9

Bradley F. Blackwell
David Felstul
Thomas W. Seamans

Managing Airport Stormwater to Reduce Attraction to Wildlife

An airport is a component of the landscape, contributing to and subject to local- and landscape-level factors that affect wildlife populations and the hazards that these species pose to aviation (Blackwell et al. 2009, Martin et al. 2011). Water resources at and near an airport, in the form of both surface water and contained runoff, are recognized by the Federal Aviation Administration (FAA) as potential attractants to wildlife that pose hazards to aviation safety (FAA 2007). Surface water, including aboveground stormwater detention/retention facilities (see U.S. Environmental Protection Agency 2006), can represent a substantial proportion of the area within siting criteria for U.S. airports. An analysis of water coverage at 49 certificated airports (FAA 2004) revealed that surface water composed on average 6.0% (standard deviation [SD] = 10.4%, range = 0.04–48.3%; B. F. Blackwell, unpublished data) of the area within the 3-km [1.9-mile] FAA siting criteria ($\overline{X}$ = 275 ha, SD = 511 ha). A recent analysis of bird–aircraft strike data for avian species involved in at least 50 total strikes reported to the FAA (1990–2008; summarized in FAA 2011) revealed that 13 of the 52 species (25%) have foraging and breeding ecologies primarily associated with water (Blackwell et al. 2013). Moreover, these 13 species were responsible for >51% of damaging strikes (Dolbeer et al. 2000, DeVault et al. 2011) during this period.

Given the obvious necessity of water as a resource to wildlife and the relative aviation hazards posed by bird species whose life histories are tied to water, aspects of species ecology should inform airport biologists in the management of natural or constructed water resources to reduce attractive features. Likewise, informed exchange between airport biologists and engineers responsible for the design of runoff containment and treatment facilities will yield facilities that minimize attractant features to birds. Our purpose for this chapter is to demonstrate how airport stormwater runoff can be managed effectively to reduce or prevent the establishment of a resource on and near airport properties. We discuss features of water resources that attract birds, describe common operational conditions at airports with regard to managing stormwater runoff, and review findings on postconstruction methods to deter bird use of stormwater facilities. In addition, we review advantages and disadvantages of novel runoff containment systems for airfields, as well as considerations for stormwater management outside of the air operations area (AOA) but within or proximate to FAA siting criteria.

Birds and Water

Short of thirst, no single factor drives avian use of water resources. Commonalities observed in avian use of natural and constructed systems, however, are important to how airport authorities plan for and manage their water resources to reduce use by birds. Within wetland systems, avian species richness is positively correlated with wetland complexes (20–30 ha for marsh and >55 ha

of marsh complex within 5 km [3 miles]), as opposed to larger (up to 180 ha), isolated marshes (Brown and Dinsmore 1986; see also Fairbairn and Dinsmore 2001). Also, wetlands with an intermediate level of emergent cover (33–66%) have been found to harbor greater species richness (Belánger and Couture 1988, Gibbs et al. 1991, Creighton et al. 1997). Working with lake systems, Suter (1994) linked abundance and richness of various avifauna populations to area, food availability, and shoreline vegetation complexity. In addition, overall mean and maximum species richness increased with nutrient load, as did maximum bird densities among guilds. Similar conditions are possible within stormwater impoundments (ponds and reservoirs) with sediment deposits accumulating over time, resulting in vegetation complexes that can support an array of invertebrate and vertebrate diversity (Le Viol et al. 2009).

In a broad sense, bird use of water resources is driven primarily by site-specific relationships of system, area, cover, food resources, and complexity with regard to neighboring resources. Recent findings for bird use of stormwater management ponds are similar to those for natural systems. Modeling avian use of stormwater management ponds in the Pacific Northwest region of the USA, which served as surrogates to those at airport facilities, revealed that surface area available for water containment, area of open water available, pond perimeter, and pond isolation were factors that predicted use by nine of 13 considered bird groups (within Accipitridae, Anatidae, Ardeidae, Charadriidae, Columbidae, Laridae, and Rallidae; Blackwell et al. 2008). Posthoc modeling by the authors revealed that the probability of pond use by birds considered hazardous to aviation (Dolbeer et al. 2000, DeVault et al. 2011) was about 100% when perimeter irregularity (i.e., the quotient associated with the ratio of pond perimeter to perimeter of a perfect circle of equal area) equaled 7. In contrast, the probability of use by birds hazardous to aviation was near zero when the facility was isolated (>8 km [5 miles] horizontal distance) from other surface-water resources.

In effectively incorporating the information discussed above with guidance on airport stormwater management, one must first understand that stormwater runoff poses multiple safety and regulatory challenges for airport managers.

