OPTIONS FOR ECOSYSTEM RESTORATION AND MANAGEMENT

SUMMARY OF HGM INFORMATION

Information obtained in this study was sufficient to conduct an HGM evaluation of historic and current ecological attributes of the Seedskadee NWR ecosystem. Seedskadee NWR contains sections of the Green and Big Sandy Rivers and their floodplains embedded within the extensive desert-type sagebrush steppe community of southwest Wyoming. Historically, annual surface water inputs to the Seedskadee NWR ecosystem were provided by highly pulsed and dynamic discharges in the Green River during spring and early summer. Discharge levels and resulting flood flows into the Green River floodplain varied among years depending on annual snow pack and melt from surrounding mountains. The northern part of Seedskadee NWR was mainly influenced by Green River flows, while the southern part of the refuge also was influenced by flows from the Big Sandy River. Historically, Green River discharges peaked in May or June in most years and were sufficient (8,000 to 10,000 cfs) to cause at least some backwater flooding into old abandoned river channels, sloughs, and floodplain swales over 50% of the years prior to Fontenelle Reservoir. Larger flood events (> 14,000 cfs) appear to have inundated deeper floodplain depressions and occurred about every 5-10 years. Very large flood events > 20,000 were rare (only 3 times since the late 1800s) but were highly important to create extensive silt deposition and scouring, channel filling or migration, nutrient deposition, and extensive areas of floodplain connectivity. Similarly, regular flooding of the Big Sandy River maintained important ecological processes in its floodplain.

The regular river backwater flooding of low elevation floodplain wetlands every 2-5 years was a primary driving process that sustained the floodplain wetlands and wet meadows of the Seedskadee NWR region. Annual variation in Green River flows and subsequent overbank and backwater flooding likely caused significant annual variation in amount and distribution of flooded wetland area and corresponding persistent emergent, and seasonal herbaceous wetland vegetation communities in the floodplain. A narrow linear riparian woodland comprised of cottonwood and willow historically apparently was present along most areas of the Green and Big Sandy Rivers on natural levee and point bar surfaces. Large Green River flood events that exceeded 20,000 cfs apparently were critical to periodically provide deposition of fine alluvial sediments on natural levees and point bar ridges and/or scour clean some floodplain ridges where cottonwood and willow seedlings could periodically germinate and have adequate soil moisture to survive (Ikeda 1989).

The primary changes to the Seedskadee NWR ecosystem since major European settlement in the late 1800s, have been: 1) alterations to the amount, timing, duration, and extent of Green River flood waters flowing into and through riparian woodland and floodplain wetlands; 2) management of the distribution and retention of water in constructed and altered wetland impoundments and natural basins; 3) reduced presence, regeneration, and health of woody riparian vegetation; 4) altered sagebrush steppe species composition and distribution; and 5) increased presence of invasive species. A critical overriding issue that affects the future management of Seedskadee NWR is the annual operation of water storage and releases from Fontenelle Reservoir. A major challenge for future management of Seedskadee NWR will be to determine how a reduced flood-driven river system, likely affected by unknown future climate changes, will affect efforts to restore and provide critical habitats and communities for wildlife (Knopf et al. 1988, Meretsky et al. 2006, Seavy et al. 2009). Past attempts to plan management of the refuge have largely been designed to continue more permanent water management among wetland impoundments, which may or may not have been consistent with objectives that seek to restore and emulate natural distribution, abundance, and processes of endemic communities. Consequently, future management issues that affect timing, distribution, and movement of water on the NWR must consider how, and if, they are contributing to desired objectives of restoring native communities and their processes on the refuge. Additionally, future management and possible expansion of the refuge must seek to define the role of the refuge lands in a larger landscape-scale conservation and restoration strategy for the Upper Green River Basin and surrounding sagebrush steppe ecosystem.

