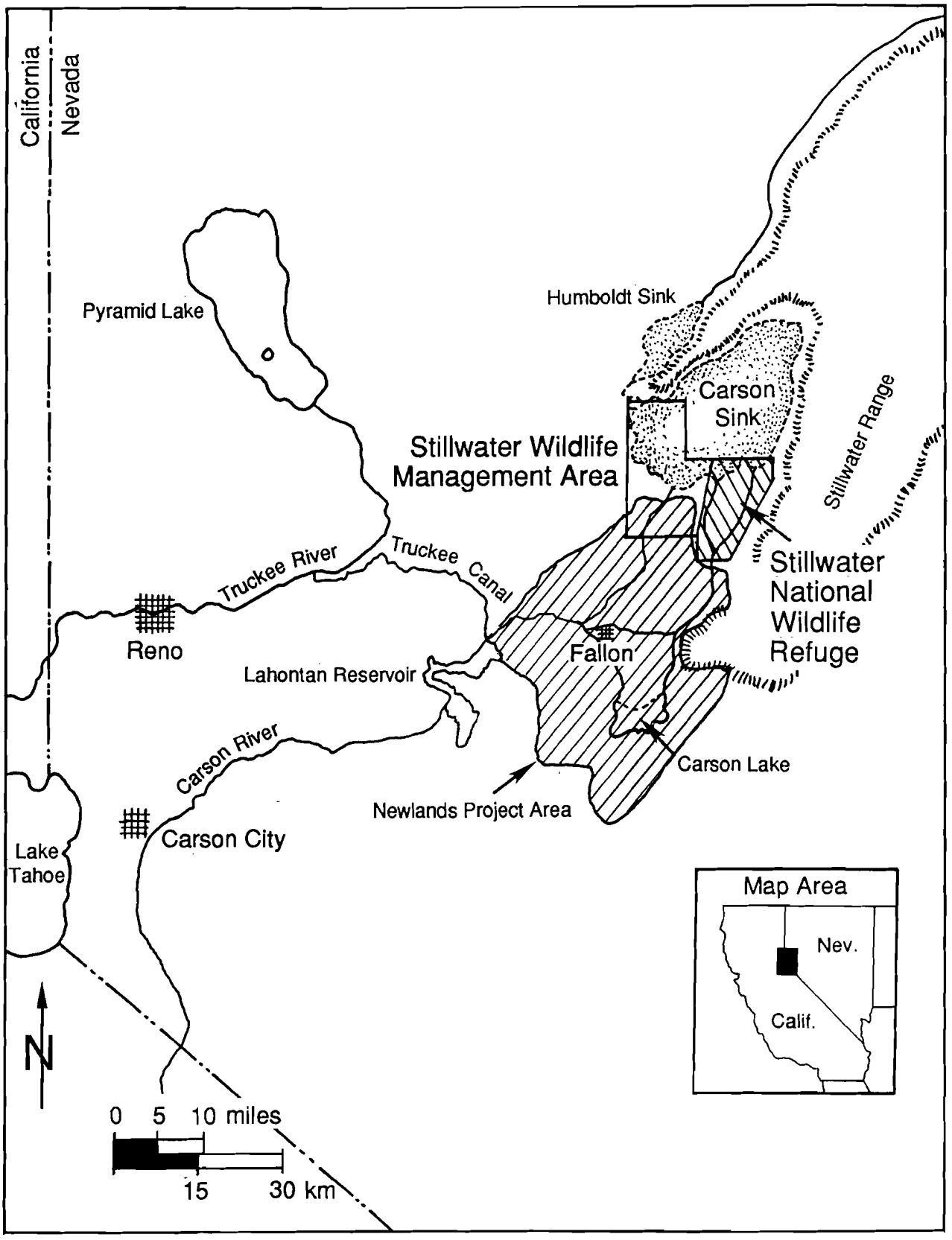

Figure 1. Stillwater National Wildlife Refuge and vicinity.

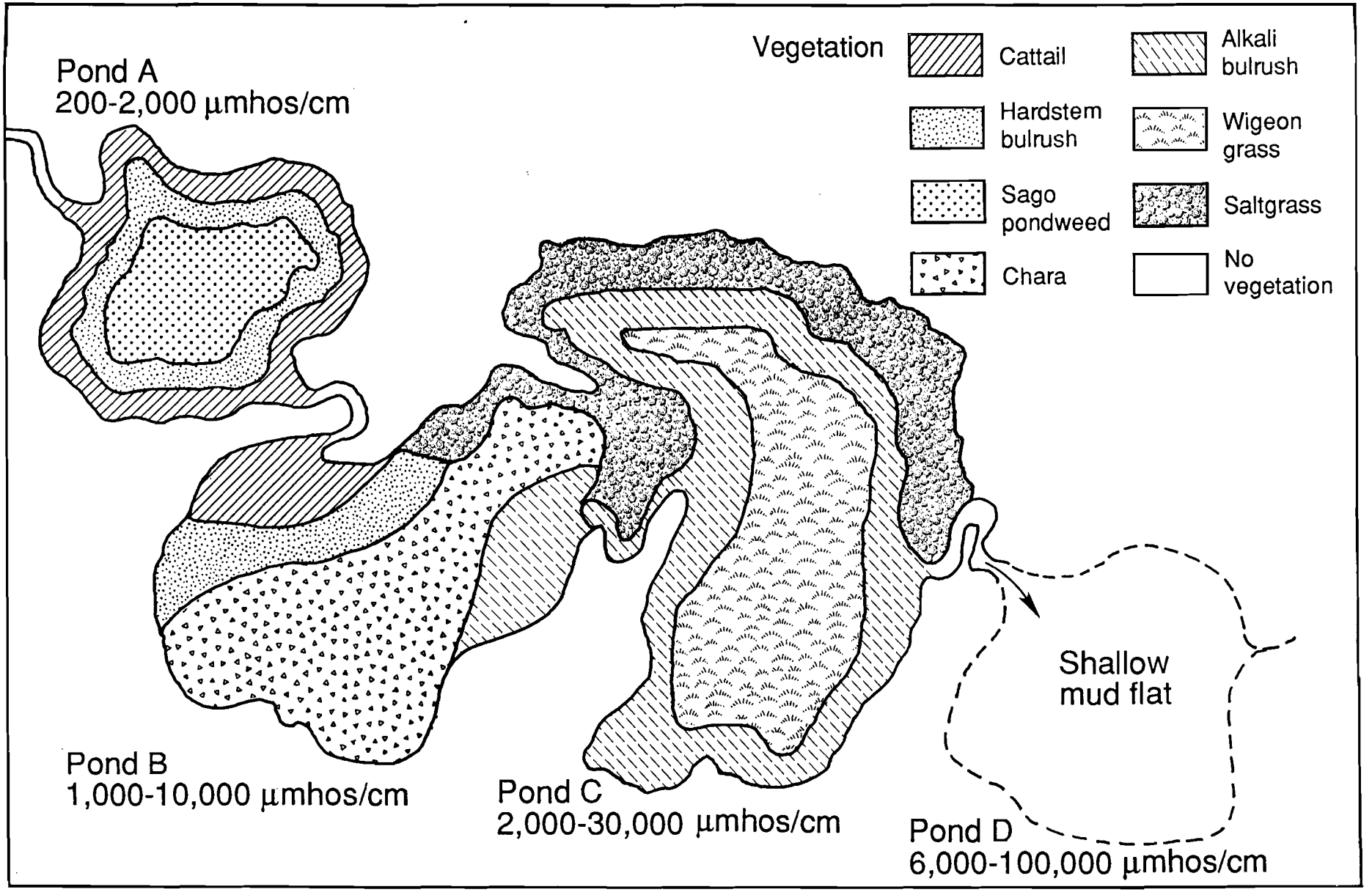

Figure 2. Hydrologic regimes of Great Basin wetlands.