Stormwater Management Practices at Airports

At U.S. airports, the immediate safety of maneuvering aircraft and water quality are the predominant concerns of FAA guidance for runoff management. Regulatory control of water-quality practices at airports stem from National Pollution Discharge Elimination System requirements under the U.S. Clean Water Act and local ordinances (FAA 2006). Best management practices (BMPs) associated with stormwater containment consider site-specific physical conditions, area of watershed (including area of impermeable surfaces on and near airport property), runoff volume or peak flow, and water-quality objectives (FAA 2006, Goff and Gentry 2006). BMP designs that can attract wildlife, particularly birds, generally require some period of exposed storage or "ponding" of runoff. These designs at airports include extended dry detention ponds intended to store runoff after a storm event for up to 48 hr; retention ponds that serve dual purposes of containing water from a storm event and treating the runoff for pollutant removal; and infiltration basins in which stored water is exfiltrated through permeable soils (FAA 2006). In addition, FAA (2008) recommends conversion of "suitable unused airport land" to lagoons and retention ponds to facilitate the collection of large volumes of glycol-based fluid waste (i.e., deicing chemicals); in this case the potential creation of a wildlife resource is not considered. However, using ponds to contain deicing chemicals poses disadvantages, in addition to possibly attracting wildlife, that are associated with effective product recovery or treatment (see Airport Cooperative Research Program 2009).

For any exposed containment of stormwater runoff, airport managers are directed to FAA (2007) for guidance on wildlife hazards, where suggested techniques focus on reducing wildlife (primarily bird) access via use of synthetic covers, floating covers, netting, or wire grids (see also International Civil Aviation Organization 1991:11–12). But these postconstruction techniques can be costly with regard to purchase, installation, and maintenance, and efficacy is not always clear. For example, overhead wires or lines in various arrangements have been effective in repelling a variety of birds (McAtee and Piper 1936; Amling 1980; Blokpoel and Tessier 1983, 1984; Forsythe and Austin 1984;

Fig. 9.1. Mallards (*Anas platyrhynchos*) under wires. Photo credit: Greg Martinelli

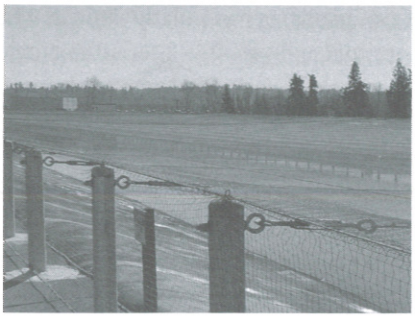

Fig. 9.2. Netted reservoir near Seattle, Washington, USA. The resource is protected physically, but it still serves as a visual attractant. Photo credit: Mike Linnell

McLaren et al. 1984; Dolbeer et al. 1988; Pochop et al. 1990), but efficacy is site specific. Pochop et al. (1990) noted that bird reaction to overhead lines varies by species, spacing, attractiveness of sites protected, age of birds, and possibly height of lines above the protected area (Fig. 9.1).

Anthony Duffiney (U.S. Department of Agriculture, Wildlife Services, unpublished data) found that the number of mute swans (*Cygnus olor*), gulls (Laridae), Canada geese (*Branta canadensis*), and most waterfowl species using containment ponds (~15.4 ha) at Detroit Metro Airport, Romulus, Michigan, USA, was reduced after installation of parallel steel wires at 30.5-m (100-foot) intervals, supported by metal posts on shore. However, icing and increased tension on the wires, as well as damage to supports during mowing, necessitated frequent year-round maintenance. In another airport application, a wire grid system installed to deter ducks, primarily mallards (*Anas platyrhynchos*), from drainages proved too costly with regard to equipment and maintenance, and effective control over all points of entry was not achieved (A. Baxter, U.K. Food and Environment Research Agency, unpublished data). When a 15-m (50-foot) grid system was installed over 2-ha wastewater ponds in North Carolina, USA, the total number of waterfowl using the ponds surprisingly increased. Canada goose numbers declined, while mallard, ring-necked duck (*Aythya collaris*), and ruddy duck (*Oxyura jamaicensis*) numbers (among other species) increased (T. W. Seamans, U.S. Department of Agriculture, unpublished data). In this case, enhanced protection from avian predators—or added resource value due to aggregations of conspecifics (e.g., Arengo and Baldassarre 2002) and absence of larger, dominant, or competitive species—could have contributed to the attractiveness of the site.

Completely covering exposed water containment systems physically and visually (e.g., via synthetic cover or floating devices that cover the exposed pond surface area) is likely the only means of effectively reducing the attraction to birds (Fig. 9.2). However, cover alternatives pose problems, as well. To our knowledge there is no candidate vegetation that might minimize available surface area of water to birds, survive both flooding and water drawdown, and not provide food, roosting, or nesting resources. Complete coverage of standing water via synthetic or floating covers will reduce solar radiation, an important factor in the control of bacterial growth (Davies and Bavor 2000), and can negatively affect pond hydraulics, oxygenation, and biological activity (e.g., see effects of pond ice cover; Semadeni-Davies 2006). Water quality in natural receiving systems might subsequently be degraded.

Management of stormwater runoff at airports to enhance aircraft safety, to achieve water-quality goals, and to minimize attractants to birds and other wildlife is complex, if not contradictory, begging the question as to whether alternatives exist that meet BMP requirements for controlling airport stormwater runoff.

