**Photo by: K.M. Kettenring**

**Final report to**
**Utah Department of Natural Resources**
**Division of Forestry, Fire & State Lands**

# Assessing approaches to manage *Phragmites* in the Great Salt Lake watershed

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## Problem statement and report overview

*Phragmites australis* (common reed; hereafter *Phragmites*) is an invasive grass that has rapidly invaded wetlands across North America (Marks et al. 1994) and is widespread and dominant in wetlands, ditches, and roadsides in northern Utah (Kulmatiski et al. 2010; Kettenring et al. 2012a; Kettenring and Mock 2012). This plant is undesirable because it crowds out native vegetation and profoundly alters habitat quality for wildlife including waterfowl and other migratory birds by creating large monotypic stands (Marks et al. 1994). Great Salt Lake (GSL) wetlands are the most important wetland habitat for migratory birds in the region and are continentally significant (Evans and Martinson 2008). Unfortunately, tens of thousands of acres of diverse native wetland vegetation have been replaced by invasive *Phragmites*, reducing the availability and quality of habitat in GSL wetlands.

Given the extent of the *Phragmites* problem in Utah and elsewhere, managers need to understand what techniques are most effective for killing *Phragmites* while fostering native plant recovery. A variety of strategies have been widely employed for *Phragmites* management including summer or fall herbicide application, mowing, burning, and flooding (Marks et al. 1994). But, as is often the case with natural resource management, due to limited time and money, there has been little monitoring of success or any systematic evaluation of management strategies across the varied environmental conditions where *Phragmites* is found, particularly in Utah. Given the interest in effective management strategies for *Phragmites,* there is a need to evaluate and monitor the success of different techniques. Another complicating factor in effective *Phragmites* management is that, contrary to popular belief, *Phragmites* spreads largely by seeds rather than rhizomes (Kettenring and Mock 2012). While a fall herbicide spray is widely used to manage *Phragmites*, this occurs *after Phragmites* has produced its seeds. Managers need additional tools to prevent seed production in conjunction with managing existing stands (e.g., mowing in conjunction with herbicide or using herbicide application earlier in the year). Finally, while the herbicide glyphosate has been widely used to manage *Phragmites*, another herbicide, imazapyr, has recently been shown to be effective for managing *Phragmites* (Mozdzer et al. 2008). Further research is needed to compare the effectiveness of these herbicides, including the best time for application, for *Phragmites* management and native plant recovery. Thus, we have embarked on a five-year set of experiments where we are evaluating potential strategies for dealing with new infestations of *Phragmites* as well as large, dense monocultures of *Phragmites*. Here we report on the effectiveness on the first year of management treatments (implemented in 2012) based on our qualitative observations from late June 2013 (**PART I**). Quantitative results are forthcoming.

Given the extent of the *Phragmites* problem in Utah and elsewhere, managers need to understand what factors explain its current distribution and how to prioritize management efforts at the landscape scale. Recent developments in remote sensing technologies now allow researchers and managers to look at widespread patterns of vegetation distribution. We have capitalized on these technologies to determine the current extent of *Phragmites* in GSL wetlands using remote sensing (http://maps.gis.usu.edu/gslw/index.html; Kettenring 2012). In turn, data collected for remote sensing can form the basis of species distribution modeling whereby one can look at relationships between the current distribution of *Phragmites* with factors that may explain its distribution. Factors such as elevation, proximity to water control structures (a proxy for disturbance), soil type, or surrounding land-use may help explain why it is found in some but not all locations along the GSL. Here we report preliminary findings on factors that best explain the current distribution of *Phragmites* in GSL wetlands (**PART II**).

Prioritizing sites for *Phragmites* management based on current distributions, model predictions about future spread, and other conservation priorities will be critical to successful management of this plant in the GSL watershed. Spatial prioritization is a useful tool for restoration planning and has been used in conservation planning, and wetland, stream, and riparian restoration (White and Fennessy 2005; Mollot and Bilby 2008). While it is becoming common to develop maps using species distribution modeling that are predicting potential areas of invasion by species, few studies have explicitly addressed what to do next with this information. There may be a high number of sites that are predicted to be susceptible to invasion. Having a framework to decide how to prioritize sites for management (based on current and predicted, future distributions), and what areas will have the most impact if managed, will improve the overall effectiveness of a *Phragmites* management program. Here we report on the initial prioritization framework that we are developing for *Phragmites* in GSL wetlands (**PART II**).

