

Evaluation of Artificial Wetlands in North Dakota: Recommendations for Future Design and Construction

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Eighteen artificial wetlands were evaluated in North Dakota in 1979 and 1980. Several recommendations are presented for artificial-wetland design and construction based on both the results of the 2-year study and the habitat requirements of breeding waterfowl. It is recommended that (a) a series of wetlands of varying sizes be built rather than one large wetland; (b) multisided, variable-depth wetlands be excavated instead of rectangular, uniformly deep borrow pits; (c) bank gradients not exceed a 10:1 to 20:1 slope; (d) nesting islands be constructed in the center of the wetland when possible; (e) adjacent upland areas be seeded with dense cover to support nesting and reduce erosion and runoff; (f) if necessary, wetlands be sealed with a clay layer to retain water; and (g) topsoil be set aside and respread to provide an adequate substrate for the growth of aquatic plants. Some suggestions for future research on artificial wetlands are also presented.

The value of wetlands as wildlife habitat and in pollution and flood control has been widely recognized (1-4). There is no need to expound the many benefits of wetland protection, enhancement, or replacement here. In accordance with U.S. Department of Transportation order 5660.1A, FHWA is committed to the protection, preservation, and enhancement of the nation's wetlands to the fullest extent practicable during the planning, construction, and operation of highway facilities and projects. FHWA procedural guidelines specify that system planners should assign preferences for highway projects to corridors that have the least number of interconnected wetlands and wetland-related resources (5).

Because of the complex nature of the wetland ecosystem, avoidance is the best method of conforming to stated FHWA goals. However, this is not always possible, and wetlands continue to disappear at an alarming rate because of changes in land use. Therefore, alternative amelioration measures must be considered, including replacement of natural habitat with constructed wetlands.

The need for fill for raising road grades and building interchanges during road construction provides an opportunity to design and construct artificial wetlands. Such was the case during addition of a second roadway to Interstate 29 in North Dakota in 1975. Unlike traditional borrow pits, which are rectangular and uniformly deep [≈ 2 m (6 ft)], the I-29 ponds were designed as potential marsh habitat (6). The North Dakota State Highway Department (NDHD) also constructed artificial wetlands along I-94 and US-2 in 1976 and 1977. Along I-29 alone, 44 ha (109 acres) of wetlands was excavated.

During 1979 and 1980, 13 artificial wetlands along I-29, 3 along US-2, and 2 along I-94 were monitored. Comparisons were made of waterfowl and marsh-bird use and macroinvertebrate and aquatic-plant diversities and densities of artificial wetlands versus nearby natural-basin wetlands (7). Waterfowl use of artificial wetlands was only slightly less than that observed on natural wetlands and that reported in previous wetland studies. The value of artificial wetlands as wildlife habitat has been reported on at previous TRB committee meetings, and more detailed information is available elsewhere (7).

Although use of the artificial wetlands by waterfowl was closely monitored, the diversity of nongame bird species and the densities of some of these spe-

cies were also recorded. The following recommendations for artificial-wetland design and construction are based on the results of our 1979-1980 fieldwork and our knowledge of the habitat requirements of target wildlife species.

GENERAL CONSIDERATIONS

Waterfowl are migratory species; they depend on specific kinds of aquatic habitat at different times of the year and during different phases of their reproductive cycle (8,9). Therefore, the design of the artificial wetland depends partly on the latitude at which it is constructed. Much of North Dakota is located within the prairie pothole region, that area of the United States and southern Canada that covers approximately 10 percent of the land area but produces more than 50 percent of the annual duck population (10). Although the specific recommendations in this paper pertain to artificial wetlands designed to support nesting waterfowl, it is assumed that nongame species will also benefit.

