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The Impact of Solar Development on Wetlands: Literature Review and Jurisdictional Scan

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Document prepared for Alberta North American Waterfowl Management Plan Partnership

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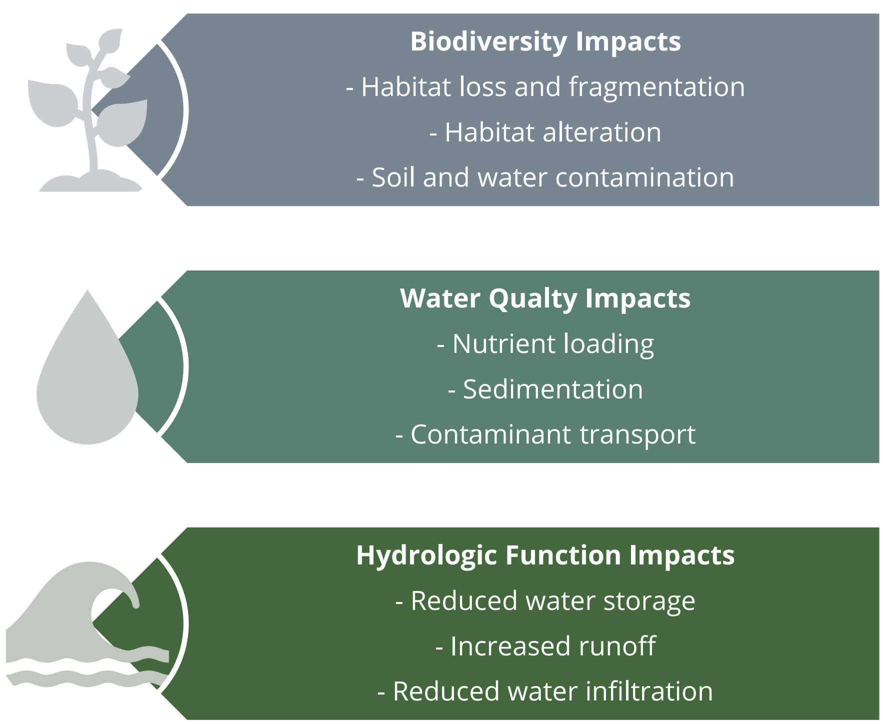
Executive Summary

This report reviews the current state of knowledge regarding the impact of solar energy development on wetlands—essential ecosystems that provide important environmental and economic benefits—and how jurisdictions across North America are responding. As the solar energy industry grows in Alberta, it is important to understand its potential impact on these critical ecosystems and their functions. The current body of knowledge on the impact of solar development on wetland function is limited; here, we summarize what information is available.

The following graphic identifies the primary potential consequences of solar energy development on wetland functions: conserving biodiversity, improving water quality, and functioning hydrology. It is important to note that not all of these consequences are unique to solar energy and best management practices to reduce impacts exist, particularly to mitigate erosion and sedimentation.



The current body of knowledge of solar development effects on wetlands is limited due to several factors. First, the impact of solar development on wetlands is highly context-dependent: there is significant variation in the type of solar technology used, solar facility design, required associated infrastructure (e.g., transmission lines, access roads), and wetland ecosystem characteristics. Second, most studies have been short-term, leading to a lack of long-term empirical data on the impact of solar development on wetlands. Finally, there has been little cumulative impact research of multiple solar facilities in wetland ecosystems, which are often designed in clusters in a given region. These limitations highlight the need for further research to better understand the specific impact of solar development on wetlands and develop effective strategies to mitigate negative effects.

We include a summary of the wetland and/or solar and wetland policies from 13 jurisdictions. Overall, those with policies to protect wetlands in North America are taking similar approaches to one another. These approaches seek to balance the need for renewable energy with the importance of protecting wetland ecosystems and their associated ecological and economic benefits. Wetland policies typically require permits for all types of activities; however, some jurisdictions highlight particular wetland types for greater protection and may include wetland buffers. While it is common for policies to include a hierarchy of wetland mitigation measures, with avoidance as the priority followed by minimization, there is often a lack of clarity on how this is determined before an alteration or removal becomes unavoidable. Particularly in landscapes with high wetland cover, it may be more difficult to completely avoid wetland features. Wetland compensation programs typically state preference for in-kind wetland replacement, and replacement within the same watershed or region. However, again there is a lack of clarity on how compensation projects are assessed for selection. There are several jurisdictions that have developed policies or guidance on solar energy development where wetlands may be affected that could inform the development of Alberta guidelines. For example, Ontario prohibits most renewable energy projects from locating directly within provincially significant wetlands in southern Ontario specifically and coastal wetlands generally. Similarly, Massachusetts and Minnesota have both developed guidelines for reviewing wetland permitting applications for solar energy projects.

Finally, we include recommendations that would improve knowledge of this field, including the design of long-term field studies on wetlands at solar energy sites, how to develop beneficial management practices, strengthening of the Alberta Wildlife Directives for Solar Energy Projects, and evaluating the effectiveness of wetland compensation fees and the success of wetland replacement projects. The appendix includes summary tables of key referenced literature, jurisdictional policies and processes related to protecting wetlands from solar energy development, and interviews.

This analysis provides insights into the key factors that determine the impact of solar development on wetlands, identify areas where further research is needed, and summarize how jurisdictions are responding to the need. By understanding the impact of solar development on wetlands, policymakers, industry stakeholders, and wetland advocates can make informed decisions that balance the need for renewable energy with the importance of protecting Alberta's natural resources.

Background

Renewable energy is growing in Alberta at a pace that will exceed the Renewable Electricity Act's goal of generating 30% of electricity from renewable sources by 2030 (Thibault, Weis, & Leach, 2023). While the benefits of moving to renewable energy sources are clear, environmental risks of development remain. For example, while the Alberta Wetland Policy (AWP) confirms the province's commitment to conserve, restore, protect, and manage wetlands, large-scale solar energy projects have the potential to negatively impact wetland values and functions. However, these impacts are not well understood. A greater understanding can provide guidance to solar energy development requirements or processes that would better protect wetland value and function.

This review was prepared for the Alberta North American Waterfowl Management Plan Partnership (AB NAWMP), to fulfill the following objectives:

1. Gain an understanding of where the current state of knowledge is regarding impacts to wetlands and wetland functions from different types of solar array panels, configurations, and installations including fixed and articulating.
2. Gain an understanding of how wetland policies and jurisdictions across North America consider the impacts of solar energy projects for regulatory decision-making.

While this review provides initial findings on the state of knowledge regarding solar energy development impact to wetlands, it is essential to note that it does not weigh the potential environmental risks against renewable energy benefits to climate change. Throughout the document, we use the term "solar energy development" to refer generally to photovoltaics (PV) at both distributed facilities (≤ 1 MW) and large utility (> 1 MW) scales. PV, which converts solar radiation into electricity, is the most common technology in North America and is the most commonly studied. Concentrated solar power (CSP), which uses mirrors to reflect and focus sunlight to generate heat and convert into electricity, is also considered due to inclusion in reviewed resources, and poses similar risks to wetlands. Where potential impacts differ, we make a note.

Methodology

Literature Review

To fulfill the two listed objectives, we undertook a comprehensive literature review. We gave priority to peer-reviewed literature; however, the review also includes grey literature, such as government reports and documents. The Mount Royal University online library and Google Scholar were used to search combinations of the following terms:

- solar, solar panel, solar array, or solar energy development;
- wetlands, wetland function, wetland value, impact on wetlands;
- floating solar array

We focused on papers published within the last 10 years, with a few exceptions to compensate for cases of limited available information. Further resources were obtained through reviewing references and jurisdiction websites. Note that this review does not include potential environmental impacts from the disposal or abandonment of solar energy infrastructure and equipment.

Jurisdictional Scan

A jurisdictional scan included a review of wetland policies, wetland function evaluation methods, wetland compensation fees, setbacks, and policies or guidelines specific to solar energy development and wetlands. Thirteen jurisdictions were reviewed in North America, including states, provinces, and one United States federal agency. To support the scan, key staff were identified and contacted for interviews. While 16 informants were contacted, nine provided interviews or information. Jurisdictions across North America with wetland policies and/or documents pertaining information on solar energy development on wetlands were identified for contact, as were all prairie provinces, and locales previously identified in *A Jurisdictional Review: Wildlife and Solar and Geothermal Energy Development* (Learned & Kinas, 2017).

Literature Review: Impacts to Wetland Function

We identified few published or grey literature reports that directly addressed the impact of solar development on wetland functions and values. The reviewed literature primarily relied on theory and scientific projections, with no long-term empirical studies on wetlands at or near solar energy developments. Most resources reviewed explored solar energy development impacts on the environment generally rather than to wetlands specifically. Nevertheless, there are commonly cited impacts that occur during construction and operation of solar energy developments that are likely to affect wetland functions directly or indirectly. We found limited information distinguishing impacts of solar array type (e.g., fixed-tilt or tracking system); however, it appears the most common type of solar array currently being used in North America is fixed, as solar trackers are generally more expensive, require more maintenance, and may not be suited for colder climates or where snow occurs (Solar Power World, 2016; Marsh, 2022).

The most significant impact to wetlands from solar energy development is the direct loss of wetlands due to the construction footprint of the facility (Grippo, Hayse, & O'Connor, 2015; Hartmann et al., 2016). Lost wetlands will no longer provide the functions of biodiversity and ecosystem health, water quality improvement, flood control, water storage, or human use opportunities. However, even in absence of direct loss, there are potential direct and indirect impacts to wetland functions, summarized in the sections below.

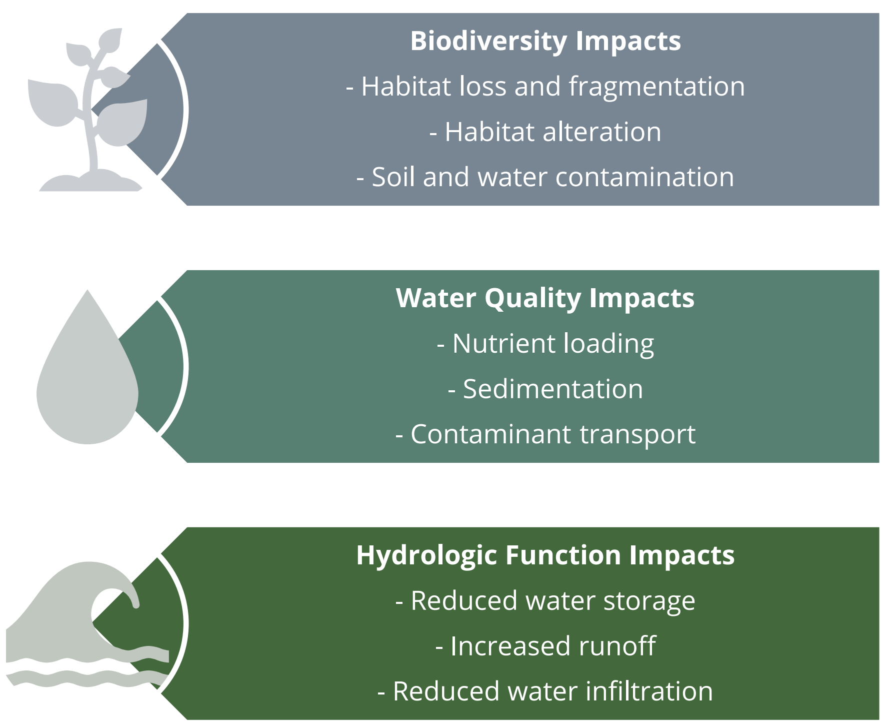


Figure 1: Summary of the potential impact to wetland functions from solar energy development.

Biodiversity

The AWP states that "wetlands are dynamic, complex habitats that contribute to biodiversity and other ecological functions" (Government of Alberta, 2013). The impact of solar energy development on biodiversity is not yet widely documented, and is typically approached on a case-by-case basis (Learned & Kinas, 2017). There are no long-term studies on how solar energy development affects either wetlands or a wetlands' ability to support biodiversity. However, there are common concerns noted in the literature. For example, developing land for solar energy will result in varying degrees of habitat loss and fragmentation, shade the land beneath the panels changing the microclimate (can be harmful or beneficial), potentially result in erosion and sedimentation, affect water-associated and water-obligate birds, and, in some sites may include practices that introduce contaminants.

Direct habitat loss and fragmentation from the developed footprint, including fencing, access roads, and transmission lines required to connect the solar energy development to the grid, may affect biodiversity (Grippo et al., 2015; Rabaia et al., 2021; US Department of Energy, 2021). Although Hamed et al. (2022) noted direct impact on biodiversity may be negligible, they indicated "Large-scale solar energy infrastructures may block the movement as well as seasonal migration of wildlife" (Hamed & Alshare, 2022). The degree of impact depends on the size, location and infrastructure associated with solar energy development. For example, utility scale solar energy projects are likely to place a barrier on certain species movements, while other species may be equipped to move through or around the development (Hernandez et al., 2014a; Exley et al., 2022). For this reason, fencing around solar energy development to prevent human access should be designed with wildlife-friendly fencing (US Department of Energy, 2021). The ecological effects of transmission lines and corridors are varied and depend on many factors, showing that proper siting of this infrastructure is crucial (Hernandez et al., 2014b).

The construction phase of solar energy development may have a profound impact on a wetlands' ability to support biodiversity. For example, construction can require vegetation removal and risk invasive species introduction (Hernandez et al., 2014a; Arrowwood Environmental & Fitzgerald Environmental, 2018; Exley, Hernandez, et al., 2021; Hamed & Alshare, 2022). In wetland areas with high tree cover, solar energy development may require tall vegetation removal that could shade the solar panels. This risks both direct and indirect biodiversity loss as it directly removes plant species and habitat, and can lead to erosion and sedimentation that can alter habitat (Arrowwood Environmental & Fitzgerald Environmental, 2018). This issue is being addressed in Vermont through project-specific permit requirements, such as only removing treetops or trees of a certain size, keeping stumps/roots in place to reduce risk of erosion, and/or reducing the number of solar panels permitted (personal communication, Zapata Courage, February 22, 2023).

Concerns of the effects of solar panels shading the ground are also commonly cited. However conclusions vary, and will depend on the solar infrastructure design, site management practices, location, and climate. Solar panels may prevent sun and rain from reaching the ground directly beneath, which may change the microclimate through reduced soil moisture and temperature, altering plant diversity (Exley, Hernandez, et al., 2021; Hamed & Alshare, 2022). Studies have found that areas under panels were more dominated by grass species than between panel rows (Arrowwood Environmental & Fitzgerald Environmental, 2018). However, initial findings from a Vermont case study indicate that, while vegetation cover was lower in areas shaded by panels, they had comparable species diversity to areas not shaded by panels (Vermont Department of Environmental Conservation, 2021). Indeed, studies have also shown that solar energy development can increase native pollinator habitat by restoring native, perennial flowers, addressing a widely recognized need (Dolezal, Torres, & O'Neal, 2021). This suggests that solar infrastructure design (layout and landscaping) greatly influences the impact solar energy development will have on ecological diversity and wetland health. Mitigations can include requiring wider spacing between panels, taller posts for panels, and/or smaller panel sizes to allow more sunlight to reach the ground. Interviews with key contacts involved in wetland permitting indicate that such mitigations are often required and determined on a project-specific basis (personal communication, Zapata Courage February 2, 2023; and David Demmer, March 9, 2023).

Bird are frequently killed or injured by impacts with built infrastructure; however, there is little available peer-reviewed data that show solar energy development has a greater effect on birds than other types of infrastructure. The lake effect hypothesis, for example, suggests birds may mistake solar panels for lakes, causing mortality, stranding, or injury of water-associated and water-obligate birds (i.e., species that can only take flight from water). This theory was developed after observations from a single facility but has not proven to be a common issue elsewhere (Kosciuch, Riser-Espinoza, Gerringer, & Erickson, 2020). A study synthesizing bird fatality studies at solar facilities in California and Nevada found that they have never exceeded 2.59 per MW per year, from both known and unknown sources (Kosciuch et al., 2020). While water-obligate species occurred at these study sites, the lake-effect hypothesis could not be confirmed because relevant information, like how water obligates perceive polarized light from PV solar panels, was not available (Kosciuch et al., 2020). While there is no conclusive evidence for the lake effect hypothesis, it is still an area of concern. It has been cited by the Alberta Utilities Commission (AUC) as a prominent reason for rejecting a solar development application within a 1000 m setback from Frank Lake, an Important Bird and Biodiversity Area (IBA) (Alberta Utilities Commission, 2023).