with residual water and contact with salt encrusted alkaline soils of dry ponds means that water quality is degraded and runoff to the next pond is more saline. By the end of spring runoff, water in the lower ponds may have a specific conductance of 6,000 - 10,000 μmhos/cm. During the summer, evaporation concentrates the salts and the ponds begin to contract. Pond D will dry out first with specific conductance reaching levels of 100,000 μmhos/cm before becoming a salt-encrusted playa. As a result of the drying and high salinities, little, if any, vegetation is found in these lower ponds. However, these ponds are extremely productive in terms of invertebrate populations during the summer when they have water. Pond C will dry out next, but may maintain moist soil conditions into the winter. Specific conductance may be as high as 30,000 μmhos/cm. Salt-tolerant plants such as saltgrass, alkali bulrush, and widgeongrass will be found in this pond. Pond B will often still have shallow water at the end of the summer with specific conductance ranging from 1,000 - 10,000 μmhos/cm. Salt-tolerant species such as alkali bulrush and chara may be found nearer the outflow and less salt-tolerant species such as cattail and hardstem bulrush near the inflow. Except in years of extreme drought, Pond A will be maintained as a permanent marsh with reasonably good water quality. Typical vegetation includes cattail, hardstem bulrush, and sago pondweed. Thus, ponds in the marsh progress from relatively permanent with fresh water at the upper end to more ephemeral and saline at the lower end. Historically, spring flows entered the marsh through the Stillwater Slough and flowed clockwise through the various marsh units (Figure 3). Thus, the units associated with the Canvasback Gun Club were typically the most permanent and freshest, while Goose Lake was the most ephemeral and saline (units south of Division Road were not created until after the Refuge was established).

The natural hydrologic regime of marshes in the valley was altered in 1915 when Lahontan Reservoir was constructed. Waters below the dam were routed through a network of channels instead of flowing through natural channels. For example, much of the water now entered through the Diagonal Drain and flowed counterclockwise through the marshes. While drain water from irrigated lands in the Newlands Project still reached the marshes, flows were more constant over a longer period in the summer, corresponding to the irrigation season, rather than arriving as a large volume of flow in the spring. In addition, approximately half of the Truckee River flow, on average, was diverted to Lahontan Reservoir for irrigation use in the summer and power generation in the winter. These changes altered the composition and cover of the marsh vegetation. For example, Dave Marshall, the first refuge biologist, estimated that between 1900 and 1952, the

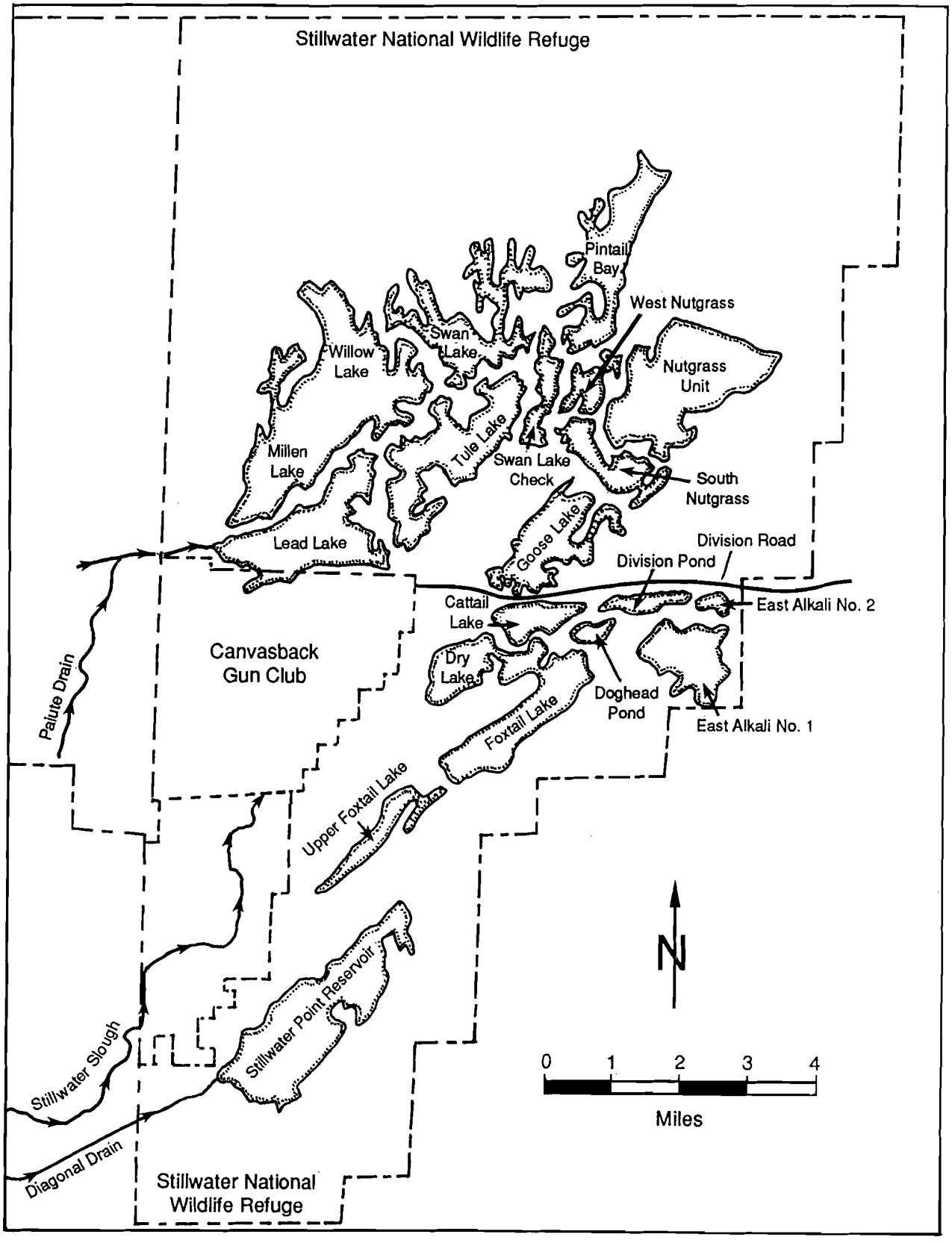

Figure 3. Marshes at the Stillwater National Wildlife Refuge.

acreage of hardstem bulrush was cut in half while the acreage of cattails almost tripled (U.S. Fish and Wildlife Service 1952).

In 1948, in an effort to control the loss of migratory bird habitat in the Lahontan Valley, the U.S. Fish and Wildlife Service, the Nevada Fish and Game Commission, and the Truckee-Carson Irrigation District entered into an agreement to manage the marshes. In order to best use available water resources, approximately 30 miles of dikes and 70 miles of canals and ditches were constructed, and over 200 water control structures were installed. Most of the wetland management units south of Division Road were created as a result of this development. With these facilities, the Service was able to manage drain flows and maintain a diversity of wetlands.

The hydrologic regime of marshes in the valley was further modified in the late 1960s when a Department of Interior Task Force recommended stopping all diversions from the Truckee River for winter power generation and limiting the maximum allocation of irrigation water for the Newlands Project to 406,000 ac-ft. Without winter power generation, large volumes of good quality water were no longer available to flush salts from the marsh or support the warm water fishery and muskrat trapping created as a result of managing waterfowl nesting habitat. The reduced volume of irrigation drainwater was no longer adequate to maintain the marshes as they had been developed in the late 1940's, and the wetland habitat subsequently decreased.