SPECIFIC DESIGN FEATURES

Size

The size of natural-wetland basins is highly variable. The artificial wetlands examined in this study ranged in size from 0.2 to 2.7 ha (0.5-7 acres). Thus, no single size is recommended. Instead, size can be determined by construction requirements for fill provided that guidelines on depth, bank gradient, and detention time are considered. Excavation of a 0.4-ha (1-acre) wetland provides 5,700 m³ (7,500 yd³) of fill; 19,000 to 23,000 m³ (25,000 to 30,000 yd³) of fill was obtained for each of the three 1.6-ha (4-acre) artificial wetlands constructed at the Lincoln Interchange on I-29.

Wetland size is positively correlated with wetland permanence; i.e., smaller wetlands [<0.6 ha (1.6 acres)] tend to be temporary or seasonal whereas larger ones [0.7 to >40.5 ha (1.7 to >100 acres)] are semipermanent, although there is a high degree of overlap in size among permanence classes (11,12). Again, different classes of wetlands vary in importance during different phases of the breeding cycle.

The importance of semipermanent ponds, where ducks and geese congregate in autumn, is obvious to hunters; however, temporary and seasonal shallow wetlands, which tend to dry out by mid to late spring, also serve a vital function in supporting waterfowl populations (13). In early spring hens depend on high levels of protein and calcium to lay viable eggs; aquatic invertebrates in shallow wetlands provide those nutrients. Thus, to maximize waterfowl productivity, artificial wetlands of varying sizes should be excavated. As an alternative, a series of small satellite ponds could be excavated around a large, central artificial wetland. One satellite-wetland design used successfully at lake Agassiz Refuge, Minnesota, is the donut: soil is excavated and bulldozed into the middle of a circle

to create a moat with a central island. Such wetlands provide a food source, a nesting site, and access to larger wetlands for brood rearing.

Shape

Wetland shape is important because waterfowl breeding pairs need isolated areas for courtship, feeding, and other activities. The amount of shoreline that each pair requires is related to the ability of one pair to see other pairs, which in turn is related to wetland shape. Artificial wetlands along I-29 were of three shapes: triangular, rectangular, and hexagonal (see Figures 1 to 3). Waterfowl pair density was significantly higher on irregular-polygon-shaped (hexagonal) wetlands than on triangular or rectangular ones in both 1979 and 1980 [Mann-Whitney $U = 0.0005$ for 1979 and 0.047 for 1980 (14)]. As with size, decisions regarding wetland shape must be made with due consideration of recommendations on bank gradient and soils, which are discussed in the following paragraphs.

Depth and Bank Gradient

Several processes are affected by wetland depth and bank gradient: water permanence, invasion and survival of aquatic vegetation, and habitat selection and feeding by waterfowl. The relationship between depth and water permanence was referred to in the previous discussion on wetland size. Periodic drought in North Dakota ensures that all but the deepest wetlands will dry out occasionally. Naturally fluctuating water levels help control aquatic-plant density, which precludes the need for intensive management and water-level manipulation.

Wetland depth has a marked effect on aquatic-plant density. By planning artificial wetlands with varying depth, the ratio of emergent vegetation to open water can be controlled. Emergent species, such as cattail (*Typha* spp.) and bulrush (*Scirpus* spp.), usually do not sprout and grow in water deeper than 60 cm (24 in.) (15-17). Studies have indicated that species density and diversity are greatest on wetlands with a 50:50 ratio between total emergent vegetation (both shoreline and center vegetation) and open water (18).

Bank gradients with a 10:1 to 20:1 slope will allow emergent vegetation to establish itself, which will further isolate shoreline habitat of waterfowl pairs. Gently sloping shorelines also provide feeding habitat for many species of shorebirds (7).

In contrast to emergent species, pondweeds (such as *Potamogeton* spp.) invade new wetlands to depths in excess of 60 cm, depending on bottom soils and water transparency (17,19). Waterfowl feed on these plants, so their accessibility to ducks is important. Plants in deep water might still provide food for diving ducks, but dabbling ducks, which tip over to feed, would not be able to reach them. In any case, maximum depth should not exceed 1 m (3 to 4 ft).

