Constructing Wetlands in the Intermountain West: Guidelines for Land Resource Managers

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Table of Contents

CONSTRUCTING WETLANDS
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Introduction

Many types of constructed wetlands exist throughout the Intermountain West. Examples include agriculturally created irrigated wetlands, livestock watering ponds, nutrient and sediment control (including wastewater treatment) wetlands, floodwater-retarding basins, wetlands created from surface coal, phosphate, and gravel extraction, potholes created with explosives or mechanical excavation, level ditches, and beaver ponds. Compared to other constructed wetlands, livestock watering ponds and agriculturally created irrigated wetlands are the most commonly constructed wetlands in the Intermountain West. By 1980, farmers and ranchers had built more than 2.1 million wetlands in the United States for livestock watering and irrigation (USDA 1997).

Agriculturally created irrigated wetlands arise from groundwater and surface runoff accumulations from irrigated croplands. A by-product of agricultural production, these wetlands lack permanent water, are small in area, located near ditches and canals, and dominated by a few emergent (herbaceous) plant species (Adamus 1993).

Livestock watering ponds are classified as retention reservoirs, dugouts or pit reservoirs, or diked dugouts or pit retention reservoirs (Lokemoen 1973, Eng et al. 1979). Retention reservoirs have short dams across intermittent streams or large gullies to intercept spring runoff or rainwater from upland slopes. Dugouts or pit reservoirs have steep sides and are filled from groundwater or surface runoff (Bue et al. 1964). Diked dugouts or pit retention reservoirs are built like regular dugouts, but spoil material is placed on the downstream side as a dam to flood the shallow area around the dugout (Payne 1992).

A variety of ecological functions, consumptive and nonconsumptive resource uses, and economic benefits occur as a result of these constructed wetlands. They include mitigation for natural wetland losses, enhanced landscape diversity, wildlife and fisheries habitat, water for irrigation and livestock, recreational opportunities, sediment control, flood storage, enhanced water quality, aesthetic value, and providing public water supplies (Samuel et al. 1978, Leedy 1981, Leedy and Franklin 1981, Olson 1981, USDA 1997). Additional values include community open spaces and increased water supplies for homes, fire protection, and industrial uses (Glazier et al. 1981).

Although these Intermountain West wetlands serve different purposes, all possess common ecosystem components of water, hydric soils, and wetland plant species. However, presence of these components does not guarantee a functioning ecosystem, especially in the early years. But, as constructed wetlands mature, these components become ecologically interrelated, gradually evolving into a functioning wetland.

Creating functioning wetlands requires careful design and construction criteria that optimize water availability and quality, hydric soil formation, and establishment of wetland vegetation. Once constructed, resource managers must fully understand the ecological interaction of biological, chemical, and physical factors prior to developing management plans to maintain or enhance ecosystem function. A carefully designed, constructed, and managed wetland should provide maximum multiple-use values.

As more constructed wetlands emerge in the Intermountain West, the demand for intensified management, based on an understanding of ecological processes, will increase. Future resource managers must be able to oversee these new wetland ecosystems while optimizing multiple-use values.

This publication provides information on ecosystem components and processes to help resource managers and landowners better understand the function of constructed wetlands, a requirement for establishing proper management practices. Guidelines on wetland design, construction, and post-construction management techniques are described to ensure successful long-term benefits of these areas.

Ecosystem Components and Processes

Ecosystem functioning in constructed wetlands is governed by the complex interaction of hydrologic processes and water quality, submerged substrate properties, and influences of wetland vegetation. The specific assemblage of wetland plant communities is due to the abiotic and biotic conditions of the ecosystem, which is a product of the component interactions. Subsequent wetland plant community development and hydrologic processes influence wetland wildlife habitat value. A brief description of these primary components and the processes associated with them will help resource managers and landowners better understand how wetlands function.

WATER PROPERTIES

Water (quantity and quality) is the critical component driving development and long-term functioning of constructed wetlands (Figure 1). To understand wetland functions, a knowledge of wetland hydrology is needed (Hollands 1990).

Figure 1. Hydrologic regimes and water quality are the primary critical components influencing development and ecosystem functioning in constructed wetlands. Without water, substrate and wetland vegetation development would not occur. (Photo by Rich Olson)

Hydrology

Water depth, period of occurrence, and duration of inundation comprise the wetland hydrology. Variations of these factors between wetlands result in site-specific hydrologic regimes. These hydrologic regimes govern abiotic conditions such as water and nutrient availability, aerobic and anaerobic soil conditions, soil particle size and composition, water chemistry features, and water velocity. Hydrologic regimes are influenced by wetland vegetation through interception of precipitation and evapotranspiration rates. Wetland plants, in turn, influence water depth, velocity, and circulation patterns within a system (Hammer 1997).

Hydrologic regimes also influence biological productivity by controlling nutrient cycling and availability, nutrient import and export, and fixed energy supplies in the form of organic particulates and decomposition rates. Nutrients in submersed substrate are unavailable to most plants under reducing conditions, but periodic drying results in oxidation of these substances, triggering an explosive growth of wetland vegetation (Hammer 1997).

Surface runoff and groundwater flow into wetland basins carry varied quantities of minerals, macro- and micronutrients, and organic matter that enhance productivity. Likewise, surface outflows and groundwater seepage export organic material, minerals, and nutrients, thereby reducing wetland productivity potential (Hammer 1997).

Water quality in constructed wetlands is partially determined by hydrologic regimes and, therefore, influences the composition of wetland vegetation, especially submerged aquatic plant species. Hydrologic regimes partially control the concentration of dissolved solids. This can restrict submerged plant growth by limiting light penetration or create toxic conditions impacting vegetation production. Evaporation from the water surface, evapotranspiration from marginal wetland vegetation, runoff, and groundwater seepage inflow all increase the concentration of dissolved solids, while direct precipitation, groundwater seepage outflow, and overflow reduce dissolved solid concentrations (Eisenlohr 1969, Rozkowska and Rozkowski 1969, Sloan 1970). Eisenlohr (1969) found fresher wetlands at higher elevations due to the flushing effect of seepage outflow, compared to wetlands at lower elevations where dissolved solids are concentrated with seepage inflow.

The hydrologic regime of a constructed wetland affects water quantity and quality, substrate (soil) properties, and biological productivity. Hydrologic regimes are established by the balance between water inflows and outflows or the water budget.

Water Budgets

A wetland water budget is simply the balance between water gains from inflow and water losses from outflow. However, the components of water budgets vary widely between wetlands due to site-specific conditions. As vegetation and organic soils develop in constructed wetlands, the water budget is modified (Hollands 1990).

Major sources of water inflow are direct precipitation, surface runoff, and seepage inflow from groundwater tables. The amount of water entering a wetland in the spring is determined by the amount of snow accumulation in the watershed, intensity of snowmelt caused by warm air temperatures, level of soil moisture at freeze-up, and depth of frost penetration in the soil during the preceding fall (Millar 1969a, Daborn 1976). Surface runoff is usually the greatest source of water inflow into a wetland basin. However, during precipitation, the structure and coverage of vegetation surrounding a wetland affects the amount of water intercepted before reaching the ground and, therefore, the amount of surface runoff (Hammer 1997).

Water outflow is primarily by evapotranspiration from marginal vegetation, seepage outflow from the pond bottom, evaporation from the water surface, and overflow around pond margins (Olson 1981). Evapotranspiration increases with increased leaf surface area exposure, solar radiation, air and surface temperatures, and wind speed (Hammer 1997).

Extensive emergent vegetation complicates the water budget by reducing evaporative water loss by sheltering the water surface from wind and radiation and increasing water loss through evapotranspiration (Eisenlohr 1965, 1969). Eisenlohr (1965) found that plant evapotranspiration rates at the beginning and end of a growing season were less than evaporative loss from the water surface. However, total evapotranspiration loss for the entire growing season on a vegetated wetland may be greater than the evaporation rate if no vegetation is present.

In dry years, when evapotranspiration is higher, water loss from a wetland filled with vegetation may deplete moisture required by wet meadow plant communities located on the outer fringes of a wetland. To decrease water loss from evapotranspiration, vegetation should be thinned with explosives or mechanical means. On sparsely vegetated wetlands, contouring basin slopes and water level manipulation may enhance wetland plant development along basin margins, thereby reducing water loss by evaporation.

Likewise, removal of peripheral vegetation through cultivation or grazing may reduce spring runoff by reducing the amount of trapped snow (Millar 1969b). Some marginal wetland vegetation is needed to prevent evaporation loss.

Working in small wetlands, Millar (1971) found the rate of water loss per unit area varied directly with the length of shoreline and inversely with wetland size. Water loss was principally by lateral seepage to transpiring marginal vegetation, evaporation from shoreline soil surfaces, and seepage to groundwater. Millar (1971) stated that during the growing season, 60 to 80 percent of the water loss is attributed to transpiration by phreatophytic (water-loving) vegetation and evaporation from the soil surface. Shoreline-related water loss accounted for 60 percent or more of total water loss in wetlands 0.1 acre or less in size and 30 to 35 percent in wetlands greater than 2.5 acres.

Adamus (1993) described the hydrologic roles of wetlands as either a sink (removing water from local surface flow systems) or source function (conserving water and providing moisture in local areas). Sink functions occur where surface water runoff is retained or converted to water vapor through evaporation or evapotranspiration by wetland vegetation. Source functions occur where wetlands act as conduits for discharging groundwater or where water inputs are increased or conserved from intercepting precipitation, detaining drifted snow, or reducing open water evaporation.

Natural Water Level Fluctuations

Seasonal water levels fluctuate to some degree in all wetlands through inflow and outflow pathways. The magnitude of water level fluctuations, in terms of water depth within wetland plant communities, is not as great in shallower basins due to gradually sloped shorelines (Figure 2). These fluctuations enhance wetland plant establishment. Moderate fluctuations periodically expose mudflats, resulting in aerobic decomposition of substrate organic material. The subsequent availability of nutrients following aerobic decomposition of organic matter, combined with optimum moisture conditions, stimulates wetland vegetation establishment and production. Natural seasonal water level fluctuations are needed to remobilize nutrients chemically bound to the substrate

Figure 2. Natural water level fluctuations occur to some degree in all wetlands and influence wetland plant establishment. Changes in water depth due to water level fluctuations are not as great in shallow wetland basins (compared to deep wetlands) due to gradually sloped shorelines. (Photo by Rich Olson)

and stimulate germination of wetland plant seeds (Welling et al. 1988).

Adamus (1993) reported that overbank flooding in constructed wetlands can increase plant and animal production by diluting high salinity and accumulated toxicants, re-suspending excessive accumulations of sediment, scouring and rejuvenating dense stands of emergent vegetation, and facilitating recolonization by crayfish, other invertebrates, and waterborne seeds of wetland plants. Stockponds in New Mexico created by damming washes (therefore receiving outside water) support more waterfowl than isolated, pit-type stockponds (Tolle 1977).

A hydrologic regime, which includes seasonal water level fluctuations, is critical for creating a functioning wetland. Hydrologic processes influence the characteristics of abiotic factors, which subsequently shape biotic factors that coalesce to create a functioning wetland (Hammer 1997).

Water Quality

A properly designed and constructed wetland can improve water quality by removing nitrogen, soluble and insoluble phosphorus, and sediment from surface runoff (Hoag and Sellers 1994). Constructed wetlands also reduce total suspended and dissolved solids, turbidity, some heavy metals, and several trace elements (Dortch 1992).