GENERAL RECOMMENDATIONS FOR ECOSYSTEM RESTORATION AND MANAGEMENT

This study is an attempt to evaluate restoration and management options that will protect, restore, and sustain natural ecosystem processes, functions, and values at Seedskadee NWR. Seedskadee NWR provides key resources to meet annual cycle requirements of many plant and animal species in the Upper Colorado River ecoregion of the western U.S. The Green River and its floodplains are an especially critical component of the river system that bisects an otherwise dry, semi-desert, ecosystem. Further, the sagebrush steppe habitats adjacent to the Green River in the Seedskadee NWR are part of the largest contiguous block of this habitat in the western U.S. This habitat supports populations of many animal species associated with this community in the Rocky Mountain ecoregion (USFWS 2010). Seedskadee NWR is an important area that also can provide opportunities for wildlife-dependent uses. These public uses are important values of the refuge, but they must be provided and managed within the context of more holistic regional landscape- and ecosystem-based management. This study does not address where, or if, the many sometimes competing uses of the refuge can be accommodated, but rather this report provides information to support The National Wildlife Refuge System Improvement Act of 1997, which seeks to ensure that the biological integrity, diversity, and environmental health of the (eco)system (in which a refuge sets) are maintained (USFWS 1999, Meretsky et al. 2006). Administrative policy that guides NWR goals includes mandates for: 1) comprehensive documentation of ecosystem attributes associated with biodiversity conservation; 2) assessment of each refuge's importance across landscape scales; and 3) recognition that restoration of historical processes is critical to achieve goals (Mertetsky et al. 2006). Most of the CCPs completed for NWRs to date, including the Seedskadee NWR CCP, have highlighted ecological restoration as a primary goal, and choose historical conditions (those prior to substantial human related changes to the landscape) as the benchmark condition (USFWS 2002, Meretsky et al. 2006). General USFWS policy, under the Improvement Act of 1997, directs managers to assess not only historical conditions, but also "opportunities and limitations to maintaining and restoring" such conditions. Furthermore, USFWS guidance documents for NWR management "favor management that restores or mimics natural ecosystem processes or functions to achieve refuge purpose(s) (USFWS 2001).

Given the above USFWS policies and mandates for management of NWRs, the basis for developing recommendations for the future management of Seedskadee NWR is the HGM approach used in this study. The HGM approach objectively seeks to understand: 1) how this ecosystem was created; 2) the fundamental physical and biological processes that historically "drove" and "sustained" the structure and functions of the system and its communities; and 3) what changes have occurred that have caused degradations and that might be reversed and restored to historic and functional conditions within a "new desired" environment. This HGM approach also evaluates the NWR within the context of appropriate regional and continental landscapes, and helps identify its "role" in meeting larger conservation goals and needs at different geographical scales. In many cases, restoration of functional ecosystems on NWR lands can help an individual refuge serve as a "core" of critical, sometimes limiting, resources than can complement and encourage restoration and management on adjacent and regional private and public lands.

Seedskadee NWR contains a relatively sharp contrast and dichotomy of communities/habitat types between the Green River and its floodplain and the adjacent upland sagebrush steppe landscape. The primary ecological process that controlled the Green River ecosystem was rising water levels in the Green River in spring and early summer that caused seasonal backwater flooding and inundation of at least some lower elevation floodplain sloughs, swales, and depressions in most years. Further, relatively regularly occurring (5-10 year periodicity) large flood events caused widespread inundation of floodplain areas and alluvial deposition/scouring events that formed dynamic topographic and water flow/soil saturation patterns in the floodplain. Both seasonal and longer term inter-annual river flow and flooding dynamics created and sustained a diversity of wetland types in the immediate floodplain and also created and sustained sites for riparian woodland germination and survival. The basic spatial and temporal pattern of this spring-flood driven ecosystem remains present, but operation of Fontenelle Dam has: 1) reduced flood peaks and frequency of spring/summer flows that caused extensive inundation and alluvial deposition/scouring in the floodplain; 2) caused artificial high flows in late summer and early fall; and 3) created high base flows in winter.

Floodplain topography and hydrology at Seedskadee NWR have been altered where extensive infrastructure has been constructed (e.g. dams, ditches, levees, water-control structures) to create and manage impounded wetlands for more permanent water regimes aimed at increasing waterfowl production. Concurrently, vegetation in wetland impoundments was dramatically changed from historic conditions where natural floodplain water regimes were predominantly seasonal and at best seimpermanent in deeper depressions. Natural wet meadow areas appear to be reduced in area and vigor on the refuge. In contrast, invasive species assemblages such as perennial pepperweed are increasing. Riparian woodland at Seedskadee NWR is rapidly deteriorating with almost no recruitment of new cottonwood seedlings and poor survival of existing trees from combined effects of fire, herbivory, and drought induced stress caused by infrequent floods and rapidly declining soil moisture in summer. Former riparian woodland is shifting to upland/grassland vegetation composition.