## PART I: *Phragmites* management studies (Chad Cranney's and Christine Rohal's M.S. projects)

***Objective: To evaluate potential*** **Phragmites** ***management strategies in small patches and large stands for restoring wetlands in the GSL watershed.***

### *Methods*

The management studies are being conducted at two spatial scales – 0.25 acre treatment areas to evaluate strategies that may be effective for dealing with initial invasions of *Phragmites* and 3 acre treatment areas to evaluate strategies that may be more effective and logistically feasible for dealing with large, well-established stands of *Phragmites*.

***Large stand study.*** We have four sites with extensive stands of *Phragmites* where we are conducting the management treatments: Ogden Bay Waterfowl Management Area (WMA), Farmington Bay WMA, sovereign lands west of Ogden Bay WMA, and sovereign lands northwest of Farmington Bay WMA. At each site, we are applying 5 treatments to each 3 acre *Phragmites* stand (15 acres total per site). The five treatments we are applying are: (1) summer glyphosate spray followed by winter mow, (2) summer imazapyr spray followed by winter mow, (3) fall glyphosate spray followed by winter mow, (4) fall imazapyr spray followed by winter mow, and (5) untreated area. Management techniques were first applied in 2012 and will be applied again in 2013 and 2014.

***Small patch study.*** We have six sites where we are evaluating *Phragmites* management treatments that might be effective for small *Phragmites* invasions (Inland Sea Shorebird Reserve, Ogden Bay WMA, Farmington Bay WMA, Bear River Migratory Bird Refuge, and two areas at TNC Shorelands Preserve). At each site, we are applying one of six management treatments to a 0.25 acre *Phragmites* patch. The six treatments we are applying at each site are: (1) summer mow, then cover with heavy duty black plastic; (2) summer mulching mow followed by fall glyphosate spray; (3) summer glyphosate spray followed by winter mow; (4) fall glyphosate spray followed by winter mow; (5) summer imazapyr spray followed by winter mow; and (6) untreated area. These treatments were first applied in 2012 and we will repeat these treatments in 2013 and 2014.

The *Phragmites* treatments for both studies were chosen based on our initial survey of GSL wetland managers (Kettenring et al. 2012b); extensive conversations with Randy Berger and other state, federal, and private managers; and our reading of the *Phragmites* management literature. We chose treatments that were logistically feasible for managers to apply, and chose a balance of treatments that represented commonly applied strategies as well as less common ones that hold great promise for GSL wetlands.

For both studies, treatment effectiveness is being assessed by looking at *Phragmites* cover and stem density, as well as native plant cover. Vegetation is being monitored with on-the-ground surveys for both studies. In addition, for the large stand study we are employing UAVs (unmanned aerial vehicles) to take high resolution (5x5cm pixels) imagery of the stands before and after management once per year (2012-2014), to look at changes in *Phragmites* and native plant cover. In addition, we are characterizing sites with respect to nitrogen (ammonium, nitrate), phosphorous (phosphate), salinity (electrical conductivity), organic matter content, and soil moisture / flooding levels, all factors that could affect treatment success. Such data will be critical for when we make recommendations on which treatments to apply in which areas of the GSL.

***Results***

***Large stand study.*** Qualitative estimates show that all treatments significantly reduced *Phragmites* cover following initial treatments in 2012. At most sites, fall treatments of both herbicides show slightly higher reductions in *Phragmites* cover when compared to summer treatments with an average of >85% reduction and >80% reduction, respectively, across all sites. Overall, imazapyr shows a slightly higher reduction of *Phragmites* cover compared to glyphosate for both summer and fall treatments. At three of the sites, at least one treatment plot had <70% reduction in *Phragmites* cover, but we believe this was due to uneven herbicide application rather than herbicide effectiveness, which resulted in very distinct strips of *Phragmites* regrowth (**Figure 1**). Also, there seems to be no correlation between the strips of *Phragmites* regrowth and the type of herbicide used, or timing of application.