The California-Nevada synthesis also found the most common species found were generally abundant in the regions where the impacts occurred, as well as sharing behavioral traits of moving at near ground level, or were associated with built structures (Kosciuch et al., 2020). A paper studying a utility scale solar energy development in South Africa found no definitive evidence of bird collision mortality due to solar panels—bird species richness and density were lower at the solar energy development than in surrounding unaltered landscapes that likely reflected a loss of shrub/woodland species. Bird fatalities at this facility were 4.5 per MW per year (Visser, Perold, Ralston-Paton, Cardenal, & Ryan, 2019).

During the construction and routine operation of a solar energy facility, contaminants such as dust suppressants, synthetic oils, rust inhibitors, antifreeze, and/or herbicides, may be introduced or accidentally released with biodiversity consequences (Hernandez et al., 2014a; Grippo et al., 2015; Bošnjaković & Tadijanović, 2019; Rabaia et al., 2021). However, there is a wide range of products used at solar energy developments (e.g., many different types of dust suppressants exist, if used at all) that will have varying impacts to the water quality, biodiversity, and hydrologic function.

Water Quality

Wetlands improve water quality by facilitating sedimentation and filtering pollutants (Government of Alberta, 2013). However, this function may be affected when landuse is changed due to human use. Solar development often results in local vegetation removal and potentially the loss of a vegetated buffer. Shading from panels may or may not affect plant diversity in the project area, depending on site characteristics (Exley, Hernandez, et al., 2021; Vermont Department of Environmental Conservation, 2021). However, there has been limited work to document this effect on wetland function (Arrowwood Environmental & Fitzgerald Environmental, 2018). As in other types of development, there is the potential introduction of contaminants (discussed above), addition of impervious surfaces, and increased erosion that can result in nutrient loading, sedimentation, reduced infiltration, and contaminant transport that can have adverse effects on water quality.

During construction, the removal of vegetation, grading or excavating soil, and the use of heavy equipment leaves the ground exposed and vulnerable to erosion by wind or rain (Hernandez et al., 2014a; Lebel, 2020; Exley, Hernandez, et al., 2021; Rabaia et al., 2021). This increased topsoil erosion can increase sedimentation and turbidity of water bodies, affecting water quality (Rabaia et al., 2021). While soil compaction and erosion are the greatest concerns during the construction phase, ongoing compaction can still occur from vehicle access for maintenance of solar panels, with similar concerns to erosion and sedimentation. Solar panels as an impervious surface are discussed in more detail below, however, increased runoff rates and volume can have lasting implications on water quality.

Hydrologic Function

Wetlands help reduce flooding and soil erosion by storing runoff and slowing its downstream release (Government of Alberta, 2013). They are important as areas of groundwater recharge and discharge and are sources of water in times of drought (Government of Alberta, 2013). The main effect of these functions from solar energy development can result from erosion and sedimentation, and increased rate and volume of water runoff.

As discussed above, construction practices may lead to increased erosion. This can remove soil and organic matter, reducing the ability of the land to absorb and hold water, and cause sedimentation that can alter the shape and size of waterbodies, further affecting water-holding capacity. This decreases groundwater recharge, and increasing flood risk and downstream erosion (Hernandez et al., 2014b; Arrowwood Environmental & Fitzgerald Environmental, 2018; Lebel, 2020; Rabaia et al., 2021). However, it is important to note that construction effects are not unique to solar energy development, and vary widely based on facility size, construction practices, and location. Strategies exist to mitigate soil compaction, such as requiring use of smaller vehicles, wider tires, or restricting heavy equipment use to when the ground is frozen (Arrowwood Environmental & Fitzgerald Environmental, 2018).

As solar panels are an impervious surface, depending on their configuration, they may lead to issues with increased volume and rate of water runoff (Cook & McCuen, 2013). Driplines can cause channels that quickly move water offsite, reducing onsite infiltration (Arrowwood Environmental & Fitzgerald Environmental, 2018). Best management practices exist to mitigate this, including proper spacing between panels, siting solar energy development on flat or gradual slopes, maintaining groundcover vegetation, and use of controls like silt fences (Maryland

Department of the Environment, 2010; Lebel, 2020). The Maryland Department of Environmental Protection has developed stormwater design guidelines for solar panels that would then allow for a solar array to be considered water-permeable (Maryland Department of the Environment, 2010). In these guidelines, vegetated areas receiving runoff must be equal or greater in length than the width of the row of solar panels. This avoids issues that would prevent meeting state stormwater management requirements (Maryland Department of the Environment, 2010).

Cook & McCuen (2013) simulated water runoff of a solar energy development pre- and post-installation and found that solar panels did not have a significant effect on runoff volume, peak, or time to peak. However, peak discharge was found to increase significantly if the ground under panels was bare or graveled (Cook & McCuen, 2013). This, and other studies, suggest that vegetation maintenance under the dripline beneath panels, and/or buffer strips at the most down-gradient rows is likely sufficient to reduce erosion (Cook & McCuen, 2013; Arrowwood Environmental & Fitzgerald Environmental, 2018).

The potential heat-island effect from solar energy development is not fully understood but, if severe, could have significant effects on hydrologic function. Studies in a desert environment have shown that large, utility-scale solar energy development can warm air temperatures, creating a heat-island effect (Barron-Gafford et al., 2016; Broadbent, Krayenhoff, Georgescu, & Sailor, 2019). While understudied, there is some concern that an increase in desert albedo could impact local temperatures and precipitation through wind pattern changes and evapotranspiration (Hamed & Alshare, 2022). However, the effects of solar energy development on surface climate are likely to vary by climate, region, PV array design, spacing, etc. (Broadbent et al., 2019). By comparison, CSP generates significantly more heat waste than PV, requiring cooling systems as mitigation. Increasingly, CSP heat waste is being used in co-generation plants, such as in desalination (Bošnjaković & Tadijanović, 2019).

Additional considerations

Decommissioning

The typical lifespan of solar energy systems are 20–35 years; however, actual operation may be shorter due to land lease or power purchase agreements for certain projects (Wyatt, 2020). Once solar infrastructure reaches its end of life, it may be repowered (refurbished or replaced), or decommissioned by removing all equipment and infrastructure, including fencing and access roads. Requirements for land reclamation will be of particular interest for the protection of wetland function. While still a relatively new industry within Alberta, many facilities will reach the end of their life in the coming decades. The AUC requires information on how an applicant plans to finance and approach decommissioning and reclamation, which is considered when deciding if the project is in the public interest (Alberta Utilities Commission, 2023).

A survey in the United States found that as of April 2021, one federal agency (Bureau of Land Management) and 15 states had solar decommissioning policies in place, and five states had pending policies (e.g., in draft, proposed bills) (Curtis, Smith, Buchanan, & Heath, 2021). Remaining states left solar decommissioning policies completely to local governments, however some provided suggested guidelines or templates that local governments could adopt (Curtis et al., 2021). The state decommissioning policies typically mandate compliance with regulations over the lifetime of the project and are a condition of the initial approval required for project development (Curtis et al., 2021). Most policies include requirements for removal of all equipment and site restoration and reclamation. In additional to a decommission plan and cost estimate, several states require financial assurance prior to construction, which has been found to increase capital costs of a solar project, leading to prolonged construction timelines, delays, and even project cancellation (Curtis et al., 2021). Other jurisdictions require a more flexible policy, allowing financial assurance during project operation or in phases. For example, in Illinois, 10% of the financial assurance must be provided prior to operation, while 50% by the end of the 6th year of operation, and all remaining by to the end of the 11th year (Curtis et al., 2021).

While decommissioning and land reclamation requirements will have the greatest direct impact to ensuring the restoration or protection of wetlands on site, additional decommissioning considerations focus on equipment disposal. Solar panels can easily be re-used, refurbished, or recycled. However, some types of solar panels may require following relevant hazardous waste disposal or recycling regulations (Hamed & Alshare, 2022). In Massachusetts, for example, the burden is on the generator of the solar panels to determine if solar panel waste is hazardous or not, which can be made by reviewing a list of materials used in manufacturing, or testing materials in "Toxicity Characteristic Leaching Procedure" (Massachusetts Department of Energy Resources, Massachusetts Department of Environmental Protection, & Massachusetts Clean Energy Center, 2015)

Project Siting

Proper siting of a solar energy project and associated infrastructure is essential to protect wetland function. For example, to avoid access roads and transmission lines reaching great distances, which increases the likelihood wetlands will be effected, solar energy projects should be located near existing grids and infrastructure (Hartmann et al., 2016). In a recent decision to reject a solar development application within the Frank Lake IBA, the AUC considered the estimated increase in bird mortality and reduction in bird population from collisions with transmission lines (Alberta Utilities Commission, 2023). This decision highlighted the importance of considering cumulative effects from associated infrastructure, as well as proper project siting.

Other siting considerations include avoiding development on steep slopes to reduce erosion risk, and locating solar energy development on previously disturbed lands (Hartmann et al., 2016). Using sites that are contaminated and disturbed, rather than undeveloped lands, for solar arrays can have permitting and mitigation advantages (Macknick, Lee, Mosey, & Melius, 2014; Mason, Molina, Ziegler, & Zuckerman, 2016). For example, wetlands that were drained for agriculture and are now being converted to solar may allow the area to recover previously lost wetland function, not least by reducing effects of pesticide/herbicide use.

Macknick et al. (2014) showed that there is sufficient disturbed and contaminated land within the United States to meet the U.S. Department of Energy goals (Macknick et al., 2014). There has also been a growing interest in, and installation of, solar energy co-located with other energy infrastructure, crop production, grazing, or bee keeping that can coexist with solar arrays (Commonwealth of Massachusetts Department of Environmental Protection, 2018; Vermont Department of Environmental Conservation, 2021).

The Vermont Department of Environmental Conservation is collecting data from five solar development sites on wet meadow type wetlands to understand the effects from the change in land use of wet hayfields to solar development. Initial findings show that soil compaction is greater in hayfields, indicating that measures to reduce compaction during solar construction or reduce mowing appear to result in better wetland condition (Vermont Department of Environmental Conservation, 2021); the mowing regime may have the biggest impact on wetland impairment. Further, the presence of shade and sun treatment areas increase habitat heterogeneity improving species diversity (Vermont Department of Environmental Conservation, 2021). The study will conclude in 2023 (Vermont Department of Environmental Conservation, 2021).

Even where wetland function is preserved, there are additional factors to consider, such as potential conversion of wetland type. For example, Maine has seen an increase in specifically the conversion of one wetland type to another (e.g., from forested to scrub/shrub or wet meadow) as a result of solar energy development, and has developed guidelines to help evaluate these impacts (State of Maine Department of Environmental Protection, 2021).

Water Consumption

Water may be required for regular operation of solar energy developments; for panel cleaning, dust suppressant, and wet cooling (Bošnjaković & Tadijanović, 2019). CSP systems typically consume more water than PV systems, although dry cooling technology is available (Bošnjaković & Tadijanović, 2019; Dhar, Naeth, Jennings, & Gamal El-Din, 2020). Not all solar energy developments will have a large water use footprint (i.e., some do not need wet cooling); water use largely depends on the technology used, climate, and management practices. However, water use could be an issue in water-stressed areas and when practices require water compensation, solar energy development should be located in areas where water is readily availability (Dhar et al., 2020).

Floating Solar Photovoltaic

Floating solar photovoltaic (FPV) are solar panels mounted on a structure that floats in a body of water. Our review did not find examples of the use of FPV on natural wetlands; however, the technology is rapidly expanding worldwide to address land use pressures and high costs of land needed for solar energy development. FPV has primarily been installed on artificial water bodies (e.g., reservoirs) used for drinking water, irrigation, or hydroelectric power. Benefits of FPV on artificial waterbodies include increased efficiency due to the cooling effect of water, reduced algal growth, and reduced evaporation (N. Lee et al., 2020; Exley, Hernandez, et al., 2021; Almeida et al., 2022). Combining FPV with hydropower is advantageous because energy grid infrastructure will already be in place. As well there are simultaneous advantages of providing energy from hydropower when sunlight is weak and storing water as energy in reservoirs when solar power production is high (N. Lee et al., 2020; Almeida et al., 2022).

However, changes in light attenuation, water temperatures and water movement from FPV may affect waterbodies. While these effect are largely hypothetical, Exley et al. (2021) simulated a lake's response to varying extents of FPV to demonstrate changes in wind speed and solar radiation on lake thermal structure—modifications to thermal dynamics can dramatically alter biogeochemical processes

(Exley, Armstrong, Page, & Jones, 2021). System design and FPV surface coverage variation were able to either mitigate impacts of climate change on waterbodies or conversely, have negative impacts on waterbody ecosystems (Exley, Armstrong, et al., 2021). Their simulation results show that site location affects phytoplankton populations more than percent surface coverage, demonstrating priority design elements to avoid negative impacts to waterbodies (Exley et al., 2022). Just as in land-mounted solar photovoltaics, field-based studies are needed to better understand potential impacts to both natural and artificial waterbodies. Interestingly, Almeida et al. (2022) noted that if Canada covered only about 5% of reservoirs with floating solar, it would be enough to satisfy its solar energy needs.

Data Gaps

There is a general lack of information on how solar energy developments directly and indirectly affect wetland function. Without experimental details, it is difficult to generalize due to the many differences in solar project size and energy capacity, panel and array design, layout, maintenance, and location characteristics. As a relatively new industry, cumulative impacts have yet to be measured. The most significant gaps include:

1. Long-term data: There is a lack of long-term data on the impact of solar development on wetland function, which limits the understanding of cumulative effects of solar energy on wetland ecosystems. This includes data on water quality, hydrologic function, solar-wildlife interactions, and connectivity.
2. Ecological thresholds: There is a need to identify the ecological thresholds beyond which the effects of solar development become detrimental to wetland function.
3. Regional variation: The effects of solar development on wetland function are highly dependent on regional and local characteristics of wetland ecosystems, such as climate, hydrology, and soil type. Therefore, there is a need for region-specific studies to better understand the effects of solar development on wetlands.
4. Cumulative effects: There is a lack of research on the cumulative effects of multiple solar facilities on wetland ecosystems, the effect of clustering in certain regions, or on solar facility effects combined with other human uses.
5. Best or beneficial management practices: Solar energy developments vary broadly in their land requirements, layout, equipment and infrastructure, and maintenance and operation practices. To effectively make decisions when wetlands are involved, there is a need to develop effective best management practices to minimize deleterious effects.

6. How solar energy compares to other developments: There is a need to understand the effects of solar energy development relative to other types of human development to fully understand the risks and benefits of solar energy.

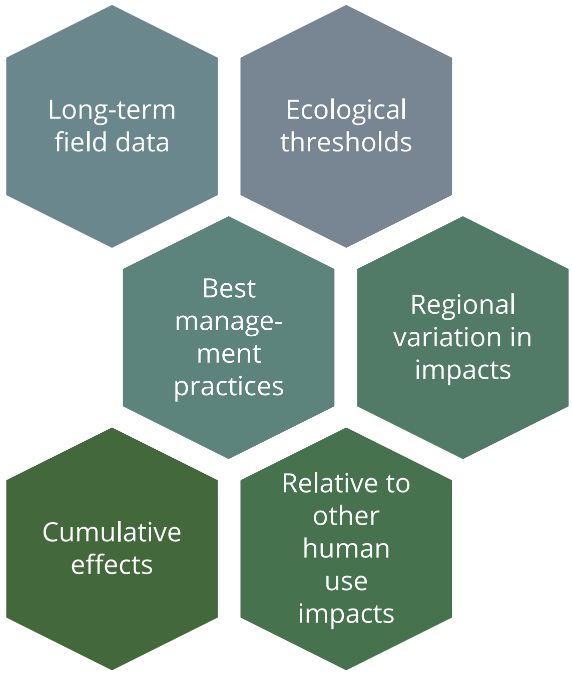


Figure 2: Data gaps in the understanding of how solar energy development affect wetland function.