Adamus (1993) described processes that improve water quality in constructed Colorado plateau wetlands:

1. **Water Deceleration/Storage.** Constructed wetlands that lack outlets (e.g. livestock ponds) or those having flat gradients with dense perennial vegetation and low hydraulic loading (e.g. large wetland area with a low amount of incoming runoff) delay downslope movement of water, permitting increased pollutant processing time.
2. **Filtration, Settling, Burial, and Stabilization.** Wetlands that physically confine suspended sediments or chemicals cause settling by physical processes (e.g. gravity) and burial by erosion-resistant, accumulating sediment or precipitate layers. Settling occurs where sediments are coarse-textured, the wetland is sheltered from wind turbulence (e.g. either from surrounding vegetation cover or under deep, permanent water), and where warm, hypersaline conditions, which otherwise keep fine sediments buoyant and inhibit plant growth, do not exist.
3. **Deoxygenation.** Generally, wetlands that are highly saline, sheltered from wind turbulence, subject to warmer temperatures, and/or have fine sediments and high primary productivity have higher oxygen deficits. Oxygen deficiency facilitates retention of some substances that impact water quality but mobilizes others.
4. **Adsorption and Physico-Chemical Precipitation.** Finer-particled sediments and high organic detritus cause greater chemical bonding of many incoming contaminants, thereby improving water quality. Those constructed wetlands most capable of this process have soils with high clay content, organic carbon, iron or aluminum and salinity levels approximately 5 parts per trillion, which promote deposition through chemical flocculation (Akhurst and Breen 1988).
5. **Uptake and Accumulation.** Wetland organisms directly accumulate and/or transform chemicals and sediment through normal metabolic processes. The degree of water purification through uptake and accumulation depends on the type of contaminant, growing season length, and resistance of plant litter to decomposition (depending on plant species, acidic or saline conditions, water temperature, water circulation, and other factors).
6. **Denitrification.** Constructed wetlands remove nitrate by bacterial denitrification processes. In Colorado, constructed wetlands removed 50 to 85 percent of the nitrogen in surface runoff from adjacent agricultural land (Rumberg 1969, Ludwick et al. 1978). Constructed wetlands with the highest denitrification rates are those fed mainly by surface runoff, especially from alfalfa fields or feedlots; those with high soil organic content; those that remain flooded or moist for the longest duration during the growing season; those that warm up earliest in

spring; and those with low salinity. These conditions support microbial populations capable of detoxifying many pesticides and other contaminants. Other researchers reporting on the purification capacity of wetlands in agricultural areas, especially in arid regions, include Rice and Smith (1982), Gersberg et al. (1983), Linn and Doran (1984), Fraser et al. (1988), Lemme (1988), Neely and Baker (1989), and Parkin and Meisinger (1989).

7. **Consumption by Wide-Ranging Animals and Combustion.** Migratory wildlife and free-ranging livestock import and export nutrients and other chemicals contained in food sources. Prescribed burning also exports chemicals from wetlands as smoke.

Water quality influences wetland vegetation establishment and production (Scheffer et al. 1984), determining the abundance of aquatic invertebrates and fish required as a food source by many wetland birds (Adamus 1993). Water quality parameters that support fish and other aquatic organisms fall within general ranges (Table 1).

Alkalinity and Acidity

Water is biologically unproductive if highly acidic (pH 5.0 or lower), with total alkalinity below 10 parts per million (Linde 1969). Water with a pH of 6.0 to 7.0 and alkalinity of at least 50 parts per million has good potential for producing aquatic organisms. Submerged vegetation preferred by waterfowl for food sources requires reasonably hard, fertile water. Soft, less fertile water inhibits production of submerged vegetation and promotes less desirable emergent plant species (Payne 1992).

Only cattails (*Typha* spp.) prevail in water with moderate acidity. As acidity decreases and alkalinity increases, a wider variety of wetland plant species occur. When water pH reaches 4.0 and lower, no wetland plant species can survive. Bell (1956) reported significant decreases in wetland vegetation at a pH of 6.6, and only emergent wetland plants were present at pH values lower than 6.4. Generally, a minimum water pH of 7.0 is required for good wetland vegetation establishment (Crawford 1942, Coe and Schmelz 1972).

Table 1. Range of water quality parameters required to support aquatic organisms (Payne 1992).

Parameter	Range of Values
pH	6.5 - 9.0
Alkalinity	≥20 mg/L
Hardness	20 - 150 mg/L
Dissolved oxygen	≥5 mg/L
Total dissolved solids	Generally, productivity positively correlated with TDS
Temperature	≤20 - 30^{o} C, depending on species and acclimation

Salinity

Substrate and water salinity levels limit production of wetland plants (Kauskik 1963, McKnight and Low 1969, Christiansen and Low 1970, Cooper and Severn 1992), and can reduce aquatic invertebrate abundance. High salinity directly reduces levels of invertebrates, amphibians, and some fish. Most isolated, saline constructed wetlands are not heavily used by fish-eating birds such as kingfishers, loons, grebes, herons, and egrets (Adamus 1993).

Hammer (1981) concluded that most biologically productive saline lakes have high alkalinity, moderate salinity, and rich soluble phosphorus levels. Salinity greater than 1.5 decisiemens per meter causes digestive stress in some birds, and salinity greater than 5.0 decisiemens per meter is considered unsatisfactory for livestock (National Academy of Sciences 1974).

Studies in Utah suggest that a specific conductance of less than 1 micromhos is excellent for waterfowl, and over 8 micromhos is restrictive (Christiansen and Low 1970). In the San Luis Valley of south-central Colorado, wetlands having the greatest diversity of herbaceous plants were seasonally flooded areas with low salinity and high water tables (Cooper and Severn 1992). Generally, freshwater impoundments have less than 1 part per trillion salinity (Payne 1992).

Organic Macronutrients

Nitrogen and phosphorus are primary metabolic nutrients, and their abundance often regulates biological productivity in wetlands (Wetzel 1975). Excessive loading of nitrogen and phosphorus can cause eutrophication, leading to algae blooms and dissolved oxygen deficits (Figure 3) (Adamus 1993). Uptake and release of nitrogen and phosphorus depend on sediment characteristics, water chemistry, and vegetation composition (Levine and Willard 1990).

Sediments, particularly inorganic clays, influence the amount of phosphorus retained in a wetland. The amount of adsorbed phosphorus depends on clay type (e.g. illite, montmorillonite, and kaolinite), amount of clay, and substrate pH. Potential adsorption also is a function of the water nutrient concentration and redox potential (soil or water’s capacity to oxidize or reduce chemical substances) at the sediment-water interface (Levine and Willard 1990).

Uptake and release of nitrogen and phosphorus within a wetland vary seasonally. During the growing season, emergent and submerged plants utilize phosphorus from sediment and water. As plants senesce in the fall, phosphorus is released from decomposing tissue into the water. Over time, with increased accumulation, this decomposing tissue becomes a major phosphorus source. This occurs where decomposition is slow and water phosphorus concentration is high (Levine and Willard 1990). Likewise, emergent and submerged plants act as a nitrogen sink during the growing season. However, nitrogen release from dead plant litter is much slower, taking months or even years (Levine and Willard 1990).

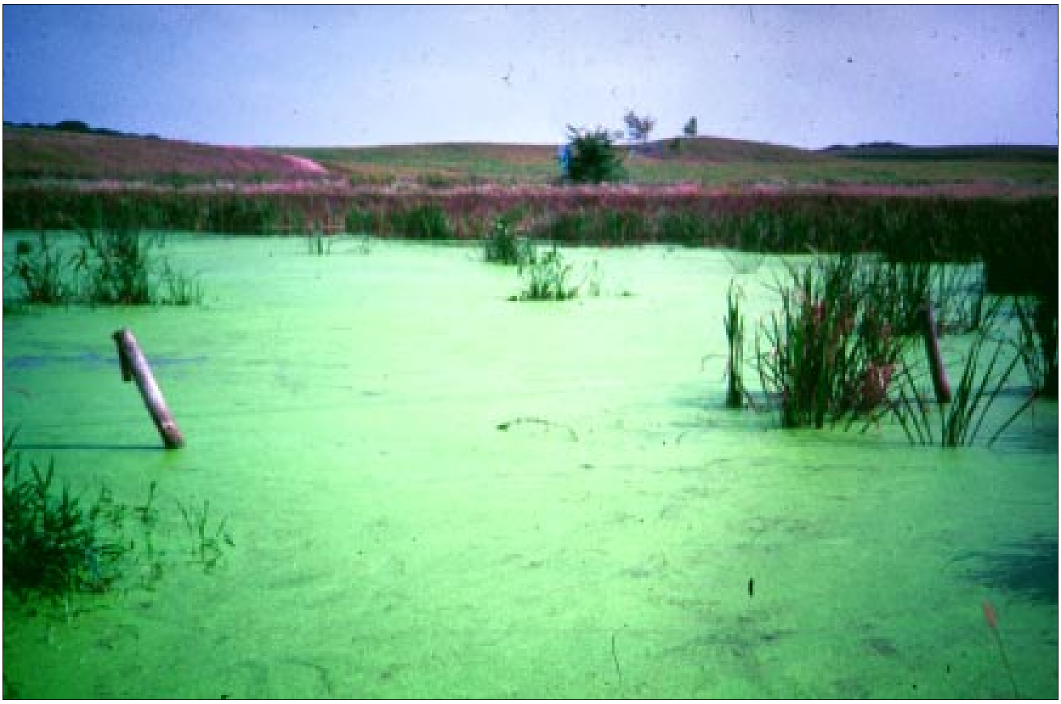


Figure 3. Accumulation of nitrogen and phosphorus, primary metabolic nutrients, can cause eutrophication that promotes algae blooms and deficits in dissolved oxygen. Low dissolved oxygen often impacts production of aquatic organisms. (Photo by Rena Baldwin)

Mere presence or absence of water and water level fluctuations influence organic macronutrient cycling. Klopatek (1978) reported that draining a wetland resulted in large releases of organic nitrogen and nitrate (NO_3) from the substrate due to increased aerobic decomposition rates. Re-flooding resulted in a net input of nitrogen into the wetland, with soil nitrogen significantly increasing within a year.

Water level fluctuations affect plant species composition, which influences nutrient cycling. During high water, nitrogen and phosphorus are released into the water by living plants. During drawdowns, nitrogen and phosphorus are released through decomposition (Levine and Willard 1990).

Adamus (1993) theorized that constructed Colorado wetlands play a greater role in removing nitrogen than in retaining phosphorus because of the high soil organic content and associated denitrifying bacteria. Also, phosphorus in the surface runoff is adsorbed by the predominately clay upland soils before the runoff reaches the wetland. Working in Wyoming, Fannin et al. (1985) found that phosphorus concentrations in rivers correlated with watershed soil erodibility, and nitrate concentration correlated with the extent of cretaceous rock formations.

Suspended Sediment and Turbidity

Wetlands receive particulate matter via runoff from surrounding uplands, litterfall from vegetation, and transported material from wave action within the wetland (Levine and Willard 1990). Highly erodible clay soils of the surrounding watershed become suspended in surface runoff before entering the wetland (Figure 4). High concentrations of suspended sediments and turbidity due to wave action limit light penetration, thereby restricting photosynthetic rates and reducing productivity of submerged plants important to waterfowl (Beeton 1958, Emerson 1961, Coe and Schmelz 1972, Adamus 1993).

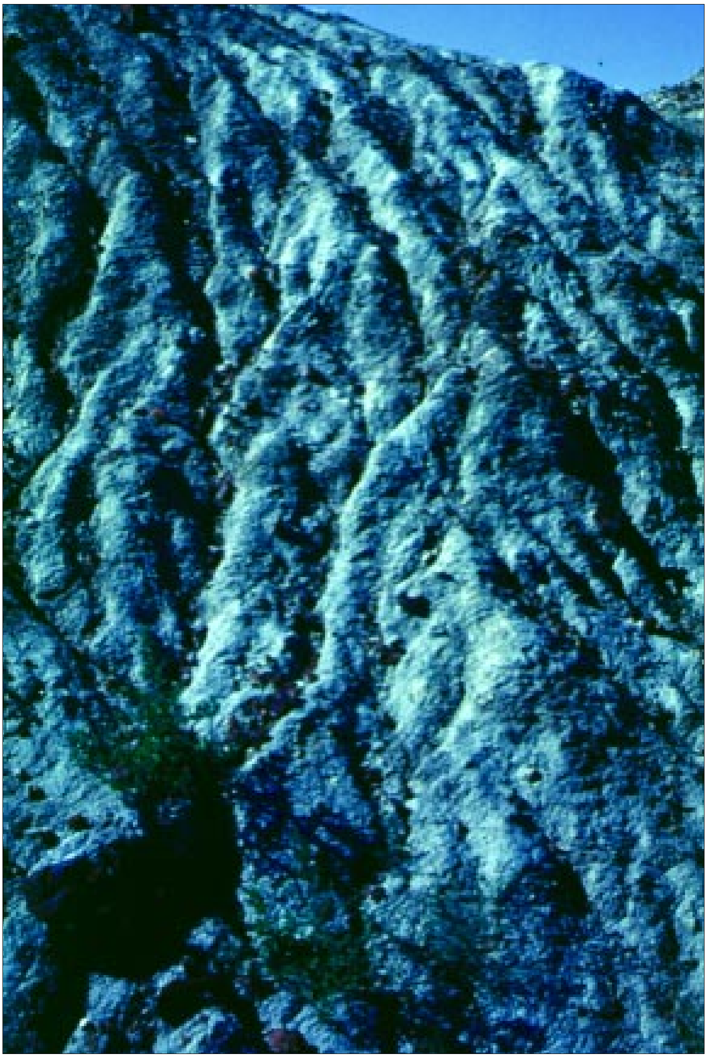


Figure 4. Highly erodible soils around wetlands often result in high concentrations of suspended sediments and turbidity in wetland waters. This condition restricts photosynthetic rates and reduces productivity of submerged wetland plants important to waterfowl. (Photo by Rich Olson)

Heavy sediment loads also rapidly diminish the storage capacity of a constructed wetland, further impacting nutrient cycling and water quality. The impact on a wetland from suspended sediments depends upon vegetation density, type of suspended solids, hydrology, and morphology of the wetland (Levine and Willard 1990).