Potential Alternatives

Higgins and Liner (2007) noted that containment and treatment of stormwater at airports, particularly runoff contaminated with deicing chemicals, via conventional

means (e.g., ponds) is particularly difficult when conditions are cold and runoff is intermittent and at high volumes over short periods. However, the authors reported an "innovative approach" using aerated gravel beds known as subsurface flow wetlands (SSFWs). According to the authors, SSFWs are insulated, aerated, easy to operate, and their construction, operation, and maintenance costs are a fraction of those at alternative conventional stormwater treatment facilities (<50%). As to wildlife hazards, SSFWs are underground and thus do not attract avian species. The authors note installations only at Edmonton International Airport (Edmonton, Alberta, Canada), Heathrow International Airport (London, United Kingdom), and Air Express Airport (Wilmington, Ohio, USA). The first two installations are horizontal flow SSFWs, while the third is a reciprocating flow (tidal), vertical flow SSFW. All three are associated with surge ponds in front of their multiple wetland basins (cells). Higgins and Liner (2007) also recognized problems associated with constructed wetlands, particularly those intended to treat glycol-contaminated stormwater runoff, as the wetlands tend to be large. A horizontal flow SSFW, like that at Heathrow, can experience plugging problems (e.g., due to freezing) in the shallow gravel of the primary cells.

As an alternative, Higgins and Liner (2007) recommended engineered wetlands known as semipassive constructed wetlands, designed so that operating and process conditions can be controlled, in contrast to the more passive operation of traditionally constructed wetlands. They suggest that engineered wetlands will allow higher levels of contaminant removals at higher throughputs and with much shorter residence times. The authors point to Buffalo Niagara International Airport, Buffalo, New York, USA, and its use of an aerated, vertical flow SSFW, engineered wetland, in which blowers introduce air under a gravel substrate 1.2–3.6 m (4–12 feet) thick. Aeration is directed upward through the gravel from a buried, fine-bubble diffusion system, countercurrent to downward percolating wastewater. The vegetated gravel surfaces of engineered wetlands are also insulated with layers of mulch or compost to prevent freezing, and the systems are designed to operate throughout northern winters and associated ambient air temperatures. In a controlled greenhouse experiment comparing performance of "surface flow, constructed wetlands" versus "subsurface flow, constructed wetlands" (essentially a SSFW, as described above) for treatment of synthetic sewer overflows, nitrogen, phosphorous, and chemical oxygen demand were removed faster by SSFWs and, in general, the end concentrations of the investigated pollutants were lower than in the surface flow constructed wetlands (Van de Moortel et al. 2009).

However, runoff management via SSFWs, or even belowground vaults for water containment, will not suffice for all locations. Other promising alternatives to control stormwater runoff that will satisfy both stormwater permit requirements and allow for safe operations at airports are a family of BMPs known collectively as low-impact development (LID; Dietz 2007, Davis 2008, Dietz and Clausen 2008) or green infrastructure (GI; see also Washington State Department of Transportation 2009; Oregon Department of Environmental Quality 2011*a*). The language of stormwater permits (U.S. Environmental Protection Agency 2012) defines these two approaches. Specifically, LID promotes the use of natural systems for infiltration, evapotranspiration, and reuse of rainwater, and can occur at a wide range of landscape scales (i.e., regional, community, and site). Similarly, GI is a comprehensive approach to water-quality protection defined by a range of natural and built systems and practices that use or mimic natural hydrologic processes to infiltrate, evapotranspirate, or reuse stormwater runoff at the site where the runoff is generated.

U.S. Environmental Protection Agency (2012) has organized LID/GI techniques into a number of categories, some of which are less applicable than others to airports, although all have techniques that are useful. Below we provide descriptions of the types of facility in each category and some general advantages and disadvantages to their use at airports. Every airport site is unique, however, and should be fully investigated before locating an LID stormwater facility on the airport property.

Category 1, Conservation Designs, includes measures such as preserving open space, clustering development, and using "skinny" streets. For airports, operational concerns largely determine layout and pavement extent. However, clustering stormwater facilities on one side and away from the runway (as per FAA 2012; see also FAA 2006) might be one type of conservation design appropriate at an airport. Clustering should decrease the frequency of wildlife crossing operational

space. In addition, stormwater facilities should be located on the same side as natural attractants, such as wetlands, rivers, roosting trees, and food sources. As a caveat, we note recommendations by Blackwell et al. (2008) relative to minimizing density of water resources in locating stormwater management ponds.

Category 2, Infiltration Practices, includes infiltration trenches, porous pavement, and rain gardens—methods that depend upon relatively quick and efficient drainage. Infiltration trenches are long, narrow, stone-filled trenches used for the collection, temporary storage, and infiltration of stormwater runoff to groundwater. Standard infiltration trench designs work well in airport environments. Depending on the trench dimensions, the facility might be considered an underground injection control device (i.e., any subsurface drain fields that release fluids underground), subject to additional permitting requirements (see also U.S. Environmental Protection Agency 1999, 2003).