The Fallon Paiute-Shoshone and Truckee-Carson-Pyramid Lake Water Rights Settlement Act, passed in 1990, contains a number of provisions related to wetland resources in the Lahontan Valley (Yardas 1992). The act directs the Secretary of Interior to sustain approximately 25,000 acres of primary wetlands in the Lahontan Valley in order to conserve fish and wildlife resources and maintain and restore biological diversity. The primary wetlands include approximately 14,000 acres of marsh at the Refuge, 10,200 acres at Carson Lake, and 800 acres in the Fallon Indian Reservation. The Secretary was authorized to acquire Newlands Project irrigation rights to meet this objective. An Environmental Impact Statement (EIS) concerning the water rights acquisition is due in 1993. The acquisition authorities were modeled after an existing program involving the Nature Conservancy and the U.S. Fish and Wildlife Service. In this program, the Nature Conservancy acquired marginal farmland within the Newlands Project, took it out of production, and transferred the associated water rights to the Refuge. In some cases, taking marginal farmlands out of production may have an added benefit in that the

associated waters no longer contain the elevated levels of arsenic, boron, and other heavy metals typically leached out of the soils through irrigation. However, differences in the relative contributions of various marginal farmlands to water quality problems in the Lahontan Valley are not currently well understood. The act also provides for the expansion of the Refuge, including possible incorporation of withdrawn BR lands. An EIS on this expansion must be completed by 1997.

The next three sections of this report summarize the discussions associated with each of the workshop objectives; types and proportions of primary wetland habitats, wetland management models that might be developed, and future information and monitoring needs. The final section of the report summarizes workshop conclusions and recommendations.

REFUGE OBJECTIVES AND WETLAND COMMUNITIES

Refuge Objectives

Current Refuge objectives address the following six basic elements:

- Production of redheads; white-faced ibis; shore and water birds; and waterfowl.
- Maintenance of redheads and canvasbacks; tundra swans; waterfowl; white-faced ibis; white pelicans; and shore, marsh, and water birds.
- Maintenance of bald eagles and peregrine falcons.
- Wildlife diversity.
- Public use.
- Cultural resources.

At some refuges, numeric objectives for fish and wildlife use-days or production provide clear criteria for both planning and operational management decisions. There was some discussion at the workshop concerning how rigidly to interpret current Refuge objectives. In particular, it was suggested that current Refuge objectives reflect an earlier hydrologic regime in which the Refuge was receiving more water and was receiving water in an unnaturally uniform temporal pattern because of power generation, large irrigation return flows, and spills from the irrigation delivery system. Thus, current Refuge objectives may weight species dependent on deep and semi-permanent marsh habitats more than would be appropriate with either a natural (pre-development) hydrologic regime or with the current hydrologic regime. On the other hand, the ability to call for deliveries of acquired water rights at specific times, as well as the internal water delivery system and multiple marsh units, provide flexibility in the types of habitat that could be provided.

There was also discussion at the workshop concerning how current or future Refuge objectives related to the potentially broader biodiversity goals in the settlement act. One position was that biodiversity goals could be expressed and tracked through

target vertebrate species. Another position was that large scale surveys of the Lahontan Valley were needed as a reference to formulate specific biodiversity objectives for the entire 25,000 acres of primary wetlands (i.e., to determine which wetland habitats and communities most need protection or enhancement). We did not resolve these issues at the workshop, either in terms of reformulating existing Refuge objectives or by identifying the areas of specific types of habitat that should be represented in the 25,000 acres of primary wetlands. Rather, we used current Refuge objectives as a general indication of the species the Refuge was trying to support and thus of the types of habitat that would be required in at least a substantial part of the 25,000 acres of primary wetlands.

Habitat Types and Conditions

Marsh management at the Refuge consists largely of providing particular combinations of vegetation and water levels that constitute habitat for various species groups. Anglin and Shellhorn (1992) summarized the general marsh habitat types of Great Basin wetlands in terms of water depth and vegetation and identified representative species associated with these habitats. The basic habitat types considered at the workshop included: uplands, mud/alkali flats, saltgrass meadow, emergent marsh (shallow and deep), and submergent marsh. Figure 4 illustrates the water depths, characteristic vegetation, and wildlife food resources associated with these habitat types. Discussion at the workshop modified the species distributions slightly from Anglin and Shellhorn's original diagram. Figure 5 shows the habitats used by various bird species for nesting, and thus those habitats contributing to avian production objectives. Figure 6 summarizes feeding habitat preferences (maintenance objectives) for a number of species. Eagle habitat consists of perch trees and food. Food in the form of young birds or fish would be provided across all the habitat types.

Hydrology and water quality are the dominant factors determining marsh vegetation. However, the relationship between hydrology and vegetation in these systems is complex and variable. In workshop discussions of water quality as it affected plant distributions, we used salinity, total dissolved solids (TDS), and conductivity interchangeably, though we recognized that the relationships between these variables were not precise. Plant species have different optima and ranges of tolerance to both water depth and salinity. We developed several tables at the workshop to identify how much

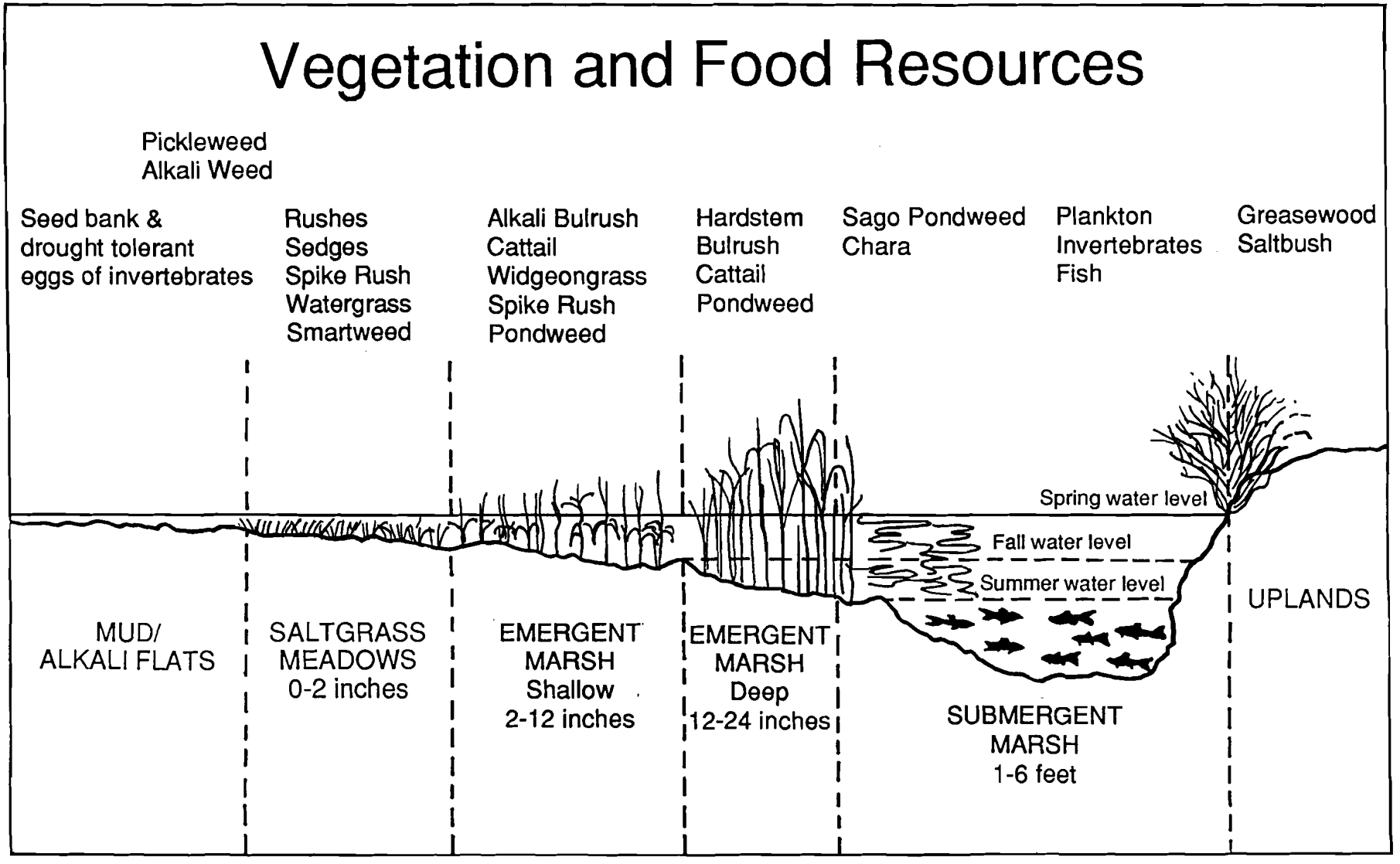

Figure 4. Vegetation and food resources of Great Basin wetlands.