Adamus (1993) expressed concerns about long-term sustainability of constructed wetlands in agricultural regions. In heavily farmed or ranched areas, heavy sediment loads in runoff combine with the effects of intensive springtime grazing, severe eutrophication, local water table disruption, and possible contamination with metals and pesticides to cumulatively threaten long-term functioning of constructed wetlands.

Heavy Metals

There are no studies describing heavy metal cycling in constructed Intermountain West wetlands. In natural wetlands, plants and soils adsorb a limited amount of heavy metals when present in soluble form. Most wetland soils with high organic matter, near neutral pH, and low oxygen concentration have heavy metals in insoluble forms. This limits transfer to plant tissue (Levine and Willard 1990).

In summary, water quality affects wetland vegetation establishment and productivity, which, in turn, influence aquatic invertebrate production and waterfowl abundance. Chemical and physical (suspended sediment) characteristics of water in created wetlands vary by region in the Intermountain West. Because of these site-specific differences and the complex interaction of water, soils, and wetland vegetation, a basic understanding of these processes is necessary before designing, constructing, and managing constructed wetlands.

SUBSTRATE PROPERTIES

Wetland soils provide a substrate for plants, support chemical transformation processes necessary for ecosystem productivity, and serve as reservoirs of minerals and nutrients for wetland plants. These hydric soils are unique since the lack of oxygen results in anaerobic reducing functions, rather than aerobic oxidizing processes characteristic of upland soils. Bacterial decomposition of organic matter and other chemical transformations are much slower under anaerobic conditions, often resulting in an accumulation of organic matter (Hammer 1997).

Hydric soils are classified as either mineral soils, having less than 12 to 20 percent organic matter, or organic soils, greater than 12 to 20 percent organic matter. In older, well-developed constructed wetlands, upper soil horizons are usually organic (or histic materials), and lower soil horizons are usually mineral soil layers due to the deposition of organic material (Hammer 1997). Organic soils have a higher percentage of pore spaces (greater than 80 percent) compared to mineral soils (less than 50 percent), and have higher water-holding capacities. However, water movement (hydraulic conductivity) is lower in organic soils compared to many mineral soils (Hammer 1997).

Cation exchange capacity (CEC), or the ability of a soil to retain cations on exchange sites, is greater for organic soils (Mitsch and Gosselink 1986). The dominate cation in organic soils is H^+, while metal cations (Ca^{2+}, Mg^{2+}, Na^+) predominate in mineral soils. Cation exchange capacity is important in chemical transformation processes that supply minerals and nutrients for aquatic plants (Hammer 1997).

Redox potential is the soil's or water's capacity to oxidize or reduce chemical substances. The range of redox potential in wetland soils is -300 to +300 millivolts. The interaction of redox potential and pH (which ranges from 3 to 11 in wetland soils) influences cation exchange capacity, which, affects the solubility and availability of minerals and nutrients for aquatic plant uptake. Typical wetland soils have a pH of 7.0 and a redox potential of -200 millivolts where common substances occur in reduced forms, for example, nitrogen as N_2O, N_2, or NH_4^+, iron as Fe^{2+}, manganese as Mn^{2+}, carbon as CH_4, and sulfur as S^- (Hammer 1997).

Little data exist on substrate characteristics of constructed wetlands or on comparisons between constructed and natural wetlands. However, several researchers reported that nitrogen, phosphorus, and organic matter increase with age in constructed wetlands (Reimold et al. 1978, Lindau and Hossner 1981, Craft et al. 1988).

Nitrogen, an essential element in plant growth, is generally found as the ammonium ion in submerged soil because conversion to nitrite and nitrate by aerobic bacteria cannot occur. However, when water levels fluctuate, regular microbial nitrification processes proceed under aerobic conditions and increase the availability of nitrogen for plant utilization (Emerson 1961, Kadlec 1962).

Periodic water level drawdowns are desirable to promote a greater rate of organic matter decomposition under aerobic conditions in substrates, with a subsequent release of available nutrients required for plant growth. Complex anaerobic reducing and aerobic oxidizing processes of substrates associated with periodic flooding and receding water levels influence nutrient cycling and subsequent germination, establishment, and production of wetland vegetation.

More research on substrate properties, chemical transformations of organic and inorganic materials, and nutrient cycling is needed to fully understand vegetation production in constructed wetlands. Until that information is available, resource managers must use data from natural wetland studies in designing and constructing wetlands.

WETLAND VEGETATION

Numerous studies have documented the importance of wetland vegetation composition and production to waterfowl and other wetland wildlife. Wetland plant species provide wildlife habitat in the form of nesting sites, food sources, and shelter from wind, sun, and predators. The highest diversity of wetland bird species occur in constructed wetlands with a variety of wetland plant community types and abundant open water (Adamus 1993). In the lower Gunnison Valley of Colorado, Rector et al. (1979) reported similar bird density between forested, shrub, and emergent plant-dominated wetlands, but the greatest bird diversity occurred in emergent plant-dominated wetlands with open water.

Wetland vegetation is the cornerstone for ecological functions, consumptive and nonconsumptive resource values, and economic benefits in constructed wetlands (Figure 5). Wetland plants assemble organic, living materials from nonliving substances, providing the foundation for all other wetland life forms (Hammer 1997).

Germination, establishment, and production of wetland vegetation in constructed wetlands is strongly affected by hydrologic regimes, water quality, and substrate properties. Fluctuating water levels, alkalinity and acidity concentrations, salinity, substrate properties, dissolved solids, and suspended sediments all influence wetland

Figure 5. Wetland vegetation is the cornerstone for ecological functions in constructed wetlands, providing the foundation for all other wetland life forms. (Photo by Rena Baldwin)

plant productivity in constructed wetlands as discussed previously.

Wetland vegetation also modifies hydrologic regimes, water quality, and substrate properties over time. Wetland vegetation influences hydrologic regimes by intercepting precipitation and runoff, trapping blowing snow, and regulating water loss through evapotranspiration processes and evaporative losses from open water surfaces. Water depth is modified by trapping sediment from runoff and contributing to the accumulation of organic matter by shedding dead plant tissue. As wetland plant communities mature and spread, the associated plant biomass modifies hydrologic regimes by influencing inflow and outflow pathways, improves water quality by filtering out pollutants from runoff, enhances soil fertility by depositing more organic matter, and reduces shoreline slopes by increasing sediment deposition from slowed surface runoff (Olson 1981).

Early plant invaders of newly constructed wetlands are cattails (*Typha angustifolia*, *Typha latifolia*, *Typha glauca*) and pondweeds (*Potamogeton* spp.). These plants thrive where moderate water acidity occurs; however, decreasing acidity leads to increases in diversity of colonizing plant species, eventually modifying conditions for further colonization and establishment by other species.

Figure 6. Basin slope is a major factor controlling the development of wetland vegetation in constructed wetlands. Interacting with fluctuating water levels, basin slope influences wetland plant community development by regulating water depth and permanence within zones of wetland plant establishment. (Photo by Rich Olson)

Environmental Factors Influencing Wetland Vegetation

A major factor governing the development of wetland vegetation in constructed wetlands is basin slope (Figure 6). Interacting with fluctuating water levels, basin slope influences wetland plant development by regulating water depth and permanence within wetland vegetation zones. Since wetland plant development is closely linked with moisture conditions, extreme basin slope limits the amount of shoreline area having favorable moisture conditions under fluctuating water levels. This results in narrower emergent communities, restricted submergent plant community zones, and lack of wet meadow communities (Olson and Barker 1979).

With submerged vegetation, deep water near shore (due to extreme basin slope) limits the amount of light penetration reaching submerged plants. Photosynthesis is severely restricted with increasing water depths, limiting community development to narrow bands near shore (Olson and Barker 1979). Basin slope can severely limit biological productivity by restricting wetland plant community development. This situation is most pronounced in strip mine ponds (Crawford 1942, Burner and Leist 1953, Davis 1971, Coe and Schmelz 1972, Hawkes 1978, Olson 1981).

Another inherent problem with steep-sloped basins is rapid shoreline erosion with subsequent increased sediment deposition resulting in chronic water turbidity, especially in wind-affected wetlands. High turbidity and increasing water depths limit effective light penetration for photosynthesis in submerged vegetation. This causes lower submerged plant productivity and reduced invertebrate abundance, discouraging waterfowl use. Additionally, rapid sediment deposition causes a constantly shifting substrate to which wetland plants anchor, resulting in reduced wetland plant community development (Olson and Barker 1979).

Constructed wetlands with shallow shoreline slopes (e.g. livestock ponds) support greater plant community diversity, distribution, and occupied area (Dane 1959, Lathwell et al. 1969). Evans and Kerbs (1977) reported that gently sloped shorelines and rapidly changing water levels encouraged greater waterfowl nesting and brood rearing due to enhanced wetland plant community development.

Water level fluctuation also influences wetland plant development in constructed wetlands. Several researchers working in natural wetlands used deliberate water level manipulations for selecting and managing specific plant communities (Schmidt 1951, Johnsgard 1956, Kadlec 1962, Robel 1962, Harris and Marshall 1963, Anderson and Glover 1967, Burgess 1969, Meeks 1969). Deliberate drawdowns facilitate organic matter decomposition under aerobic conditions and enhance seed germination of aquatic plants, resulting in lush emergent vegetation cover.

Other environmental factors, such as substrate texture and fertility, attribute to successful wetland plant development. Moyle (1945, 1956), Moyle and Hotchkiss (1945), Sculthorpe (1967), and Modlin (1970) indicated that plant distribution depends upon bottom soil texture, bottom soil fertility, and water quality. In a California study, Mall (1969) concluded the length of soil submergence is most important, followed by soil salinity concentrations. Veatch (1932) reported prolific aquatic plant growth on soft, slimy, sedimentary peat or organic mud bottoms and reduced growth on nearly pure sand, cobbles, or hard rock. Potzger and Van Engel (1942) included physical factors of the substrate (soil texture, wave action causing coarse soils, and slope) as primary influences in wetland plant establishment. Zutshi (1975) stated that prolific plant growth was associated with shallow water, rich organic soils, and minimal wave action.

Wave action can significantly impact wetland plants. Wave height and erosive force is dependent on water depth, the “fetch” (width) of open water, presence or absence of particular vegetation types, and substrate material. Wave action is a major force affecting bank erosion, and often plays a paramount role in flushing sediment, nutrients, and other materials from wetlands (Kusler 1988). Jupp and Spence (1977) reported that submerged slender pondweed (*Potamogeton filiformis*) and sago pondweed (*Potamogeton pectinatus*) were limited by wave action. Waves reduced plant biomass directly in exposed areas and indirectly by creating coarse, nutrient-poor bottom soils.

Figure 7. Heavy livestock grazing and vegetation trampling around constructed wetlands increases water turbidity and reduces biological productivity. Judicious livestock grazing management, however, can enhance waterfowl nesting productivity by stimulating vegetation production used by waterfowl for nesting cover. (Photo by Rich Olson)

Dane (1959) reported that plant species composition in wetlands is governed by basin slope, nature of the bottom soils, water clarity, depth, and extent of water level fluctuation. Riley (1960) stressed that flora density is determined by a complex set of factors including basin age, slope, water depth, water pH, soil fertility, and soil pH.

Biological Impacts on Wetland Vegetation

Livestock grazing has a considerable impact on wetland vegetation (Figure 7). Rumble (1979) reported that excessive grazing and trampling of shoreline vegetation increased pond turbidity and reduced biological productivity. The number of waterfowl broods using a severely grazed pond was reduced.