Porous pavement is an open-graded concrete or asphalt mix placed in a manner that results in a high degree of interstitial spaces or voids within the cemented aggregate. This technique demonstrates a high volume of absorption or storage within the voids and infiltration to subsoils. The pavement might be permeable concrete or asphalt, manufactured systems such as interlocking brick, or a combination of sand and brick lattice. At airports, porous pavement is suitable for passenger parking areas or service roads that are used occasionally. Concerns about weight-bearing capacity (FAA 2009) generally will not allow its use where aircraft are maneuvering or parking, including runway, taxiway, and clearway. In colder climates, the use of porous pavement in areas where grit is applied for traction, such as on parking lots, can result in pore clogging, standing water, or icy conditions.

Another infiltration practice, the rain garden, is an excavated depression, usually back-filled with an amended soil mixture and planted with a variety of native plants that tolerate saturated soils. Most rain gardens are constructed with up to 0.3 m (1 foot) of freeboard above the soil surface, which provides temporary ponding until runoff can infiltrate. A selling point of rain gardens emphasizes their wildlife habitat benefits from the plantings (food, shelter, nesting space). Coupled with the potential for extended ponding, however, rain gardens can become undesired wildlife attractants. Minus the "garden" plantings, the facility would function similarly to an infiltration basin, providing the desired infiltration with a lower risk of attracting wildlife.

Key considerations for Infiltration Practices include siting where soils provide good infiltration during wet weather and adequate maintenance to prevent clogging. Infiltration facilities should not be used in areas with high groundwater tables, which might be the case for airport facilities located next to water bodies. These techniques also require extra pretreatment to remove solids that might clog the facility and cause ponding.

Category 3, Runoff Storage Practices, includes the use of rain barrels, cisterns, and green roofs, and works best in areas that can have substantial rainfall during warmer, typically drier months, such as the midwestern and southeastern USA. A rain barrel can capture runoff from a thunderstorm and be used for irrigation within days or weeks. Airports irrigate vegetation around terminals, and these types of storage methods can be connected to irrigation systems, lowering labor requirements while containing runoff that might pool elsewhere or be conveyed to stormwater management ponds on site. In climates such as the Pacific Northwest, the majority of rainfall occurs in winter, when soils are saturated and many plants are dormant. Capturing and storing most of the rainfall from the winter for use in the summer would require large cisterns. Because of the large amount of impervious area at airports, green roofs will likely be the most practical runoff storage method.

Green roofs, also known as ecoroofs, are a type of LID that covers a roof with vegetation (Oberndorfer et al. 2007, Dvorak and Volder 2010; see also airport applications by Velazquez 2005). There are two main types of green roofs. Extensive green roofs are shallow (<20 cm [8 inches] of soil), with simple, low-growing plant communities that require less maintenance. Intensive green roofs have deeper soils and usually more complex plant systems; they are often referred to as rooftop gardens (Oberndorfer et al. 2007).

Controlling rooftop runoff, a component of the overall watershed area, via green roofs has a number of benefits. In addition to reducing runoff volume, the method reduces the urban heat island effect and building energy requirements (Oberndorfer et al. 2007, Dvorak and Volder 2010). Costs associated with construction of a green roof range 10–14% over conventional methods,

but over the long term the annual cost can be cheaper because the vegetated environment provides a greater life cycle for the roof (40–60 years instead of the 20 years typical of a conventional roof; Carter and Keeler 2008). Essentially, the vegetation and soil provide a thermal mass that lessens wear and tear on the roof from the shrink/swell cycle (Oberndorfer et al. 2007).

A number of airports have green roofs in place. Chicago O'Hare International Airport, Chicago, Illinois, USA, for example, has found success using native grasses selected carefully to avoid wildlife attractants, and it now has >3,000 m^2 (32,292 $feet^2$) of green roof on airport buildings (McAllister 2009). Native grasses were selected as ideal candidates for the control tower's vegetated roof, making it the first FAA facility of its kind in the nation. In 2010, Portland International Airport (PDX), Portland, Oregon, USA, installed a 929 m^2 (10,000 $feet^2$) green roof on their new operations building (Fig. 9.3). The green roof contains 10.2-cm-deep trays with *Sedum* sp. and includes a patio area for use by employees (a component that could dissuade use by loafing birds).

We note, however, that green roofs have been proposed as potential wildlife habitat in urban areas. Brenneisen (2006) noted that the technical substrates developed for green roofs—emphasizing lightweight, consistent drainage—and efficient installation (designs compatible for use at airports) are suboptimal for biodiversity (e.g., see Brenneisen 2003). Others have noted that species richness in spiders and beetles is positively correlated with plant species richness and topographic variability in green roof designs (Oberndorfer et al. 2007). Personnel at PDX report swarms of bees when the *Sedum* sp. flowers; the bees posed no problems for operations. However, an outbreak of slugs (*Deroceras reticultatum*) on the tray-based system at PDX attracted gulls (Laridae; PDX, unpublished data); there remains the necessity to monitor performance of green roofs relative to wildlife use.