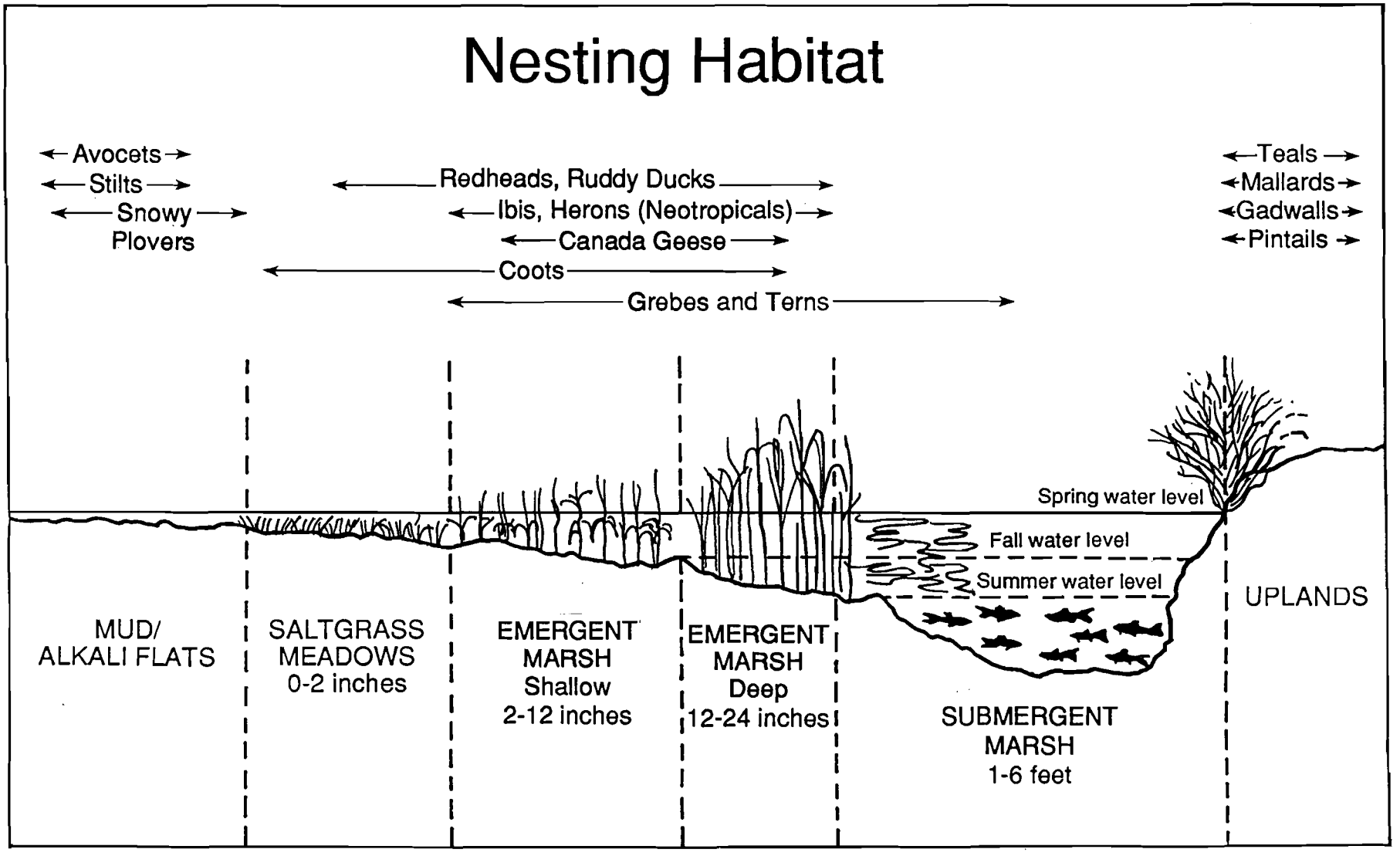

Figure 5. Nesting habitat of Great Basin wetlands.

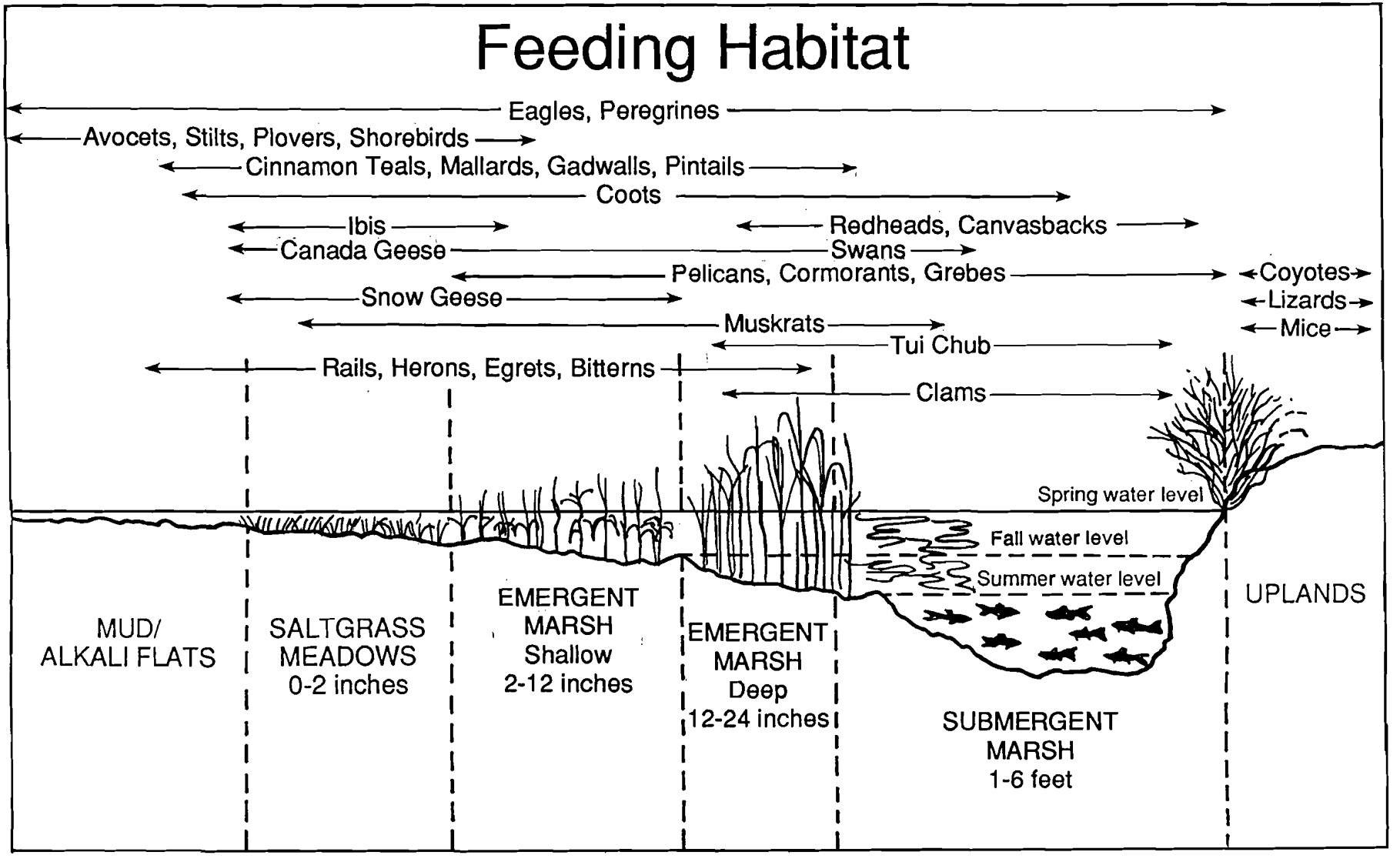

Figure 6. Feeding habitat of Great Basin wetlands.

was known about the salinity and water depth distributions of important plant species at the Refuge. Table 1 lists conductivity (as a surrogate for salinity) ranges for submergent aquatic vegetation which are found primarily in the submergent marsh habitat type. Table 2 lists the conductivity ranges associated with "moist soil" plants that typically occur on drier sites representing the mud/alkali flats and saltgrass meadow habitat types. However, these plants require moist soil to germinate and will tolerate shallow inundation.