Jurisdictional Scan

This section summarizes the key findings from a jurisdictional scan, focusing on gaining on understanding of how jurisdictions in North America attempt to protect wetlands from impact by development, through policies and permitting requirements. The sections below highlight the types of wetlands that are offered protection by various jurisdictions, evaluation tools used to evaluate wetland function, wetland buffer requirements, and compensation for wetlands loss. A summary table provides information on wetland policies for each province and state reviewed. Appendix II includes a summary table of wetland policies and permitting requirements, and Appendix III includes jurisdictional contacts and interview summaries.

Key Findings

Most jurisdictions reviewed have wetland policies in place that acknowledge the importance of protecting wetland functions and/or values in those policies. While some jurisdictions provide greater protection for wetlands of higher value, most include all wetlands in their policies. A hierarchical approach to wetland mitigation. The hierarchy places avoidance as the best option, followed by minimization then mitigation as a last resort. While this hierarchy is common in wetland policies in North America, there is often a lack of clarity on how the first two steps are assessed before mitigation or replacement is allowed. Importantly, in areas with less wetland coverage in their land base, it will be easier for development to avoid wetlands altogether. For example, Alberta's land base contains 20% wetland cover, compared to Vermont's 5% and Massachusetts 11%—both states with robust wetland protection policies (U.S. Geological Survey [USGS], 1992; Adams et al., 2014; Alberta Environment and Sustainable Resource Development (ESRD), 2015). While four jurisdictions have developed policies or guidelines specific to solar development on wetlands, most have not.

Types of Wetlands Protected

While many jurisdictions include regulations for all wetland types in their policies, there are a few that have distinguished wetlands and their protections or permitting requirements. For example, wetlands in Vermont are ranked from most to least significant in the functions they provide as Class I, II or III. Any activity within a Class I or II wetland or buffer zone (30.5 m for Class I, 15.2 m for Class II) requires a permit, unless exempt. For Class I wetlands, which are identified as exceptional or irreplaceable, and healthy, intact, and in good condition, permits will not be granted, unless the project meets a compelling need to protect public health or safety. Manitoba requires a license for wetlands defined as Class 3–5 which require compensation for loss, although generally does not issue licenses for Class 4 and 5, and allows a more streamlined process for low-risk impacts to Class 1 and 2. Similarly, Nova Scotia does not approve alterations to wetlands that have been identified as a Wetland of Special Significance, which include all salt marshes, wetlands under the North American Waterfowl Management Plan (NAWMP) and secured for conservation, and wetlands within Ramsar sites, provincial wildlife areas, wilderness areas, provincial parks, nature reserves or private conservation lands. Ontario also protects what has been classified as "provincially significant wetlands", coastal wetlands, and their adjacent areas from development altogether except in very limited circumstances.

Wetland Alteration Permitting Requirements

Wetland alteration permit requirements vary depending on the jurisdiction and project. Alterations may be permanent or temporary, and temporary permits will have required timelines in which to complete the activity and restore wetlands. Typically, applications may include the following information:

- Site location and description, including wetland delineation and details on ecological features.
- Description of activity, including extend of wetland alteration or disturbance.
- Alternatives analysis and reasoning that avoidance or minimization is not possible. Some jurisdictions may require a strong case that the alteration is necessary for the public good alongside the reasoning (e.g., Vermont).
- Environmental assessment detailing the potential impacts of the proposed activity, including impacts on hydrology, water quality, vegetation, and wildlife may be required depending on the activity.
- Wetland functional assessments (e.g., Nova Scotia requires WESP-AC results).
- Mitigation plan detailing how adverse impacts will be minimized or offset, including compensatory fees and/or wetland creation or restoration.
- A monitoring and reporting plan detailing any ongoing monitoring of wetland areas is required. Length of post-construction monitoring varies by jurisdiction and project. For example, in Nova Scotia, a wetland alteration approval may require monitoring of remaining wetlands within the site for several years post construction to ensure that effects do not exceed what is identified in the application.
- Additional supporting documents may include hydrological studies and engineering plans.
- Permit fees.

A wetland alteration permit is just one approval a solar energy development requires. Additional approvals for solar energy may have to consider other important ecosystems and species at risk, as well as requirements for decommissioning and reclamation, all of which may contribute to the protection of wetland function. For example, for solar energy project approval in Alberta, the AUC requires the submission of a renewable energy referral report from Alberta Environment and Protected Areas that evaluates if a project will have significant changes to wildlife or wildlife habitat.

WETLAND BUFFERS

In addition to wetland alteration, some jurisdictions also require permits for alteration to a buffer around a wetland. Massachusetts requires a permit within a 30.5 m (100 ft) buffer around wetlands, however, also has solar guidance that allows development within this buffer with proper oversight. Prince Edward Island requires a permit for activity within 15 m of a wetland. New Jersey includes upland buffers adjacent to wetlands as well as “transition areas” of areas within a 45.7 m (150 ft) buffer from a freshwater wetland in their wetland policy. Additional buffers may be placed during the permitting process on a case-by-case basis or as required by some local governments in some areas. The Wildlife Directive for Alberta Solar Energy Projects includes standard 100.1.9 “...the solar energy project must not occur within 100 m of any wetland class (bog, fen, marsh, shallow open water, swamp) identified in Table 1 in the Alberta Wetland Classification System except for wetland classes with Water Permanence listed as Temporary” (Government of Alberta, 2017). However, this is not mandated if a proponent can show they are unable to avoid this buffer.

Wetland Function Evaluation Tools

Several jurisdictions, such as Nova Scotia and Alberta, use function-based wetland assessments that evaluate a wetland’s functions to inform wetland compensation ratios. These tools, such as WESP-AC (Nova Scotia) and ABWRET-A (Alberta) include a rapid field assessment and GIS analysis. The models are calibrated to a reference dataset of wetlands to approximate the relative performance of wetlands within a region. While these types of tools are widely used in North America, there may be calibration bias that affect wetland scores. One study evaluated the development and use of the ABRET-A tool, and found that wetlands used for calibration did not represent the general wetland population, underrepresented bogs and overrepresented fens, and lead to scores that underestimated functional value (Rooney et al., 2022). Further, it found that wetlands targeted for permitted loss were larger and closer to roads than the typical wetland, and were clustered around major cities (Rooney et al., 2022).

In addition to using modeling tools, some jurisdictions require that identified wetland functions be considered when making permitting decisions with no quantification or ranking. For example, Vermont state wetland ecologists use a wetlands evaluation form that identifies if a wetland has the 10 possible functions and values as identified in the Vermont Wetland Rules, such as providing surface and groundwater protection or wildlife habitat (Vermont Department of Environmental Conservation, 2019).

Wetland Compensation

Wetland compensation is being used by the jurisdictions reviewed to offset wetland loss to development. In the United States, wetland compensation programs are regulated under the Clean Water Act, which requires developers obtain a permit from the Army Corps of Engineers to develop wetlands; but this can also be required by state programs. In Canada, wetland compensation programs are managed at the provincial or territorial level. Programs in both countries typically require developers to create or restore wetlands onsite or offsite or to contribute to a wetland compensation fund. In some cases, developers may be required to purchase wetland credits from a wetland compensation program.

While jurisdictions slightly differ in their approach, wetland replacement favors an in-kind wetland type replacement, and in the same region as the loss. The service areas in which replacement must apply varies, for example within the same watershed, ecoregion, or other defined geographical area (Kihslinger, Libre, Ma, Okuno, & Gardner, 2020). Wetland replacements are typically determined by a ratio of lost or impaired wetland size, and the type of resource or type of mitigation to be used. Some jurisdictions determine ratios based on the lost wetland's evaluated value, including in Alberta and Minnesota. Other jurisdictions may determine a ratio using the uncertainty of replacing the lost wetland functions. For example, Nova Scotia and Prince Edward Island require higher compensation fees for creation of new wetlands due to the greater risk of not recouping the ecosystem function lost by the development. The primary input that determines *in lieu* compensation fees is land value, as well as the cost of the wetland mitigation project (design, construction, administration, contingency), as in Alberta, Massachusetts, and Nova Scotia. However, these fees are typically fixed by service area and may not be sufficient unless reviewed periodically to account for increased land values, labour, and material costs. As well, fees may not be cost prohibitive to most developers, lowering the incentive to avoid wetland impact. Another approach, used in Maine, is to use a resource-dependent formula. The Maine Natural Resource Conservation Program uses a base rate calculated using regional estimates of construction and monitoring plus land cost, then applies a resource multiplier. For example, a wetland-specific formula is used, adding fees for impacts to uplands that affect aquatic organisms (e.g., vernal pool species) (Kihslinger et al., 2020).

Mitigation banking is a wetland compensation alternative popular in the United States to encourage a commodity approach to conservation. Wetland mitigation banks are created when a developer or other entity creates or restores wetlands and then sells "credits" earned for restored wetlands to others who need to compensate for wetland losses elsewhere. The credits are then used to offset the loss of wetlands that occur due to permitted activities such as development or mining. While mitigation banking can be cost effective and flexible, it may not be an effective means to achieve no-net-loss of wetlands, and can lead to a redistribution of the ecosystem services provided by wetlands when mitigation credits are applied at a distance from where the original loss occurs (Levrel, Scemama, & Vaissière, 2017).

Policies or Guidelines Specific to Solar Energy Development

A handful of jurisdictions have developed policies or guidelines specifically for solar energy development when wetlands are involved. For example, both Maine and Minnesota have developed guidance documents for permitting solar developments on wetlands. This was a response to policies that did not quite address issues that arose with the increase in demand for solar energy (e.g., in Maine, wetland type conversion had more potential to occur in larger areas with solar than in linear developments). While Alberta can be included in this handful of jurisdictions, due to the Wildlife Directives for Alberta Solar Energy Development, the sections below summarize how other states and provinces are responding to the issue of solar energy development on wetlands:

- Ontario:
    - Renewable Energy Approvals Regulation (under the Environmental Protection Act) prohibits most activities associated with renewable energy projects from locations directly within provincially significant wetlands in southern Ontario and coastal wetlands.
- Maine:
    - Guidance for Evaluating Wetland Conversion Impacts: an assessment of wetland functions that may be lost, degraded, or altered by a proposed project is required for all projects, including solar projects, that involve freshwater wetland alterations of 1,393.5 m^2 (15,000 ft^2) or more, or freshwater wetland of special significance alterations of 46.5 m^2 (500 ft^2) or more (State of Maine Department of Environmental Protection, 2021).
- Massachusetts:
    - MassDEP Wetlands Program Policy 17-1: Photovoltaic System Solar Array Review. This policy outlines the approach for reviewing solar energy projects on wetlands, including the documentation of avoidance, minimization, and mitigation. It discourages siting solar within jurisdictional wetlands and encourages siting on upland properties. Includes consideration of direct and indirect impacts.
    - Guidance on Agriculture and Solar Energy Under the Wetlands Protection Act and the Solar Massachusetts Renewable Target (SMART) Program: provides regulatory guidance on the applicability of the Wetlands Protection Act for dual-use solar systems.

    - Developed a FAQ sheet on floating solar photovoltaic projects, the only jurisdiction that we reviewed with information on floating solar projects.
- Minnesota:
    - Guidance on Reviewing Solar Panel Projects for Wetland Conservation Act (WCA) Compliance: provides a suggested approach for evaluating projects for WCA compliance when involving solar panels on posts/pilings. Typically posts/pilings are allowed within WCA, however, solar differs in effects from traditional development using posts/pilings. Requires the evaluation of wetland function pre-project and anticipated function post-project.
- New Jersey:
    - The New Jersey Department of Environmental Protection's (NJDEP) Bureau of Climate Change and Clean Energy developed and updates a solar siting analysis that identifies land as preferred, not-preferred, or indeterminate to guide where to encourage and discourage solar energy development. Wetlands are included in the not-preferred land.

Recommendations

The following are recommendations to advance our understanding of how to protect wetland function from potential effects of solar energy development.

Develop long-term wetland monitoring studies

There is a general lack of empirical data on the impact of solar development on wetland function. Developing long-term wetland monitoring studies at solar energy sites will advance understanding of:

- direct and indirect impacts to water quality and hydrological function
- solar-wildlife interactions
- impacts on local and regional wildlife connectivity
- impacts on wetland connectivity
- relationship between landuse efficiency and landscape integrity (e.g., is it better to reduce overall footprint by aggregating solar panels, or spread panels out to allow corridors for habitat and wildlife movement?)
- cumulative impacts
- regional variation (how effects differ based on regional and local characteristics of wetland ecosystems)
- benefits and drawbacks of combining solar and agriculture
- how solar energy compares to other types of development
- if wetland mitigation projects are replacing lost functions

Develop best management practices

To ensure that solar energy development (construction and operation) poses the least impact on wetlands, it is important to develop, and regularly update, BMPs specific for wetlands using best available data. To develop best (or beneficial) management practices, consider the following:

- Review existing best management practices that may be available directly from industry or from other jurisdictions.
  - Reviewed resources that could inform best management practices include the Southern Environmental Law Center's "The Environmental Review of Solar Farms in the Southeast U.S. — Maximizing Benefits & Minimizing Impacts to Drive Smart, Sustainable Development of Solar Power" and the Maryland Department of Environment's "Stormwater Design Guidance" (Maryland Department of the Environment, 2010; Southern Environmental Law Center, 2017).

    - The Vermont Department of Environmental Conservation is concluding a study that monitored five solar development sites on wet meadow type wetlands in 2023. We recommend to follow-up with this department for results.
  - Encourage solar energy development on marginal or degraded lands as a best practice, with preference for restoring wetland function lost to previous land use.

Leverage existing policies

Strengthen or update key components of existing wetland protection policies in Alberta:

  - Enforce the 100 m setback from wetlands required by the Alberta Wildlife Directive for Solar Energy Projects to ensure its intent to protect wildlife dependent on all wetlands.
  - Consider increasing wetland compensation fees to increase incentive of wetland avoidance.

Identify areas to encourage solar energy development

Solar provides a clean, sustainable energy source that helps combat climate change; the industry will continue to grow in Alberta. As the renewable energy sector grows, it is imperative to actively encourage solar energy development while avoiding areas that are most damaging to wetlands and important ecosystems.

  - Encourage and support municipalities to undertake a solar-siting analysis to identify appropriate sites for solar energy development, including the Municipal Land Suitability Tool process (T. Lee, Sanderson, Greenaway, & Kinas, 2020). Wetlands should be included as areas where development is discouraged.

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Appendix

Appendix I: Summary of literature reviewed.

Document type	Reference	Summary
Publication - peer reviewed	G. Exley et al., “Scientific and stakeholder evidence-based assessment: Ecosystem response to floating solar photovoltaics and implications for sustainability” Renew. Sustain. Energy Rev., vol. 152: 111639, 2021, doi: 10.1016/j.rser.2021.111639.	This paper systematically reviewed existing literature and gathered stakeholder expertise through an international survey and workshop. It summarized existing knowledge on how floating solar photovoltaics interact with hosting water bodies and the implications for ecosystem function. Floating solar photovoltaics (FPV) are increasing worldwide, but there is little scientific evidence on their effects on water bodies, which could have implications on ecosystem services. Through existing knowledge and stakeholder expertise, evidence indicated that floating solar arrays on water bodies pose a range of potential physical, chemical, and biological effects. These are largely driven by changes in light attenuation, water temperatures and water movement. Findings highlight the critical need for research to enhance understanding how FPVs affect water bodies, and the need for more monitoring of FPV installations. Monitoring of water chemistry is a priority as stakeholders perceived this as the greatest threat. Design of FPVs can and should be adapted to specific location and anticipated ecological impacts.
Publication - Peer Reviewed	M. Grippo, J. W. Hayse, and B. L. O’Connor, “Solar Energy Development and Aquatic Ecosystems in the Southwestern United States: Potential Impacts, Mitigation, and Research Needs” Environ. Manage., vol. 55, no. 1, pp. 244–256, 2015, doi: 10.1007/s00267-014-0384-x.	This paper reviews the potential effects, mitigation and research needs of utility-scale solar energy development on aquatic habitat and associated biological communities, with particular emphasis on intermittent (seasonally dry stream, especially during times of low rainfall or high heat) and ephemeral waters. States with the greatest potential for impacts to aquatic habitat are concerned with the loss, fragmentation, or prolonged drying of ephemeral water bodies and drainage networks resulting from the loss of desert washes within the construction footprint of solar facilities. Accidental release of contaminants, application of dust suppressants, and increased sedimentation could also degrade water quality. The primary means to reduce impacts to aquatic habitats is to avoid construction activity near perennial and intermittent surface waters, following by measures to minimize erosion, sedimentation, and contaminants. It concludes that significant data gaps make solar facility impact assessment and mitigation difficult.