Category 4, Runoff Conveyance Practices, includes check dams, undersized culverts, and long flow paths designed to slow down and detain water for better pollutant removal, but can also create wildlife habitat, via standing water, if not properly maintained. In contrast, the long, linear nature of grassy swales might be suited for use along runways, taxiways, perimeter roads, and other paved areas (Fig. 9.4).

Category 5, Filtration Practices, includes rain gardens and vegetated swales (also described under Category 2), as well as vegetated buffers. As filtration mechanisms, however, the primary function of these methods is to remove pollutants by filtering runoff either through vegetation or by slowing flow, thereby removing suspended pollutants through settling or filtration media in the facilities (e.g., soils amended with organic or inorganic materials). Flow then enters the stormwater conveyance system rather than infiltrating to the ground, as in Category 2 approaches. When fitted with an underdrain to return flow to the conveyance system, rain gardens serve as filtration devices. Vegetated swales, also called bioswales, are vegetation-lined channels designed to remove suspended solids from stormwater. Biological uptake, biotransformation, sorption, and ion exchange are potential secondary pollutant removal processes.

Potential problems associated with filtration practices, particularly rain gardens and swales, include standing water, vegetation that attract wildlife, and weight-bearing capabilities of amended soils. Compost material is a common soil amendment because of the pollutant removal capability at relatively low cost. Where the longitudinal slope is slight, water tables are high, or continuous base flow is likely to result in saturated soil conditions, underdrains will be required to prevent standing water. Wet swales should not be used. The use of check dams across the swale to slow flows is also discouraged, as water will pool behind the dams. If flow velocities are too high through the swale, erosion can result, and the swale might need to be broken into smaller sections.

Another filtration practice, vegetated buffers (also known as vegetated filter strips), are land areas of planted vegetation and amended soils situated between the pavement surface and a surface-water collection system, basin, wetland, stream, or river. Vegetated buffers receive overland runoff from the adjacent impervious areas and rely on their flat cross slope and dense vegetation to maintain sheet flows. These buffers slow the runoff velocities, trapping sediment and other pollutants and providing some infiltration and biologic uptake.

Seattle–Tacoma International Airport (SEA), Seattle, Washington, USA, has monitored the effectiveness of vegetated buffers along their runways and taxiways and found acceptable pollutant removal within short distances (Beck and Parametrix 2006). The airport

Fig. 9.3. Green roof at Portland International Airport, Portland, Oregon, USA. Photo credit: David Felstul

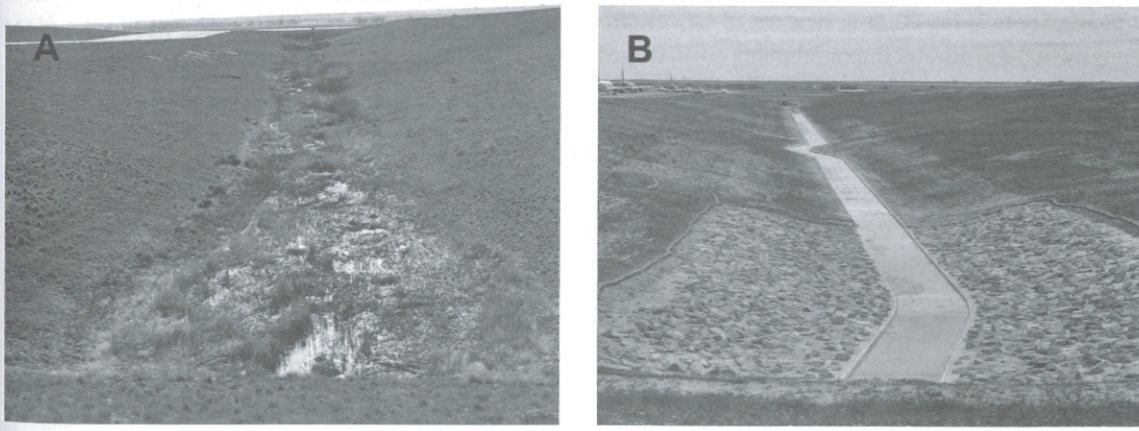

Fig. 9.4. Swale and conveyance system at Denver International Airport, Denver, Colorado, USA: (A) before and (B) after improvements to the channel. Photo credit: Kendra Cross

also has added compost amendments to the soils to increase the effectiveness of pollutant removal, but the compost-amended soils attracted earthworms. If these soils are located next to paved operational areas, earthworms can invade the pavement during and after rains, providing a food source for birds (e.g., gulls). However, SEA found that using biosolids instead of compost amendments provided the high organic content for pollutant removal without attracting the large numbers of worms (S. Osmek, SEA, personal communication).