Table 1. Conductivity distribution of submergent and floating aquatic plant species.

Conductivity range (µmhos/cm)		
200-2,000	2,000-10,000	10,000-50,000+
horned pondweed	sago pondweed	widgeongrass
curly pondweed	Western pondweed	chara
Lemna		

Table 2. Conductivity distribution of moist soil plant species.

Conductivity range (µmhos/cm)		
200-2,000	2,000-10,000	10,000-50,000+
saltgrass	saltgrass	saltgrass
watergrass	pickleweed	pickleweed
smartweed	bassia	bassia
kochia	swamp timothy	
swamp timothy	smartweed	

Finally, Table 3 summarizes the distribution of emergent plant species with respect to both water depth and conductivity. These species would occur primarily in the shallow and deep emergent marsh habitat types. Although cattail and hardstem bulrush persist

in the intermediate, 2,000-10,000 μmhos/cm conductivity class, they require the fresher water conditions of the 200-2,000 μmhos/cm class to become established.

Table 3. Distribution of emergent plant species by water depth and conductivity.

Water depth (feet)	Conductivity (μmhos/cm)		
	200-2,000	2,000-10,000	10,000-50,000+
0-1	reed arrowhead spike rush cattail alkali bulrush hardstem bulrush rush sedges	cattail alkali bulrush hardstem bulrush	alkali bulrush
1-2	cattail alkali bulrush hardstem bulrush	cattail alkali bulrush hardstem bulrush	alkali bulrush
2-3	cattail hardstem bulrush	cattail hardstem bulrush	

Much of the spatial and temporal pattern of salinity in these marsh areas is produced by the progressive concentration of salts from evapotranspiration. Downstream units tend to have higher concentrations because they are receiving flows that have already been subject to evapotranspiration in upstream units. Similarly, concentrations tend to increase from spring through the summer as water levels and volumes decline because evapotranspiration losses are exceeding inflows of water. Finally intra-unit variations in salinity result from imperfect mixing.

Discussion

The focus of the workshop was on evaluating the utility of existing information and identifying potential new information to support the planning and management decisions facing Stillwater Refuge, rather than producing a definitive analysis of habitat types and vegetation patterns. From this perspective, the development and discussion of Figures 4-6 and Tables 1-3 at the workshop provided substantial insight into how much is known concerning species-habitat relations for the Refuge management units. In particular,

- Habitat preferences are reasonably well defined for a variety of animal species, including the target species (primarily migratory birds) identified in current Refuge objectives.

- Wildlife habitat preferences are expressed in terms of cover types defined in terms of combinations of water depths and vegetation.

- Vegetation differences can be reasonably well predicted by differences in the environmental variables of water depth and salinity, with conductivity and total dissolved solids serving as surrogates of salinity. Complicating factors include preexisting vegetation and the sequence or timing of hydrologic conditions.

- Current management and planning of the marsh systems in the Lahontan Valley is most limited by the ability to forecast the environmental conditions of water depth and salinity that would be created in different units as a result of water management decisions, rather than the ability to relate those environmental conditions to vegetation or to relate the resulting habitat to animal species responses.

Other sources of information about environmental conditions, vegetation, and habitat utilization of Lahontan Valley wetlands include ethnographic studies of historical use and knowledge of marsh resources by native Americans (Fowler 1993; Raven and Elston 1989), published surveys of the area (Billings 1945; Marshall 1949, 1952), and Refuge monitoring records. The biological literature on Lahontan Valley wetlands was considered limited in scope and spatial scale (Nachlinger 1993). Refuge monitoring records are a rich source of data on trends in marsh vegetation, hydrologic and salinity

conditions, and wildlife utilization within the Refuge. Deficiencies of the monitoring records include temporal gaps, inconsistent and weakly documented sampling protocols, and their restricted spatial focus of Stillwater Refuge marsh units as opposed to the larger set of Lahontan Valley habitats. A strong argument was made at the workshop that more information on the occurrence and species composition of wetland habitat types in areas outside the Refuge is needed to support the formulation of habitat objectives for the entire 25,000 acres of primary wetlands.

WETLAND MANAGEMENT MODELS

Management of Refuge marshes involves manipulation of inflows, and thus water depths, to management units in order to create or maintain the wetland communities and associated salinity conditions described in the previous section. Given a limit to the water rights the Refuge will be able to acquire in the future, and the complexity of the current water delivery and management system, various wetland models have been proposed to help refuge staff manage the marshes. Workshop participants discussed these models and decided that a water management model was necessary to make best use of available water in the future. Discussions during the workshop helped refine the specifications for such a model. This model might eventually be linked to a wetland vegetation model or a geographic information system (GIS) to predict acreage of different vegetation types flooded during the year.

Water Management Model

In order to better specify the type of water management model required, workshop participants discussed the spatial and temporal resolution of the model, the management actions the user should be able to manipulate in the model, the output variables the model should provide to the user, and the input data required. The following sections summarize participants' preliminary decisions concerning each of these aspects.

Spatial resolution

Spatial resolution involves both the overall area represented by the model and the extent to which that area is subdivided. Although the Refuge currently has management authority only for marsh units within it's boundaries, it was recommended that a water management model represent a larger area encompassing the Refuge, including the Canvasback Gun Club, the Fallon Indian Reservation, and Carson Lake. This area was suggested because of language in the settlement act concerning maintenance of 25,000 acres of primary wetlands and potential expansion of the refuge boundaries. The model should represent individual management units within this area. For the Refuge and the Canvasback Gun Club, these are the units specified in Figure 7. Management units on the Indian Reservation and within Carson Lake will have to be added to this diagram.