Plans can also include a central island in the wetland that provides a safe nesting site. One problem associated with artificial-wetland construction, particularly when the wetlands enhance rather than replace habitat, is that they attract predators from surrounding areas. Safe nesting sites can reduce high levels of predation. Several small man-made islands in prairie wetlands were studied by Johnson et al. (20). Islands were constructed in dry wetlands by using rocks and soil from the marsh bottom. Construction costs averaged \$50 per island, and construction time for islands that ranged in size from 0.0002 to 0.01 ha (0.0005 to 0.02 acres) was 1 to 2 hr. Densities of mallards (*Anas platyrhynchos*) on islands averaged 135 nests/ha compared with 0.03 nests/ha on adjacent upland habitat (20). Predators can be excluded from the islands successfully except during periods of low water.

Vegetation

The artificial wetlands studied in North Dakota were not seeded with aquatic vegetation. Chance invasion occurred within 1 year of construction (6). However, after 5 years plant diversity remained lower in artificial wetlands than in nearby natural-basin wetlands. It appears that the conditions for plant invasion and colonization are more important than actual seeding within the wetlands (7).

In contrast, grading and seeding areas adjacent to wetlands with dense nesting cover are important to provide adequate upland habitat. Recommendations

Figure 1. Triangular-shaped artificial wetland with surface area of approximately 1.48 ha (3.7 acres).

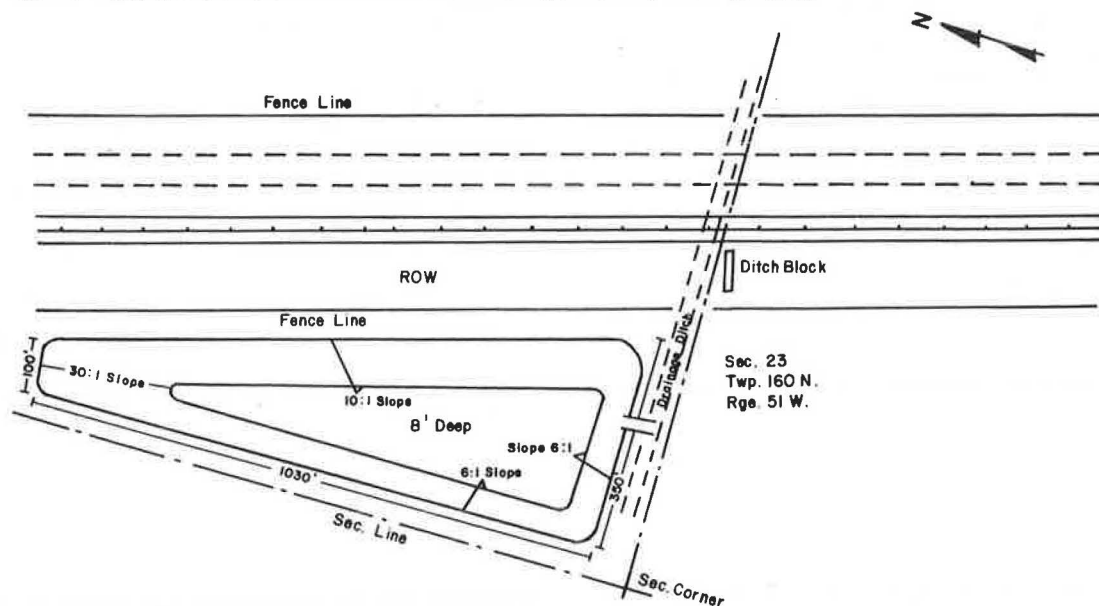


Figure 2. Rectangular artificial wetlands with mean surface area of approximately 0.6 ha (1.54 acres).