In Montana, Berg (1956) found that plant density, average plant height, and plant diversity increased in wetland plant communities fenced from livestock grazing. Waterfowl nesting densities and brood production increased within fenced areas, especially on larger reservoirs. Lokemoen (1973) reported that reduced grazing pressure improved waterfowl habitat through enhanced wetland plant development. Breeding pairs were significantly more numerous on lightly grazed ponds with grassy shorelines, while broods were more numerous on ponds with brushy shorelines of emergent vegetation.

Ecological processes in constructed wetlands are similar to natural wetlands in that they are governed by a complex, interrelated set of primary components that include hydrologic processes and water quality, substrate properties, and influences from wetland plant communities. These ecosystem components are continually interacting at different rates. Over time, interactive relationships between these components evolve into a fully functioning wetland that provides a host of consumptive and nonconsumptive values and benefits.

Design and Construction Criteria

Developing constructed wetlands includes three phases: pre-construction considerations, constructing critical components, and monitoring post-construction ecosystem functioning. Many wetland creation projects sufficiently address pre-construction and development aspects but fail to conduct follow-up monitoring to evaluate success (Levine and Willard 1990).

PRE-CONSTRUCTION CONSIDERATIONS

Before starting any wetland project, goals and objectives must be carefully planned in terms of desired hydrology, wetland plant community associations, intended purpose and function of the wetland, and expected values. These parameters will determine site selection, configuration of the excavated basin, vegetation species to plant, timing of construction, and other factors. Regional natural wetlands, if present, can be used as template reference areas during construction and follow-up monitoring to determine success (Brooks 1990).

Wetland construction should be planned by sketching a cross-sectional view of basin contours and slopes, and drafting an aerial view of surface shoreline configuration, island development, upland cover areas, fencing (if any), topsoil stockpile sites, water control structure locations, access routes, observation points, and other physical developments. Consult with the local Natural Resources Conservation Service (NRCS) office to verify that your construction design meets legal and safety requirements (Figure 8). Also, contact the State Engineer's Office or other appropriate governmental agency for clearance on water rights, as well as the Army Corps of Engineers for a permit to move soil or manipulate water flow. Adequate planning will prevent many unanticipated problems later and reduce costs (Olson 1990).

The most important components for successful wetland development are establishing good water control and designing basin morphometry characteristics that optimize hydrologic regimes and wetland plant community development. Properly locating the wetland project is of utmost importance for maximizing the potential development of the primary ecosystem components discussed earlier: hydrology and water quality, substrate properties, and wetland vegetation development.

Figure 8. Before wetland construction begins, carefully plan basin morphometry, shoreline configuration, island development, upland wildlife cover areas, location of water control structures, and other physical developments. Consult with your local NRCS office to verify that your construction plan satisfies legal and safety requirements. (Photo by Rena Baldwin)

Selecting Wetland Sites

Areas that at one time supported an historic wetland lost from sedimentation, deliberate filling, or long-term degradation of water quality should be the first priority for site selection. These sites can support a functioning wetland and already contain wetland plant seed banks, substrate nutrients, and potential hydrology. Second choice locations are sites adjacent to existing permanent water sources, such as lakes, rivers, and water channels, where establishing hydrologic regimes is convenient. Upland areas situated over a water table close to the ground surface are good third choice locations (Levine and Willard 1990).

From an economic standpoint, locate the wetland where the largest storage volume can be obtained with the least amount of excavation. A good site is one where a dam can be built across a narrow section of a valley, the side slopes are steep, and the slope of the valley floor permits a large area to be flooded (Figure 9).

For wetlands where surface runoff is the main source of water, the contributing drainage area must be large enough to maintain water in the pond during droughts. However, the drainage area should not be so large that expensive overflow structures are needed to bypass excess runoff during large storms.

Figure 9. To save construction costs, place the constructed wetland where the largest water storage volume can be obtained with the least amount of excavation. A good location is where a dam can be built across a narrow valley section and the slope of the valley floor permits a large area to be flooded. (Photo by Rich Olson)

The amount of runoff that can be expected annually from a given watershed depends upon many interrelated factors. The physical characteristics that directly affect the water yield are relief, soil infiltration, plant cover, and surface storage. Storm characteristics, such as amount, intensity, and duration of rainfall, also affect water yield. These characteristics vary widely by location, but each must be considered when evaluating the watershed area conditions for selecting a particular wetland location (USDA 1997).

Once project locations are selected, potential hydrology, expected water quality characteristics, and substrate properties must be evaluated. Hydrology factors include the extent and periodicity of water level fluctuations (the most important), water depth potential, expected wave action, and degree of sheltering from wind and waves.

Important water quality factors to consider include potential turbidity, alkalinity and acidity, pH, nutrient levels, heavy metal concentration, and organic contaminant sources. Wetlands should be located where year-round water supplies maintain continuous inflow and outflow flushing to avoid stagnation problems. Vegetation established near the upper end of a constructed wetland at the source of water inflow will trap sediment to improve water quality and extend the useful life of the wetland for wildlife and livestock. Likewise, off-site watering access points for livestock will reduce sediment deposition in the wetland to maintain water transparency for good aquatic plant growth (Olson 1990).

Substrate characteristics to consider are texture, nutrient levels, contamination potential by heavy metals or organic toxicants, and the presence of a viable seedbank (Levine and Willard 1990). Soils should hold water without excessive seepage. Clays or fine silts are particularly desirable. Sandy soils should be avoided unless there is an underlying hardpan of clays or fine silts. Adding bentonite or other clays to seal a seeping wetland basin will inflate construction costs but may be necessary on some sites.

To maintain the required depth and capacity of a wetland, the inflow must be reasonably free of silt from an eroding watershed. The best protection is adequate application and maintenance of erosion control practices on the contributing drainage area. Land under permanent cover of trees, grass, or forbs is the most desirable drainage area. Cultivated areas protected by conservation practices, such as terraces, conservation tillage, stripcropping, or conservation cropping systems, are the next best watershed conditions.

If an eroding or inadequately protected watershed must be used to supply wetland water, delay wetland construction until conservation practices are established. In any event, protection of the drainage area should be started as soon as possible (USDA 1997).

Waterfowl and Fisheries Habitat Considerations

A major consideration when constructing livestock watering and agriculturally created irrigated wetlands is wildlife and fisheries habitat. Resource managers and landowners contemplating wetland construction often are interested in information about habitat needs of waterfowl and fish.

Waterfowl require a variety of habitat types for reproduction, feeding, staging, molting, and brood rearing. Using ducks as an example, shallow wetlands are required in spring for mating; heavily vegetated grass or shrub uplands are needed for nesting in late spring; shallow wetlands interspersed with emergent shoreline vegetation and open water facilitate brood rearing; and large areas of open water are used for molting and staging (Figure 10) (Smith 1953, Atlantic Flyway Council 1972, Poston 1981).

Diving ducks (e.g. ruddy, canvasback, redhead, lesser scaup, and ringneck) require deeper, open water areas in larger wetlands while dabbling ducks (e.g. mallard, pintail, gadwall, teal, and widgeon) need shallower, emergent vegetation zones in smaller wetlands with heavy upland residual vegetation for nesting (Table 2). Geese prefer large, open water wetlands with adjacent grain crops for feeding locations. Shorebirds (e.g. plovers, rails, sandpipers, avocets, and phalaropes) feed on exposed mudflats of shallow, gradually sloped wetlands. Wading birds (e.g. herons, egrets, and bitterns) feed on invertebrates, fish, and amphibians found in shallow water along wetland margins (Cole et al. 1996).

Figure 10. For optimum waterfowl production, a diverse wetland habitat is required for nesting, feeding, staging, molting, and brood rearing. Combinations of heavily vegetated uplands, shallow water shorelines with emergent wetland vegetation, and open water areas are ideal. (Photo by Rich Olson)

These specialized wetland habitats are sometimes called temporary (heavy, residual upland nesting cover), seasonal (shallow, emergent vegetation and mudflats), semi-permanent (submerged vegetation areas), and permanent (open water) wetland zones (Figure 11). Water depth and duration influence the presence and extent of these zones in a wetland, and both can be manipulated by regulating water outflow and inflow pathways. The ability to control water depth and duration allows resource managers and landowners to create various wetland vegetation zones for waterfowl, while managing water for agricultural purposes.

Another consideration for selecting wetland locations is wetland density within the larger regional area. To optimize waterfowl breeding habitat, many researchers emphasize locating wetlands within "complexes" of seasonal, semi-permanent, and permanent wetland types (Evans and Black 1956, Kantrud and Stewart 1977, Dwyer et al. 1979, Ruwaldt et al. 1979, Brown and Dinsmore 1986). This arrangement allows for maximum dispersal of territorial breeding pairs, provides high-protein food sources (invertebrates) for breeding hens (from ephemeral wetlands), and still offers permanent, open-water wetlands for brood security when seasonal wetlands are dry.

For fish, wetland depth and size are the most important aspects of pond design.

Table 2. General habitat requirements for diving and dabbling ducks.

Diving Ducks (Ruddy, Canvasback, Redhead, Lesser Scaup, Ringneck, Common Goldeneye, Barrows Goldeneye, Bufflehead, and Common Merganser)

- Nests over water or immediately adjacent to water; requires good interspersion of tall emergent vegetation and shallow open water
- Minimum wetland size required for good production is 5 acres
- Larger pond sizes and better interspersion of tall, moderate, and low emergent vegetation growth with open water increases potential for production
- Most productive brood habitat is highly diverse vegetation, with productive submerged rooted aquatic vegetation and associated aquatic invertebrate insects
- Management practices for diving ducks generally produce habitat requirements for other ducks, geese, swans, cranes, and shorebirds
- Common goldeneye, Barrows goldeneye, bufflehead, and common merganser prefer cavity or bank nesting wetland habitat characteristics

Dabbling Ducks (Mallard, Pintail, Gadwall, Teal, and Widgeon)

- Dabbling ducks are upland, dry site nesters preferring heavy residual vegetation with overhanging cover for nesting
- Earlier nesters (mallard and pintail) require the greatest amount of heavy residual vegetation cover with preferred vegetation height of at least 18 inches
- Mallards and pintails may nest up to 1 mile from a wetland
- The most secure and productive areas for brooding dabbling ducks have a diverse and productive array of submerged aquatic plants with associated aquatic invertebrate insects, an interspersion of tall emergent vegetation in open water areas along some shorelines, and other shoreline areas with an abundance of low or moderate height sedges, rushes, and seed-producing emergent vegetation
- Minimum desired wetland size for brood-rearing is 1½ acres
- Islands provide secure nest sites for all dabbling ducks, and should be linear in shape with dense vegetation cover for nesting

Wetlands should be at least 8 feet deep over one-third of the surface area at low-water periods to avoid low dissolved oxygen levels that cause summer or winter fish kills. In addition, wetlands should have limited shallow water (less than 3 feet) areas to discourage aquatic vegetation growth that depletes dissolved oxygen in the water. Deeper wetlands have more water volume for storing surplus dissolved oxygen to prevent fish kills (Kehmeier 1985).

Wetland size influences potential fish production levels. Generally, wetlands of 1 to 5 acres are adequate for fish production. Wetlands less than an acre should be stocked with fish that can be supplementally fed such as trout or channel catfish.