Publication - peer reviewed	K. Kosciuch, D. Riser-Espinoza, M. Gerringer, and W. Erickson, “A summary of bird mortality at photovoltaic utility scale solar facilities in the Southwestern U.S.” PLoS One, vol. 15, no. 4, pp. 1–21, 2020, doi: 10.1371/journal.pone.0232034.	This paper synthesized results from bird mortality monitoring studies at 10 PV solar facilities across 13 years in California and Nevada. It found only two papers in the peer-reviewed literature that present mortality monitoring at utility scale PV facilities. They found variability in the distribution of avian orders and species among and within Bird Conservation Regions and found that water-obligate birds occurred at 90% of site-years in the Sonoran and Mojave Deserts Bird Conservation Region. They found the cause of mortality could not be determined for about 61% of intact carcasses and about 54% of all carcasses were feather spots, introducing uncertainly into the interpretation of the fatality estimates. The average annual mortality estimate calculated for PV (high-end estimate of 2.49 birds per MW per year) is lower than reported by another study that included one PV facility. They provide a summary of mortalities in bird conservation regions where the facilities are located, and conclude that expanding solar development to a wider range of regions is limited by the locations of facilities with fatality monitoring data.
Publication - Peer Reviewed	E. Visser, V. Perold, S. Ralston-Paton, A. C. Cardenal, and P. G. Ryan, “Assessing the impacts of a utility-scale photovoltaic solar energy facility on birds in the Northern Cape, South Africa” Renew. Energy, vol. 133, pp. 1285–1294, 2019, doi: 10.1016/j.renene.2018.08.106.	This study reports how one of South Africa's largest PV facilities (96MW, 180 ha) has altered bird communities and assesses the risk of avian collision mortality. Bird species richness and density within the PV facility (38 species, 1.80 ± 0.50 birds /ha) tended to be lower than the boundary zone (50 species, 2.63 ± 0.86 birds /ha) and adjacent untransformed land (47 species, 2.57 ± 0.86 birds /ha). Only eight fatalities were detected during 3 months of survey of the solar field for bird carcasses and other signs of collisions. The extrapolated mortality for the facility was 435 birds per year. No threatened species were affected by the PV facility, but further data are required to better understand the risk of PV solar energy developments on birds.
Publication - Peer Reviewed	L. M. Cook and R. H. McCuen, “Hydrologic Response of Solar Farms” J. Hydrol. Eng., vol. 18, no. 5, pp. 536–541, 2013, doi: 10.1061/(asce)he.1943-5584.0000530.	This study simulated runoff under pre and post-panel installation conditions to determine the hydrologic effects of solar farms. They examine whether storm-water management is needed to control runoff volumes and rates. Modeling showed that the panels themselves did not have a significant effect on the runoff volumes, peaks, or times to peak. However, if ground cover under panels is gravel or bare, peak discharge may increase significantly with storm-water management required. In addition, the kinetic energy of the flow that drains from the panels was found to be greater than that of the rainfall, which could cause erosion at the base on the panels. It is recommended that grass beneath the panels be well maintained and/or a buffer strip be placed after the most downgradient row of panels.

Publication - Peer Reviewed	G. Exley, A. Armstrong, T. Page, and I. D. Jones, “Floating photovoltaics could mitigate climate change impacts on water body temperature and stratification” Sol. Energy, vol. 219, no. March, pp. 24–33, 2021, doi: 10.1016/j.solener.2021.01.076.	To better understand how floating solar photovoltaics affect water temperature and FPV stratification by both sheltering the water's surface from wind and limiting the solar radiation reaching the water column. To overcome this knowledge gap, they modeled the effects of FPV-induced changes in wind speed and solar radiation on lake thermal structure using the one-dimensional, process-based MyLake model. Depending on how they are used, FPV have the potential to mitigate some of the impacts of climate change on water bodies and could be a useful tool for area managers to mitigate changes to water quality. Conversely, FPV installations could induce deleterious impacts on standing water ecosystems. They conclude that little is known about the impacts of floating solar, so projects should be individually assessed.
Publication - Peer Reviewed	M. K. H. Rabaia et al., “Environmental impacts of solar energy systems: A review” Sci. Total Environ., vol. 754, p. 141989, 2021, doi: 10.1016/j.scitotenv.2020.141989.	This paper discusses the adverse environmental impacts of several commercial and emerging solar energy systems at both small and utility scales. Their approach follows all stages, from design, manufacturing, materials, construction/installation throughout the operational lifetime and decommissioning. There are some health and environmental impacts from the actual manufacturing of solar panels, as small quantities of harmful and flammable materials are used. They also consider energy consumption due to the transportation, installation, and disposal of PV modules among other harmful impacts. They identify concerns from water usage for construction, dust control and cooling, land resources and erosion from vegetation removal, land leveling, soil compaction, construction of roads, etc. Further, soil erosion decreases availability of soil resources that leads to biodiversity loss and can impede vegetation recovery. Most effects are based on scientific reports and hypothetical scenarios without actual field measurements.
Publication - Peer Reviewed	T. A. Hamed and A. Alshare, “Environmental Impact of Solar and Wind energy-A Review” J. Sustain. Dev. Energy, Water Environ. Syst., vol. 10, no. 2, pp. 1–23, 2022, doi: 10.13044/j.sdewes.d9.0387.	This literature review summarizes the environmental impact of solar and wind energy systems from the perspective of land use, water consumption, biodiversity impacts, visual and noise effects, human health, and microclimate effects.
Publication - Peer Reviewed	A. Dhar, M. A. Naeth, P. D. Jennings, and M. Gamal El-Din, “Perspectives on environmental impacts and a land reclamation strategy for solar and wind energy systems” Sci. Total Environ., vol. 718, p. 134602, 2020, doi: 10.1016/j.scitotenv.2019.134602.	This literature review provides current perspectives on environmental issues associated with solar and wind energy development, strategies to mitigate environmental impacts, and potential reclamation practices to solar and wind energy planners and developers. The major environmental drawback of solar and wind energy plants are: bird mortality, biodiversity and habitat loss, noise, visual impact, and hazardous chemicals used in solar panels. Available mitigation measures to minimize these adverse environmental impacts and appropriate reclamation are discussed.

Publication - Peer Reviewed	R. R. Hernandez et al., “Environmental impacts of utility-scale solar energy” Renew. Sustain. Energy Rev., vol. 29, no. November 2017, pp. 766–779, 2014, doi: 10.1016/j.rser.2013.08.041.	This paper synthesized literature across numerous disciplines to understand the direct and indirect environmental impacts—both beneficial and adverse—of utility-scale solar energy (USSE) development, including impacts on biodiversity, land use and landcover change, soils, water resources, and human health.
Publication - peer reviewed	R. C. Rooney, O. Royall, D. T. Robinson, D. Cobbaert, M. Trites-Russel, and M. Wilson, “Evaluating the development and use of a rapid wetland assessment tool (ABWRET-A) in policy implementation in Alberta, Canada” Environ. Sci. Policy, vol. 136, pp. 575–587, 2022, doi: https://doi.org/10.1016/j.envsci.2022.07.020.	The functional value of over 2000 wetlands targeted for loss was compared to the pool of over 200 wetlands used to calibrate ABWRET-A and to the general population of wetlands in Alberta's settled region. The purpose is to assess the application of the ABWRET-A tool is supporting achievement of Alberta’s wetland policy objectives. They found statistically significant biases in the selection of wetland used for ABWRET-A calibration. Selected wetlands are not representative of the provincial inventory because those targeted for permitted loss are differ in size, distance to nearest road, type, and permanence class. Further, it appears this bias in selection affects the wetland scoring.
Publication - Peer Reviewed	M. Bošnjaković and V. Tadijanović, “Environment impact of a concentrated solar power plant” Teh. Glas., vol. 13, no. 1, pp. 68–74, 2019, doi: 10.31803/tg-20180911085644.	This paper analyses the effect of concentrated solar power technology on the environment in terms of water consumption, land use, waste heat, gas emissions, pollutants (including leakage of heat transfer fluid through pipelines and tanks), effects on flora and fauna, noise, and visual obstruction. The effects on the environment depend on whether thermal energy storage is included in the plant. Water is mainly used for cooling the system, but also for cleaning the mirror’s surface. To reduce water consumption, other cooling technologies (e.g., air cooling) are being developed. The available literature data show large variation in the plant size, geographic location, and applied technology.
Publication - Peer Reviewed	R. Kihslinger, C. Libre, K. Ma, E. Okuno, and R. C. Gardner, “In-Lieu Fee Mitigation: Review of Program Instruments and Implementation Across the Country” SSRN Electron. J., no. June, 2020, doi: 10.2139/ssrn.3619484.	This comprehensive report outlines the range of practice in ILF mitigation and describes innovative approaches across the United States. They report on the development of effective mitigation programs that enhance the capacity of state/local/tribal governments and others to develop or oversee ILF programs. They cite a broad survey of trends and lessons learned with regards to how program sponsors are executing ILF compensatory mitigation. They discuss broad trends and lessons learned in program administration, watershed approach, service areas, credits, feeds, mitigation projects, financial assurances, project monitoring, long-term management, data management, and audits.
Publication - Peer Reviewed	G. A. Barron-Gafford, R. L. Minor, N. A. Allen, A. D. Cronin, A. E. Brooks, and M. A. Pavao-Zuckerman, “The photovoltaic heat island effect: Larger solar power plants increase local temperatures” Sci. Rep., vol. 6, no. September, pp. 1–7, 2016, doi: 10.1038/srep35070.	This study monitored the growing concern that PV installations may cause a “heat island” (PVHI) effect at three sites that represented a natural desert ecosystem, a traditional built environment (parking lot surrounded by commercial buildings), and a PV power plant. They found that temperatures over the PV plant were regularly 3–4 °C warmer than wildlands at night, which is in direct contrast to other studies based on models that suggested that PV systems should decrease ambient temperatures.

Publication - Peer Reviewed	A. M. Broadbent, E. S. Krayenhoff, M. Georgescu, and D. J. Sailor, “The observed effects of utility-scale photovoltaics on near-surface air temperature and energy balance” J. Appl. Meteorol. Climatol., vol. 58, no. 5, pp. 989–1006, 2019, doi: 10.1175/JAMC-D-18-0271.1.	This study presents data from two eddy covariance observational towers, placed within and adjacent to a utility-scale PV array in southern Arizona. Average daily maximum 1.5 m air temperature at the PV array was 1.38 °C warmer than the reference (i.e., non-PV) site, whereas no significant difference in 1.5 m nocturnal air temperature was observed. They demonstrate the importance of targeted observational campaigns to inform process-based understanding associated with PV systems. This study further establishes a basis for observationally based PV energy balance models that may be used to examine climatic effects due to large-scale deployment.
Publication - Peer Reviewed	A. G. Dolezal, J. Torres, and M. E. O’Neal, “Can Solar Energy Fuel Pollinator Conservation?” Environ. Entomol., vol. 50, no. 4, pp. 757–761, 2021, doi: 10.1093/ee/nvab041.	This paper summarized key findings from ecology, bee conservation, and experience working with members of the solar industry. They suggest that the addition of native, perennial flowering vegetation will promote wild bee conservation and more sustainable honey beekeeping. They note a need for oversight and future research to avoid misapplication of the promising practice of incorporating pollinator-friendly habitat with solar energy production. Best practices for implementation are discussed.
Publication - commentary	C. Y. Lebel, “Solar and Stormwater: Plan Better to Avoid Me” Nat. Resour. Environ., vol. 34, no. 3, pp. 50–52, 2020.	This is a commentary piece that cautions of stormwater pollution risks from solar energy development. The author notes that stormwater discharge is of great concern during solar array installation and can cause pollution of waterways from erosion and sediments. The National Pollutant Discharge Elimination System (NPDES) construction general permit (CGP) requires the development of a Stormwater Pollution Prevention Plan (SWPPP). The author identifies Pennsylvania, Massachusetts, and Connecticut as jurisdictions attempting to address this issue.
Publication - commentary	R. M. Almeida et al., “Floating solar power: evaluate trade-offs,” Nature, vol. 606, 2022.	Based on expert opinion, this commentary paper discuss the potential environmental and social trade offs of floating solar power. The benefits of floating solar arrays on reservoirs include cooling effect of water on the panels, reduced evaporation (good for irrigation, drinking water, hydropower), benefits of floating solar on hydroelectric reservoirs (using existing grid infrastructure, addresses the twin challenges of providing energy when sunlight is weak and storing it as potential energy in reservoirs when solar-power production is high). Some reservoirs produce methane from decaying submerged plant matter, but floating solar panels covering just over just 2% of the water surface can double the energy production, therefore halving the carbon intensity. However, they note that trade-offs between the expansion of "floatovoltaics" and environmental, social, and economic goals remain largely unexplored in both concept and practice, as even artificial reservoirs can provide habitat. An interesting note: if Canada covered only about 5% of reservoirs with floating solar, it would be enough to satisfy its solar-energy needs. Can increase water temperature when over half the water body is covered. Shading could have cascading effects (could be positive or negative), but effects are largely unknown and likely dependent on how much of surface is covered.

Report	Vermont Department of Environmental Conservation, “Solar Development in Agricultural Wetlands” no. December 2021.	This report describes short term monitoring of five sites with solar development in wet meadow type wetlands. Monitoring included vegetation, soils, hydrology (qualitative), and other physical data. The study will continue and will inform policy, BMPs, and permitting requirements for applications to install solar panels in wetlands previously used for agriculture. The most significant factor affecting wetland condition, regardless of the presence of solar panels, was found to be the mowing regime. Wetlands with solar panels tended to have higher condition scores, as measured by plant diversity, than hayfields. Frequently mowed wetlands are impaired, whereas a single mowing in late summer or fall (successional meadow) often results in higher condition than a hayfield. However, if a monoculture of reed canary grass is present, this usually resulted in lower wetland quality than a more frequently mowed wetland where reed canary grass is less dense. Measures to reduce soil compaction during construction or mowing appear to result in better wetland condition. While soil chemistry does not appear to be significantly different between wet hayfields and solar arrays, and water nutrients were not assessed in this study, a conversion from hayfield to a solar farm does mean less manure spreading or other fertilization, which could potentially lead to better water quality.
Report	Vermont Legislature Solar Siting Task Force, “Solar Siting Task Force Report” pp. 1–20, 2016.	This is a report of the design, siting, and regulatory review of solar electric generation facilities. It describes proposed legislation with the rationale for each proposal and makes recommendations in its Support Development and Implementation of Multi-Agency Proposal. An opportunity exists to provide incentives for farmers and landowners to place solar on prior converted wetland soils where there is currently little incentive. AAFM and ANR are developing a proposal to incentivize the siting of solar generation on certain operating farms in locations that will improve water quality and provide a financial incentive to farmers to take these lands out of production. This proposal could be a win-win-win for the farm, for water quality, and for renewable energy generation. The Task Force encourages AAFM and ANR to continue their work toward development of a proposal for consideration by the Legislature.
Report	P. Adamus, “Manual for the Wetland Ecosystem Services Protocol for the United States (WESPUS)” 2011.	A manual on how to use the Wetland Ecosystem Services Protocol for the United States (WESPUS). This is a standardized method intended for use in rapidly assessing ecosystem services (functions and values) of all wetland types throughout temperate North America. It assesses these services primarily at the scale of an individual wetland rather than across large landscapes. However, WESPUS considers many landscape factors, especially as they relate to the values of a wetland’s functions. It automatically generates scores intended to reflect a wetland’s ability to support the following functions: water storage and delay, sediment retention and stabilization, phosphorus retention, nitrate removal and retention, thermoregulation, carbon sequestration, organic matter export, pollinator habitat, aquatic invertebrate habitat, anadromous fish habitat, non-anadromous fish habitat, amphibian and reptile habitat, waterbird feeding habitat, waterbird nesting habitat, songbird, raptor and mammal habitat, pollinator habitat, and native plant diversity.