Upland areas on Seedskadee are driven by the relatively arid climate and geological history of the region. Low annual precipitation, high evapotranspiration rates, and sandy alkaline soils created a sagebrush steppe community throughout much of western Wyoming, southern Idaho, northern Nevada, and southern Oregon (West 1988). Herbivory and fire were important ecological drivers in this ecosystem, but fire was relatively infrequent and grazing was mainly by seasonally present large browsers and low numbers of granivores. After European immigration and settlement in southwestern Wyoming, this sagebrush community became heavily grazed by livestock, was burned more frequently, and many areas such as alluvial fans adjacent to floodplains or riparian areas (such as at Seedskadee NWR) were physically altered by roads, rail beds, fences, and ditches. Although livestock grazing now is reduced or eliminated on most of the uplands on Seedskadee NWR, the historical sagebrush steppe habitat is still greatly altered from the past grazing intensity that caused a reduction in abundance and distribution of native plant species including loss of native perennial bunchgrasses, expansion of some shrubs such as rabbitbrush, introduction of many annual weeds and grasses such as cheatgrass, and soil/slope erosion.

Clearly, Seedskadee NWR is, and will continue to be, highly affected by the presence and operation of Fontenelle Reservoir and Dam. The impetus for establishing Seedskadee NWR was to mitigate fish and wildlife habitat losses from the reservoir (and other older proposed diversions of water from the Green River). Consequently, future management of Seedskadee must attempt to sustain and restore historical communities and resources in this region of the Green River Valley and to manage all habitats (sagebrush steppe, floodplain wetlands, riparian woodland, riverine) to provide historical resources used and required by native animal species within the constraints imposed by the management of water storage and releases from Fontenelle Reservoir. Given this management context, and based on the HGM context of information obtained and analyzed in this study, we believe that future management of Seedskadee NWR should seek to:

1. Maintain and restore the physical and hydrological character of the Green River (below Fontenelle Reservoir) and the Big Sandy River as best possible.

2. Restore the natural topography, water regimes, and surface water flow and flooding patterns from the Green River into and across the Green River floodplain and sheetwater runoff into and across adjacent terraces and alluvial fans.

3. Restore and maintain the diversity, composition, distribution, and regenerating mechanisms of native vegetation communities in relationship to topographic and geomorphic landscape position.

The following general recommendations are suggested to meet these ecosystem restoration and management goals for Seedskadee NWR.

1. Maintain and restore the physical and hydrological character of the Green River (below Fontenelle Reservoir) and the Big Sandy River as best possible.

The general physical position and geomorphology of the Green River below Fontenelle Dam have not been altered greatly, although several rock weirs and sills and other structures have been constructed to facilitate diversion of water into Seedskadee NWR impounded wetlands, provide watering gaps for livestock, and stabilize channel banks. Similarly, the physical nature of the lower Big Sandy River is only moderately altered from its historical condition. The Green River channel below Fontenelle Dam is not highly incised at present, but the reduced sediment loads in the river below the dam could potentially lead to eventual incision (Auble et al. 1997, Auble and Scott 1988, Glass 2002). The current low sediment loads in the Green River at Seedskadee NWR have an effect on downstream alluvial deposition in floodplains, which could alter nutrient levels and replenishment in floodplains, establishment of germination sites for riparian woodlands, and creation of topographic/bathymetry diversity and dynamics in the river that influence water velocity, turbidity, and structural features and diversity. In contrast, increased channel bank erosion that causes bank destabilization and increased sediment loading can occur where bank sites are altered by livestock, deforestation, and human activity. While no imminent large changes to the physical features of the Green or Big Sandy Rivers are foreseen, land managers must be vigilant to future proposals or actions that would alter the physical nature of the rivers and their inherent dynamics of flow and sediments and to smaller, cumulative changes in the physical integrity of the river channels and their floodplains.

In contrast to physical features, the hydrologic character of the Green River is greatly altered from the pre-Fontenelle Reservoir period. As currently operated, Fontenelle Reservoir has relatively little flexibility in water management as dictated by annual variation in watershed precipitation, water and land use, and downstream needs in the entire Colorado River system. Water flows in the Big Sandy River are less altered from historical periods, but still are affected to some degree by the reservoir on the river channel near Farson, Wyoming. Working closely with the BOR and negotiating water management guidelines for Fontenelle Reservoir will be important to a) maintain a more natural seasonal pattern of river discharge with a unimodal late spring-early summer discharge followed by gradual declines to low winter base levels, b) provide more regular (i.e., in ca. 50% of years if possible) peak flows > 8,000 to 10,000 cfs that allow at least some backwater flooding into floodplain sloughs, abandoned river channels, and swales; and c) occasionally allow high peak flows > 15,000 cfs that cause more extensive inundation of the Seedskadee NWR floodplain. Ideally, a flood discharge of > 20,000 cfs would occur about every 40 to 50 years to provide sediment and nutrient dynamics sufficient to create cottonwood regeneration sites, replenish nutrients and sediments in wetlands, and allow river migrations to occur.