Stormwater permits, such as that issued to the Port of Portland (Oregon Department of Environmental Quality 2011*a*), now require that LID and GI techniques be emphasized in training and in project design. In its permit fact sheet, Oregon Department of Environmental Quality (2011*b*) notes the critical aspect of

prioritizing and incorporating LID, GI, or equivalent approaches; other program conditions such as optimizing on-site retention (i.e., infiltration, evapotranspiration, and water capture and reuse), targeting natural surface or predevelopment hydrologic functions, and minimizing hydrological and water-quality impacts of stormwater runoff from impervious surfaces.

Privately Owned Stormwater Facilities

Most public airports have large tracts of open, undeveloped land that provide added margins of safety and noise mitigation (e.g., Blackwell et al. 2009). These areas inevitably include habitats that can pose hazards to aviation, particularly if they attract wildlife to an airport's AOA or airspace. For all airports, a distance of 8 km (5 miles) between the farthest edge of the airport's AOA and the hazardous wildlife attractant is recommended if the attractant could contribute to wildlife movement into or across the approach or departure airspace (FAA 2007). However, airports and the FAA do not necessarily have control over all properties within or proximate to siting criteria. In some instances, privately owned stormwater impoundments are managed for priorities that also can pose immediate hazards to aviation safety, such as general enhancement of wildlife habitat (McGuckin and Brown 1995, White and Main 2005) or use by birds for residential enjoyment, as well as biodiversity goals (Brand and Snodgrass 2009, Le Viol et al. 2009).

These contrasting priorities create a need to investigate design and management strategies that will reduce the relative attractiveness or utility of stormwater impoundments to species recognized as hazardous to aviation (see Dolbeer et al. 2000, DeVault et al. 2011) while selectively targeting species (e.g., warblers, Parulidae) that pose little hazard to aviation. Specifically, impoundments within or proximate to FAA siting criteria should be designed to minimize perimeter, surface area, and the ratio of emergent vegetation to open water (B. Fox, Auburn University, unpublished data). We recommend that these facilities reduce or eliminate grass areas along the pond shoreline (to reduce loafing by Canada geese) or use boulders or vegetation to break up the line of sight so as to enhance perceived predation risk (e.g., Smith et al. 1999).

Summary

Surface water composes a substantial portion (on average 6%) of U.S. airport areas within the 3-km siting criteria (B. F. Blackwell, unpublished data). Approximately 25% of bird species involved in ≥50 strikes reported to the FAA (1990–2008) have foraging and breeding ecologies closely associated with water, and over half of these species are responsible for strikes that result in aircraft damage. Research examining avian use of stormwater detention and retention ponds indicates that facility surface area, perimeter irregularity, and density of water resources within a 1-km radius are positively correlated with use by birds. Near the AOA and within or proximate to FAA siting criteria, the complete coverage of ponds physically and visually will provide the most effective means of reducing the attraction to birds. However, cover alternatives pose problems because of cost, maintenance, and water-quality issues. Both SSFW and LID/GI methods provide means of reducing peak flow, enhancing infiltration and contaminant removal, as well as reducing standing water and volume of runoff that must be contained. These methods help meet immediate safety needs for aircraft maneuvering within the AOA, while also reducing or removing water resources from wildlife use over short and long terms.

LITERATURE CITED

Airport Cooperative Research Program. 2009. Deicing planning guidelines and practices for stormwater management systems. ACRP Report 14. Transportation Research Board, Washington, D.C., USA.

Amling, W. 1980. Exclusion of gulls from reservoirs in Orange County, California. Proceedings of the Vertebrate Pest Conference 9:29–30.

Arengo, F., and G. A. Baldassarre. 2002. Patch choice and foraging behavior of nonbreeding American flamingos in Yucatan, Mexico. Condor 104:452–457.

Beck, R. W., and Parametrix. 2006. Seattle–Tacoma International Airport stormwater engineering report. Port of Seattle, Seattle, Washington, USA.

Belánger, L., and R. Couture 1988. Use of man-made ponds by dabbling duck broods. Journal of Wildlife Management 52:718–723.

Blackwell, B. F., T. L. DeVault, E. Fernandez-Juricic, and R. A. Dolbeer. 2009. Wildlife collisions with aircraft: a missing component of land-use planning for airports. Landscape and Urban Planning 93:1–9.

Blackwell, B. F., L. M. Schafer, D. A. Helon, and M. A. Linnell. 2008. Bird use of stormwater-management ponds: decreasing avian attractants on airports. Landscape and Urban Planning 86:162–170.

Blackwell, B. F., T. W. Seamans, P. M. Schmidt, T. L. DeVault, J. L. Belant, M. J. Whittingham, J. A. Martin, and E. Fernández-Juricic. 2013. A framework for managing airport grasslands and birds amidst conflicting priorities. Ibis 155:199–203.

Blokpoel, H., and G. D. Tessier. 1983. Monofilament lines exclude ring-billed gulls from traditional nesting areas. Proceedings of the Bird Control Seminar 9:15–19.

Blokpoel, H., and G. D. Tessier. 1984. Overhead wires and monofilament lines exclude ring-billed gulls from public places. Wildlife Society Bulletin 12:55–58.