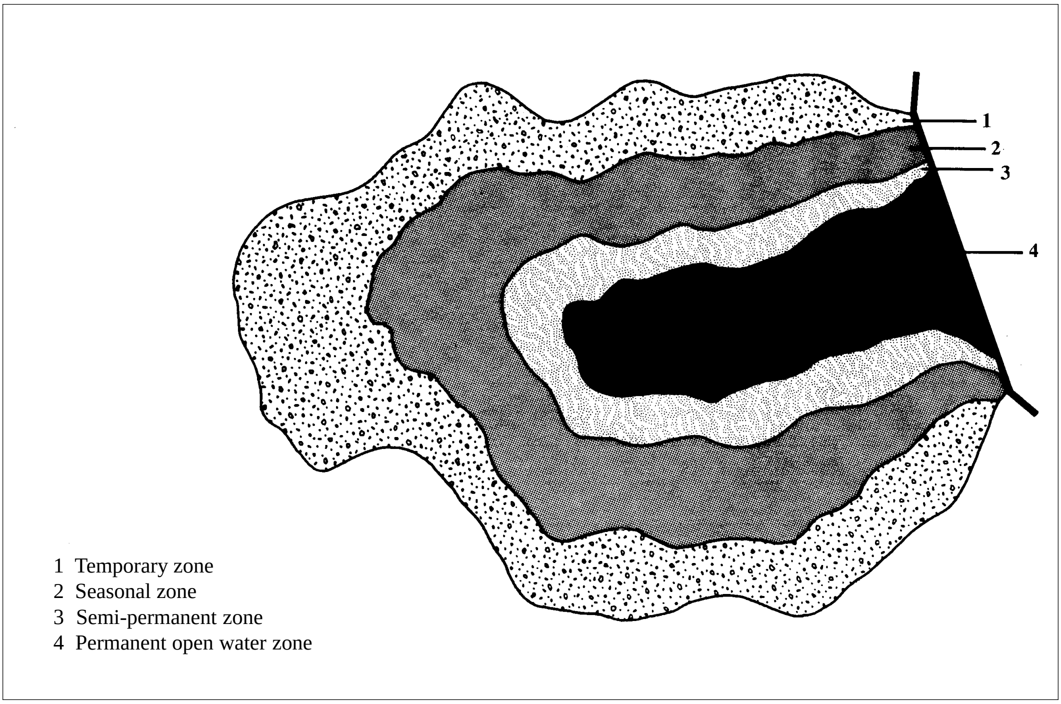


Figure 11. Zones of different wetland plant communities based on water depth and duration are commonly called temporary (heavy, residual upland nesting cover), seasonal (shallow, emergent vegetation), semi-permanent (submerged vegetation areas), and permanent (open water areas). Natural or controlled water level fluctuations determine the development of wetland plant community zones.

Water temperature is a key factor regulating fish species composition, growth and spawning rates, and dissolved oxygen concentrations. Water depth, elevation, water source, and flushing rate all influence water temperature. Trout will not survive in water above 70° F, while warmwater fish (bass, catfish, and bluegill) do poorly in water below 70° F.

Dissolved oxygen deficiency is a common problem caused by warmer water temperatures, shallow water depths, smaller basin water volume, lower photosynthetic rates of submerged plants, and high bacterial decomposition rates of organic matter. Most fish require a minimum of 5 parts per million (ppm) dissolved oxygen. If fisheries habitat is a primary objective for a constructed wetland, then pond depth, size, water source, water temperature, and flushing rates need to be considered before construction begins (Kehmeier 1985).

Recommendations of constructing deeper water depths, larger basin water volumes, and reduced shallow water area for optimum fish habitat are not ideal for creating waterfowl habitat, especially for dabbling ducks. Goals and objectives must be carefully planned before starting any construction project.

Livestock Considerations

If constructed wetlands will be used for watering livestock, locate a wetland near each pasture or grazing unit so livestock do not have to travel long distances for water. Well-placed watering sources encourage uniform grazing and aid in grassland management.

Avoid constructing wetlands where drainage from feedlots, corrals, and farmsteads can reach them. Heavy organic macronutrient loads from these areas rapidly degrade water quality. Use permanent diversions to redirect runoff from these sources in the event no other suitable wetland location is available (USDA 1997).

Selected sites should provide easy access routes for heavy equipment required in excavation work. Difficult access for heavy equipment will increase construction costs.

The wetland construction project must be planned within a budget. Smaller projects can be accomplished with tractors and equipment already available on most farms and ranches. Larger projects require heavy equipment, large labor commitments, and substantial materials, so they should be planned carefully.

CRITICAL COMPONENTS OF CONSTRUCTED WETLANDS

Basin Morphometry

Basin size (area) is generally governed by limitations of the construction site and specific project objectives. If possible, excavated basins must be designed to accommodate maximum potential runoff from spring thaws and peak rainstorms (Figure 12). The surrounding watershed area and amount of estimated runoff during peak flows must be determined to calculate basin size (Olson 1990).

If waterfowl production is a primary concern, basins should be at least 1 acre or larger to attract waterfowl (Hudson 1983). However, Williams (1985) reported that bird species diversity increases with a wetland area up to 10 acres, with subsequent stability of species richness in larger wetlands.

Water depths should be varied throughout the basin to attract a wide variety of flora and fauna. Maximum water depth should not exceed 4 to 8 feet for optimum wetland plant development. Where fish stocking is planned, an area with minimal depths of at least 8 feet are required to avoid winter kill. Deep wetlands will be oligotrophic, while shallow wetlands will be more eutrophic with greater amounts of wetland vegetation and higher primary productivity (Brooks 1990). Again, specific project objectives will dictate final water depths. Dikes and/or dams should be constructed with slopes of 3:1 or 5:1 and rip-rap placed on the top and pondward toe of the dike to resist wave erosion (Farmes 1985). Common causes of dike or dam failure are overtopping of water, undermining, soil sloughing, or seepage along water control structures placed through the dike or dam (USDA 1992). Detailed engineering design specifications for dikes and dams are described in the NRCS Engineering Field Handbook (USDA 1992) and NRCS Handbook No. 590 (USDA 1997).

Shorelines should consist primarily of gently sloping gradients (less than 5°) if the primary objective is to maximize wetland vegetation production and waterfowl use.

Figure 12. Excavated wetland basins must be designed to accomodate maximum potential runoff from the surrounding watershed. However, basin size can be limited by existing site features. (Photo by Rena Baldwin)

However, include some shoreline slopes up to 90° to increase diversity in shoreline water depths and provide benefits to other wildlife and fish species (Brooks 1990). Avoid steep-sloped shorelines in areas with potential substrate instability problems to reduce erosion and sedimentation.

Contour the shoreline so shallow shelves comprise 25 to 30 percent of the basin area, and deep, open water areas comprise 70 to 75 percent of the basin area. This construction design will result in emergent vegetation to open water ratios of about 1:3 or 1:4, attracting high waterfowl numbers (Levine and Willard 1990). Kaminski and Prince (1981) documented maximum bird diversity in wetlands with a 50:50 ratio of open water to emergent vegetation. The Wyoming Game and Fish Department (1976) recommends at least 30 percent emergent cover for waterfowl habitat.

Convoluted shorelines are another design feature to produce irregular basin shapes (Figure 13). A high shoreline development index (length of shoreline divided by the circumference of a circle of equal area) provides more edge habitat for wildlife and reduces wind and wave impacts to emergent and submerged vegetation (Brooks 1984). An irregular basin shape also disperses water flows, helping to maximize retention time, which benefits flood control objectives and water quality treatment time (Brooks 1990).

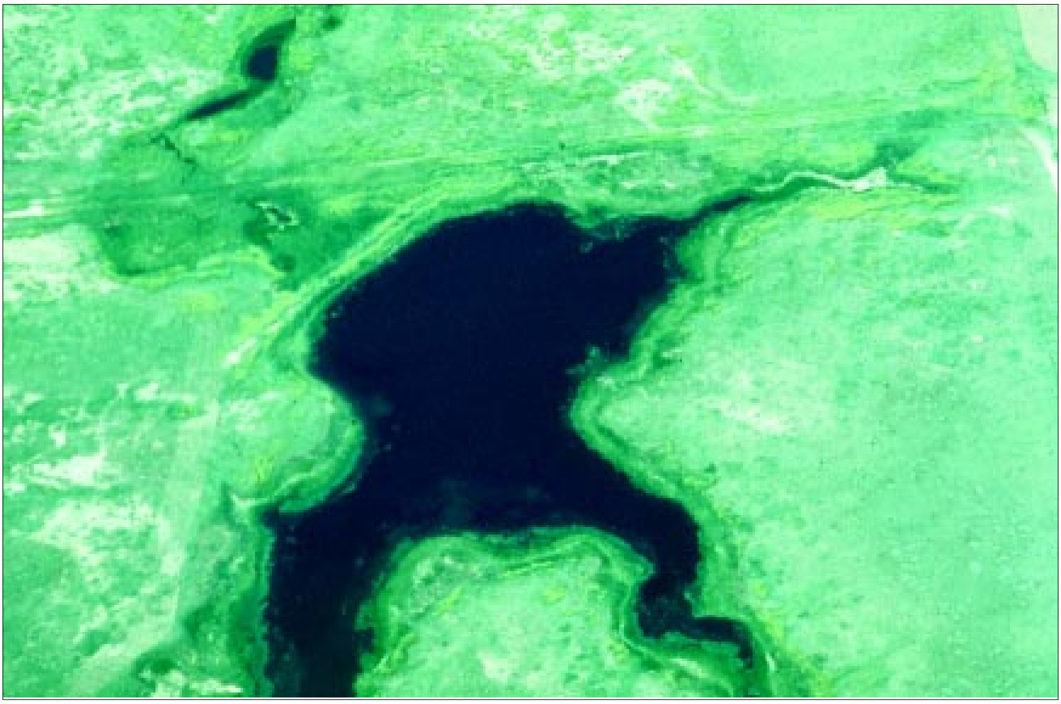


Figure 13. Irregular constructed wetland shorelines provide more edge habitat for wildlife, reduce wind and wave impacts on wetland vegetation, and enhance water quality treatment time by dispersing water flows. (Photo by Rich Olson)

Usually, prevailing topography and landform will largely determine shoreline shape, orientation, and configuration of a constructed wetland. However, the following guidelines should help in designing basin shape and shoreline configuration (Olson 1990):

- To promote shoreline irregularity, the basin should be excavated in a crescent, kidney, oakleaf, dog leg, or other appropriately varied configuration rather than a uniform circular or rectangular shape. Irregular shorelines produce high ratios of shoreline length to open water (edge effect), maximizing the habitat diversity preferred by waterfowl. The resulting small bays, peninsulas, and shoals attract waterfowl and provide aesthetic values.
- Broadly shaped basins will accomodate a greater variety and interspersion of bottom contours compared to long, narrow wetlands, adding additional habitat diversity.
- The wetland should be oriented with shallower areas on the windward side parallel to prevailing winds to minimize shoreline erosion and reduce degradation of wetland plant communities from wave action in shallow water.

Figure 14. Islands should be developed during construction by mounding excavated basin material with bulldozers, draglines, scrapers, or dredgers. Linear-shaped islands with irregular shoreline contours, approximately 50 feet wide and 200 feet long with gradually sloped shorelines, are ideal for waterfowl use. (Photo by Rena Baldwin)

Islands

Islands provide additional habitat diversity by increasing the shoreline to open water edge. Nesting wetland birds are attracted to islands for protection from terrestrial predation and disturbance.

During construction, excavated material should be used for islands to lower construction costs associated with transporting material from the basin. Draglines, dozers, scrapers, or dredgers can be used to mound basin material during construction (Figure 14). Smaller, more numerous islands are preferred over larger islands to discourage predation of waterfowl nests.

Settled height of islands should be at least 2 feet above the normally expected spring water level. Linear-shaped islands with irregular shoreline contours, approximately ¼ acre in size, 50 feet wide and 200 feet long with shallow, sloped shorelines, are recommended for maximum wildlife value. Since most dabbling ducks nest within 25 feet of the shoreline, optimum island width is at least 50 feet.

Islands should be located in permanent water areas exceeding 1 foot in water depth in protected, upwind sides of the basin away from excessive wave or ice action, at least 150 feet from the shoreline. Rip-rapping, or layering with rock, may be

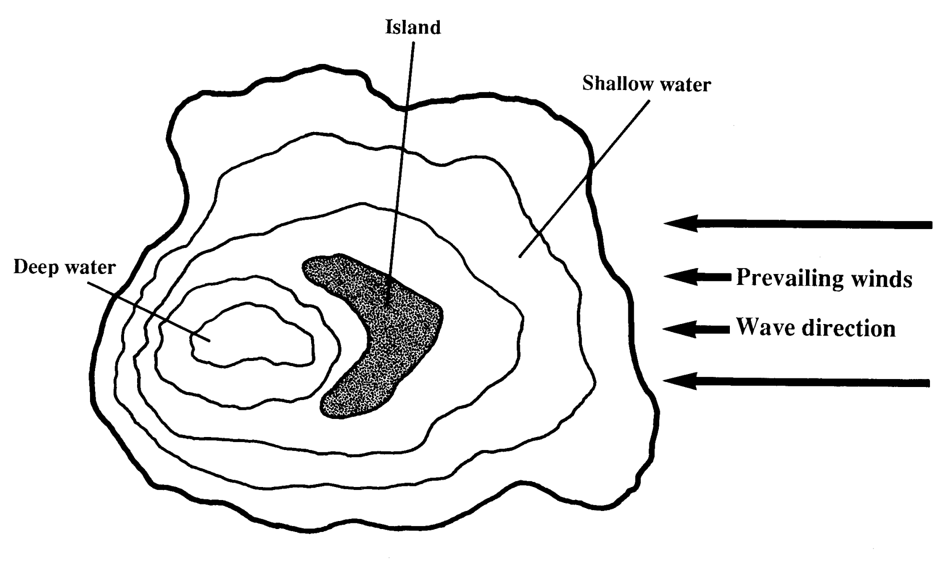


Figure 15. A linear to horseshoe-shaped island configuration oriented toward the prevailing wind direction will reduce wave impacts to wetland vegetation and erodible substrate soils on the leeward side and offer protection for waterfowl.

required to prevent erosion of islands constructed with soil too poor for vegetation establishment. A horseshoe-shaped configuration oriented toward prevailing winds will break initial wave intensity and provide a small bay-like area on the leeward side for protection (Figure 15).