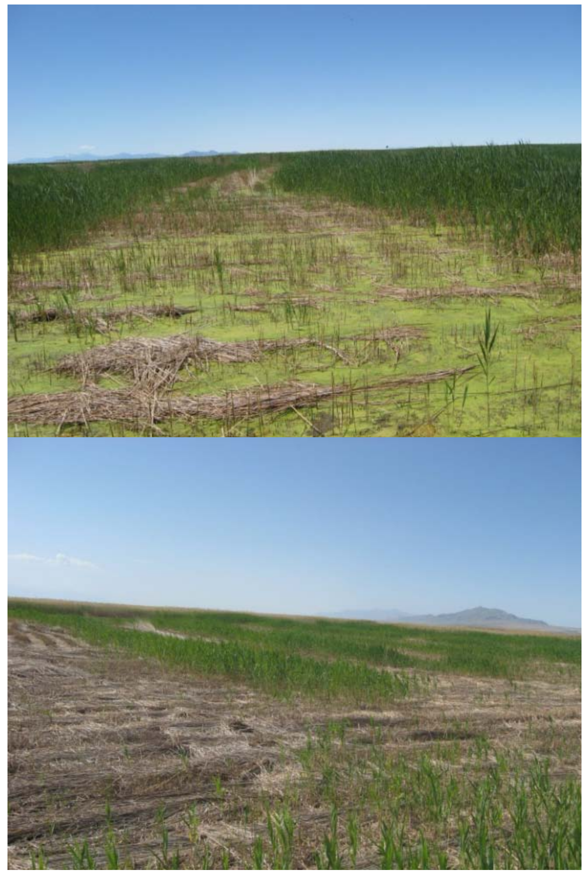

**Figure 1:** Ogden Bay summer glyphosate (top) and Howard Slough summer imazapyr treatments (bottom) showing strips of *Phragmites* regrowth. Photos by C. Cranney.

Emergence of native vegetation was very minimal in all treatment areas with only traces of *Schoenoplectus maritimus* (alkali bulrush), *Rumex crispus* (curly dock), and *Typha* spp. (cattails). We believe one factor contributing to the low number of native vegetation observed is the layer of dead *Phragmites* left behind from mowing. At most sites, this layer of dead *Phragmites* is 25-35 cm deep. In areas with water levels deeper than 12 cm, much of the dead *Phragmites* has decomposed faster or been flushed out, leading to open water areas with large amounts of *Lemna* spp. (duckweed) and some algae. At this point, there is no distinguishable difference in the amount of native vegetation returning and the type of treatment used.

***Small patch study***. After one year of treatments, it is still inconclusive as to which treatment provides the best results in terms of both *Phragmites* removal and native species return, but some general observations can be made. The most obvious conclusion is that the summer mow, followed by black plastic treatment was the least effective in removing living *Phragmites* from the area. This treatment reduced the height, density, and vigor of the *Phragmites* that returned, but still resulted in high cover of *Phragmites* (**Figure 2**). The two summer herbicide (imazapyr and glyphosate) (**Figure 3**), winter mow treatments were both effective in removing living *Phragmites*, with imazapyr potentially being more effective. The fall glyphosate, winter mow treatment was also quite effective in removing living *Phragmites*, but not noticeably better or worse than the summer sprays. The summer mow, fall glyphosate spray treatment was consistently very effective at removing living *Phragmites* (**Figure 4**), perhaps because the *Phragmites* was less dense when sprayed which allowed for better herbicide coverage.

**Figure 2**. *Phragmites* growing back after the black plastic treatment. Photo by C.B. Rohal.

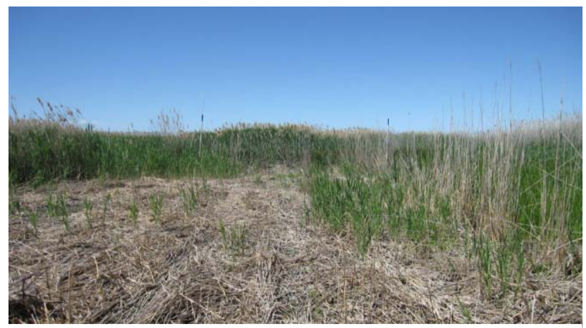

**Figure 3**. A representative herbicide spray plot. This plot was sprayed in the summer with glyphosate. Photo by C.B. Rohal.