Ultimately, the hydrology of the entire Green River ecosystem will depend on protecting the integrity of the upstream watersheds of the Green and Big Sandy Rivers with special emphasis on the more immediate lands in their floodplains and drainages. This need will require coordinated efforts of land owners and managers to protect surface and subsurface landscapes of the region including the geohydrology of the system. Vigilance against efforts to extract or divert more surface or subsurface water, alter flow patterns and pathways, and contamination of soils and water in the watersheds and floodplain corridors must be maintained.

2. Restore the natural topography, water regimes, and surface water flow and flooding patterns from the Green River into and across the Green River floodplain and sheetwater runoff into and across adjacent terraces and alluvial fans.

Many changes have occurred to the Seedskadee NWR floodplain from alterations in topography, water movement patterns, and water regimes. Certain of these changes have been directly caused by, or are associated with, construction and management of Fontenelle Reservoir. These include some past infrastructure that sought to move water to upland areas for irrigated croplands (e.g., the Hay Field area) and reduced spring discharge peaks that no longer flow into or through relict river channels, sloughs, and swales. Other changes occurred from construction of roads, water gaps, ditches, weirs, and water-control structures. Still other changes were purposeful attempts to modify natural flooding and drying regimes in wetlands to create more permanent and regularly occurring water regimes to increase open water and persistent emergent vegetation habitats and encourage waterfowl nesting. Collectively, these alterations have caused changes in vegetation communities and resources used and needed by select animal groups. If a goal of the refuge is to restore the naturally occurring physical and biotic diversity and productivity of the Seedskadee NWR ecosystem, then at least some restoration of natural topography, water flow pathways, and seasonal water regimes will be needed. This restoration will require changes in physical features and management of wetland impoundments.

First, an evaluation of all roads, ditches, weirs, fence lines, water gaps, etc. on the refuge should be made to determine if they are necessary, beneficial or detrimental to management objectives, and whether they can be modified or removed. As an example, some old small berms were constructed in floodplain wet meadow and grassland areas in an attempt to impound or divert water. If these structures disrupt sheetflow of runoff or flood water, disconnect natural swales or sloughs, or deter flood water movement into floodplain depressions they should be removed. Other infrastructure such as ditches formerly constructed to move water across floodplains for irrigation purposes, should be removed if they are not helpful to a desired wetland management need. Likewise, some internal levees constructed in impounded wetlands create impediments to independent water management among wetland units/pools and disrupt, or actually prevent, most floodwater levels from entering and flowing through the impoundments.

Second, the "new" lower flood pulse peaks on the Green River now seldom reach levels where river water can back or overflow into floodplain swales and depressions. Peak flows post-Fontenelle Reservoir average about 4,000 cfs lower than prior to the reservoir (e.g., Fig. 23), which equates to about a 2-4 foot lower river stage elevation at Seedskadee NWR during peak events. Where former river-floodplain connection entry points have been modified or artificially filled with sediment, they potentially could be reconnected and opened by excavating the fill material and lowering the natural levee entry points by 2-4 feet. Additionally, sediment or debris material that now obstructs or prevents flood flows in naturally occurring sloughs and swales should be removed. Clearing, deepening, and restoring natural water flow pathways will require careful engineering given the probability of new reduced flood flows in the Green River at Seedskadee NWR. While some deepening of sloughs and swales may be a bit artificial, it is consistent with attempting to restore the process of overbank and backwater flooding that was so critical to sustain this ecosystem.

Third, water management objectives for the individual wetland impoundments on Seedskadee NWR should be reviewed. Historically, the Green River floodplain at Seedskadee contained a diverse mosaic of depressions that reflected past river migration, alluvial deposition, and current scouring. The LIDAR maps for the refuge demonstrate this topographic diversity and the interrelationships of elevation and relative flooding regimes. Very few deep depressions occurred in the Seedskadee floodplain except for a few remnant oxbows and abandoned channels such as was within the Northern units (Fig. 16). These deeper wetlands apparently were regularly recharged by floodwaters on average about every 2-3 years and they probably retained at least some surface water throughout the summer and into fall. In very wet years, water likely was present throughout the year, while in dry years these deeper depressions may have had little if any water. Generally, few floodplain wetlands had water in late fall and winter at Seedskadee NWR; the only open water would have been in the river channel. The inter-annual dynamic flooding regimes in the deeper floodplain depressions helped maintain nutrient and vegetation cycling in these wetlands and attracted larger numbers of breeding waterbirds in wet years (see e.g., review in van der Valk 1989 and Heitmeyer and Fredrickson 2005). Most wetland depressions in the Green River floodplain at Seedskadee, however, were small swales in former ridge-and-swale river point bars. For example, the ridge-swale topography complexes in the Hamp, Pal, and Sagebrush units are marked (Fig. 6). These natural swales did not become inundated as often or as deeply as abandoned channel depressions, and the swales had seasonal water regimes that were recharged in spring and early summer and then dried relatively quickly into fall. Some higher elevation swale sites may have only contained a small amount of water from onsite precipitation or runoff in spring with rarer flooding by very large (and rare) flood events. Lower elevation swales likely flooded more regularly from moderate Green River flood events, especially those sites with connectivity to the river via backwater sloughs. Wet meadow habitats also were present in many floodplain locations that received only short duration sheetflow of water across relatively flat floodplain areas during spring flood and runoff events. These meadows did not impound water, except in shallow depressions, which dried quickly following inundation events.