Islands should be at least 200 feet apart, but not more than 500 feet apart, to avoid territorial conflicts by waterfowl (Payne 1992). One island per 4 acres of surface water is recommended. Other types of constructed islands include rock islands, culverts set on end and filled with soil or sod, round flax bales set on end, and brush islands (limbs, 6 to 10 inches in diameter, arranged in criss-cross fashion with hay or straw added).

Hydrology

Water level fluctuations are critical for enhancing wetland vegetation development. Design and construction activities should include provisions for installing water control structures to manage water levels.

For dikes or dams less than 1 foot tall, vegetated spillways can be used to release excess water accumulation in a constructed wetland. However, dikes or dams taller than 1 foot should include a water control structure. These can be a straight drop structure equipped with removable stoplogs of treated lumber, a pipe provided with a swivel elbow and riser tube, a pipe drop inlet structure equipped with a valve for flow

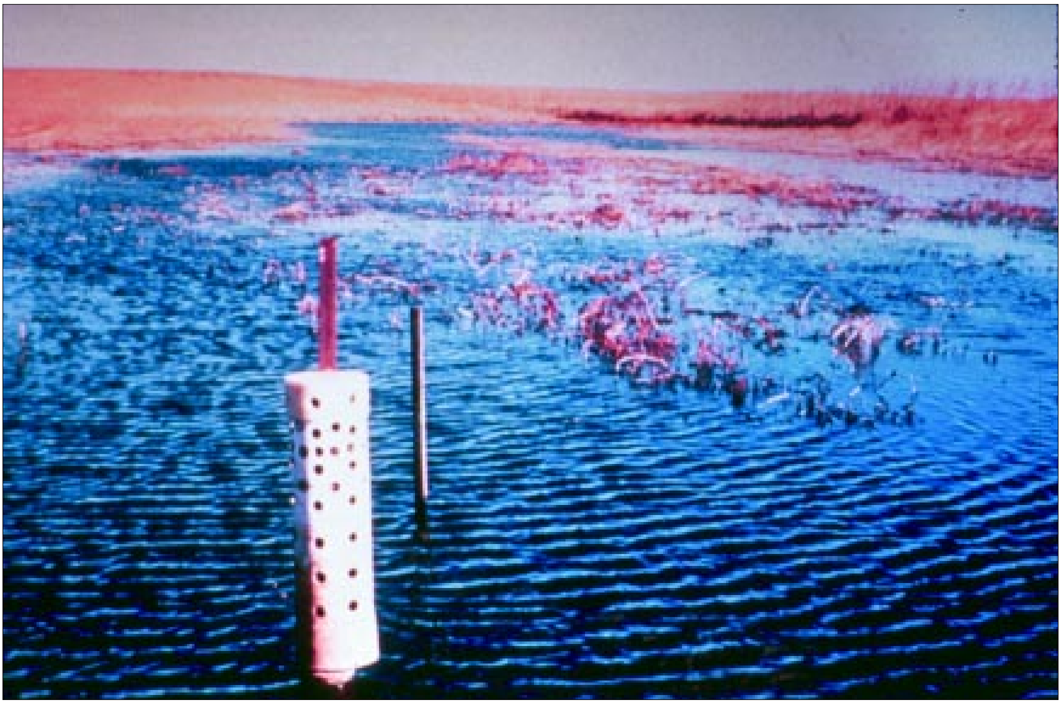


Figure 16. A common water control structure consists of a perforated PVC pipe connected to a submerged non-perforated PVC extending through a dam or dike, with a flow control valve to regulate water levels in the constructed wetland. (Photo by Rena Baldwin)

control, or a pipe with a perforated riser (Figure 16). Detailed specifications on water control structures and their installation are described in the NRCS Handbook No. 590 (USDA 1997).

Where water level control is possible, consider planting wetland vegetation in areas where waves and ice heaving have minimal impact when water levels are reduced. The erosive force of wave action and ice heaving can prevent successful wetland plant establishment in shallow areas and uproot established vegetation (Levine and Willard 1990). Where water levels cannot be manipulated, such as closed wetland basins, select plant species that are tolerant of potential natural water level fluctuations.

Substrate

Both upland and wetland (hydric) soil conditions are critical to successful vegetation establishment, development, and nutrient cycling in constructed wetlands. Wetland plants do not prosper on either excessively hard or soft basin substrates (Kadlec and Wentz 1974).

Upland soil management is critical to properly protect the system from sediment and chemical and thermal pollution. Vegetated uplands reduce surface water evaporation in the wetland by reducing winds, allow more groundwater infiltration, produce temporary ponds in depressional areas, and reduce peak infiltration rates that cause abnormal water table fluctuations and droughty surface conditions. The ability of upland soils to retain water is dependent upon soil texture (eg. sand vs. clay), soil depth, organic matter content, and distribution of pore sizes. Sediment yields from newly graded upland areas are highest during the first 6 months after construction and decrease by 50 percent during the next 6 months as revegetation progresses. Revegetation of exposed upland soils must be accomplished rapidly to avoid the impacts of reduced light transmission, increased water temperatures, and deposition of suspended solids on sensitive organisms due to sediment transport (Brooks 1990).

Exposed upland soils should be seeded, fertilized, and mulched (straw or hay is best) as soon as possible. Where acidic conditions exist, add lime to raise the pH to at least 5.5. Seed mixture recommendations can be obtained from the regional NRCS office (Brooks 1990). In some cases, buffers of trees and shrubs may be planted around the wetland to remove 50 to 75 percent of sediments and provide wildlife travel corridors. A buffer width of 50 to 65 feet is recommended (Barfield and Albrecht 1982).

Hydric soils can be developed by transporting substrate materials from a local existing wetland or constructed using various amendments. Sometimes soils from roadside ditches or other wet depressional areas serve the same purpose. These soils generally have high organic matter content and serve as a seed source for wetland plant establishment. To construct hydric soils, mix 30 percent (by volume) of livestock manure with 70 percent fertile topsoil to supply organic matter and nitrogen sources. Some resource managers add small quantities of superphosphate around each plant propagule to enhance establishment and growth (Brooks 1990). Soil tests will identify the need for fertilizers or other amendments, such as lime, in the case of high acidity.

Wetlands created below water table levels rarely require sealing. However, perched wetlands require a clay lining on the basin bottom and along the sides to prevent seepage. Bentonite clay, compacted to a thickness of 12 inches, is recommended (Brooks 1990). Other methods used to seal constructed wetlands are compacting on-site soil material and installing a flexible plastic membrane that covers the entire wetland basin (USDA 1992).

Revegetation

Two commonly accepted revegetation techniques are natural colonization and artificial establishment. Natural colonization occurs from air or waterborne seed transport, invasion from adjacent wetlands, or from seed banks within a substrate transplanted from other areas. Artificial establishment consists of seeding or transplanting whole plants, shoots, rhizomes, or tubers.

Natural colonization from a transplanted substrate is inexpensive. Seed banks contain high seed densities to provide higher establishment potential, and seed viability is up to 30 years, offering more resiliency to changing wetland conditions. Plus, established plants are better adapted to site-specific environmental conditions. The main disadvantages are potential erosion problems prior to full vegetation establishment and little control over initial plant species composition.

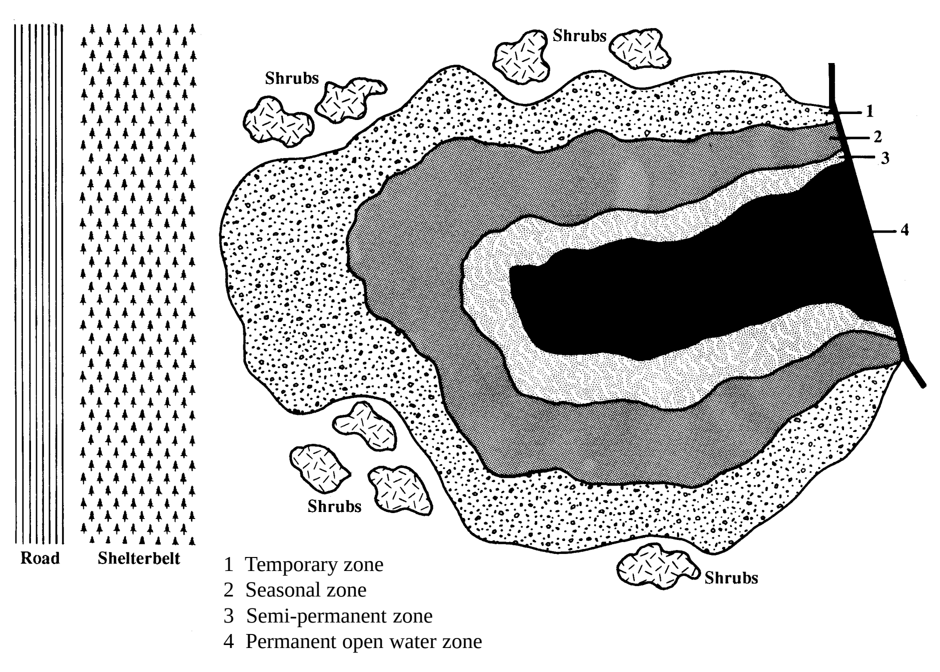


Figure 17. Design the constructed wetland to include several shrub stands around the wetland basin to increase wildlife habitat diversity. Where frequent human disturbance occurs, such as a road near the wetland, establish a shelterbelt to minimize impacts to wetland wildlife.

Artificial establishment is expensive and time-consuming, but species composition can be controlled. When artificially revegetating a constructed wetland, select plant species best suited for the environmental conditions by considering: availability of planting stock (seeds, rhizomes, tubers, and whole plants), the size of the planting area, the planting method, density, and timing for planting after selecting the species and propagule type (Levine and Willard 1990).

Factors to consider in selecting plants for artificial establishment include (USDA 1992):

- Goals and objectives of the project
- Water supply characteristics such as flooding levels, fluctuations, duration, water quality, and water volume
- Substrate characteristics (texture, slope, elevation)
- Water depth in the planting area
- Slope of the planting area
- Length of the growing season
- Surrounding habitat and land uses (plant species must be compatible with surrounding land uses)
- Wind and wave effects (select plant species more tolerant of wind and wave action)

- Water currents and velocity (applies to wetlands adjacent to steep gradient streams or rivers)
- Costs of seed, tubers, rhizomes, or whole plant

On shoreline areas where wave erosion may exist, tubers of hardstem bullrush and cattail can be planted to increase soil stability. Tubers should be collected from the immediate vicinity and planted in late spring at 12- to 18-inch intervals covered with 3 to 6 inches of soil. Plantings should be at the water line to ensure adequate moisture (Olson 1990).

Seeding constructed landforms (e.g. islands and dikes) and disturbed upland areas with grasses, legumes, shrubs, and trees will enhance the area for wildlife. Seeding reduces weed problems in adjacent croplands by pre-empting natural weed development and also will retard initial erosional soil loss (Olson 1990).

Establishing adjacent upland cover, if needed, also is important for waterfowl and other wetland wildlife requiring nesting, feeding, resting, and brood-rearing habitat. Ideally, the area of upland cover should equal the total wetland area, with adequate residual vegetation for nesting and protection. Upland areas interspersed with shrubs and trees provide variety in cover strata and offer optimum wildlife habitat. Seeding and planting supplemental herbaceous and woody plants can improve upland wildlife habitat quality (Olson 1990).