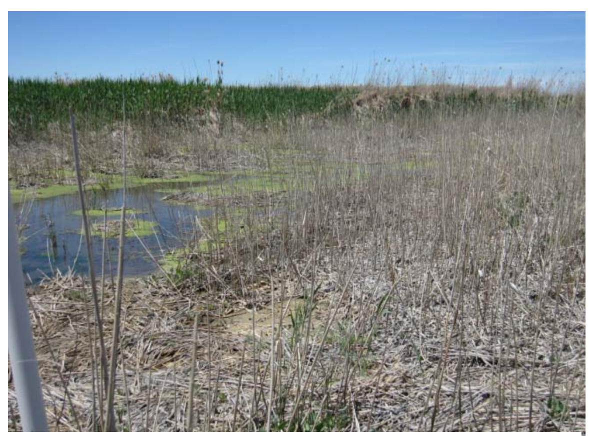

**Figure 4**. The summer mow, fall spray treatment. Resprouting of *Phragmites* is minimal. Photo by C.B. Rohal.

The very large amounts of litter left behind from mowing seemed to be the most substantial impediment to the regrowth of native species in all plots, but more so in the plots that were mowed in the winter. The fall glyphosate, winter mow treatment consistently had very high amounts of litter, greater than the summer spray treatments (perhaps because it had more time to accumulate biomass).  The summer mow followed by a fall glyphosate spray treatment resulted in substantially less litter, which was reflected in seemingly higher numbers of native species reemerging.  Nevertheless, the return of native species at this early stage seems to be driven more by site than by treatments.

## PART II: *Phragmites* distribution modeling and prioritization framework (Lexine Long's M.S. project)

***Objective: Determine what factors best explain the current distribution of* Phragmites *in GSL wetlands and to develop a watershed-wide prioritization scheme for managing* Phragmites**

***Methods***

***Multi spectral imagery data collection.*** We acquired high-resolution multi-spectral imagery in May and June, 2011, of the eastern third of the GSL using USU's airborne multispectral digital imagery system.  Images were acquired at 1-m resolution, with imagery in 4 bands: red, green, blue, and near-infra red.  We used ERDAS Imagine 2010 software to perform supervised classification of the imagery (i.e., to delineate the vegetation shown in the imagery into vegetation types listed in **Table 1)**.  Supervised classification is performed by using training pixels for each vegetation class based on known data determined from ground truthing surveys.  The computer then assigns the remaining pixels to the class that most closely matches the training pixels according to the multispectral signature.  The final product of this imagery classification process was a raster dataset consisting of the nine different vegetation classes (**Table 1**) for all wetland areas on the eastern third of the GSL.

**Table 1**.  Wetland vegetation classes

| **Vegetation classes:** |
|---|
| *Phragmites australis* (common reed) |
| *Typha* spp. (cattail) |
| *Schoenoplectus acutus* (hardstem bulrush) |
| *Distichlis spicata* (saltgrass) |
| Native emergent plants (bulrushes, sedges) |
| *Salicornia* spp. (pickleweed) |
| Mudflat/ playa wetlands |
| Open water |
| Upland |

**Phragmites *species distribution modeling*.** To better understand what determines *Phragmites* presence and help predict its future expansion in the GSL region, we are determining relationships between the current distribution of *Phragmites* and a suite of different environmental variables.  To do this, we developed species distribution models to determine important environmental and management variables for *Phragmites* presence. Species distribution models are useful tools that can relate the presence and distribution of a certain species with environmental, geographic, or management predictors (Elith *et al.* 2006). We selected predictor variables to capture environmental characteristics that may be important at a site (such as nutrient levels, hydrology, etc), as well as variables to try to measure disturbance (such as land use or road density) that may drive *Phragmites* distribution.