Collectively, the HGM information for Seedskadee NWR indicate that most historical wetlands and wet meadows had seasonal water regimes and that even the deeper depressions had regular, perhaps almost annual, drying in late summer and fall. Consequently, wetland habitats were most extensive and available during spring and early summer and provided resources primarily to spring migrant waterbirds. During wet years more floodplain wetlands were inundated for longer periods in summer and attracted more waterbirds to stay and breed locally. Current water management of most wetland impoundments has overemphasized permanent and emergent vegetation for breeding waterbirds, and underemphasized seasonal flooding regimes most important for spring migrants, relative to historical pre-Fontenelle flooding regimes. Further, artificial high water levels and river discharge in fall and winter may be providing more fall/winter habitat for waterbirds and in the area, but at some ecological cost of altered water regimes and seasonal productivity of the sites.

3. Restore and maintain the diversity, composition, distribution, and regenerating mechanisms of native vegetation communities in relationship to topographic and geomorphic landscape position.

Seven major vegetation communities (sagebrush steppe, mesic upland, floodplain grassland-wet meadow, seasonal herbaceous wetland, semipermanent emergent wetland, riparian woodland, and riverine) historically were present at Seedskadee NWR and they were distributed along geomorphic, soil, topographic, and flood frequency gradients (Table 8, Figs 20,21). Precise mapping of the potential historical distribution of these communities on Seedskadee NWR was constrained to some degree by coarse-scale soil mapping. In contrast, the recently completed LIDAR topographic information greatly enabled understanding of potential water regimes (Fig. 16). The spatial patterns of historical community distribution are relatively distinct (Table 8, Fig. 21). Obviously, riverine habitats were/are within active river channels and seasonally connected river chutes and sloughs. Deeper floodplain depressions, especially relict abandoned channel oxbows, contained open water-persistent emergent wetland habitats. Floodplain swales supported seasonal herbaceous communities while floodplain ridges and other relatively high floodplain area supported wet meadow habitats. Riparian forest was present on natural levees and other floodplain point bar ridge sites where alluvial deposition occurred and porous soils provided more prolonged and elevated groundwater during drying summer and fall periods. Uplands adjacent to floodplains, including alluvial fans that extended into the floodplain supported sagebrush steppe communities.

The above described community relationships with abiotic ecosystem attributes provides a guideline for determining which communities belong where in the Seedskadee NWR ecosystem, and which sites are appropriate for restoration of specific community types. For example, restoration of riparian forest, which is rapidly deteriorating, should be on relatively recent alluvial deposition/scour sites near the Green or Big Sandy Rivers (or seasonally connected abandoned river channels and sloughs) that have regular overbank/backwater flooding and prolonged soil moisture in the tree root zone through the growing season. Further, if natural recruitment of cottonwood cannot occur because of presently reduced occurrence of large flood events that deposit alluvial material and create bare soil surfaces for seed set and germination, then direct plantings of seedlings may be successful if they are in topographic and soil locations conducive to higher groundwater tables along the river (Scott et al. 1993, Braatne et al. 1996, Friedman et al. 1995). Future restoration and management of communities at Seedskadee NWR will require a careful evaluation of site characteristics to determine what the site historically supported and now is capable of supporting given alterations to the system.