Report	BC Wildlife Federation, “Wetland ecosystem services protocol report,” 2021.	Report outlining the use of WESP, a standardized and regionally specific tool to support decision makers by allowing the comparison, ranking, and prioritization of wetlands based on their functions and benefits of interest. Before the tool can be applied at the project level, it must be calibrated with a baseline dataset of wetlands that approximate the relative performance of wetland functions within a region. Once the calibration process is complete, the tool will be available for trained technicians to assess wetlands through 60 field-based questions and 50 office-based GIS questions. As of 2022, the Skeena region has a completed calibration data set, and the Georgia Depression, Southern Interior Mountains, and Boreal and Taiga Plains ecoprovinces were partially complete.
Report	H. M. Hartmann et al., “Understanding Emerging Impacts and Requirements Related to Utility-Scale Solar Development” 2016.	This is a multi-stakeholder assessment including federal and state agencies, industry, NGOs, and academia. An expanding utility scale solar development industry presents issues and challenges related to environmental and human impact. This report discusses novel approaches for addressing these issues that have been identified by a multi-stakeholder collaborative group. It considers how to minimize potential impacts through better siting of solar projects, whether on previously used lands such as formerly contaminated sites or using tools such as ecological landscape assessments and cultural heritage values and risk assessments that assemble regional-scale models of the distribution of sensitive resources. The report concludes that approaches to address emerging impacts of utility scale solar energy development should be developed jointly by regulators, industry, and other stakeholders.
Report	Southern Environmental Law Center, “The Environmental Review of Solar Farms in the Southeast U.S. - Maximizing Benefits & Minimizing Impacts to Drive Smart, Sustainable Development of Solar Power” p. 18, 2017, [Online]. Available: https://www.southernenvironment.org/uploads/words_docs/Solar_EnvReviewProcess_SitingSolar_Final.pdf.	This document reviews relevant policy for solar farm approval in the southeast United States. It provides an overview of the Environmental Review Processes and examples of best practices that developers are embracing to maximize benefits and minimize environmental effects. Specifically relevant to wetlands, the document recommends that developers should enforce a protective buffer around wetland areas to ensure wetland protection and that developers consider alternatives to protect wetland vital functions when developing solar projects. Key mitigations are minimizing soil disturbance associated with moving trees, stumps, brush, and other unwanted vegetation near wetland areas; limiting erosion, overland flow, and runoff that could impact wetlands; preventing disposal or storage of logs or logging debris in areas adjacent to water bodies to protect water quality, and maintaining the natural contour of the site and ensuring that activities do not immediately or gradually convert the wetland to a non-wetland.

Report	J. Mason, I. Molina, A. Ziegler, and S. Zuckerman, "Literature Review of Solar in Wetlands" 2016.	This report explores the relationship between solar photovoltaic projects on wetland ecosystems and the local community, with a focus on wet meadows. Recommendations are provided to assist the Watershed Management Division of the Vermont Department of Environmental Conservation in making permitting decisions. Many of the fields where solar arrays were being built were old hay fields. If these fields were left uncut, they would turn into wet or shrub meadows. It was argued that if these fields were not bought by solar developers, they would continue to be used as farmland, a more intensive practice than solar. Impacts to wetlands from solar development can occur due to lengthy (years) construction as well as decreased light reaching soil surface resulting in low plant productivity and potentially reduced carbon sequestration. However, conflicting information suggests that former agriculture land benefits from solar installations by providing a regenerative period for vegetation and soils and thus improving carbon storage. Controlling vegetation through mechanical and chemical techniques causes disturbance, damages vegetation communities and can create potential for contamination from pesticides. The report references a short-term Vermont study that showed no significant decrease in vegetative coverage or species richness under panels, and no observed secondary effects on wetland parameters.
Report	Arrowwood Environmental and Fitzgerald Environmental, "Literature Review of Monitoring Methodology and Wetland Impacts from Solar Facilities Literature Review of Monitoring Methodology and Wetland Impacts from Solar Facilities" 2018.	This paper reviews the current scientific literature on topics related to solar development in agricultural wetlands. It identifies the scope of scientific research that has been conducted and reviews conclusions on the effects of solar development on wetland function. The authors found no published works that directly address the potential impacts of solar facilities on wetland function and found that most literature focuses on broad impacts—from panel production, greenhouse gas emissions, energy payback time, and comparisons with traditional energy sources.
Report	J. Macknick, C. Lee, G. Mosey, and J. Melius, "Solar development on contaminated and disturbed lands" Sol. Energy Sites Considerations Areas Veg. or Contam. Disturb. Lands, no. December, pp. 23–83, 2014.	A significant amount of land classified as contaminated and disturbed across the United States has the potential to host developments of utility-scale solar power. This report examines the prospect of developing utility and commercial-scale concentrated solar power (CSP) and solar photovoltaics (PV) technologies on degraded and environmentally contaminated lands. The potential for solar development on contaminated and disturbed lands was assessed and for the largest and highest solar resource sites, the economic impacts and feasibility were evaluated.
Report	US Department of Energy, "Solar Impacts on Wildlife and Ecosystems" no. November 2021.	This document was developed as a response to a request for information on solar trends and siting, species and habitat impacts, avoidance, mitigation and monitoring, and resources needed. It summarizes feedback from 43 respondents, including representatives from the solar industry, the electric utility industry, research institutes, conservation and environmental non-profits, and local, state, and federal governments.
Report	R. Kauffman, Here comes the sun: solar law in Alberta, no. August. 2021.	This report by the Environmental Law Centre provides Alberta law and policy context of solar energy development. The report is organized into four parts: Part 1 highlights the relevance of solar energy to meet energy needs and mitigate greenhouse gas emissions, Part 2 identifies the relevant regulatory framework in Alberta, Part 3 highlights select jurisdictional approaches that

		could be applied to Alberta to increase solar energy production, and Part 4 identifies policy and regularly recommendations to strengthen the solar industry in Alberta.

Appendix II: Summary table of wetland policies and permitting requirements

State/Province	Wetland Policy	Tools and procedures to evaluate wetland function or value	Wetland replacement and/or compensation	Solar-specific policies and procedures
Alberta	Alberta Wetland Policy: • Applies to all natural and restored natural wetlands, as well as those constructed for wetland replacement. • Goal is to conserve, restore, protect, and manage Alberta's wetlands through flexible management that considers environmental, social, and economic considerations. • Focuses on protecting wetlands of highest value, considering regional context, and conserving/restoring wetlands and their benefits where losses have been high. • Wetland value is assessed based on biodiversity and ecological health, water quality improvement, hydrologic function, human uses, and relative abundance. • Mitigation hierarchy of "avoid, mitigate, or replace". Replacement should be a last resort; however it is difficult to preclude wetland loss on private land.	Alberta Wetland Rapid Evaluation Tool – Actual (ABWRET-A): combines onsite observations and offsite spatial data to estimate value relative to other wetlands. The tool evaluates a suite of wetland functions such as surface water storage, stream flow support, and plant and wildlife habitats using wetland function indicators. Results must be obtained and attached to a Wetland Assessment and Impact Report (WAIR), required for most activities that may impact a wetland. Includes a field component that must be completed during the growing season. Alberta Wetland Rapid Evaluation Tool – Desktop (ABRET-D): offset spatial data used to estimate wetland value required for a Wetland Assessment and Impact Form (WAIF), which is used in place of a WAIR for short-term and eligible low-risk activities. These activities typically follow standard mitigation techniques.	Wetlands will be replaced type-for-type; where this is not achievable, seek to replace wetland value. It is preferred that replacement take place in the area of original wetland loss. Can be an *in lieu* fee payment or permittee-responsible replacement. *In lieu* fees can be used for restorative replacement (e.g., restoration, enhancement, or construction) or non-restorative (e.g., advancing wetland science and wetland management). ABWRET values (A-D) are used to determine required replacement ratios and costs when avoidance is not possible. Ratios are determined with a matrix. Ratios as high as 8:1 (replacing a high value wetland with lower values) but as low as 0.125:1 (replacing a low value wetland with higher value). Midpoint ratio is 3:1.	Wildlife Directive for Alberta Solar Energy Projects: Provides direction for minimizing effects to wildlife and wildlife habitat during the siting, construction, and operational phases of solar energy projects. *Standard 100.1.9 states "the solar energy project* ***must not occur within 100 m of any wetland class*** *(bog, fen, marsh, shallow open water, swamp) identified in Table 1 in the Alberta Wetland Classification System except for wetland classes with Water Permanence listed as Temporary."* Additional standards on setbacks and timing restrictions for wildlife and wildlife features detected at solar energy projects are described in the directives (Government of Alberta, 2017). Alberta Utility Commission (AUC) Rule 007 requires solar applications demonstrate environmental concerns are addressed. Proponents must obtain a Renewable Referral Report from an AEP wildlife biologist and submit with their application (small-scale projects less than 1 MW excluded). The Wildlife Directive assists the AEP wildlife biologist in

	• Proponent is responsible for demonstrating that alternative projects, designs and/or sites have been thoroughly considered and justifiably ruled out. • Monitoring may be required to evaluate minimization efforts and is the responsibility of the proponent. • Permanent loss of a wetland or portion will require wetland replacement based on wetland area lost and relative value of that area. Alberta Water Act • Primary legislative basis for implementing the Wetland Policy. • Promote the conservation and management of water while recognizing the need for economic growth and prosperity and flexible management. • Regulates and enforces actions that affect water and water-use management, the aquatic environment, fish habitat protection practices, and storm water management. • Water Act approvals are required when an activity will affect a water body or when the works will divert and use surface or groundwater.		Current *in lieu* fee is ~$20,000 CAD per hectare (based on D value wetland), then ratio applied. Fee varies by natural region and basin and on the average cost of wetland restoration work, monitoring cost, an administrative fee, and the average value of land within the area of original loss.	providing consistent information submitted to the AUC.
California	Wetlands in California are protected by many federal and state laws, regulations and policies enforced by several agencies	California Rapid Assessment Method (CRAM) is a cost-effective rapid assessment method for monitoring and	Wetland compensatory mitigation is measured in units of one tenth of an acre,	This review did not identify solar-specific policy or procedures for wetlands.

	protecting wetland extent, water quality, wildlife and wildlife habitats, vegetation communities and beneficial uses. • No net loss of wetlands policy signed by executive order. • Cannot create any disturbance within a wetland boundary without pursuing permits for the impact and potentially compensatory mitigation. • The permitting process is time-consuming and complex. • A wetland delineation is required to show the true wetland extent, including vegetation types, high water mark, and saturated soil conditions. • Permits may be required from the California Department of Fish and Wildlife (dredging/filling of wetlands), U.S. Army Corps of Engineers (alteration of waters of the U.S.), California Coastal Commission (impacted wetlands within coastal zone), California State Water Resources Control Board (discharge or fill of wetlands), and Regional Water Quality Control Board (discharge into wetlands). • Activities of lower impact have a streamlined order of mitigation to incentivize proponents to avoid and mitigation to quickly obtain permits.	assessing the ecological conditions of California wetlands. It takes less than half a day to assess a wetland area and is designed to evaluate the condition of the wetland based on its landscape setting, hydrology, physical structure and biological structure. The methodology is standardized over seven wetland types. CRAM is used to incorporate condition data into decision-making, protect existing wetlands and can be used alongside monitoring data to assess the performance of compensatory mitigation and restoration projects.	and it typically at a minimum of 1:1 replacement. The California Coastal Commission ratio (for coastal wetlands) is as high as 4:1 replacement. Prefers compensation through mitigation banks of *in lieu* fees within the same watersheds. If banks aren't available, they will allow permittee to build or restore within the same watershed. Compensation fees vary by the mitigation bank (established by the Army Corps of Engineers). However, it is typical that rarer wetlands, such as vernal pools, will be more expensive.	
Manitoba	Manitoba Sustainable Watersheds Act and Water Rights Act:	Manitoba Wetland Assessment Method is a tool that allows wetland professionals to rate the health of	Proposed loss of wetland benefits must be offset by compensation for lost wetland acres as required. Proponents can pay an	This review did not identify solar-specific policy or procedures for wetlands.

	• Registration process for lower-risk projects (minor culvert changes, wetland restoration, class 1–2 wetland drainage) and licensing process for higher-risk projects (class 3–5 wetland loss or alteration). • Approach based on mitigation hierarchy of "avoid, minimize, compensate". • Loss or alteration of Class 3 wetlands will require compensation. • License will generally not be issued for drainage of Class 4 (semi-permanent) and 5 (permanent) wetlands. • Proponents demonstrate use of mitigation process including how all options have been considered to avoid and minimize wetland impacts.	individual wetlands and results in a wetland health score. This health score is based on 12 functions that wetlands provide. Wetlands are scored as Exceptional, High, Moderate or Low. Developed by the Manitoba Habitat Heritage Corporation with Manitoba Sustainable Development	approved organization to restore or enhance wetlands or proponents can perform the restoration or enhancement themselves. • Fee is based on replacement ratio of 2:1 to restore, 3:1 to enhance, and 3:1 for permanent protection of an existing wetland. • Payment can be calculated by a formula (area impacted × 2 × $6,000) or based on price negotiated with an approved organization.	
Maine	The Natural Resources Protection Act: • Establishes that development activities may not unreasonably harm freshwater wetlands. • The accompanying Department rules, Chapter 310, <u>Wetlands and Waterbodies Protection</u>, interpret and further specify the provisions of the Act by requiring the avoidance of wetland impacts, minimization of impacts that cannot be avoided, and compensation for the loss of wetland function.	This review did not identify a standard wetland evaluation tool.	Uses a resource-dependent formula, that uses a base rate (calculated using estimates of regional construction and monitoring costs plus county unimproved land cost) and applies a resource multiplier (adjustment factor that reflects the significance of specific resources). The multipliers are: 2:1 for projects ≥ 20,000 square feet. 2:1 for areas of special significance (e.g., peatlands dominated by shrubs, sedges, and sphagnum moss, coastal wetlands, great ponds, and others).	<u>Guidance for Evaluating Wetland Conversion Impacts:</u> declares that the Department of Environmental Protection will require a functional assessment for all development projects, including solar, that involve freshwater wetland alterations of 15,000 square feet or more or 500 square feet or more of freshwater wetlands of special significance. These thresholds include the sum of both direct (e.g., fill) and indirect impacts (e.g., shading by solar panels). While the overall impact will be evaluated on a case-by-case basis as part of the application process, most cases will require compensation for the conversation of

			Wetland compensation fee = [Direct wetland impact/sq. ft. × (natural resource enhancement & restoration cost/sq. ft. + avg. assessed land valuation/sq. ft)] × resource multiplier. Additional fees are then added for impacts to uplands that affect aquatic organisms (e.g., vernal pool species). For example: Vernal pool compensation fee = (Direct wetland impacts within the Significant Vernal Pool habitat/sq. ft. × [natural resource enhancement & restoration cost/sq. ft. + avg. assessed land valuation/sq. ft)] × (resource multiplier of 2) + (Direct non-wetland impacts within the Significant Vernal Pool habitat/sq. ft. × avg. assessed land valuation/sq. ft.)	freshwater wetlands in excess of 15,000 square feet. This was prompted by an increase in solar applications that resulted in wetland type conversion. While the department previously saw wetland conversion, these were primarily in linear projects (e.g., transmission lines), and the amount converted tended to be small. Solar tends to be more concentrated and has the potential to affect large wetland areas (State of Maine Department of Environmental Protection, 2021).
Massachusetts	Massachusetts Wetland Protection Act: • Protects wetlands and the public interests (values) they serve, including flood control, prevention of pollution and storm damage, and protection of public and private water supplies, groundwater supply, fisheries, land containing shellfish, and wildlife habitat.	This review did not identify a standard wetland evaluation tool.	Compensatory mitigation to create, restore, or enhance wetlands can be made through *in lieu* fee payments within one of four service areas corresponding to a major bioregion. The state average is $13.84/sq. ft. which attempts to capture the full cost of restoring the resource, including cost of land, administration, construction,	MassDEP Wetlands Program Policy 17-1: Photovoltaic System Solar Array Review: Policy outlines the approach for reviewing ground-mounted solar photovoltaic systems in wetlands. It strongly encourages siting of solar on upland properties, and placement within jurisdictional wetlands is strongly discouraged. Placement within wetland buffer zones (100 ft) may be permissible with proper oversight. Alterations to resource areas include direct