Species distribution models are created by using presence and absence data points for a species and relating those data to environmental and/or management predictor variables. We used the final classified imagery to generate presence and absence points for *Phragmites* species distribution modeling. We generated 1500 random *Phragmites* presence points. One thousand of those presence points were for training and 500 were set aside for model validation. We also generated 1500 random absence points (i.e., areas where *Phragmites* does not exist), which were stratified between the remaining non-*Phragmites* vegetation classes. We also set aside 500 of the absence points to use as an independent verification data set.

We obtained data for the predictor variables from available datasets around the GSL. Most of these datasets were publically available from the State of Utah Automated Geographic Reference Center (http://gis.utah.gov/). Other data sets were obtained from Environmental Protection Agency (EPA) data, National Resource Conservation Service (NRCS) data, and management records from wetland managers around the GSL. See **Table 2** for a full list of predictor variables currently in the model. We are currently still compiling data for several predictor variables (such as soil type) and these will be added to the model shortly.

**Table 2**. *Phragmites* presence predictor variables

| Abbreviation | Description |
|---|---|
| ImpoundedS | Wetland impoundment status |
| HU_8_Name | Level 8 watershed |
| LandCvrCode | Dominant land cover within a 100 m buffer |
| Elevation | Elevation based on 1m DEM from LiDAR |
| WRPOD | Distance to nearest water control structure (m) |
| ShoreDist | Distance from GSL shoreline (m) |
| RoadDist | Distance to nearest road (m) |
| Aspect | Aspect based on 1m DEM from LiDAR |
| PointSource | Distance from point source pollution |
| RiverIn | Distance from freshwater inflow into GSL (as a measure of differences in salinity) |
| WaterDist | Distance to open water |
| Arm | GSL "arm" – north or south |

We used random forest models, which are a type of classification procedure that aggregates different classification tree models, for our analysis. Benefits of using random forests include having a higher accuracy than just single classification tree models, flexibility to perform different types of data analysis, and the ability to model complex interactions between variables (Cutler *et al.* 2007). Additionally, random forest models are fully non-parametric and do not make any assumptions about the distribution of data (such as normality). We used R statistical software for all modeling analysis. To test the accuracy of our model we used both 10-fold cross validation (which repeatedly tests the model fit on a subset of the data) and used the data points that were set aside as an independent data set. We used the Area Under the Curve (AUC) as an accuracy assessment. AUC is a measure of a model's ability to correctly discriminate between presences and absences. AUC ranges from 0 to 1, where 1 is a perfect discrimination between presence and absences and 0.5 is no better than by chance. Instead of using statistical significance to select variables to be included in models, random forests ranks variables by importance based on an algorithm (Cutler *et al.* 2007). This allows you to determine the most important variables in predicting *Phragmites* distribution.

***Results***

The top predictor variables for our preliminary model included distance to open water, elevation, distance to point source pollution outflow, distance to freshwater inflow, and distance from shoreline (**Figure 5**). These are only preliminary results, and several predictor variables will be added to the model as they are ready, which could change the variable importance order. However, these top predictor variables are consistent with prior research with *Phragmites* in other regions, so we do not expect the top variables to change much with the addition of new variables. Distance to open water was a very important predictor for *Phragmites* presence, which is expected since it is a wetland plant. The distance to open water is a measure of the hydrology of an area. Distance to point source of pollution was an important predictor, and other studies have found that higher nutrient levels often correspond with *Phragmites* presence as well (King *et al.* 2007; Chambers *et al.* 2008). Hoffman et al. (2008) found that elevation and distance from river were the most important predictor variables for *Phragmites* along the North Platte River in Nebraska. A similar project that involved *Phragmites* mapping around the Great Lakes found that topography, land use, and road density were important predictors of *Phragmites* habitat suitability (Huberty *et al.* 2012).