SPECIFIC RECOMMENDATIONS FOR RESTORATION AND MANAGEMENT OPTIONS

Maintain and Restore the Physical and Hydrological Character of the Green and Big Sandy Rivers

The impetus for establishing Seedskadee NWR was the need to mitigate and protect a portion of the Green River and its floodplain following construction of Fontenelle Reservoir. Consequently, management of Seedskadee NWR must seek to protect and restore the section of the Green River ecosystem below Fontenelle within the constraints of the operation of Fontenelle Dam. As such, restoration and management of the refuge must clearly understand the ecological character of the river system prior to Fontenelle and identify the best options to protect and restore the physical and hydrological integrity of the river, its floodplain, and the associated communities it supported. Clearly, many issues related to the future management of the Green River are not under the control of the refuge, but the USFWS does have the opportunity and responsibility to manage Seedskadee NWR in an exemplary way that achieves its authorized purpose and contributes to the overall sustainability of the Green River system. Ultimately, achieving the greatest sustainability possible will require efforts to protect the upstream watershed of the Green and Big Sandy Rivers and work with BOR to manage water releases in the most natural flow regime possible. Specific actions that seem important to this end include:

1. Protect the physical integrity of the Green and Big Sandy Rivers and their upstream watersheds.

- Do not construct additional dams, levees, or channel-bank stabilization structures on the Green or Big Sandy rivers.
- Remove and do not place hard point or bank stabilization structures along the channel banks of the Green and Big Sandy rivers unless they protect critical property or structures.
- Remove, or place spillways in levees along the Green and Big Sandy rivers.
- Protect banks of rivers from physical disturbance, especially from livestock.
- If river channel incision begins to occur, carefully engineer rock weirs or other grade-control structures/measures, in the affected river area.
- Reconnect river channels with remnant side channels, abandoned channels, sloughs, and chutes.
- Encourage and participate in sustainable range management programs throughout the Upper Green River watershed.
- Protect alluvial fans and terraces along the Green and Big Sandy River valleys from detrimental development, mining, and topographic alteration and support private lands programs to maintain natural topographic features and communities.
- Evaluate opportunities to expand the boundaries and protection capabilities of Seedskadee NWR.
- Support programs to restore natural vegetation communities in areas of the Green River watershed that are potentially subject to high soil erosion and water intensive land uses including marginal agricultural lands.

2. Cooperate with the BOR to manage water releases from Fontenelle Reservoir in a more natural seasonal and inter-annual flow regime.

- Seek to maintain a more natural seasonal river flow regime of unimodal late-spring to early-summer peak discharges followed by gradual declines to low winter base levels in the Green River.
- Provide peak spring-early summer discharges of > 8,000 cfs whenever possible to provide at least some connectivity of river flood water with Green River floodplain wetland and off-channel depressions.
- In very wet years, seek to provide spring flood pulses as high as possible, preferably with occasional discharges > 15,000 cfs.
- Attempt to provide a high discharge of > 20,000 cfs about every 40 to 50 years.
- Reduce artificial high fall releases and discharges. Preferably, more water would be released in spring-summer and less in fall.

Restore Natural Topography, Water Flow Patterns, and Water Regimes

The restoration of historic ecological communities and their key driving ecological processes at Seedskadee NWR will require at least some restoration of natural topography, water flow patterns, and water regimes (e.g., Stanford et al. 1996). As stated above, part of this restoration will require achieving water releases from Fontenelle Reservoir that are more natural, both seasonally and long term. If these releases and more natural river flow regimes can be achieved, impediments to river-floodplain connectivity on the refuge should not be intentionally maintained, nor should present water management strategies in refuge wetland impoundments be preferred over natural flooding and drying regimes. The ultimate goal for Seedskadee NWR is to protect and restore natural integrity, functions, and values of the unique western riparian corridor and adjacent sagebrush steppe, and not try to create unnatural artificial conditions or communities on the refuge.

The inherent geomorphic surfaces, soils, topography, and former hydrology of wetland impoundments should be considered when deciding management and development strategies. Specific changes to the Seedskadee NWR system that seem helpful in this regard include:

1. Restore natural topography and reconnect natural water flow patterns and pathways where possible.

- Evaluate all levees, roads, ditches, and water-control structures to determine if they are necessary, or are detrimental to, restoration of natural water flow patterns and water regimes in floodplains and uplands. Identify structures that can be used to help emulate natural flow patterns and conversely, remove or modify those structures that are not necessary or that are deterring natural water flow patterns.

- Do not construct additional wetland impoundments, roads, levees, or water-control structures that alter water flow into and across the floodplain.

- Restore at least some natural topography in wetland impoundments, and former agricultural lands that can be restored to native vegetation.

- Remove islands and deposition sites in wetlands.

- Improve water flow into and through historic floodplain abandoned channels, sloughs, and depressions by removing or lowering obstructions, levees, weirs, sills, and dams across these drainages and depressions.

- Evaluate the potential to "cut" fill material at entry points of relict floodplain channels, sloughs, and swales where the Green and Big Sandy Rivers would back or overflow into these sites. Also, remove or cut material from high spots in these channels that prohibit water movement through the floodplains and that could potentially flood extensive areas during high flow events.