Upland nesting areas and islands should be seeded with a dense nesting cover mixture that includes wheatgrasses, yellow sweet clover, and alfalfa. In established grass stands, mulching with ripened seed hay can be used to convert ordinary grasslands into dense nesting cover. This technique may be convenient for landowners who have established haying operations (Olson 1990). Appendix B lists wetland plants that will enhance waterfowl habitat.

Planting shrub seedlings in several well-dispersed clumps within upland grass meadows is recommended for optimum habitat diversity. When located near areas of frequent human disturbance, hedgerow and/or shelterbelt plantings will minimize the impact to wetland wildlife (Figure 17). Grass and legume seedings should be initiated in late fall before the first snowfall or early the following spring. Shrub and tree seedlings are best planted early the following spring in frost-free soils. Livestock should be fenced out of newly seeded areas for the first 2 years to allow adequate stand establishment (Olson 1990).

POST-CONSTRUCTION MONITORING

Monitoring the progress of a constructed wetland after completion is essential for determining project success and identifying the need for mid-course corrections. The monitoring plan should describe what factors will be monitored, methods for gathering the information, required intervals and overall time periods for monitoring, and how collected data will be interpreted (Levine and Willard 1990).

D'Avanzo (1990) listed 6 criteria used to evaluate success in a wetland development project:

- Compare the vegetation growth characteristics (e.g. biomass or density) in constructed and natural wetlands after 2 or more growing seasons
- Determine the types of plants invading the created site with regard to habitat requirements (e.g. upland or wetland)
- Evaluate the establishment success of planted species
- Compare animal species composition and biomass in constructed and natural wetlands
- Compare the chemical composition of constructed wetland soils to natural wetlands
- Assess changes in geologic or hydrologic features over time

These criteria typically are used in wetland ecosystem studies. In addition, plants are emphasized as wetland indicators because they reflect the hydrologic regime and perform numerous important functions (D'Avanzo 1987).

Post-Construction Management

Long-term management following successful wetland construction efforts is just as important as initial design and construction for maintaining ecosystem functioning. Popular long-term management practices include manipulating water levels, controlled burning, mechanical treatments to maintain emergent vegetation to open water ratios, and controlled livestock grazing to enhance upland nesting cover (Levine and Willard 1990).

MANIPULATING WATER LEVELS

Wetland vegetation requires periodic flooding and drawdown to maintain community vigor and productivity. Drawdowns expose shoreline mudflats and allow accumulated organic matter to decompose and release nutrients for future plant growth, germination of dormant wetland plant seeds in the substrate, enhanced breeding and brood-rearing habitat for waterfowl by increasing interspersion of wetland vegetation cover, availability of wetland plant seeds for feeding waterfowl, stimulated production of aquatic invertebrates used as food sources by waterfowl, and flushing the system of excess salts and contaminants (Figure 18) (Payne 1992). Long-term flooding will prevent new wetland plant establishment and results in over-mature, decadent vegetation of little wildlife value. Wetland plant density and diversity will decline with prolonged flooding (Olson 1990).

Natural wetlands experience cyclic seasonal water level fluctuations from spring runoff and over-summer drawdown due to evaporation and plant evapotranspiration. Water control structures in constructed wetlands allow resource managers or landowners to simulate naturally occurring water level fluctuations.

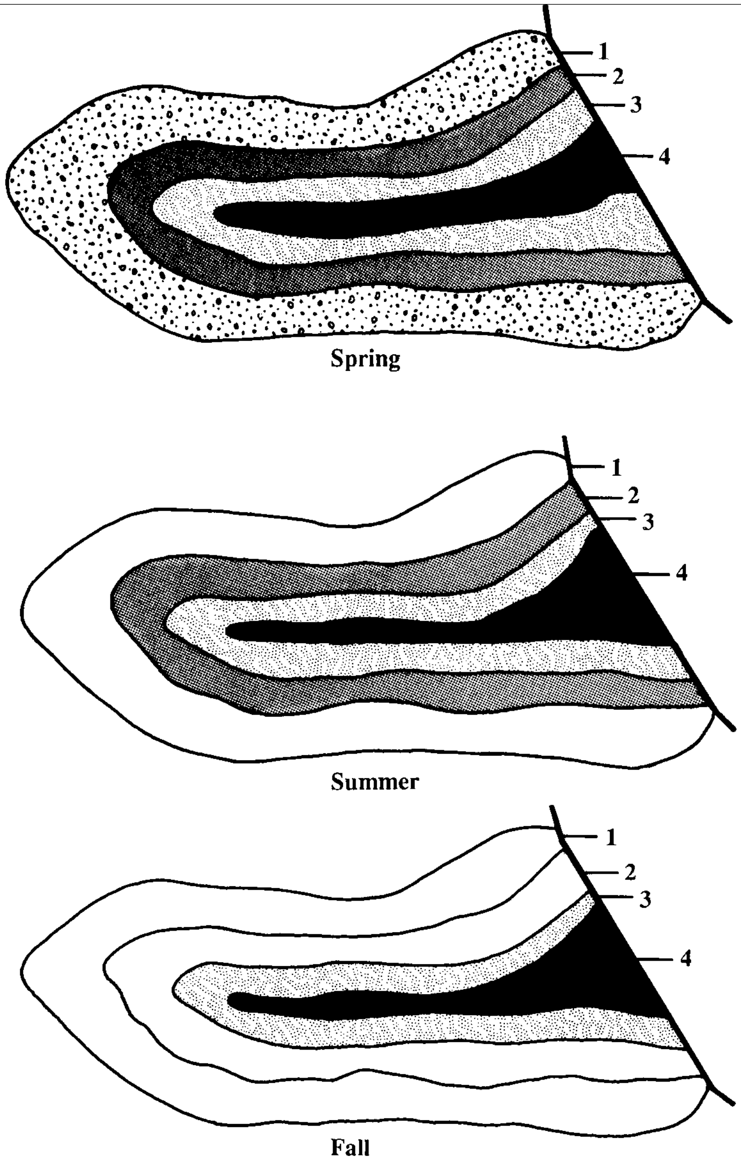
Ideally, constructed wetlands should have two drainage outlets: an uncontrolled, automatic, slow-release overflow pipe to prevent major flooding during excessive

Figure 18. Planned periodic water level drawdowns are needed to facilitate organic matter decomposition on exposed mudflats, stimulate germination of wetland plant seeds embedded in the substrate, stimulate production of aquatic invertebrates, and enhance wetland plant production. (Photo by Rich Olson)

runoff or precipitation and a major valve-controlled drain with the ability to drain the entire wetland. The valve-controlled outlet should be located where it can completely drain temporary, seasonal, semi-permanent, and permanent open water areas.

During spring runoff, water will rapidly cover the outer temporary and seasonal wetland zones (Figure 19). A prescribed drawdown will gradually expose the substrate within these outer zones, permitting germination of new wetland vegetation. Slow drawdowns, in comparison to rapid drawdowns, generally produce vegetation of greater density and diversity without impacting wildlife use. Periodic rainstorms during drawdown will create small water level fluctuations beneficial to wetland plant establishment (Olson 1990).

Prescribed drawdowns on constructed wetlands should be planned to permit maximum water availability for spring migrating waterfowl, while still allowing enough time to encourage wetland plant germination and seed production before fall frosts. These periods depend on local growing season length. Nelson et al. (1978) recommends the following water level manipulation to improve Intermountain West wetlands: raise water levels to maximum capacity from March 1 to mid-May; maintain stable water levels from mid-May to July; abruptly reduce water levels during the first



1 Temporary zone
2 Seasonal zone
3 Semi-permanent zone
4 Permanent open water zone

Figure 19. In spring, runoff water from the surrounding watershed fills the wetland basin, covering the outer temporary and seasonal wetland vegetation zones. Slow water level drawdowns, either natural or manipulated, gradually expose these zones through summer and fall, resulting in high wetland vegetation production to enhance waterfowl habitat.

2 weeks of July; raise water levels again beginning in October to flood feeding areas for migratory waterfowl; and lower water levels to a minimum pool from late October through December. This allows time for germination and re-establishment of new wetland vegetation and provides water for migrating waterfowl. Drawdowns can be implemented annually or at other yearly intervals depending on the desired goal of vegetation cover and vigor to maintain healthy plant communities.

Studies indicate that optimum wetland vegetation production occurs when yearly drawdowns expose the outer temporary and seasonal wetland zones coupled with a complete drawdown to expose semi-permanent and permanent open water substrate once every 5 to 7 years (Table 3). Maintenance on drainage valves and outlets can be completed during the total wetland drawdown period (Olson 1990).

Table 3. Summary of basic wetland management principles to consider when constructing wetlands.

- The most diverse and greatest biomass of wetland vegetation production occurs when water transparency is at least 5 feet, minimum water level fluctuations occur through spring and fall, and high water quality is maintained.
- Maintenance of good water quality is important to prevent stagnation, eutrophication (e.g. algae blooms), and disease outbreaks in waterfowl. Rules of thumb include maintaining good water interchange through all shallow water wetland areas, especially during ice-free periods, and never exceeding 5,000 parts per million in total dissolved solids. Less than 500 parts per million is best for optimum aquatic organism production; 500 to 2,000 parts per million is considered good to fair.
- If the constructed wetland is located within an existing wetland complex or situated on a previous wetland site, rarely do you need to plant emergent or submergent wetland vegetation. Generally, wetland vegetation will colonize these sites within 3 years of construction, provided hydrologic regimes are established.
- When planning a constructed wetland, include shallow water areas where mudflats are exposed during periodic water level drawdowns.
- Avoid promoting water regimes in wetlands that cause excessive encroachment of open water areas by tall emergent vegetation. The rule of thumb is to not exceed 30 to 40 percent of tall emergents interspersed in open water areas.
- The evaporative surface area relative to water inflow governs total dissolved solid buildup more than soil alkalinity.
- Different emergent plant species respond to different seasonal periods and duration of water inundation. This is especially important in establishing desired wetland plant species, emergent plant communities, and long-term perpetuation of wetland vegetation.

Figure 20. Controlled burning creates openings in dense stands of emergent wetland vegetation, eliminates partially decomposed organic matter accumulations, produces nutrient-rich vegetation growth, temporarily eliminates nuisance noxious weeds and fish (carp), and creates edges to enhance wildlife habitat. (Photo by Rich Olson)

CONTROLLED BURNING

Controlled burning is used in wetlands to create openings in dense stands of emergent vegetation, to eliminate partially decomposed organic matter during drawdowns, to promote nutrient-rich forage production after burning, to temporarily eliminate nuisance plant (noxious weeds) and animal (carp and muskrat) species, to create a wildlife edge to enhance habitat quality, and to expose shed seeds, green shoots and rhizomes for feeding waterfowl (Figure 20) (Levine and Willard 1990). The greatest value of prescribed burning is improving waterfowl habitat quality through economically beneficial natural methods. However, prescribed burns are often difficult to control, especially where dense stands of accumulated litter exist (Weller 1981).

Prescribed wetland burns are classified as cover burns, root burns, or deep peat burns, depending on the wetland water level conditions at the time of burning (Lynch 1941). Cover burns are conducted to remove dense emergent vegetation where water depths are 3 to 5 inches above rhizomes near the substrate surface (Lynch 1941, Hoffpauer 1968). Cover burns do not significantly alter wetland plant community composition since only top-growth stems are removed without damaging rhizome systems.

Root burns are conducted during water level drawdown phases where rhizomes of emergent wetland plants are damaged from heat generated by burning top-growth stems. Root burns often alter vegetation composition by removing undesirable plants and stimulating growth of dormant wetland plant seeds in the substrate (Lynch 1941).

Deep peat burns, although uncommon in most Intermountain West wetlands, occur under extremely dry substrate conditions where thick layers of organic matter accumulations prevail within the substrate. Heavy organic matter accumulations burn for long time periods, generating high temperature levels, which kill rhizome systems and sterilize dormant wetland plant seeds in the substrate (Hoffpauer 1968).

Prescribed burning of both upland and wetland vegetation communities produce optimum waterfowl habitat improvements when conducted in late summer or early fall. Avoid spring burning when waterfowl nesting and brood-rearing activities are at peak levels.