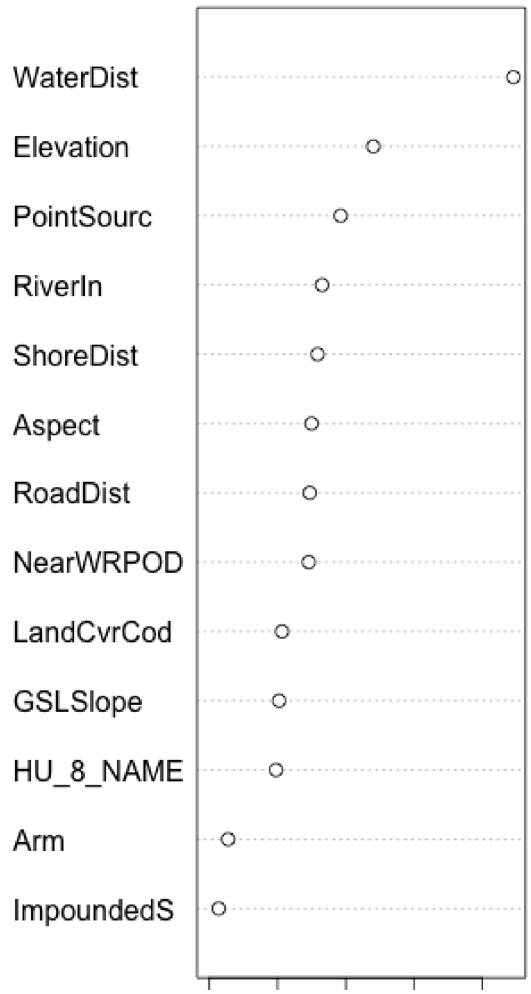


**Figure 5**. *Phragmites* random forest model variables ranked by importance (top variables are most important, bottom variables are least important).

The final result of the *Phragmites* species distribution modeling will not only be information on what variables are the most important in predicting *Phragmites* presence, but also a map of areas that are suitable habitat for *Phragmites*. Since these areas are suitable habitat for *Phragmites*, they should be considered more vulnerable to *Phragmites* invasion. These areas identified as vulnerable to *Phragmites* invasion will be added as a layer in our online interactive Great Salt Lake Vegetation Map (http://maps.gis.usu.edu/gslw/index.html). This vulnerability map can be an important resource for wetland managers, and can help with early detection of new *Phragmites* stands, as well as help with prioritizing areas for management. We will be using the results of the vulnerability map in our *Phragmites* management and restoration prioritization framework.

***Prioritizing sites for* Phragmites *management***

To determine sites that should be targeted for *Phragmites* management and wetland restoration around the GSL, we are developing a multi-criteria GIS prioritization model, and a corresponding spatially explicit map that ranks *Phragmites* patches by priority for management. GIS-based multi-criteria analysis has been used in other conservation and restoration applications as a way of prioritizing conservation or management actions (Orsi and Geneletti 2010). We will use information about areas we identified as having a high suitability for *Phragmites* invasion in the species distribution model, as well as other environmental and land management variables. We selected variables for the prioritization model based on their known importance to *Phragmites* distribution, and selected management variables based on their importance to *Phragmites* management as determined by wetland manager expert knowledge (such as ease of site access, and ability to manipulate water levels). We will carry out our prioritization analysis at the patch scale because setting priorities based on the patch scale will be more useful from both an ecological and management standpoint than doing the analysis on the pixel scale. Pixels will be aggregated into patches based on pixels that are contiguous and are the same vegetation type.

Our prioritization model will be based on a two part analysis – an assessment of the need for restoration of a patch, and an assessment of the likelihood that restoration will succeed in that patch. The ***restoration need*** score attempts to capture areas that have patches of *Phragmites* that would have a major benefit to the overall landscape if managed (**Table 3**) including areas that would be good wetland habitat if restored, such as areas with lots of desirable emergent vegetation in the vicinity. The ***restoration feasibility*** score is a measure of how likely restoration success is for that patch (**Table 4**). The feasibility score largely includes management or landscape disturbance factors that influence how feasible a site will be to restore. Each patch will receive both a restoration need score and a restoration feasibility score.