	• The law protects not only wetlands, but other resource areas, such as land subject to flooding (100 year floodplains), the riverfront area (added by the Rivers Protection Act), and land under water bodies, waterways, salt ponds, fish runs, and the ocean. • A permit is required from the local conservation commission to "remove, fill, dredge, or alter" any wetland, floodplain, bank, land under a water body, or land within 100 feet of a wetland or 200 feet of a perennial stream or river. • The conservation commission ensures that proposed activities will not alter resource areas and the public interests they provide by reviewing projects on a case-by-case basis. • Prohibits most destruction of wetlands and naturally vegetated riverfront areas and requires replacement of flood storage loss when floodplains are filled. • The permit, or order of conditions, will either approve the project with special conditions that will protect the public interests or deny the project if impacts to resource areas cannot be avoided or mitigated. • Only 5000 square feet of alteration is allowed in Bordering Vegetated		monitoring and contingency amount for corrective actions. A minimum of 1:1 mitigation ratio is generally applied, with up to 15:1 depending on resource category, form of mitigation and project. The state's Department of Fish and Game is the Army Corps approved sponsor of the program.	impacts associated with constructing solar arrays as well as indirect wetland alterations resulting from either decreased sunlight from panel shading or increased solar exposure from the selective cutting of tree canopies. Highlights information required to document avoidance (e.g., discussion on location, panel size reduction, spacing, or use of more efficient panels), minimization (e.g., measures to minimize vegetation removal) and mitigation (e.g., monitoring plans to evaluate success), and recommendations on stormwater management measures (Commonwealth of Massachusetts Department of Environmental Protection, 2017). Guidance on Agriculture and Solar Energy Under the Wetlands Protection Act and the Solar Massachusetts Renewable Target (SMART) Program: The SMART program provides financial incentives to farmers for the development of new solar photovoltaic energy sources. This document provides regulatory guidance on the applicability of the Wetlands Protection Act for dual-use solar systems. A permit may be granted if the project follows BMPs including (1) limiting the capacity of the system to no more than 2 MW; (2) a requirement that the lower edge of the panel be at least 8 feet above the ground for a fixed tilt panel system, or 10 feet at horizontal position for tracking systems;

	Wetlands, providing at least 1:1 replacement. A majority of the cities and towns in Massachusetts have their own wetlands ordinances/bylaws that provide protections to wetlands over and above state law. Inland and Coastal Wetlands Restriction Acts: • Permanent restriction orders have been placed on selected wetlands in over 50 communities. • Restriction orders have been recorded at the Registries of Deeds in the counties where the properties are located to inform future landowners of the restriction.			(3) designed so that the maximum sunlight reduction due to shading from the panels on any square foot of land under the dual-use system may be no more than 50%; (4) designed to optimize a balance between electrical generation and agricultural production, and (5) continuous agricultural production over the 20-year SMART program period. (Commonwealth of Massachusetts Department of Environmental Protection, 2018) Floating Solar Photovoltaic Projects Frequently Asked Questions – FAQs: Wetlands Protection document provides answers to questions and more about wetland impacts from floating solar projects for applicants, conservation commissions, and the public (Commonwealth of Massachusetts Department of Environmental Protection, n.d.).
Minnesota	Wetland Conservation Act: • Regulates activities within wetlands that are *not* public waters (of which Department of Natural Resources has regulatory jurisdiction). • Wetland replacement required for unavoidable impacts that do not qualify for exemption or no-loss provision. • Focuses on whether a project results in a significant alteration of a wetland's function of value. Public Waters Work Permit Program:	WCA is administered by local government units (LGU) with oversight by the Minnesota Board of Water and Soil Resources. Each LGU has a Technical Evaluation Panel (TEP) to provide technical expertise and recommendations on WCA compliance. Minnesota is currently working on the development of a new rapid assessment tool for wetlands. The method will be trialed in 2023.	Wetland replacement must restore the public value of wetlands lost. Replacement ratios favor in-kind (similar type and function) wetland replacements and may occur at more than one location. **Wetland banking program** includes private wetland banks that have "credits" used to offset authorized wetland effects. The replacement ratio is 2.5 credits for each acre of wetland affected, except in greater than 80% areas or on agricultural land; the ratio here is 1.5 credits for each acre of wetland affected. The ratio can be	Guidance on Reviewing Solar Panel Projects for Wetland Conservation Act (WCA) Compliance May 14, 2021: This document suggests an approach to evaluate projects for WCA compliance when they involve solar panel installations on posts or pilings. The local WCA TEP must evaluate wetland function prior to the project and anticipated functioning after project completion. There is no quantitative method or score that results in a specific decision (Minnesota Board of Water and Soil Resources, 2021).

	• Regulates water development activities below the ordinary high-water level (OHWL) in public waters and public wetlands (wetlands not included in public waters that are ≥10 or more acres in unincorporated areas or ≥2.5 ac. in incorporated areas). • Addresses activities including filling, excavation, shore protection, bridges and culverts, structures, docks, marinas, water-level controls, dredging, and dams. Additionally, some local governments and watershed districts in Minnesota have adopted their own wetland and wetland buffer ordinances.		reduced when credits purchased are within the same bank service area of lost wetland or if replacement is mostly in-kind. A private market determines the credit price. Cost of credits in 2022 ranged from an average of $13,196.18 to $99,121.72 depending on service area.	
New Jersey	The Freshwater Wetlands Protection Act (FWPA): • Provides a permitting program that regulates all activities in freshwater wetlands, as well as in "transition areas" or upland buffers adjacent to wetlands. • Transition areas are the 150 ft buffer from a freshwater wetland. • Any state issued permits also satisfies federal requirements. However, there is a region (Hackensack Meadowlands Development Commission) that remains under federal jurisdiction. • Has provisions for approved forestry and agricultural activities, as well as	This review did not identify a standard wetland evaluation tool.	New Jersey has an *in lieu* fee mitigation program, in which a proponent can pay a fee to a wetland mitigation fund that will be used to fund mitigation projects. The monetary contributions, as well as the number of credits generated from a project, are determined on a case-by-case basis. Projects will be funded primarily within the same water region where the impact occurs. A secondary service area (adjacent water region) will be considered if after three years, no credits are available in the primary service area.	Solar Siting Analysis Update was released by the New Jersey Department of Environmental Protection's (NJDEP) Bureau of Climate Change and Clean Energy in 2017. It identified sites where the department would encourage or discourage solar installation. Lands were identified as preferred, not-preferred, or indeterminate. Not-preferred lands were largely characterized as forests, wetlands, agricultural lands, and open space that the Department sets out to protect and preserve, and totaled 63% of land (New Jersey Department of Environmental Protection, 2017).

	the production of salt, hay and mosquito control activities. • Wetland mitigation is required for some general permits and when an applicant receives an individual permit. • There are seven methods for providing mitigation for permanent disturbance: restoration, creation, enhancement, preservation, credit purchase, *in lieu* fee, and land donation. The Wetlands Act of 1970: • Requires permits for activities proposed within tidal and estuarine wetlands. All wetlands to be protected are shown on regulatory maps. Unmapped wetland areas are regulated by the FWPA.		The state requires a replacement ratio of 2:1 for creation/restoration and at higher rates for enhancement and preservation of wetlands. For coastal wetlands the ratio may vary between 1:1 and 2:1 depending on the resource impacted (New Jersey Department of Environmental Protection, 1989).	
Nova Scotia	Nova Scotia Wetland Conservation Policy: • Comprehensive policy to ensure the benefits wetlands provide are maintained. • Identifies the services and functions wetlands provides. • Objective of no loss in Wetlands of Special Significance (WSS) and the goal of preventing net loss in area and function for other wetlands. • Objective to encourage use of buffers to better ensure integrity of wetlands adjacent to development.	Wetland Ecosystem Service Protocol for Atlantic Canada (WESP-AC) is a standardized method for rapidly assessing natural wetland functions and benefits in tidal and non-tidal wetlands in Atlantic Canada. It has been regionally calibrated for each Atlantic province and has both a field and office component. Assessment variables then entered into a computer model that uses a logic-based algorithm to generate scores and ratings for listed attributes. An interpretive tool takes information inputted into the model to provide a classification based	Compensation for wetland loss include replacement ratios of 2:1 for restoration or expansion, ≥3:1 for enhancement and 4:1 for creation due to risk involved in success. Compensation fees depend on project complexity and location and can cost around $30,000 to $10,000 per hectare. Additional types of compensation may be approved, typically alongside restoration, enhancement, or creation efforts of at least 1:1 replacement ratio, including:	This review did not identify solar-specific policy or procedures for wetlands.

	• Applies to all wetlands with some exceptions, including wetlands in agricultural drainage ditches, under 100 m^2, constructed stormwater wetlands.
	• Policy does not support approvals to alterations of WSS unless deemed necessary for public function. WSS include:
	  ○ all salt marshes
	  ○ wetlands within Ramsar sites, Provincial Wildlife Area, Provincial Park, Nature Reserve, Wilderness Area, or private conservation lands
	  ○ intact or restored wetlands that are project sites under the North American Waterfowl Management Plan (NAWMP) and secured for conservation
	  ○ wetlands known to support at-risk species as designated under the federal Species at Risk Act ; or the Nova Scotia Endangered Species Act
	  ○ wetlands in designated protected water areas as described within Section 106 of the Environment Act
	• Follows mitigation sequence hierarchy of "avoid, minimize, compensate".
		on functionality and has the potential of identifying WSS (Nova Scotia Environment and Climate Change, n.d.).	• protecting existing wetland or adjacent buffers
			• constructing naturalized stormwater or wastewater retention wetlands
			• creating public access facilities and interpretive centres
			• publishing public education materials
			• funding research to support improved wetland policy	

Ontario	Provincial Policy Statement • Provides direction to municipalities on land use planning and development decisions. • Protects provincially significant wetlands and coastal wetlands and their adjacent areas from development except in very limited circumstances. • A provincially significant wetland is one that has high biological, social, hydrological, and special feature components, and has been designated as significant by the Ministry of Natural Resources and Forestry. Conservation Authorities Act • Regulations prohibit certain activities in and around wetlands without permission from a conservation authority. • Conservation authorities are responsible for issuing permits for activities that may impact wetlands and can require mitigation measures to minimize impacts to wetlands. Provincial land use plans • Provide additional guidance for wetlands. A Wetland Conservation Strategy for Ontario 2017–2030	Ontario Wetland Evaluation System defines, identifies, and measures wetland functions and values. It was created to inform Ontario's land use planning process. Wetlands are assessed based on their perceived value in maintaining natural processes (ecosystem values such as groundwater storage and habitat). They are also assessed on the benefits provided to society (human utility values such as flood damage prevention and improved water quality). The system ranks wetlands relative to one another to determine protection as "provincially significant" (Government of Ontario, n.d.).	While the Ontario government has assessed the creation of a wetland offsetting program, there is not currently a program in place.	Renewable Energy Approvals Regulation (under the Environmental Protection Act) Prohibits most activities associated with renewable energy projects from locating directly within provincially significant wetlands in southern Ontario and significant coastal wetlands, while enabling a risk-based approach to minor encroachments from infrastructure.

	• Describes Ontario's commitment to halt net loss of wetland area and function in southern Ontario by 2025 and by 2030 to have achieved an overall net gain in wetland area.			
Prince Edward Island	Environmental Protection Act Watercourse and Wetland Protection Regulations • Prohibits alteration of watercourses or wetlands without a license or a Watercourse or Wetland Activity Permit. • Prohibits alteration or disturbance of ground or soil within 15 meters of a watercourse or wetland boundary without a license of Buffer Zone Activity Permit. This, however, does not apply to cultivating an agricultural crop. • Applications screened to determine if it is a project or undertaking. If undertaking triggers an Environmental Impact Assessment. Wetland Policy for Prince Edward Island • Follows a policy of no net loss. • Requires proponent to provide compensation funding or conduct work to replace wetlands lost in the public interest. • Wetland replacement considers wetland function, area, type of wetland, geographic context, and time frame.	This review did not identify a standard wetland evaluation tool.	Preferred methods of compensation are wetland restoration and enhancement, with wetland creation also considered. Securement of a wetland alone is not normally considered adequate. Compensation can include the financing of wetland-related research and education. Functional losses should be restored in priority order of onsite, as close to the site as possible, or in the same ecosystem. They should occur in the same wetland type, or secondarily in another wetland type. Compensation ratios are justified based on the inherent uncertainty of replacing the loss of wetland functions, and may be greater than 1:1 replacement, depending on the degree of uncertainty. Compensation ratios should be negotiated both for wetlands directly and indirectly affected by the development In any mitigation package that is negotiated, monitoring must	This review did not identify solar-specific policy or procedures for wetlands. Prince Edward Island Watercourse, Wetland and Buffer Zone Activity Guidelines document provides information for the planning and designing of watercourse, wetlands, or buffer zone activities. It was developed with the intent of promoting/ensuring environmentally acceptable activities. The document notes that it is less expensive and more effective to prevent or minimize the impacts of an activity at the design stage, rather than trying to control or mitigate harmful effects of a poorly planned project (PEI Department of Communities Land and Environment, 2012).

	• Endorses a hierarchical approach, with avoidance as the top priority. • In the rare case where development on wetlands cannot be avoided entirely, such effects are reduced through minimization. • Compensation is a last resort and should only be considered for residual effects that were impossible to mitigate.		be included within both minimization and compensation activities.	
Saskatchewan	No wetland policy or setback requirements. Alterations to wetlands captured in the environmental assessment process. Environmental Assessment Act: • Requires the development proponent to conduct an Environmental Impact Assessment (EIA) and to submit an Environmental Impact Statement (EIS) for review and approval by the Minister of Environment. • Projects with minor or no impacts may be screened out. • Projects meeting definition for "development" may trigger additional studies as a part of the EIA process. • Projects that meet the definition of development include industrial, energy, mine, water management, waste management, and transportation. • Large-scale solar projects would likely meet the definition.	This review did not identify a standard wetland evaluation tool.	Compensation is determined on a case-by-case basis.	This review did not identify solar-specific policy or procedures for wetlands.

Vermont	Vermont Wetland Rules (VWR):
	• Regulates activities within significant wetlands and their buffers, with the goal of no net loss of wetlands and their functions.
	  o Significant wetlands are Class I and II wetlands, based on the significance of the functions and values they provide.
	  o Class I buffer = 100 ft; Class II buffer = 50 ft.
	• Burden of proof is on the applicant to show activity complies with WVR.
	• Mitigation sequencing: applicant must demonstrate, in the following order, that the activity:
	  o cannot practicably be located outside wetland or on another site
	  o has taken all practical measures to avoid adverse impacts, and
	  o is planned to minimize adverse impacts and has developed a plan for prompt restoration
	• Compensation is considered only when it is in full compliance and still results in adverse effect. Includes establishing new wetlands or enlarging an existing wetland boundary.
		The Wetlands Evaluation Form is used by State Wetland Ecologists to determine the functions and values of a wetland based on the VWR. It is not quantitative but identifies the 10 possible functions and values of a wetland as described in the VWR.
		
		Many wetlands are already presumed to be significant in the VWR if it is mapped on the Vermont Significant Wetland Inventory (VSWI) map, contiguous to a VSWI wetland, and meets the presumptions of significance listed in the VWR (e.g., same size as VSWI mapped wetlands, vernal pool, providing amphibian breeding habitat).
			Compensation may include payment of fees to a federal "*in lieu* fee" program or mitigation bank.
			