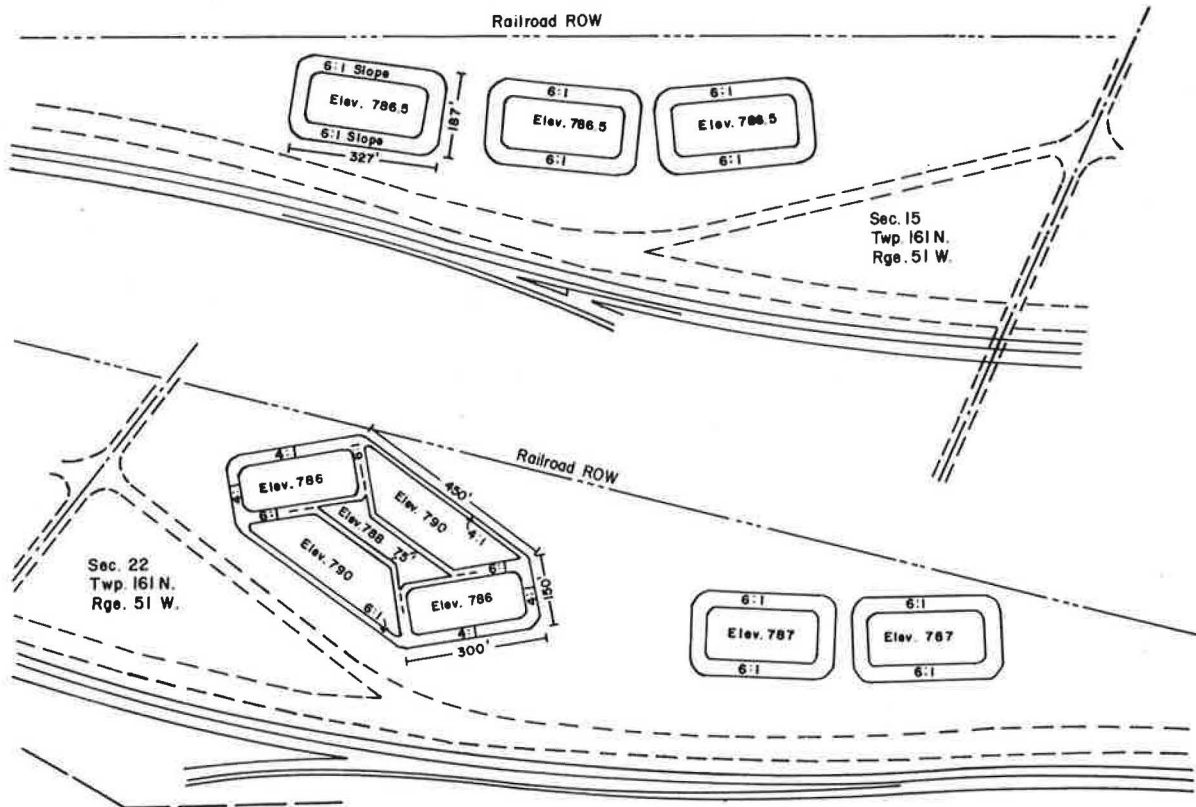
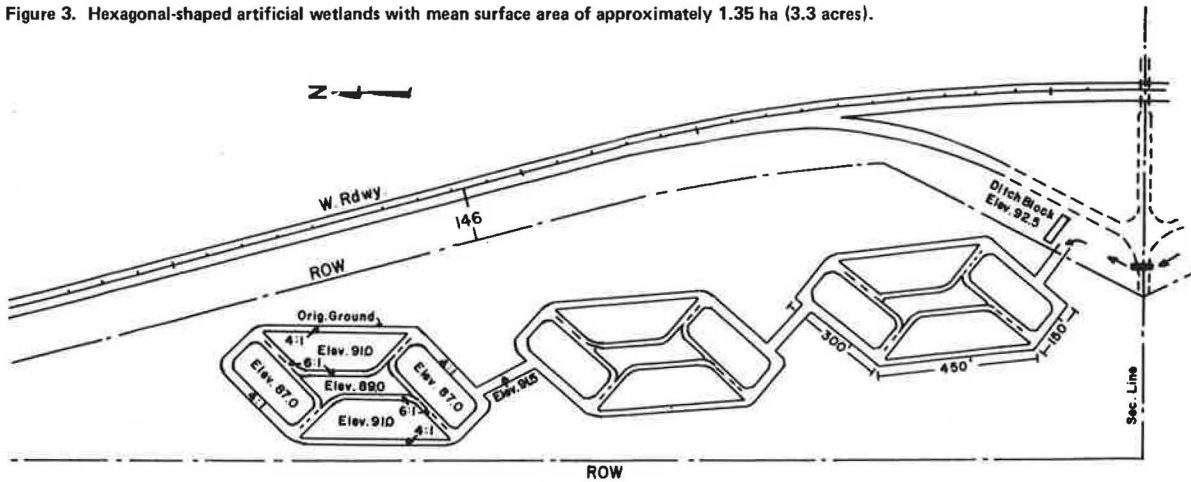