Brand, A. B., and J. W. Snodgrass. 2009. Value of artificial habitats for amphibian reproduction in altered landscapes. Conservation Biology 24:295–301.

Brenneisen, S. 2003. The benefits of biodiversity from green roofs: key design consequences. Proceedings of the North American Green Roof Conference 1:323–329.

Brenneisen, S. 2006. Space for urban wildlife: designing green roofs as habitats in Switzerland. Urban Habitats 4:27–36.

Brown, M., and J. J. Dinsmore. 1986. Implications of marsh size management and isolation for marsh bird management. Journal of Wildlife Management 50:392–397.

Carter, T., and A. Keeler. 2008. Life-cycle cost-benefit analysis of extensive vegetated roof systems. Journal of Environmental Management 87:350–363.

Creighton, J. H., R. D. Sayler, J. E. Tabor, and M. J. Monda. 1997. Effects of wetland excavation on avian communities in eastern Washington. Wetlands 17:216–227.

Davies, C. M., and H. J. Bavor. 2000. The fate of stormwater-associated bacteria in constructed wetland and water pollution control pond systems. Journal of Applied Microbiology 89:349–360.

Davis, A. P. 2008. Field performance of bioretention: hydrology impacts. Journal of Hydrologic Engineering 13:90–95.

DeVault, T. L., J. L. Belant, B. F. Blackwell, and T. W. Seamans. 2011. Interspecific variation in wildlife hazards to aircraft: implications for airport wildlife management. Wildlife Society Bulletin 35:394–402.

Dietz, M. E. 2007. Low impact development practices: a review of current research and recommendations for future directions. Water, Air, and Soil Pollution 186:351–363.

Dietz, M. E., and J. C. Clausen. 2008. Stormwater runoff and export changes with development in a traditional and low impact subdivision. Journal of Environmental Management 87:560–566.

Dolbeer, R. A., P. P. Woronecki, E. C. Cleary, and E. B. Butler. 1988. Site evaluation of gull exclusion device at Fresh Kill Landfill, Staten Island, NY. Bird Damage Research Report No. 411. Denver Wildlife Research Center, Ohio Field Station, Sandusky, USA.

Dolbeer, R. A., S. E. Wright, and E. C. Cleary. 2000. Ranking the hazard level of wildlife species to aviation. Wildlife Society Bulletin 28:372–378.

Dvorak, B., and A. Volder. 2010. Green roof vegetation for North American ecoregions: a literature review. Landscape and Urban Planning 96:197–213.

FAA. Federal Aviation Administration. 2004. Title 14 U.S. Code of Federal Regulations. Part 139: certification of airports. U.S. Department of Transportation, Washington, D.C., USA.

FAA. Federal Aviation Administration. 2006. Surface drainage design. Advisory Circular 150/5320-5C. U.S. Department of Transportation, Washington, D.C., USA.

FAA. Federal Aviation Administration. 2007. Hazardous wildlife attractants on or near airports. Advisory Circular 150/5200-33B. U.S. Department of Transportation, Washington, D.C., USA.

FAA. Federal Aviation Administration. 2008. Management of airport industrial waste. Advisory Circular 150/5320-15A. U.S. Department of Transportation, Washington, D.C., USA.

FAA. Federal Aviation Administration. 2009. Airport pavement design and evaluation. Advisory Circular 15/5320-6E. U.S. Department of Transportation, Washington, D.C., USA.

FAA. Federal Aviation Administration. 2011. FAA wildlife strike database. http://wildlife-mitigation.tc.faa.gov/wildlife/default.aspx.

FAA. Federal Aviation Administration. 2012. Airport design. Advisory Circular150/5300-13A. U.S. Department of Transportation, Washington, D.C., USA.

Fairbairn, S. E., and J. J. Dinsmore. 2001. Local and landscape-level influences on wetland bird communities of the prairie pothole region of Iowa, USA. Wetlands 21:41–47.

Forsythe, D. M., and T. W. Austin. 1984. Effectiveness of an overhead wire barrier system in reducing gull use at the BFI Jedburg Sanitary Landfill, Berkeley and Dorchester counties, South Carolina. Pages 253–263 *in* M. J. Harrison, S. A. Gauthreaux, and L. A. Abron-Robinson, editors. Proceedings: conference and training workshop on wildlife hazards to aircraft, May 22 to May 25, 1984, Charleston, South Carolina. U.S. Department of Transportation Report DOT/FAA/AAS/84-1. Defense Technical Information Center, Washington, D.C., USA.

Gibbs, J. P., J. R. Longcore, D. G. McAuley, and J. K. Ringelman. 1991. Use of wetland habitats by selected nongame waterbirds in Maine. Publication 9. U.S. Fish and Wildlife Service, Washington, D.C., USA.

Goff, K. M., and R. W. Gentry. 2006. The influence of watershed and development characteristics on the cumulative impacts of stormwater detention ponds. Water Resources Management 20:829–860.