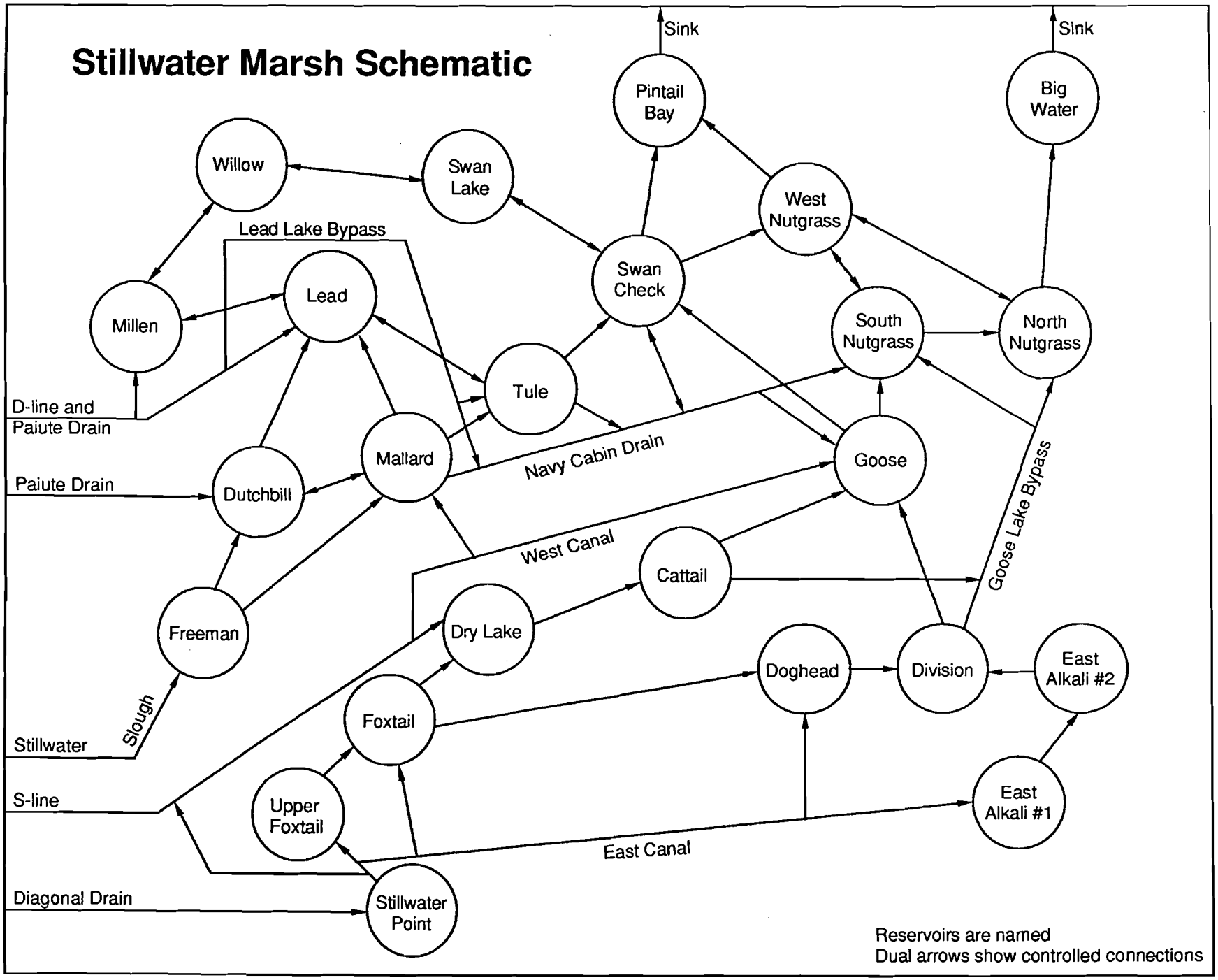

Figure 7. Stillwater Marsh schematic.

Temporal resolution

Temporal resolution involves both the time frame represented by a run of the model and how often output variables should be calculated during that time frame. The primary purpose of this model would be to help refuge staff develop annual management plans for the various marsh units. Therefore, users should be able to run the model for a one-year time period. However, multiple-year runs should also be possible in order to evaluate longer-term consequences of management decisions.

Participants decided that monthly calculations of output variables would be sufficient to develop and evaluate management plans. However, the model might have to use daily or weekly input variables and calculations to maintain hydrologic integrity (e.g., a calculation based on average monthly evapotranspiration could result in the "loss" of more water than a unit contained during that month).

Output variables

For each management unit, the model should, at a minimum, provide monthly calculations for surface acres flooded, surface elevation, and water depths in specific spatial zones. The water depth in specific spatial zones is especially important because it would allow refuge staff to integrate information concerning wetland plant germination, current vegetation composition, and wildlife habitat needs with predictions of water level changes associated with proposed management actions. For example, knowing when a certain spatial zone will be a mudflat would allow refuge staff to predict the type of vegetation that may germinate in that zone in the coming year. Knowing when existing zones of vegetation will be flooded to different depths would provide information on potential nesting and brood rearing cover. Such depth information would also allow an assessment concerning volume of water used per unit area of habitat created. A water management model that does not consider spatial zones within a unit would not provide adequate information. For example, consider the diagrams of water depths in Figure 8. A model that provided a monthly depth profile for the unit as a whole, rather than for spatial zones, would only be able to tell the user that the surface area flooded 0-1 ft deep was the same in June as it was in May and that the total surface area flooded had decreased. However, refuge staff need to know, for example, that the outer zone was flooded in May but not in June.

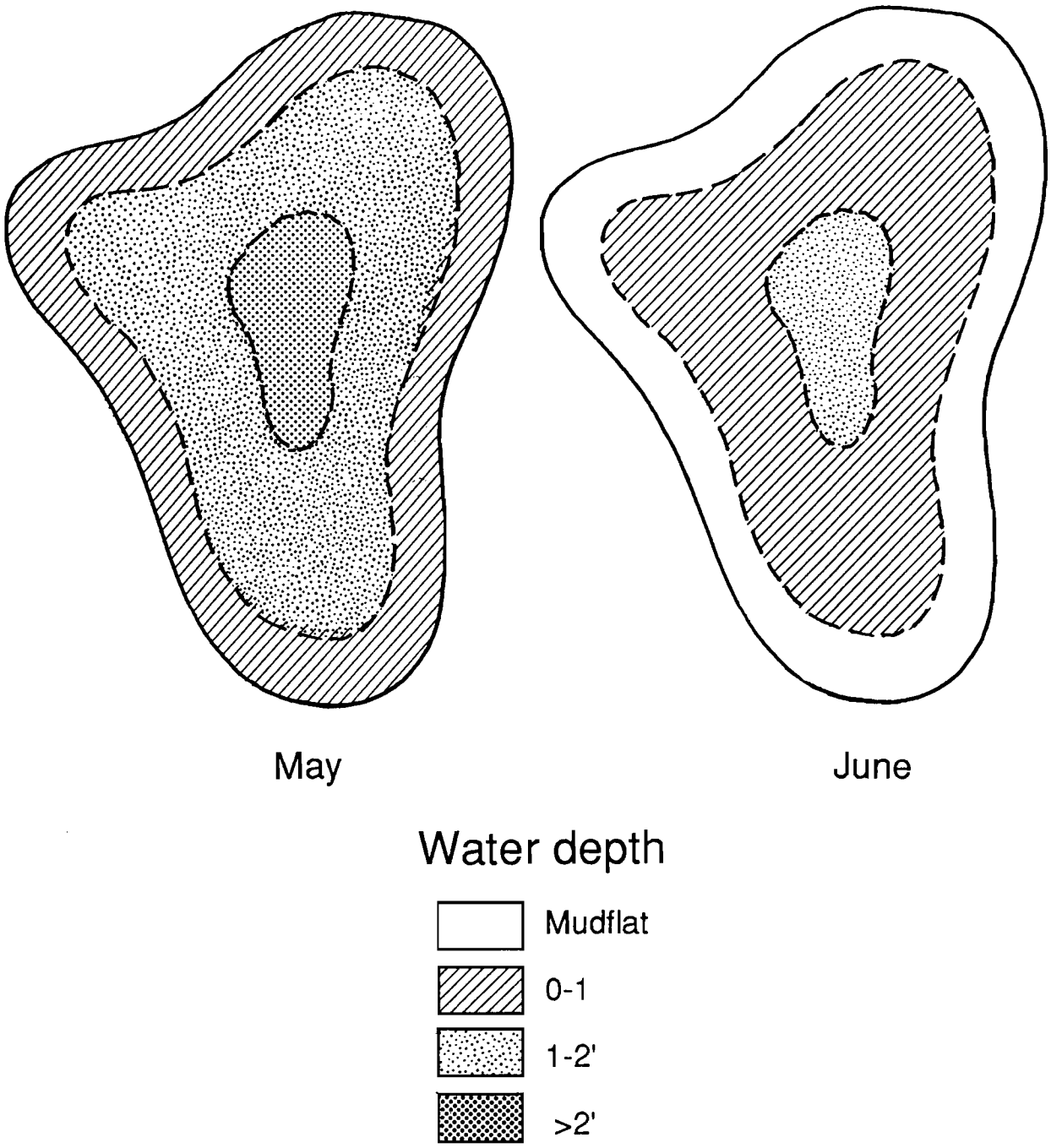

Figure 8. Water depth zones in a hypothetical wetland management unit.