Figure 3. Hexagonal-shaped artificial wetlands with mean surface area of approximately 1.35 ha (3.3 acres).



for seeding mixtures and land use management are readily available in the literature (21-24).

Soils

Soils play two crucial roles in wetland development: holding water in the wetland and providing an adequate substrate for plant growth. After excavation most wetland bottoms must be sealed with a clay (bentonite) layer. Deep, sandy-bottom artificial wetlands along US-2 dried out much earlier in the season than expected (7).

Topsoil removed during excavation should be set aside and respread in the wetland. In North Dakota both plant and macroinvertebrate densities were lower in artificial wetlands with clay bottoms than in those respread with topsoil (7). There are some

problems associated with stockpiling muck (substrate material removed from natural wetlands). If this material is to be used in the new artificial wetland, it should be stockpiled in upland areas, not in other wetlands. Muck should be respread within 4 weeks to avoid deterioration from freezing, desiccation, and decomposition. If only a limited amount of topsoil is available, other organic matter, such as hay, should be added to stimulate development of a detritus food chain (25).

Water Quality and Hydrology

Densities and diversities of aquatic plants and macroinvertebrates can be affected by water clarity, pH, and salinity (total ionized material). Clarity becomes increasingly important with depth; turbidity

prevents sunlight from reaching aquatic plants growing in deep water. Suspended matter also depletes the amount of oxygen available to macroinvertebrates and can physically abrade invertebrates. If the surrounding upland areas are properly seeded, runoff will be reduced and turbidity controlled. Artificial wetlands examined in North Dakota were clear to depths of 1 to 2 m (3 to 7 ft) (7).

The pH of the water will certainly have an impact on the type of vegetation that the wetland will support. The species composition of an acid bog differs markedly from that of an alkaline wetland. Water samples collected from artificial wetlands in North Dakota ranged in pH from ≈ 8 to 10. Although pH was not a limiting factor for wetlands excavated near highways in North Dakota, low pH and the presence of heavy metals in the soils have been problems in wetlands constructed on surface-mined land. To overcome this problem, attempts have been made to seal reclamation wetlands with clay and even with plastic liners to prevent leaching of acid soil and deleterious substances.

Total ionized material in water (measured as electrical conductance) has effects on plant species composition similar to those of pH. Electrical conductance is an indicator of wetland salinity (25, 26). In states where large amounts of salt are used to control ice on roads, artificial wetlands close to highways may be affected by runoff (27). Salinity may increase to levels that are toxic to plant and invertebrate life. Salt runoff is an important consideration in designing a water-inflow system for an artificial wetland. Many artificial wetlands along North Dakota highways were constructed on excess parcels of land near interchanges. A channel was excavated from the wetland to the right-of-way. A ditch block was placed in the right-of-way at the head of the channel to shunt water collected in the right-of-way to the wetlands. Acceptable velocity within the channel was determined to be approximately 0.37 m/sec (1.2 ft/sec). By the Manning equation,

$$V = (1.49/n) R^{2/3} S^{1/2} \quad (1)$$

where

- n = empirical roughness = 0.07,
- R = hydraulic radius of the channel = 2 x 10 ft, and
- S = estimated slope = 0.002 (0.2-ft drop/100 ft).