Higgins, J., and M. Liner. 2007. Engineering runoff solutions. Airport Business 21:22–25.

International Civil Aviation Organization. 1991. Bird control and reduction. Airport Services Manual, Document 9137-AN/898, Part 3. Montreal, Quebec, Canada.

Le Viol, I., J. Mocq, R. Julliard, and C. Kebiriou. 2009. The contribution of motorway stormwater retention ponds to the biodiversity of aquatic macroinvertebrates. Biological Conservation 42:3163–3171.

Martin, J. A., J. L. Belant, T. L. DeVault, L. W. Burger Jr., B. F. Blackwell, S. K. Riffell, and G. Wang. 2011. Wildlife risk to aviation: a multi-scale issue requires a multi-scale solution. Human–Wildlife Interactions 5:198–203.

McAllister, B. 2009. Plan green; build clean. Airport Business. January:9–11. http://www.aviationpros.com/article/10373438/plan-green-build-clean.

McAtee, W. L., and S. E. Piper. 1936. Excluding birds from reservoirs and fishponds. Leaflet No. 120. U.S. Department of Agriculture, Washington, D.C., USA.

McGuckin, C. P., and R. D. Brown. 1995. A landscape ecological model for wildlife enhancement of stormwater management practices in urban greenways. Landscape and Urban Planning 33:227–246.

McLaren, M. A., R. E. Harris, and J. W. Richardson. 1984. Effectiveness of an overhead wire barrier in deterring gulls from feeding at a sanitary landfill. Pages 241–251 *in* M. J. Harrison, S. A. Gauthreaux, and L. A. Abron-Robinson, editors. Proceedings: conference and training workshop on wildlife hazards to aircraft, May 22 to May 25, 1984, Charleston, South Carolina. U.S. Department of Transportation Report DOT/FAA/AAS/84-1. Defense Technical Information Center, Washington, D.C., USA.

Oberndorfer, E., J. Lundholm, B. Bass, R. R. Coffman, H. Doshi, N. Dunnett, S. Gaffin, M. Köhler, K. K. Y. Liu, and B. Rowe. 2007. Green roofs as urban ecosystems: ecological structures, functions, and services. Bioscience 57:823–833.

Oregon Department of Environmental Quality. 2011*a*. National Pollutant Discharge Elimination System permit: Municipal Separate Storm Sewer System (MS4) discharge permit. Issued to the City of Portland and Port of Portland. Portland, Oregon, USA. http://www.portlandoregon.gov/bes/37485.

Oregon Department of Environmental Quality. 2011*b*. City of Portland and Port of Portland National Pollutant Discharge Elimination System permit: Municipal Separate Storm Sewer System (MS4) permit evaluation report and fact sheet. File No. 108015. Portland, Oregon, USA. http://www.portlandoregon.gov/bes/article/322159.

Pochop, P. A., R. J. Johnson, and D. A. Aguero. 1990. The status of lines in bird damage control–review. Proceedings of the Vertebrate Pest Conference 14:317–324.

Semadeni-Davies, A. 2006. Winter performance of an urban stormwater pond in southern Sweden. Hydrological Processes 20:165–182.

Smith, A. E., S. R. Craven, and P. D. Curtis. 1999. Managing Canada geese in urban environments. Jack Berryman Institute Publication 16. Cornell University Cooperative Extension, Ithaca, New York, USA.

Suter, W. 1994. Overwintering waterfowl on Swiss lakes: how are abundance and species richness influenced by trophic status and lake morphology? Hydrobiologia 279/280:1–4.

U.S. Environmental Protection Agency. 1999. Preliminary data summary of urban stormwater best management practices. EPA-821-R-99-012. Washington, D.C., USA.

U.S. Environmental Protection Agency. 2003. When are stormwater discharges regulated as class V wells? EPA 816-F-03-001. Washington, D.C., USA.

U.S. Environmental Protection Agency. 2006. Dry detention ponds. http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=browse&Rbutton=detail&bmp=67.

U.S. Environmental Protection Agency. 2012. Stormwater program. http://cfpub.epa.gov/npdes/home.cfm?program_id=6.

Van de Moortel, A. M. K., D. P. L. Rousseau, F. M G. Tack, and N. De Pauw. 2009. A comparative study of surface and subsurface flow constructed wetlands for treatment of combined sewer overflows: a greenhouse experiment. Ecological Engineering 35:175–183.

Velazquez, L. S. 2005. European airport greenroofs—a potential model for North America. http://www.greenroofs.com/pdfs/exclusives-european%20_airport_greenroofs.pdf.

Washington State Department of Transportation. 2009. Aviation stormwater design manual: managing wildlife hazards near airports Seattle, Washington, USA. http://www.wsdot.wa.gov/NR/rdonlyres/587C0B2B-07B2-4D60-90DD-5E57E93F40E1/0/TableofContentsStormwater.pdf.

White, C. L., and M. B. Main. 2005. Waterbird use of created wetlands in golf-course landscapes. Wildlife Society Bulletin 33:411–421.