Several options for providing information concerning water depths in spatial zones were discussed. First, each unit could be subdivided into concentric zones, perhaps based on 6-inch depth increments. Model output would then consist of the average water depth in each of these zones each month, which would be integrated with information on existing vegetation and plant germination requirements by refuge staff. This option should be implemented initially because it is the least costly and uses the same bathymetry information required for other outputs described above. This option might also provide output that could be easily linked to a geographic information system. Second, a vegetation simulation model could be developed that used water depth and TDS information from the water management model to explicitly predict vegetation composition and depth of inundation for concentric bands in each management unit. Such a model could produce output information on acreage/depth for each vegetation community (e.g., acres of cattails flooded 0-1 ft deep, acres of cattails flooded 1-2 ft deep). A final option would be to link output from the water management model to a GIS. The GIS would contain spatial data on vegetation in each unit. Output from the model could be used to display water depth profiles for each unit. By overlaying these two data themes, the GIS could produce estimates of the acres of each vegetation type in each of the water depth classes. While this option may not be implemented initially, care should be taken when developing the water management model to ensure that model output can be easily imported into the GIS and converted into appropriate depth profiles.

The model should also be able to predict average TDS in each management unit. Although TDS gradients develop within management units, it will not be possible to incorporate such complexity in the water management model initially. Instead, the model will assume complete mixing within a unit and conservation of salts (times a factor to crudely account for various losses). If the model results are not adequate, then refinements such as explicitly accounting for salt becoming encrusted on the surface as units dry out, deflation, and seepage losses will be considered. Incorporating a more explicit TDS accounting component, assuming that baseline data exist, would greatly increase the complexity and cost of a wetland management model.

Management actions

The model should allow the user to manipulate the timing, amount, and source of water deliveries to each management unit. This might be implemented by having the user specify target volumes (or surface acres flooded), and perhaps target TDS levels, for each

unit for each month of the year. If a unit was below its target volume, or above its TDS target, the model would try to reach the target by "calling for" water deliveries, subject to constraints on remaining water rights as predicted by the Bureau of Reclamation and the Below Lahontan Reservoir hydrology models. If a unit exceeded its target volume, the model would try to spill excess water into ditches or down-gradient management units.

At a minimum, the model should represent the current delivery and management system. It would be nice if the model also provided the capability to close down some existing ditches (as has been proposed based on contaminant issues) or to add a few additional connections (e.g., Diagonal to East Canal).

Input data

Three general categories of input data are needed for this type of model. First, data would be entered by the user for each model run to represent initial conditions and proposed management actions. These data would include volume and TDS for each unit at the beginning of the year, volume and TDS targets for each unit for each month, and the configuration of the water delivery system (i.e., what ditches and connections between units are possible for this model run). Second, basic capacities and characteristics of the units and water management system would be required, but would remain fairly constant unless new construction or dredging was done. These data would include depth/area curves for each unit (depth/volume can be calculated from depth/area), stage/discharge curves for water control structures, capacities of delivery ditches, and monthly evapotranspiration rates by unit or vegetation community. Finally, predictions of monthly water availability would be provided by other hydrologic models and would serve as constraints as the model tries to meet monthly targets.

Hardware Considerations

The wetland management model should be developed so that it is user-friendly and can be run by staff on computers at the Refuge headquarters. While initial work on a water management model (e.g., development of general structure, demonstration of feasibility and utility) should utilize a hardware/software platform that allows for rapid prototyping and development, it is strongly recommended that the final model be delivered on an IBM-compatible platform. If the model is to be linked with a GIS as described above, then the model should contain an option for generating output in a

format compatible with the GIS hardware and software. Hardware and software standards for GIS applications in Region 1 are currently being developed.

Data Needs

The wetland management model outlined above is based on a relatively simple mass balance calculation of water in connected units. Inflows of water (precipitation, surface inflow, subsurface inflow) are balanced with outflows (evapotranspiration, surface outflow, subsurface outflow), with change in storage accounting for any difference in inflows and outflows for each unit. The accuracy of the model will depend on how well these inflows and outflows can be estimated. Direct precipitation is a relatively small flow and can probably be reasonably estimated from precipitation records at least for a monthly time step. Assuming surface flows can be accurately estimated from measurements or from the results of water management decisions, the two most critical variables are evapotranspiration and subsurface flow.

Subsurface flow

Subsurface flow is difficult to measure directly and is most easily obtained by difference after the other flows and change in volume have been measured. However, in a modeling context there will have to be some calculation of what subsurface flow would be under various conditions. The most convenient situation would be if subsurface flow is small enough relative to other flows that it could be ignored. The U. S. Geological Survey is currently measuring surface inflows and outflows, change in storage volume, and water tables in adjacent wells for one Refuge management unit. Details of this study were not available at the workshop, but the results may identify the relative importance of subsurface flow or at least suggest a combined estimate of subsurface flow (most likely a net loss) and evapotranspiration.

Evapotranspiration

There are many formulae for modeling the rate of evapotranspiration, ranging from a simple partitioning of an annual total to complex equations incorporating solar radiation, wind speed, cloud cover, humidity, and vegetation. Field measurements consist of 1) a standard pan evaporation station for estimating evaporation from a defined open water

surface and 2) difference methods that account for all the other flows and changes in storage and then attribute the residual to evapotranspiration.

The very high rates of evapotranspiration in the Lahontan Valley make evapotranspiration an extremely important part of a water budget calculation. Accordingly, workshop participants recommended that standard pan evaporation stations be established at Stillwater Refuge and Carson Lake. The nearest existing station has a somewhat different microclimate than the marsh sites and there has been a continuing controversy about the appropriateness of using off-site pan evaporation data. This seemed an issue that could be resolved with some relatively straightforward measurements. If a reasonable relation could be developed among stations there would be no need to continue to maintain all the stations over the long term.

However, accurate pan evaporation measurements or estimates do not solve the whole problem. Pan evaporation data must be combined with some type of water budget monitoring of actual units in order to estimate the factor or factors relating pan evaporation to the actual evapotranspiration from real marsh units. Practically, such factors may also end up incorporating some part of net subsurface flow as well because of the difficulty of independently measuring these rates in the field with difference-based methods.

Bathymetry

Good bathymetry, or topographic data, on the marsh units is important to a water budget model for several reasons. This is the basic information used to relate the volume of water in a unit to water surface elevation, or stage, and to the surface area of the unit. Stage-volume curves allow volume changes to be tracked from the easily obtained stage readings and convert model predictions of volume to water depth, which is a more meaningful habitat variable. Area-volume curves relate volume to wetted surface area, which is also an important habitat variable. Wetted surface area is also a critical variable in the water balance calculation itself because of its influence on total evapotranspiration losses. Rates of evapotranspiration are estimated as a quantity of water per area. This rate is then multiplied by the respective area of open water or wetted vegetation to obtain the total loss from the unit for some time interval. Thus the shape of the area-volume curve can have a substantial influence on the water balance of a unit by determining whether a given volume is spread over a large area and subject to high total

evapotranspiration losses, or concentrated in a smaller, deeper area and subject to proportionally lower evapotranspiration losses. These general considerations are especially important in the Lahontan Valley marshes with high rates of evapotranspiration and quite shallow topographic relief.

The Refuge has detailed, current (1987) topographic maps prepared by photogrammetry using surveyed control points and bench marks. The data are limited, though, because areas under water when the photography was taken are depicted as flat with no underwater elevations. These missing data areas need to be filled in and similar topographic data need to be developed for Carson Lake and Fallon Indian Reservation. Extreme low water conditions greatly simplify this job.

There are several methods that could be used to obtain the additional elevation data. Photogrammetry from new photography flown when the units are dry is one approach. Ground surveying with a level and tape, or a total station surveying instrument, is another approach. Global Positioning System (GPS) instruments might be used to establish horizontal (x,y) locations, but would probably not be accurate enough for elevation (z). A variant of this approach is to use the water surface as a level and determine the horizontal locations of the water's edge by surveying, GPS, or photography. The Refuge has experimented with this approach using a GPS instrument. The Refuge also has a laser level instrument and has used it to survey several cross sections. An experienced land surveyor, or engineer, should be consulted to help choose the most efficient approach.