Higher scour-producing velocities in channels or culverts could be decreased by energy-dissipating designs or structures (i.e., multiple culverts or walls to spread flow). If water volume is too low, dilution may not be sufficient to prevent high salt concentration (27). Because salt is not used on North Dakota highways, this problem was not encountered in this research.

The ditch block and channel system, together with a high water table and normal precipitation, ensured adequate water levels in the North Dakota artificial wetlands. Only in 1980, a year of severe drought, did the wetlands dry out early in the season. The respective detention times for hexagonal, rectangular, and triangular artificial wetlands were estimated to be 13, 17, and 18 days, based on respective total volumes of 273,121, 363,518, and 297,267 ft³ and an estimated daily flow rate of 21,600 ft³ (annual precipitation = 18 in.).

Several methods are available for maintaining preferred water levels in wetlands in areas where natural hydrologic conditions are less than ideal.

Detailed plans of various types of artificial wetlands that include devices for water-level manipulation have been prepared by the Atlantic Waterfowl Council Committee on Habitat Management and Development (28). Extensive postconstruction management of artificial wetlands will increase their cost, however, and therefore cannot be included in the plans unless sufficient funds and personnel are available.

COST FACTORS

It is not uncommon for the costs of managing intensively developed waterfowl areas to exceed \$10 per acre per year, particularly in diked marshes with elaborate programs of water-level manipulation (9). Actual cost figures for construction of multi-sided, variable-depth artificial wetlands are not available; however, the cost probably exceeds that of traditional borrow pits because additional fine grading is required. In addition, earthmoving equipment does not have the maneuverability that is necessary and special machinery must sometimes be used.

Although setting aside topsoil should not increase construction costs, respreading it might because respreading is a time-consuming task, particularly when the bottom of the borrow area is wet, as it often is.

If nesting islands, as described previously, are constructed at the time of initial wetland construction, they can probably be completed for less than the \$50 per island estimate given by Johnson et al. (20).

As indicated, there has been little or no maintenance cost for the North Dakota wetlands studied. For wetlands that require more intensive postconstruction management, costs could be defrayed by leasing the wetlands to a wildlife or sports club. State regulations may prohibit hunting near major highways and within 0.5 km (0.25 mile) of an inhabited dwelling. Therefore, hunting laws should be considered before site selection if plans include using the wetlands for this purpose.

Regardless of whether the artificial wetlands benefit hunters, they usually do enhance the aesthetic value of the highway for drivers (29).

FUTURE RESEARCH NEEDS

Research on artificial wetlands in North Dakota continues. Phase 2, which began in 1981, should provide additional information on plant and invertebrate abundance in new wetlands. The purpose of phase 1, on which this paper is based, was to attempt to evaluate constructed ponds as a means of replacing natural-wetland habitat affected by highway projects. Of course, it is not possible to do that unless one has determined the value of what has been replaced. Therefore, what is needed is a long-term study of a natural wetland before highway construction and, later, an evaluation of the artificial wetland that replaced it. Only then can we determine how well habitat can be reconstructed.

Finally, many of the design features recommended here were not included in the North Dakota artificial wetlands; rather, these recommendations are made in response to shortcomings perceived in those wetlands. Therefore, a series of state-of-the-art artificial wetlands should be constructed and studied intensively by using accepted wetland evaluation techniques. A study of several artificial wetlands in which one or more design features per wetland have been manipulated may yield information on wetland ecosystems that is not available now.

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