			Compensation is allowed for Class II wetlands only to reduce effects on protected functions that can be compensated.
			
			Compensation for Class I wetlands are only considered upon showing the adverse impacts are necessary for meeting a compelling need to protect public health or safety.
				While there are no policies specific to solar energy development, Vermont Wetland Rules are robust and cover solar energy activities that may adversely impact a significant wetland and its functions. Vermont Department of Environmental Conservation staff negotiate appropriate mitigation plans on a case-by-case basis and have compiled case studies to better understand the direct and indirect impacts to wetlands from solar energy developments.
				
				Keeping Solar Projects Wetland Friendly: Tips for identifying and protecting wetlands: Document that guides solar developments to minimize costs and avoid wetland violations. Any solar development activity occurring within a protected wetland or its 50 ft buffer requires a permit (Vermont Department of Environmental Conservation, 2015).

United States	There are many federal laws, regulations, and policies to protect wetlands in the United States, such as the Clean Water Act, Farm Bill, Rivers and Harbors Act,	The EPA's National Wetlands Monitoring Workgroup supports the concept of a Level 1, 2 and 3 approach to wetland monitoring. Level 1 is a landscape	Compensatory mitigation can include restoration, creation, enhancement and, in certain circumstances, preservation of	This review did not identify solar-specific policy or procedures for wetlands.

	Coastal Zone Management Act, and Executive Orders (Protection of Wetlands, Floodplain Management). Here, we focus on the Clean Water Act as administered by the U.S. Army Corps of Engineers (USACE) and the Environmental Protection Agency (EPA). Federal Clean Water Act • Section 404 requires a permit from the Army Corps of Engineers to discharge dredged or fill materials into certain wetlands. • No discharge of dredged or fill material will be permitted if a practicable alternative exists that is less damaging to the aquatic environment or if the nation's waters would be significantly degraded. • An applicant must show that steps have been taken to avoid impacts to wetlands, streams, and other aquatic resources; that potential impacts have been minimized; and that compensation will be provided for all remaining unavoidable impacts. • Section 401 provides water quality certification program intended to ensure dredging projects in wetlands do not result in a violation of state water quality standards.	assessment, level 2 is a rapid assessment, and level 3 is an intensive site assessment. Many states have their own level 2 rapid wetland assessments. Those that don't are able to use the USA Rapid Assessment Method (RAM) developed as part of the National Wetlands Condition Assessment (NWCA) (Stein et al., 2019). NWCA is a collaborative survey of wetlands examining the chemical, physical and biological integrity of wetlands through a set of commonly used and accepted indicators. Indicators were developed for vegetation, soil, hydrology, water chemistry, algae, and buffer, based on their utility in reflecting ecological condition of wetlands or key indicators of stress that may influence condition across broad national and regional scales. An example of level 3 is a Hydrogeomorphic Approach or Biological Assessment meant to give detailed information on how well a wetland is functioning. They can be used to certify that permits are maintaining water quality, strengthen water quality standards and evaluate the success of restoration (United States Environmental Protection Agency, 2022).	wetlands, streams, or other aquatic resources. The following three mechanisms can be used to provide compensatory mitigation: • mitigation banks • *in lieu* fee programs • permittee-responsible mitigation A regulatory *in lieu* fee and Bank Information Tracking System (RIBITS) was developed by the U.S. Army Corps of Engineers with support from Environmental Protection Agency and the U.S. Fish and Wildlife Service to provide better information on mitigation and conservation banking and *in lieu* fee programs across the country. The value of credits from a mitigation bank is determined by quantifying the wetland functions or acres restored or created.	

	• Recognizes states have the primary authority and responsibility for setting water quality standards. • Section 402 requires a National Pollutant Discharge Elimination System (NPDES) permit for a discharge of water (including wastewater and storm water) from a “point source” (a discrete conveyance such as a pipe, ditch, or channel) to any surface water body.			

Appendix III: Contacts and interview summaries

The table below outlines the jurisdictions contacted for interviews to better understand how they are responding to solar energy development on wetlands.

Date of correspondence	Contact information	Summary of correspondence	Key notes

22/02/2023	Zapata Courage
	
	District Wetland Ecologist,
	Vermont Department of Environmental Conservation, Watershed Management Division, Wetlands Program
	
	zapata.courage@vermont.gov
		• VT energy goals to be 75% renewable by 2032: many lessons learned on siting of solar every development over the last >10 years.
		• Current challenges:
		  ○ lack of accurate wetland mapping
		  ○ lack of understanding of wetland regulations from out-of-state developers
		  ○ private agricultural agreements with solar developers: Is this interfering with wetland conservation? Is solar development less impactful than ag production?
		  ○ effects are calculated by ground disturbance not actual coverage of area by panels
		  ○ no long-term studies on impact of solar to wetlands
		• Key concerns:
		  ○ vegetation removal to reduce shading/increase sunlight to panels
		  ○ potential conversion of wetland type
		  ○ potential change of use by wildlife (grassland birds, wildlife movement)
		  ○ may increase erosion risk and impact water quality
		  ○ potential reduction of functional buffers
		  ○ tie-ins to utility grid requires additional infrastructure that has potential to impact wetlands
		• Projects may trigger a federal Army Corps of Engineers permit, and they can charge a compensation fee serviced through Ducks Unlimited, calculated on a square-foot basis.
		• Fish and Wildlife compensations may additionally apply for certain species and may trigger mitigation and pre-construction monitoring.
			• Vermont has a robust solar industry to meet energy goals, and strong wetland protection rules that place the onus on developers.
			• Vermont Wetland Rules list 10 wetland services:
			  ○ Water storage, water quality protection, fish habitat, wildlife habitat, exemplary natural community, sensitive species, education and research, recreational value and economic benefits, open space and aesthetics, and erosion control.
			• Regulated Class I wetlands and their 100 ft buffer and Class II wetlands and their 50 ft buffer zone, activity must have no undue adverse effect on protected functions and values.
			• It is difficult for a solar company to demonstrate they are unable find an alternative location that avoids wetland impact in the State of Vermont; they do say “no” to applicants.
			• Mitigation requirements are site-specific and can vary widely, and can address key concerns of ground disturbance, erosion, vegetation removal.
			• The final report for a 5 year study looking at effects of solar panels in agricultural wet meadow type wetlands is expected to be completed winter 2023.
			  ○ Early results indicate that mowing regime may be the most significant factor affecting wetland condition regardless of the presence of solar panels, and wetlands with solar panels tended to score higher in condition as measured by plant diversity than hayfields.

		• Vermont DEC captured more activity than was triggered by the Army Corps. The Vermont permitting process is where they can specify site, mitigation, monitoring requirements. • The solar project's purpose must be clearly defined and valid to justify wetland impairment. For example, "providing solar energy to the state" is too broad and is not recommended. • The applicant must meet the burden of proof (following mitigation sequencing), to show that proposed activity in any Class I or II wetland or its buffer zone comply, and it will have no undue adverse effect on protected functions and values. • The applicant must demonstrate that the proposed activity cannot practicably be located outside the wetland/buffer or on another site owned or controlled by the applicant or reasonable available to satisfy the basic project purpose. Practicability is based on factors within the applicant's control and it is the applicant's responsibility to conduct due diligence for natural resource impacts when siting a project, including identification of other potential sites and/or alternative locations. • It is difficult for a solar company to demonstrate they are unable to find an alternative location in the State of Vermont, and they cannot have a purpose so narrowly defined that they can't avoid or minimize impacts. • Negotiate during permitting conversations. For example, an applicant wants to construct a 2 MW system, but can only ask for 1 MW due to site constraints to protect the wetland. ACOE can redefine the project purpose in broader terms. • Some impairment is not avoidable. For example, to avoid a development being landlocked, an access road may have to go through a wetland. In that case, a permit would require mitigation, such as a culvert to provide aquatic passage. • Mitigation requirements are determined case-by-case due to the variability in solar projects and sites. District wetland ecologists approve mitigation plans.	

		• Examples of requirements imposed at permitting: erosion control, shade management (cutting of trees/vegetation to maximize sunlight reaching panels—can allow only cutting tops of trees vs. entire tree, or only cutting trees over a certain height), plantings, invasive plant management at site, no-mow or reduced mow areas.
		• The goal is to avoid direct impacts and 10 of the wetland services identified by State of Vermont.
		• Good project siting is important (e.g., not developing on slope, keeping vegetation) and developers are supportive as proper siting can avoid costly issues and/or violations.
		• Some projects may trigger stormwater management needs (e.g., sites that have extensive access roads).
		• It is possible to have sites on prime agriculture land. This is regulated by the agriculture agency through VT Public Utility Commission (PUC) and may require compensation based on a ratio.
		• From notes on observations made at solar site visits:
		  ○ Top-dress cables: reduce ground impact and have cement bases on gravel-filled foundation minimized settling and helps with water infiltration and movement, contains rocks so they do not become embedded and scatter throughout area.
		  ○ Use the formula of three times the length of an object for placement of fencing, spacing between rows and tree clearing.
		  ○ Drip line under panels at midline, up to 2–3 inches deep. Potentially from ground disturbance with no matting or other conditions to minimize impact.
		  ○ Site maintained as lawn appears to handle runoff better. Panels at the site have a mounted fabric strip at midline: may help to disperse water, therefore less concentrated drip.
		  ○ No ice observed under panels, indicating drier conditions overall; buildup of snow and ice in front of panels, could this cause damming?	

02/03/2023	John Gallop Wetland Specialist, Nova Scotia Department of Environment and Climate Change John.Gallop@novascotia.ca	• Solar development remains new to Nova Scotia, from his understanding. He has only reviewed one alteration application for solar. • Currently trying to determine the best approach for wetland compensation, mitigations, etc. relative to solar and talking internally about this issue. • Internally discussed potentially developing some guidance for solar and wetlands. • Wetland alterations reviewed in Nova Scotia—no set definition for alteration, but includes filling, draining, etc. and would require approval. Vegetation removal is not considered an alteration. • Applications need to highlight the alterations, and if approved, may require compensation. • Compensation—primary is for restoration and enhancement are preferred, secondary is for research. • Compensation is determined on a 2:1 ratio based on the project. Restoration is 2:1, creation is 4:1 because there is more risk involved in wetland success. • They will accept primary in combination with secondary. • Requires monitoring for 5 years to look for indirect impacts and may trigger a need for further compensation. • WESP was implemented in 2022 and is more comprehensive than the previous NovaWet. It provides more valuable output. • Wetlands of special significance—include provincial parks, salt marshes, wetlands deemed high value so they typically don't allow for alterations on these. Occasionally, if it is for necessary public functions such as a highways, higher compensation might increase to a 4:1 ratio (this is the only time ratio would be associated with value). • The fee is calculated by a "boots on the ground" cost of replacement. Currently around $3.20 per square meter. • The wetland alteration approval application—approval is in the name, so they don't typically decline many applications. As long as they can prove mitigation sequence, it's usually well received.	• Solar development is new to Nova Scotia; however, the jurisdiction has had internal discussions of the need to determine the best approach for handling solar on wetlands. • The Nova Scotia Wetland Conservation Policy does not support approvals to alterations to Wetlands of Special Significance (WSS) unless deemed for a necessary public function. This helps to protect the most valuable wetlands in the province. • Compensation is determined based on the fee to create, restore or enhance a wetland, and a ratio. Replacement by restoration or enhancement (which is preferred) is a 2:1 ratio, creation is based on a 4:1 ratio because of the greater risk involved. • Wetland alteration approval applications are typically approved if proponents can describe the steps taken in the mitigation sequence.

		• They don't have specific wetland mitigation measures, but typical measures that come up in an environmental protection plan. Inspectors have some measures to mitigate things like sedimentation and erosion. • No regulated buffers around wetlands. Unless it's close to a watercourse, then there is a 20 m buffer. • WSS does allow to conserve high valued wetland function. • If 5 year monitoring determines signs of direct impact to wetlands, then the area delineated must be compensated. • They don't want to discourage solar development. They have approvals for 10 years. Monitoring will allow enforcement if the project is affecting more than indicated in application. • Monitoring can consist of vegetation transects on unaltered parcels, monitoring wells for changes in surface water. This is project-specific. Each year the proponent provides a report to an inspector for review of indirect impact.	
02/03/2023	Jeff Dereniwski Senior Environmental Assessment Administrator Environmental Assessment and Stewardship, Ministry of Environment, Government of Saskatchewan Jeff.Dereniwski@gov.sk.ca	• Saskatchewan does not have a wetland policy. The Environmental Assessment Process captures the majority of impacts to wetlands (excluding from agriculture). • There are no wetland setback guidelines applied, but there will be for species at risk, and potentially for certain activities. These will be determined on a case-by-case basis. • The effects of solar developments to wetlands and the environment is something that is being considered, but not necessarily for a lack of specific wetland policy or policy for solar projects. • All development projects are assessed in the same way, wetland issues could be captured through assessments on native prairie, sensitive ecosystems, etc.	• While Saskatchewan does not have a wetland policy or policies specific to solar energy development, most alterations to wetlands from all development would be included in their environmental assessment process. • Large-scale solar projects would likely trigger a full environmental assessment. • There are two levels of environmental assessment. The first is a screening and desktop review. If high risk identified, the next steps would be triggered. • Saskatchewan does not have a formal offsetting calculation but is determined on a case-by-case basis. • No setback requirements are applied to all wetlands. However this may be required for species at risk.

		• The approval process is very flexible and looks at some specific effects. For example, determining if a review is required for a renewable energy project comes down to siting.
		• Small scale (less than 1 MW) projects can typically move forward with other permitting requirements, and large scale (over 1 MW) will typically go through a review process.
		• They have not seen many large projects, but they have the potential to go under a full environmental assessment.
		• Environmental assessment:
		  ○ Two different levels: a screening or ministerial determination — pre-disturbance of the site is assessed as is the footprint and the larger area. There is a desktop assessment of rare and endangered species, habitat, unique features, field surveys to verify, and public engagement.
		  ○ If anything is identified as higher risk, then mitigation measures would be considered. If impacts can't be minimized, it would initiate next steps, such as what the other siting options are, offsetting, more rigorous requirements.
		• There is no formal calculator or offsetting guidance, determined on a case-by-case basis. Mainly this would apply to potash on offsetting programs.
		• There have been some internal conversations on ratios for these fees that could apply.
		• Mitigation requirements overlap among activities when it comes to working near or around wetlands. This includes overlap with species at risk protocols. There are activity restriction guidelines (avoiding breeding seasons) that can dictate what work can occur at what time of year.
		• They do lean on best management practices, such as working in frozen conditions for erosion control.
		• The main experience with renewable energy in Saskatchewan has been with wind energy. This doesn't require permitting under the	

		Environmental Protection Act, where traditional development projects are permitted. • Wind is managed through environmental assessment approval with conditions. This triggers a concern for bird and bat mortality. May be post-construction monitoring and decommissioning requirements.	