MECHANICAL TREATMENTS

A variety of mechanical treatments are used to open dense stands of emergent wetland vegetation, prevent growth of prolific woody vegetation, and increase water depth by removing sediment accumulations. These practices include cutting, crushing, disking, dozing, and dredging using a variety of different implements.

Cutting commonly opens dense stands of emergent vegetation by using hand tools, mowers attached to floating machines, mowers on wheeled and tracked machines for cutting vegetation on exposed substrate following water level drawdown, or with machines operated from the wetland shoreline. Cutting is most effective when followed by flooding. Regrowth of emergent plants is inhibited because oxygen transfer to the rhizomes through stems and shoots is eliminated by the overlying water (Payne 1992). Total shoot densities of cattail and bulrush decrease with increased depth of flooding (Murkin and Ward 1980).

Crushing emergent vegetation followed by flooding is effective for creating openings in emergent vegetation. It works best if timed to the low period of carbohydrate storage in the rhizomes when plants are flowering. Crushers consist of a large drum with 8 angle-iron cleats welded at equal intervals along the drum. Metal blades (4 inches wide with sharpened edges) are bolted to the cleats. The drum is filled with water to provide weight. All-terrain vehicles are used to pull the crusher on exposed or partially exposed (6 inches of water) substrate (Payne 1992).

Disking is used on adjacent upland areas to break up stands of sod-forming grasses too dense for wildlife or to prevent regrowth of woody vegetation. On exposed wetland substrates after water level drawdown, disking aerates and exposes drained soils to sunlight, facilitating organic matter decomposition and increasing soil fertility for stimulating wetland plant production. Disking emergent plants, such as cattail, is ineffective because of their resprouting ability (Payne 1992).

Bulldozing and dredging are used to remove stands of dense emergent vegetation following a water level drawdown or to deepen areas by removing accumulated

Figure 21. Bulldozing is used to remove stands of dense emergent vegetation or accumulated sediments following a water level drawdown. This mechanical treatment produces more open water areas in densely vegetated wetlands and increases water depth. (Photo by Rich Olson)

sediments (Figure 21). Dredging can be either mechanical, using buckets and scoops, or hydraulic, using a pump to lift and transport sediment from the wetland bottom to a shoreline disposal site. A comprehensive description of each method and implement type are discussed in Payne (1992).

CONTROLLED LIVESTOCK GRAZING

Agricultural activities such as livestock grazing and irrigation can be incorporated within the post-construction management plan if applied judiciously. Grazing to enhance vegetation vigor and extracting water for irrigation should be carefully timed to provide benefits to both wildlife and agriculture.

Livestock grazing management is used to improve plant community composition and production in upland areas for waterfowl nesting and brood rearing and occasionally to control dense stands of emergent shoreline vegetation (e.g. cattails and bulrush) by trampling. Livestock grazing is not recommended for newly constructed wetlands where young vegetation is establishing, but older constructed wetlands may be grazed where vegetation dominance is a problem (Payne 1992).

Livestock should not be permitted to overgraze wetland fringes and adjacent uplands where waterfowl and other wildlife nest, feed, rear broods, and seek

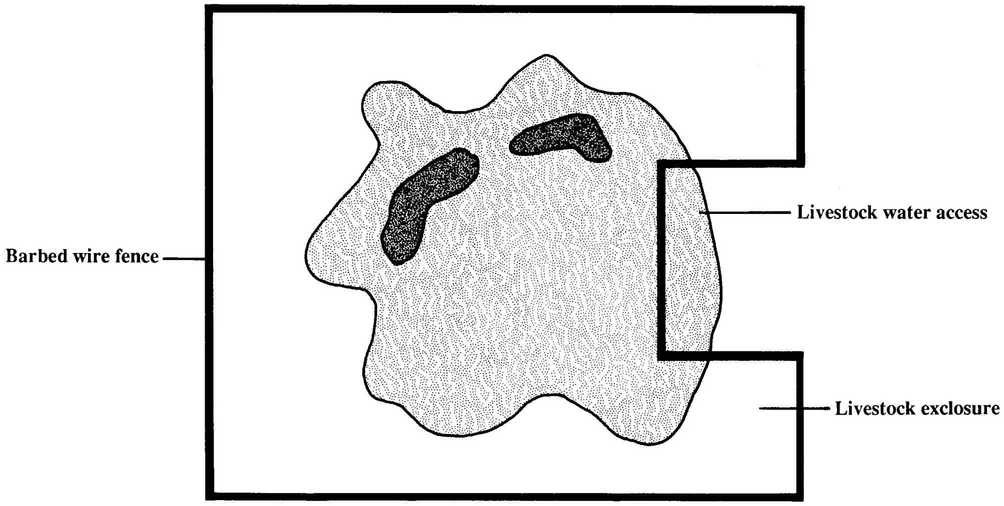


Figure 22. When integrating livestock grazing with waterfowl habitat development on constructed wetlands, consider fencing the entire wetland area to regulate livestock access. A livestock watering gap can be strategically located to provide access to water.

protective cover. However, moderate grazing at a specific time of the year and a proper stocking rate will stimulate vegetation production and maintain plant community composition. Depending on the particular site, prescribed livestock grazing once every 3 to 5 years will enhance vegetation cover for wildlife. However, livestock operators should experiment with this recommended interval to determine the optimum grazing management strategy for the specific site (Olson 1990).

Late summer or fall grazing is recommended rather than early spring or summer grazing to avoid disturbing nesting waterfowl and other wetland birds. Ideally, livestock grazing should be excluded from waterfowl nesting areas during the months of May and June to permit successful nesting and brood-rearing activities. Livestock should be removed when the vegetation shows signs of trampling or excessive use. In some situations, heavy livestock grazing on selected locations can enhance conditions for species, such as Canada geese, which prefer areas of low vegetation height that provide unobstructed vision to detect predators or other disturbances.

If financially feasible, the entire wetland complex should be fenced to regulate livestock grazing. A livestock watering gap could be strategically located to provide access to water (Figure 22), or off-site water could be developed by piping water to a holding tank. Fencing should be constructed into the permanent open-water wetland zone to prevent livestock from walking around the water gap during low-water periods and gaining access to the enclosed area. Gates should be included at strategic locations along the fence to allow periodic grazing of the exclosed vegetation. Haying within the enclosed wetland area can be detrimental to wildlife, especially if forage is cut in late spring or early summer during nesting and brood rearing.

Water normally released for prescribed drawdowns can be used for irrigation purposes. Rapidly accumulating spring runoff, if used for irrigation purposes, must be released in a short time to prevent flooding ground cover within the outer temporary wetland zone. Accumulated water within the seasonal wetland zone can be released slowly over a longer period for irrigation use, while simultaneously creating a planned water level drawdown to stimulate wetland vegetation growth. Water in the semi-permanent and permanent wetland zones can be used for irrigation during years when a full drawdown is needed for removing accumulated sediment, regenerating wetland plants, and maintaining the dam, water control structure, and wetland outlets (Olson 1990).

Summary

A variety of potential consumptive, nonconsumptive, and economic benefits exist for constructed wetlands, including enhanced landscape diversity, wildlife and fisheries habitat, agricultural values, recreational activities, sediment retention, water pollution control, public water supplies, and industrial uses. However, long-term management plans developed from research-based knowledge of ecosystem processes are required before multiple use values of these constructed wetlands can be realized.

Ecosystem function on constructed wetlands, like natural wetland systems, is governed by a complex, interrelated matrix of environmental factors that include hydrology, water quality, substrate properties, basin physical characteristics, and wetland plant community dynamics. Our current knowledge about ecological processes in constructed impoundments of the Intermountain West is extremely limited, as evidenced by the existing available literature.

Herein lies the challenge for present and future wetland resource managers and landowners. Before comprehensive, long-term management plans can be formulated for these unique wetland ecosystems, we must identify voids in our knowledge about constructed wetland ecosystem functioning, adopt research programs to obtain this information, and develop subsequent management practices that optimize multiple use values.

The implications of developing management plans for these constructed impoundments are far reaching, considering the number of existing constructed wetlands already requiring management attention and the potential number of future impoundments under construction consideration. As the demand for livestock watering sources grows, public desire for consumptive and nonconsumptive resource use increases, and pressures to enhance economic gains continue, more constructed impoundments will emerge. Wetland managers and landowners must be prepared to intensively manage these new habitats to optimize multiple uses and restore value in previously constructed impoundments.

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Appendix A:

DEFINITIONS OF WETLAND TERMS

Cation Exchange Capacity: The ability of a soil to fix cations on exchange sites. The dominant cation in organic soils is H^+.

Drawdown: Taking water from a wetland and exposing the substrate to air for a specified period of time.

Eutrophic: A water body rich in organic macronutrients and generally characterized by reduced water clarity.

Oligotrophic: A water body low in organic macronutrients and generally characterized by high water clarity.

Permanent Open Water Zone: A deep water zone that maintains stable water levels all year. Common plant species include submergent aquatic plants such as water milfoil (*Myriophyllum exalbescens*), coontail (*Ceratophyllum demersum*), and sago pondweed (*Potamogeton pectinatus*).

Redox Potential: Refers to the soil's or water's capacity to oxidize or reduce chemical substances.

Seasonal Wetland Zone: A zone where shallow-marsh vegetation dominates the central wetland areas that normally maintain surface water for an extended period in spring and early summer but frequently dry up during late summer and fall. In deeper, more permanent wetlands, this zone often occurs as a concentric band inside the wet meadow zone. Common plant species include moderately coarse grasses, spike rush (*Eleocharis palustris*), sedges, and a variety of forbs.

Semi-permanent Wetland Zone: A zone where deep-marsh vegetation dominates the central wetland areas that ordinarily maintain surface water throughout the spring and summer and frequently maintain surface water into fall and winter. In deeper, more permanent wetlands, this zone often occurs as a concentric band inside the seasonal wetland zone. Common plant species generally include coarser and taller wetland plants such as cattail (*Typha* spp.), hardstem bulrush (*Scirpus acutus*), and softstem bulrush (*Scirpus validus*).

Temporary Wetland Zone: A peripheral band of vegetation around most deeper wetlands where water loss from bottom seepage is fairly rapid. Surface water remains only a few weeks after spring snowmelt and occasionally for several days after heavy rainstorms in late spring, summer, and fall. Common plant species include fine-textured grasses, rushes (*Juncus* spp.), sedges (*Carex* spp.), and a variety of forbs.

Appendix B:

COMMON WETLAND PLANTS AND WATERFOWL VALUES

Nesting and Escape Cover:

- Reed canarygrass (*Phalaris arundinacea*)
- Redtop (*Agrostis alba*)
- Garrison creeping foxtail (*Alopecurus arundinacea*)
- Barnyard grass (*Echinochloa crusgalli*)
- Switchgrass (*Panicum virgatum*)
- Orchardgrass (*Dactylis glomerata*)
- Bulrushes (*Scirpus* spp.)
- Cattail (*Typha* spp.)
- Wheatgrasses (*Agropyron* spp.)
- Alfalfa (*Medicago sativa*)
- Sweet clover (*Melilotus officinalis*)
- Smooth brome (*Bromus inermis*)
- Retired cropland (CRP) and ungrazed or moderately grazed areas with residual vegetation

Brood Cover:

- Bulrushes (*Scirpus* spp.)
- Cattail (*Typha* spp.)
- Sedges (*Carex* spp.)
- Whitetop (*Scolochloa festucacea*)
- Bur reed (*Sparganium* spp.)
- Rushes (*Juncus* spp.)

Food Species:

- Flooded Areas-
  - Pondweeds (*Potamogeton* spp. [Sago pondweed (*Potamogeton pectinatus*) preferred]
  - Wild millet (*Echinochloa crusgalli*)
  - Sedges (*Carex* spp.)
  - Smartweed (*Polygonum* spp.)
  - Alkali bulrush (*Scirpus maritimus*)
  - Widgeongrass (*Ruppia maritima*)
  - Duckweed (*Lemna* spp.)
  - Coontail (*Ceratophyllum* spp.)
  - Spike rush (*Eleocharis* spp.)
  - Muskgrass (*Chara* spp.)
- Dryland Areas-
  - Corn (*Zea mays*)
  - Wheat (*Triticum aestivum*)
  - Barley (*Hordeum vulgare*)
  - Proso millet (*Panicum miliaceum*)
  - Foxtail millet (*Setaria italica*)
  - Cereal rye (*Secale cerceale*)
  - Clover (*Trifolium* spp.)
  - Oats (*Avena sativa*)