**Table 3.** Variables that will be used to calculate the restoration need score.

| Variable | Explanation / justification for use of variable |
|---|---|
| Vegetation class | Based on the classified remote sensing imagery. The vegetation class determines whether a patch is *Phragmites* (and thus requiring restoration), or another type of emergent vegetation. |
| Vulnerable to future invasion | Whether or not a patch has been identified as vulnerable to future invasion based on the results of the *Phragmites* species distribution modeling. |
| Patch size | Larger patches (if successfully restored) will potentially contribute more to overall wildlife value of a wetland complex. |
| Nearest neighbor vegetation class | The closest vegetation class. This is useful to determine if there is desirable wetland vegetation nearby to recolonize *Phragmites* managed areas and that is already providing important wildlife habitat. |
| Patch edge to core ratio | Geometric configuration of *Phragmites* patches can potentially affect how fast they expand. Patches that can expand faster would have a higher priority for control. |

**Table 4.** Variables that will be used to calculate the restoration feasibility score.

| Variable | Explanation / justification for use of variable |
|---|---|
| Land ownership | State, federal, private, or non-profit. Different management agencies have varying goals and resources for *Phragmites* management and wetland restoration, which can influence restoration success. |
| Active management | Whether or not a patch was in an area that was actively managed, including management of *Phragmites.* We assume actively managed areas are more feasible for future restoration compared with unmanaged areas. |
| Water level manipulation | Whether or not a patch is in an area where the water level is actively manipulated, as this can influence the ability of managers to manage *Phragmites*. |
| Cost of management | An estimate of cost of management based on patch size, access, etc. |
| Site access | How easy a site is to access by managers. |
| Water depth | What the water level of the site is typically managed as (low, medium, high). Different water depths will affect different wetland management goals. |
| Vegetation class diversity within 150m buffer | Areas with high diversity of non-*Phragmites* vegetation may be better at resisting future reinvasion by *Phragmites*. |
| Wetland type | Based on the National Wetland Inventory classification. Management or restoration activities may be more successful in some types of wetlands than others. |
| Patch size | Smaller patches will be easier to manage and more successful. |

<u>Scenario Development</u>

We will develop four alternative restoration scenarios based on the restoration need and feasibility maps. Each patch will have a restoration need (either low or high) score, and a restoration feasibility score (either low or high). The combination of these scores will determine which scenario each patch falls into. We will create separate maps for each scenario.

***Scenario 1 (Low need / Low feasibility)*** – These patches would be areas that have a low need for restoration (such as patches that are not close to suitable *Phragmites* habitat and not as likely to expand), but also low feasibility (difficult to access, for example). These areas could be put lowest on the priority list when dealing with limited resources.

***Scenario 2 (High need / Low feasibility)* –** These patches would have a high restoration need (such as large areas of *Phragmites),* but low feasibility. They may require lots of effort to manage, are difficult to access, or have other management factors that contribute to a low possibility of success. These may be areas that managers would want to put lower down on the priority list for management when dealing with limited resources, and first focus on the high need areas that also have a higher feasibility.

***Scenario 3 (Low need / High feasibility)* –** These patches would be good areas to target for management and restoration because they may be easy targets with high potential for success. For example, these might be areas that are small isolated patches of *Phragmites* that are easy to access, and surrounded by a lot of emergent wetland vegetation. These would be areas that are "low hanging fruit" to manage and restore, but could have a benefit in reducing the expansion of *Phragmites* around the lake.

***Scenario 4 (High need / High feasibility)* –** These patches may be large core *Phragmites* areas surrounded by lots of healthy wetland habitat that could have a big impact on the overall wetland condition if managed. These are areas that would require more effort for management and restoration than Scenario 3 but still have a good chance of succeeding because of a high feasibility score (easy access, water level manipulation ability, etc.). Since these areas are high need, they may be bigger projects, but would still be worth the effort as they could eliminate large sources of *Phragmites* expansion.

Creating these different restoration priority scenarios allows for wetland managers to determine what types of patches they want to focus their efforts on, and could choose to focus management efforts on patches from just one scenario, or a combination of scenarios based on their resources and goals. Landscape scale assessment is needed in order to see different spatial configurations that may maximize the overall effectiveness of *Phragmites* management and restoration. Our *Phragmites* restoration prioritization analysis could aid coordinated *Phragmites* management efforts and allow for more efficient and effective use of resources when managing *Phragmites* around the GSL.

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