2. Manage wetland impoundments and natural floodplain depressions for more natural seasonal and long-term water regimes based on their HGM-attribute position.

- The Hamp Unit is located on an inside-bend point-bar geomorphic surface with a relict abandoned channel slough at the downstream end of the river bend where floodwaters from the Green River historically entered this area (Fig. 6a). The unit was originally developed into impoundments with the desire to create more permanent open-water emergent vegetation habitats for breeding waterfowl. Most of the unit is a classic river point-bar ridge-and-swale geomorphic surface where only short duration seasonal inundation occurred, except during high flow conditions on the Green River (Fig. 16a). Ideally, the unit should be managed as a more seasonally flooded wetland regime and seasonal herbaceous/wet meadow community. Infrastructure that deters floodwater entry from the bottom end of the unit should be modified or removed to allow high flow events to back into the abandoned channel sloughs and point bar swales.

- The Hawley Unit contains several natural topographic depression features including a relict abandoned channel oxbow (Figs. 6b,16b). The Green River also has two side chute channels adjacent to the floodplain. This area apparently has been a site of relatively recent river migration. Development of the site has diverted water into and through the unit to the more southern downstream impoundments and also created subdivided impoundments. The water management of impoundment pools typically has sought to create more permanent open water and emergent vegetation habitats. This management seems appropriate, but more natural dynamics of spring inundation followed by summer and fall drying should be encouraged. These semipermanent wetlands also periodically dried every 3-5 years when Green River peak flows in spring were low. Because water must be diverted into Hawley to supply water to downstream units, it is always flooded first and is flooded more regularly among years. Recognizing this "control" function, the unit should be occasionally dried to prevent the substantial encroachment and filling of the unit with dense monocultures of emergent vegetation, especially cattail. In the absence of more regular drying, other vegetation controls may be needed.

- The Lower Hawley Unit contains former channels of the Green River and a point bar ridge-and-swale geomorphic surface on the south end (Fig. 6c). The floodplain depressions in this area likely flooded regularly when the Green River rose in spring and summer and the deeper relict oxbows may have been a large part of the more permanent wetlands in the system (Fig. 16c). Currently, water-control infrastructure moves water from the Hawley Unit into and through the unit, through the Sagebrush Unit, and finally to the southern Dunkle Unit. Several levees create subimpoundments in the Lower Hawley impoundment and they prevent high flows of the Green River from entering the unit. Managing water regimes and wetland vegetation in Lower Hawley in a manner similar to the Hawley Unit seems appropriate, and should include rotational flooding and drying of subimpoundments to emulate natural flooding-drying dynamics. Also, the outside levees of the impoundment should be evaluated to find appropriate potential breach or spillway sites where high flows of the Green River could enter the floodplain.

- The Pal Unit is a slightly higher elevation point bar river bend surface on the east side of the Green River and it includes a relict horseshoe-shaped abandoned river channel on the northeast side (Fig. 6c). The Unit historically contained riparian woodland along the river, seasonal herbaceous wetlands in swales and wet meadow grassland on ridges. The higher elevation areas in the unit historically apparently were flooded for short durations during spring flood events (Fig. 16c). Only a few water-control structures are present in the unit and they primarily are used to hold water in swales. Higher elevations in the unit are most suited for short duration seasonal flooding and wet meadow communities. In these areas existing water-control structures should be removed or modified to allow natural sheetwater flow from floodwater and runoff to occur. Deeper relict abandoned channel areas apparently had frequent inundation from high river flow events and probably had semipermanent water regimes that supported persistent emergent vegetation communities. Infrastructure should be evaluated to make sure river floodwater can continue to inundate these depressions frequently.

- The Sagebrush Unit is within a widely meandering portion of the Green River and includes point bar ridges and swales on two inside bends of the river with a cutoff abandoned channel behind the point bar (Fig. 6d). Historically, the high natural levees and probably ridges on point bars contained riparian woodland, the swales contained seasonal herbaceous wetlands, and the old cutoff river channel was semipermanent emergent wetland (Fig. 16d). Water currently is moved to the Unit from the upstream infrastructure associated with the Hawley units, and when river flows have been low, this and the Dunkle Unit have received less water. Consequently, the site has been developed to retain water in deeper areas of swales and the old oxbow. Future management and redesign of the unit should consider providing a complex of riparian woodland on ridges and the natural levee along inside point bar bends of the river, natural short duration seasonal flooding in swales, and more semipermanent water regimes in the old oxbow depression. Water-control structures that prevent high flows of the Green River from entering and inundating swales and depressions should be removed or modified.