09/03/2023	David Demmer
	
	Wetland Specialist | CMWP
	Minnesota Wetland Professional Certification Program
	Minnesota Board of Water and Soil Resources
	
	david.demmer@state.mn.us
		• Minnesota has robust wetland protection policies, with language in protecting wetland function and values—this is unique.
		• They have an outdated rapid assessment protocol (MnRAM) that isn't maintained. They have another functional assessment for vegetation that is used in the forested area where necessary vegetation removal will have a big impact.
		• They are exploring a grant from the U.S. Environmental Protection Agency to develop a rapid evaluation method, and plan to do a trial on it this year.
		• They have developed guidelines specifically for assessing impact of solar projects because the WCA definition of impact precludes posts and pilings. As solar is on posts and pilings it could include this, but could have additional impacts (for example, shading from the panels). Hence, the guidance is to examine at how the solar project will impact wetland function and values.
		    ○ One of the few states that have solar specific guidance.
		• Main concerns of solar on wetlands:
		    ○ Shading can lead to monocultures, dredging and filling. This will all impact the function of wetlands.
		    ○ Projects are unique, so it's impossible to use a cookie-cutter approach to all solar projects. For example, they can range from about 2 to 2600 acres in area, and on either pristine swamps or degraded hay field. As well, every company deals with infrastructure and maintenance needs differently. Some may want a paved road for regular access, others won't and can construct during winter on frozen ground. Some companies will prioritize as many panels as close to the grid
			• Minnesota's wetland policy aims to protect wetland function and values.
			• They have developed solar energy specific guidelines for development proposed for wetlands.
			• Main concerns for solar on wetlands include shading leading to monocultures, the dredging and filling associated with development impacting wetland function, and difficulties of applying generic regulations to a development type that varies widely (for example, solar projects vary widely in size, location, infrastructure, and maintenance needs).
			• Mitigation requirements are determined on a case-by-case basis, and often include reconfigurations and adjustments to mitigate for shading such as taller posts, tilted panels, and greater panel spacing to allow for sunlight to reach the ground.
			• Mitigation sequence of "avoid, mitigate, then replace".
			• The state has a wetland banking system consisting of nine bank service areas. The system is driven by the private market, and pricing is based on supply and demand.
			• Local jurisdictions may have additional restrictions related to wetland development.

		as possible, others will have smaller footprints in rural communities. • Mitigation requirements are on a case-by-case basis, and often include reconfigurations, adjustments to mitigate for shading such as requiring taller posts and/or tilted panels, spacing so sunlight can reach the ground. • There is significant consideration of the solar panel configuration as well as consideration of how they can execute a project with avoidance. • Construction standards exist to mitigate impacts. • WCA applicants must go through the sequencing steps of avoiding, mitigating and then replacing. The need to consider and demonstrate offsite options/alternatives and prove they've done everything they can before they fall into the replacement category. • For replacement, Minnesota has a robust wetland banking system. o Wetland banking system – sites that have been restored to wetlands, been permitted, and are now being monitored. Within these banks are credits (cost per square foot). o There are 9 BSA (bank service areas) total. Some larger than others, but they are all quite large. o The banking system is market driven, so prices are determined by the private market and based on supply and demand. When there is less supply of wetland banks, prices go up. Around metro areas, higher property values result in higher banking credit prices. Price may also vary by the land area an applicant wants to buy (the larger, potentially less per square foot). Example, prices have ranged from about $0.25 USD to $2.00 USD per square foot. o Replacement ratios can be reduced when credits from an approved bank are applied within same bank service area as affected wetlands, or when replacement is mostly in-kind and occurs within same major watershed or county as impacted wetland.	

		• Public waters – wetlands through DNR—mapped public water that includes all perennial streams and lakes generally—relatively major watercourses. Public waters on a map are defined clearly through DNR. Doesn't have a robust compliance system but there are many restrictions (e.g., can't build on the lake). • State level regulations do not have any required setbacks or buffers. They establish minimum criteria while local regulations can be more restrictive. Only a few metro areas have buffers. • Has directly seen more proposals for fixed arrays in projects. Not sure how much it matters when determining wetland impact but could potentially see an argument that moving, articulating panels may allow sunlight to hit the vegetation that wouldn't otherwise with a fixed panel. Has never heard of a regulator specifically endorsing or favoring articulating panels. • The actual array type is still just one of the factors when evaluating the project's impact on a wetland. Other factors, such as the amount of wetland covered, sensitivity and condition of wetland, post-project disturbance factors, and vegetation management plan, are equally important.	
28/02/2023 – 03/03/2023 (email correspondence)	Thomas Maguire Senior Wetlands Resiliency Coordinator, Wetlands Program, Massachusetts Department of Environmental Protection thomas.maguire@state.ma.us	• Massachusetts's Wetlands Program Policy 17-1: Photovoltaic System Solar Array Review contains guidelines for solar projects occurring on wetlands. • Massachusetts Wetland regulations apply to "wetland resource areas" that refers to all types of wetlands in the state. • No wetland impairment is allowed in some resource areas without a permit. Only 5000 square feet of alteration is allowed in bordering vegetated wetlands (e.g., swamps, marshes) at the discretion of the Issuing Authority (municipal conservation commission of MassDEP upon appeal), providing at least 1:1 replacement is provided. • Many of the restrictions on selected wetlands in the Wetland Protection Act were adopted prior to the adoption of the act [MGL Chapter 131 section 40, adopted in 1972, combining the Jones Act (1963) with the Hatch Act (1965)]. The Jones Act protected interests	• Massachusetts has robust wetland protection policies that apply to all wetland resources and precludes or limits wetland impairment of certain wetland resources. • At least a 1:1 wetland replacement is required. • Mitigations are determined on a case-by-case basis. • The state has a policy specific to solar energy development, providing guidelines for project occurring on wetlands.

		in coastal wetlands and the Hatch Act protected interests in inland wetlands. • Mitigations are applied on a case-by-case basis. However, underlying performance standards for each resource area still apply and must be met (e.g., if a solar farm is proposed in a Bordering Vegetated Wetland, the alteration is limited to 5000 square feet with at least 1:1 replacement). • Suggested jurisdictions with wetland policies that deal with solar development: Vermont, New Jersey	
07/03/2023	Beth Payne Wetlands Permitting and Planning Unit Supervisor, Division of Water Quality, California State Water Resources Control Board Elizabeth.Payne@waterboards.ca.gov	• California has broad in-state jurisdictions. • Federal Clean Water Act – work jointly with Army Corps for discharge into federal waterways. • Federal waterways – defined in regulations. Army Corps required section 404 clean water act. • The Army Corps also have delegated authority to the state. The state has to provide permission to get the permit from federal government. • There is required monitoring or mitigation monitoring. • Existing authority from the Clean Water Act is broader. Anything left over that isn't avoided or mitigated must be compensated. • California regulates any waterbody and also issues state-only permits. May not need a federal permit but would still need a California permit. • Federal level – an area of controversy for decades about what types of wetland classes. "Navigable waters" anything connected to navigable as well… wetlands adjacent or touching, significant connection to. There are various definitions based on who's in charge as well as litigation. • Regulations are very complicated and staff take years to fully understand. • Porter-Cologne policy – defines "water of the state" as any surface water, groundwater, and coastal waters. • Water board – further defined which wetlands will be regulated (which are waters of the state, and which are not). May regulate	• While federal policies apply to navigable waters (including anything connected to navigable water), California has a broader jurisdiction covering all waterbodies. • Wetland compensation occurs at a minimum of 1:1 ratio and prefers banks or *in lieu* fees within the same watershed. • Compensation fees vary among mitigation banks. • Typically, wetlands like vernal pools will be more expensive to compensate. • The policy is for no net loss of wetlands, the state has lost 90% of wetlands since settlement. • The state considers projects somewhat on a case-by-case basis but have preset mitigation amounts. For small projects like culvert replacements, road grading of certain extents (activities of low impact) there is a streamlined approach to follow. • No specific policy for solar on wetlands.

		ones not of state in a different way. Defined which wetlands are jurisdictional, but not other water bodies. They are working on defining other water bodies on streams or in riparian areas. New regulations are controversial in California and it took 15 years to get water policy through public and scientific review. • Mitigations – federal Army Corps: 404b army corps guidelines show how mitigations should be assessed and how to consider function; whether in the same watershed or if it is rare or unique. • 1:1 minimum mitigation compensation – if you fill one acre, need to restore, or build one acre. • Prefer banks or *in lieu* fees in the same watersheds. • Fees vary by bank – Army Corps have set up a mitigation bank that varies widely. Typically, rarer wetlands like vernal pools will be more expensive. • Will work with wildlife agencies where there are special species effects to mitigate wetland damage. • The state allows the permittee to build/restore if in same watershed and banks aren't available. • California lost 90% of wetlands since settlement. They have a no net loss policy. • To some extent they examine projects case by case, but they have preset mitigation amounts for small projects such as culvert replacements, electrical/utility, road grading of certain extents — activities with small impacts. For these, they have streamlined orders to follow. It incentivizes following this mitigation to get permits quickly if they avoid and mitigate.	

15/03/2023	Marsha Trites-Russell
	
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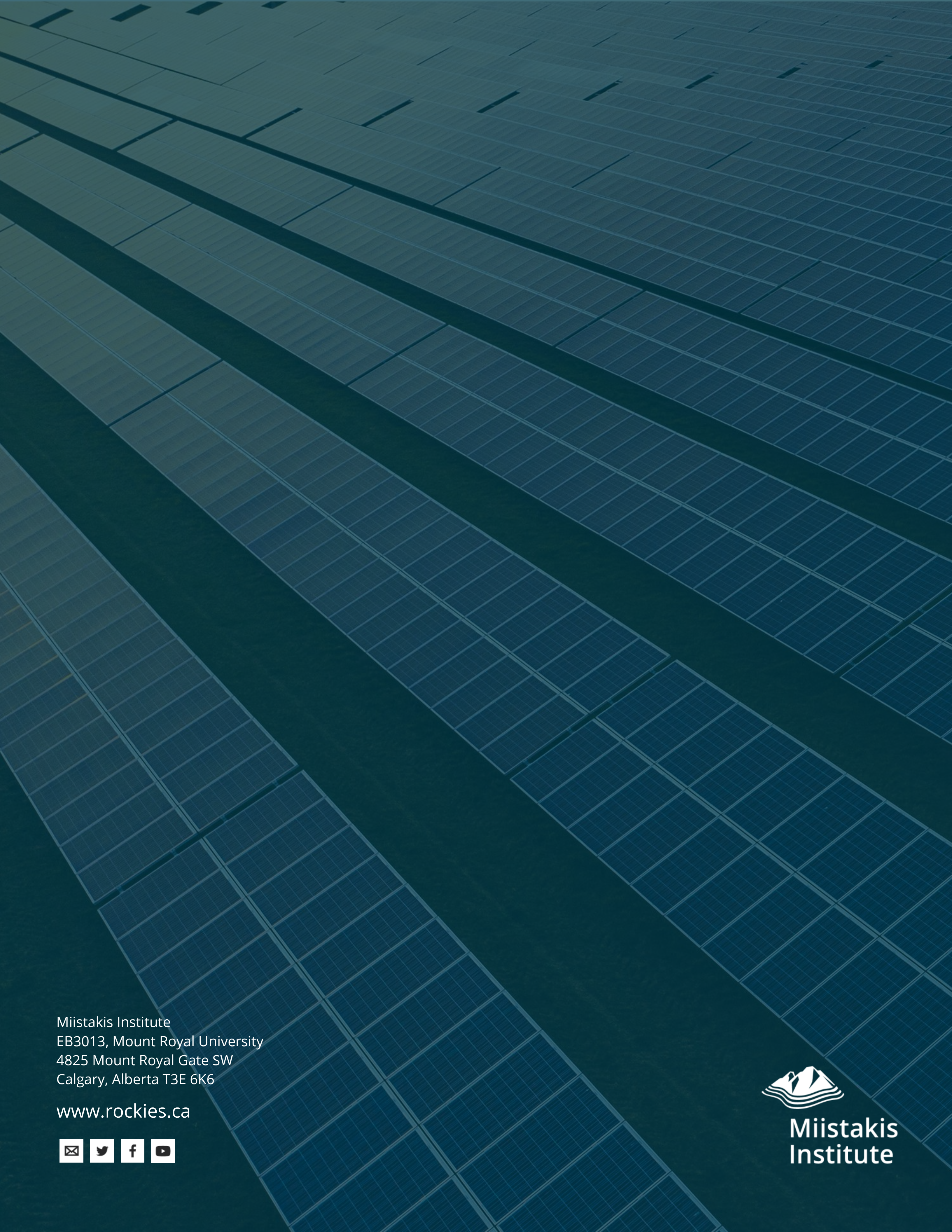
		• Alberta Wetland Policy has a mitigation hierarchy of "avoid, minimize, and replace". However, it can be difficult to require avoidance as opposed to replacement.
		• The policy is administered under the Water Act, and there is some legislative support for requiring wetland avoidance, such as if a species at risk is found, or if it is on public land. Then the government of Alberta can decide. If on private land, it can be difficult to reject wetland development, especially with many
			• It is difficult to say no to activities that result in loss of wetlands on private land despite the hierarchy of "avoid, minimize, and replace" in the wetland policy.
			  ○ Wetlands are very prevalent in Alberta, so it's likely development on a parcel of land cannot occur without impacting wetlands.
			  ○ The Water Act focuses on waterbodies that provide aquatic benefits.

		mitigation options. Proponents do have to justify why they can't avoid impact. • In Alberta, wetlands are so prevalent, it is difficult to completely avoid affecting wetlands with many developments. • ABWRET is used to determine replacement ratios based on the A-D values. *In lieu* fees are based on per hectare at a D value wetland. If you have an A value wetland, then for each one hectare, you pay for 8 hectares of D. • Fees have not changed since the Alberta Wetland Policy was implemented. Some jurisdictions are revisiting the fee to account for inflation and increased prices. • Now, it can cost more to replace a wetland than is collected for the *in lieu* fee. • The fee would not be prohibitive to large, wealthy developers. However, it could be for small farmers looking to develop their land. It's just included in the cost of doing business in Alberta. • Monitoring requirements for developments affecting wetlands are determined on a case-by-case basis, varying by project and location. If an applicant is completely removing a wetland, then there isn't much to monitor. However, if impairing a portion of a wetland and unsure how that wetland will persist, then post construction monitoring can be required. • There are some developments that automatically trigger monitoring requests, such as sand and gravel operations, or peat harvesting. By default these require some water quality monitoring. • Under the Water Act, it's easier to say no to development on open water bodies, with aquatic resources/ fish habitat. • Solar development may have different types of impacts to wetlands. Likely to be less impactful than some operations, but more than others. • WAIF is required for lower-risk activities. Potential for solar to be put under here instead of full WAIR that requires field surveys. Solar may need some additional review.	• *In lieu* wetland replacement fees have not been updated since implementation in 2015. These may not be cost prohibitive for many developers.

		• Not sure if the majority of development applications are following the 100 m setback in the Wildlife Directives for Solar Energy Development. Dryer wetlands may not be covered in this directive.	
23/03/2023 (email correspondence)	Shawn Hill A/Watercourse/Wetland Alteration Supervisor, Environmental Land Management Section, Prince Edward Island Environment, Energy and Climate Action SJHILL@gov.pe.ca	• Prince Edward Island (PEI) has no policies on solar energy development in wetlands. It is not a development we would permit and our stated policy would encourage avoidance. This means solar energy, or any other, development would have to occur in an area that is NOT in a wetland, or a wetland buffer (15 m). • Wetland compensation on PEI is as follows; value @ $6100/acre × 3 (compensation ratio) = $18,300 per acre for wetland loss compensation. Compensation is only considered when the proposed project cannot be avoided, mitigated, and is strongly in the public interest. • We do not use the WESP on PEI (yet). It was used during a very large highway expansion, but other than that, it has not been used on a routine basis on PEI. There is a good inventory of wetlands on PEI, however, some of the more difficult to identify wetland types remain unmapped. • We believe the policy is achieving a no net loss of wetlands on PEI in most cases. A problem we see is that the compensation fee is still very low relative to the true value of wetlands. We hope to address this in the coming years.	• PEI policy encourages avoidance of wetlands, including avoidance of the 15 m wetland buffer. • Compensation is valued at $6100/acre, applied at the compensation ratio. • Currently no wetland evaluation method, although used WESP during a large highway expansion. • While the policy appears to be achieving its no net loss goal, the compensation fee may be low relative to true value of wetlands. They are hoping to address this in the coming years.
24/03/2023 (email correspondence)	Scott Beaton Habitat Conservation Specialist Manitoba Habitat Heritage Corporation sbeaton@mhhc.mb.ca	• Solar development is not being considered in Manitoba. There is much more significant loss from other developments in this province. • The Manitoba Wetland Assessment Method (MB WAM) Worksheet allows wetland professionals to rate the health of individual wetlands and results in a wetland health score. The health score is based on 12 functions that wetlands provide, like water storage and habitat for ducks. If a wetland is able to effectively deliver all	

		12 functions, or if it is a very special wetland, then its health is rated as Exceptional. All other wetlands are scored as High, Moderate or Low. Based on these health ratings, well-informed land management decisions can be made consistently across Manitoba.	



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