The additional elevation data should be at least as detailed as the existing topographic maps. Furthermore, there are considerable advantages to having georeferenced (map or coordinate based) elevation data. It is possible to derive area-volume curves by methods that do not also produce elevation contours with accurate horizontal (x,y) locations. Although such area-volume curves would be adequate for the water balance calculation, they would not support any analysis of which spatial areas were under how much water. Given the possible linkage of output from the wetland management water model to a GIS, it seems prudent to base the area-volume relations on solid georeferenced elevation data to avoid additional surveying that might be required for the GIS.

Monitoring

Calibration, refinement, and verification of the wetland management model will require field measurement. Selected flows, water surface elevations, and water surface areas must be measured over time and compared to model output in order to calibrate estimates of actual evapotranspiration and subsurface flow, and to verify that stage-volume and area-volume curves are sufficiently accurate. The proposed approach to modeling TDS is a severe simplification and is best viewed as an estimate of the "salt concentration potential" in different units. These model estimates need to be compared to field measurements of conductivity or salinity. The importance of continued data collection to verify and recalibrate the hydrologic relations and parameters cannot be overstated.

The Refuge has a continuing program of monitoring vegetation and wildlife use. This program should be continued and perhaps expanded to make it as consistent as possible with the spatial form of model outputs. The wetland management model will not directly predict vegetation or wildlife use. Thus, management decisions will have to be based on a combination of water depths and areas predicted by the water management model, and vegetation and wildlife information obtained from future monitoring as well as existing records. As such, it would also be useful to synthesize existing reports and understanding concerning water management of Refuge, Fallon Reservation, and Canvasback Gun Club marshes and Carson Lake. A GIS would be an excellent framework for integrating model predictions, field observations of hydrologic conditions, and existing monitoring programs focused on vegetation and wildlife use.

VALLEY-WIDE CONSIDERATIONS

One of the provisions of the 1990 Water Rights Settlement Act is for the Secretary of the Interior to consider, by 1997, possible expansion of the Refuge boundaries. This mandate, along with a general concern about how well the Refuge and other primary wetlands represent and protect the biodiversity of the Lahontan Valley, stimulated a proposal by The Nature Conservancy to conduct a valley-wide survey and classification of wetland vegetation. This effort would involve a one-time vegetation survey of 100-150 plots conducted over 3-6 weeks. Concomitantly, environmental variables (e.g., soil type, slope, aspect, elevation, landform, water depth, and soil and water chemistry) would be measured at the site visit or determined from existing data sources such as soil surveys. Classification analyses of the patterns of plant species occurrence and correlations with the environmental variables would identify distinct communities or cover types with an indication of the environmental gradients associated with each.

One of the more useful results of the workshop was a clarification of what would and would not be accomplished by such a study. Given the temporal variability of important environmental variables determining vegetation (e.g., water depth), the temporal variability in marsh vegetation at any site, and the detail of vegetation differences important to wildlife, this type of extensive, one-time survey would likely not produce information on vegetation responses to environmental conditions that was sufficiently detailed to contribute to short-term water management decisions or a wetland management model. Furthermore, for practical reasons an initial effort would focus on plant communities. However, a classification of plant communities would provide a solid foundation for later consideration of other components of biodiversity.

The principal benefit of a valley-wide survey and classification would be to place the Refuge and other primary wetlands in a larger biodiversity context. It would define important components of biodiversity that are (or are not) represented and protected within the 25,000 acres of primary wetlands specified in the settlement act and would therefore be useful for establishing habitat objectives and for evaluating possible expansion of the Refuge boundaries. This type of coarse, landscape-level analysis is similar in many respects to the predictive model of prehistoric land-use developed for the Stillwater Wildlife Management Area and currently being expanded to a larger area (Raven and Elston 1989; Raven 1990). That model predicts the distribution and composition of

archaeological sites over a grid of 1-km^2 cells, using variables such as soil type. With some attention to the underlying data themes, such as soil type, it might be possible to integrate the results of a vegetation survey with the archaeological model in a common GIS. This would provide a powerful tool for large scale planning activities such as acquisition. It would also provide a foundation for adding additional landscape-level spatial variables including other components of biodiversity (e.g., vertebrate distributions) and possibly contributions of various areas to water quality.

CONCLUSIONS AND RECOMMENDED ACTIONS

The objectives of the workshop described in this report were to evaluate existing information concerning wetland communities in the Lahontan Valley, discuss wetland management models that might be developed to help manage the 25,000 acres of primary wetlands specified in the settlement act, and identify future information and monitoring needs to support wetland management decisions in general and the management model in particular. The conclusions and recommendations of workshop participants are summarized below.

Refuge Objectives and Wetland Communities

1. Wildlife habitat preferences, expressed in terms of cover types defined by combinations of water depths and vegetation, are reasonably well known for a variety of animal species, including target species identified in current Refuge objectives.

2. Differences in vegetation communities can be reasonably well predicted by differences in water depth and salinity.

3. Current management and planning of marsh management units is most limited by the ability to forecast water depth and salinity conditions that would be created in different management units as a result of water management decisions, rather than the ability to relate those environmental conditions to vegetation or to relate the resulting habitat to animal species responses.

4. A wetland management model would help forecast the water depth and salinity conditions resulting from management actions as described above. A GIS would allow these forecasts and existing information concerning vegetation communities and wildlife habitat preferences to be better utilized to support management decisions. Specific recommendations concerning models and a GIS are listed below.

Wetland Management Models

1. A wetland management model should be developed that includes the 25,000 acres of primary wetlands specified in the settlement act (the Refuge, Canvasback Gun Club, Fallon Indian Reservation, Carson Lake). For each marsh or management unit, the model should provide monthly output on surface acres flooded, surface elevation, water depths in defined spatial zones, and average TDS. The model should allow the user to manipulate the timing, amount, and source of water deliveries to each marsh or management unit and should provide the capability to make single-year model runs to help develop annual management plans or multiple-year runs to evaluate longer-term consequences of management decisions.

2. An existing wetland management model provides many of the capabilities described above. This model could be expanded to include the Fallon Indian Reservation and Carson Lake and modified to predict water depths in specified spatial zones within marshes or management units.

3. Development and calibration of a wetland management model will require additional data collection and continued monitoring. The primary needs are to:

   a. Establish pan evaporation stations and conduct water budget monitoring for selected wetland management units.

   b. Finish topographic mapping of refuge management units and develop topographic maps for Carson Lake and the Fallon Indian Reservation. The elevation data should be at least as detailed as the existing topographic maps and there would be significant advantages to developing georeferenced elevation data for eventual inclusion in a GIS.

   c. Establish monitoring programs for selected flows, water surface elevation and area, and water salinity. Current Refuge monitoring of vegetation and wildlife use should be continued or expanded to make it as consistent as possible with the spatial form of model outputs and a GIS.

4. Existing information and understanding concerning wetland management at the Refuge, Canvasback Gun Club, Fallon Indian Reservation, and Carson Lake should be synthesized.

Valley-wide Considerations

1. Wetland plant communities throughout the Lahontan Valley should be inventoried and classified. While such a study would not likely produce information sufficiently detailed to contribute to short-term wetland management decisions, it would define important components of biodiversity that are or are not protected within the 25,000 acres of primary wetlands specified in the settlement act. Such information would be very useful for evaluating possible expansion of the Refuge boundaries.

2. With some attention to the underlying data themes, it might be possible to integrate the results of the wetland plant community survey with the archaeological model in a common GIS. Future monitoring of marsh conditions, vegetation, and wildlife use for the 25,000 acres of primary wetlands could also be incorporated into this GIS and used to support future management decisions.

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