- The Cottonwood Unit is a typical inside-bend point-bar surface that contains several ridge-and-swale topographic complexes. The swales in these areas apparently became inundated when river discharges exceeded 14,000 to 17,000 cfs; the entry point of flooding was at the downstream bottom ends of the river bends. In this unit all water-control structures that prevent occasional river backwater from entering the point-bar swales should be removed or modified to allow river flows to cross them.

- The Dunkle Unit contains a point-bar bend of the Green River, crevasse splays on the upper bend area, and old relict channels behind the point bar (Fig. 6e). The point bar bend has higher elevations and only shallow swales that probably historically supported riparian woodland and shrub wetland. Relict channels behind the point bar likely were flooded during high flow events of the Green River (Fig. 16e). The few water-control structures in the unit attempt to capture and hold water that is diverted from the upstream Hawley units. Because the unit is the farthest from the Hamp diversion point, it has a less regular water source. Given the less reliable source of water and its point bar setting, water-control structures should be removed if they deter floodwater entry during high Green River discharge times and where structures are retained, the water regimes should be seasonal.

Sustain and Restore Natural Vegetation Communities

The native mosaic of vegetation communities at Seedskadee NWR were important components of the Green River ecosystem and the entire Upper Colorado River ecoregion. Sustaining, and restoring where necessary, the distribution and types of historical habitats is important to the long term capability of the entire ecoregion to support system functions, values, and services. The general types and distribution of communities at Seedskadee NWR have not changed dramatically from historic patterns, but the following major alterations have occurred:

- Upland sagebrush steppe has altered species composition including invasion by nonnative annual grasses and weeds.
- Riparian woodlands are rapidly deteriorating and almost no natural recruitment of cottonwood is occurring.
- Many floodplain wetland depressions have been impounded with more permanent water regimes and open water-emergent vegetation and less seasonal herbaceous and wet meadow communities.
- Off channel side and high flow channels, sloughs, swales, and oxbows have been disconnected with the Green River.

Restoration and maintenance of native communities seems possible and desirable (at least to certain degrees) at Seedskadee NWR. Consequently, the basis for future conservation, restoration, and management of plant communities on Seedskadee NWR should be guided by ecological attributes identified in the HGM matrix and maps provided in this report based on geomorphology, soil, topography, and hydrology features (Table 8, Fig. 21). Specific actions to assist this restoration include:

1. Protect and restore native vegetation composition to upland sagebrush steppe areas.

- Protect all existing sagebrush steppe areas from conversion to other habitat types, fragmentation, and disturbance from livestock and vehicles.
- Encourage natural fire regimes, with long return intervals, in uplands and especially in drainage areas and washes.
- Carefully manage some decadent sagebrush areas with select thinning and reduce the occurrence and extent of rabbitbrush where it is artificially high.
- Control invasive weeds and grasses.

2. Restore linear bands of riparian woodland along the Green and Big Sandy Rivers.

- Attempt to maintain existing areas of riparian woodland with protection from extensive browsing and trampling from native ungulates and livestock and suppression of fires.
- Work with BOR to restore more natural flow regimes in the Green River (see earlier recommendations section) that include: 1) occasional high discharges that can flood higher elevation natural levees and ridges in floodplains, 2) gradual declines in water levels (< 4 cm/day) in summer, and 3) low base flows in winter (to prevent excessive water levels and ice scouring).
- Target restoration sites that have sandy loam soils on natural levees of active and relict river channels and sloughs and ridges in point bar river bend areas where high, more sustained, groundwater levels occur during summer. These sites typically are on inside bend point bar sites.
- Evaluate some use of physical disturbance in the above sites to provide bare-soil surfaces for cottonwood and willow seed set and germination. In sites where no seed source or bare soils are present, plant seedlings with protective wire or wrap to prevent browsing and damage to seedlings from ungulates and beaver (e.g., Glass 2002, Breck et al. 2003, Scott et al. 2008).
- Continue monitoring and evaluation studies on biotic and abiotic components of riparian woodland communities and restoration efforts.

3. Restore complexes of floodplain wetland communities with natural water regimes.

- Restore connectivity of the Green River and floodplain depressions and restore water flow pathways in floodplains as suggested previously.
- Change infrastructure and management of wetland impoundments as listed above.
- Control invasive plants in floodplains and restore native species composition to wet meadow areas.

- Manage wetland impoundments for annually dynamic water regimes and reduce monotypic stands of tall emergents, especially cattail, to increase productivity of semipermanent wetland areas such as relict oxbows.

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