Wetland restoration design modifications to mitigate climate change impacts at Delaware Water Gap National Recreation Area: A case study report

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Abstract

Historic temperature and precipitation trends, and their projected climate change effects, were used to inform the development of wetland design tactics to restore a 30-acre degraded wetland at Delaware Water Gap National Recreation Area. The adverse effects of climate change to be addressed in the restoration design include increasing average daily air temperatures, rising stream and groundwater temperatures, increasing stream erosion, increasing precipitation, and increasing lake evaporation. Specific actions or tactics were developed that provide prescriptive direction in how restoration strategies can be translated to changes in on-the-ground conditions. Traditional on-the-ground tactics are described, along with modifications to the traditional tactics that should facilitate adaptation and increase the system's capacity to survive adverse effects of climate change.

Introduction

The traditional paradigm of wetland restoration management suggests restoring degraded wetlands to natural or pre-disturbance conditions as a "first defense" that will provide the best conditions for the physical and biological processes to adapt to climate change effects. Because climate change effects are causing changes more rapidly, wetland managers have to embrace a new paradigm when designing wetland restorations, i.e., we are no longer designing wetlands just to restore predisturbance conditions; we are now challenged to design wetland restorations that will also facilitate adaptation and increase resilience capacity over the long term.

This paper describes a case study where tactics were designed to create on-the-ground physical and biological conditions that (1) restore the wetland and riverine systems to predisturbance conditions; and (2) reduce vulnerability, and increase the opportunity for resilience, to predicted adverse effects of climate change by modifying traditional physical and biological construction tactics. ("Tactics," are defined here as specific actions that provide prescriptive direction in how restoration strategies can be translated to changes in on-the-ground conditions.)

The restoration project

The Watergate wetland restoration project site is located within the boundaries of Delaware Water Gap National Recreation Area (DEWA). The 30-acre restoration site is a highly disturbed wetland area that historically contained spring seeps, wetland meadows, forested wetlands, and a stream system with associated floodplains. These hydrologic systems were disturbed by the construction of ten artificial surface-water lakes or ponds; the modification of groundwater hydrology; and the modification of hydraulic and geomorphological conditions of the perennial Van Campens Brook by the installation of numerous dams and water diversions, the modification of channel dimensions, and the creation of on-line pond impoundments. Adjacent floodplain wetlands were replanted with manicured bluegrass (Figure 1).

Climate change effect predictions

Staudinger et al. (2015) characterize climate change predictions across the Northeast region within which DEWA and the restoration site are located. Gonzalez (2016) completed an analysis of local watershed conditions in order to verify the applicability of the broader Northeast region climate change predictions and trends to the local site level at DEWA. In the Northeast region, the general climate change effects cited by Staudinger et al. (2015) and the site-specific effects predicted by Gonzalez (2016) are as follows.

Rising temperatures. Warming will occur in every

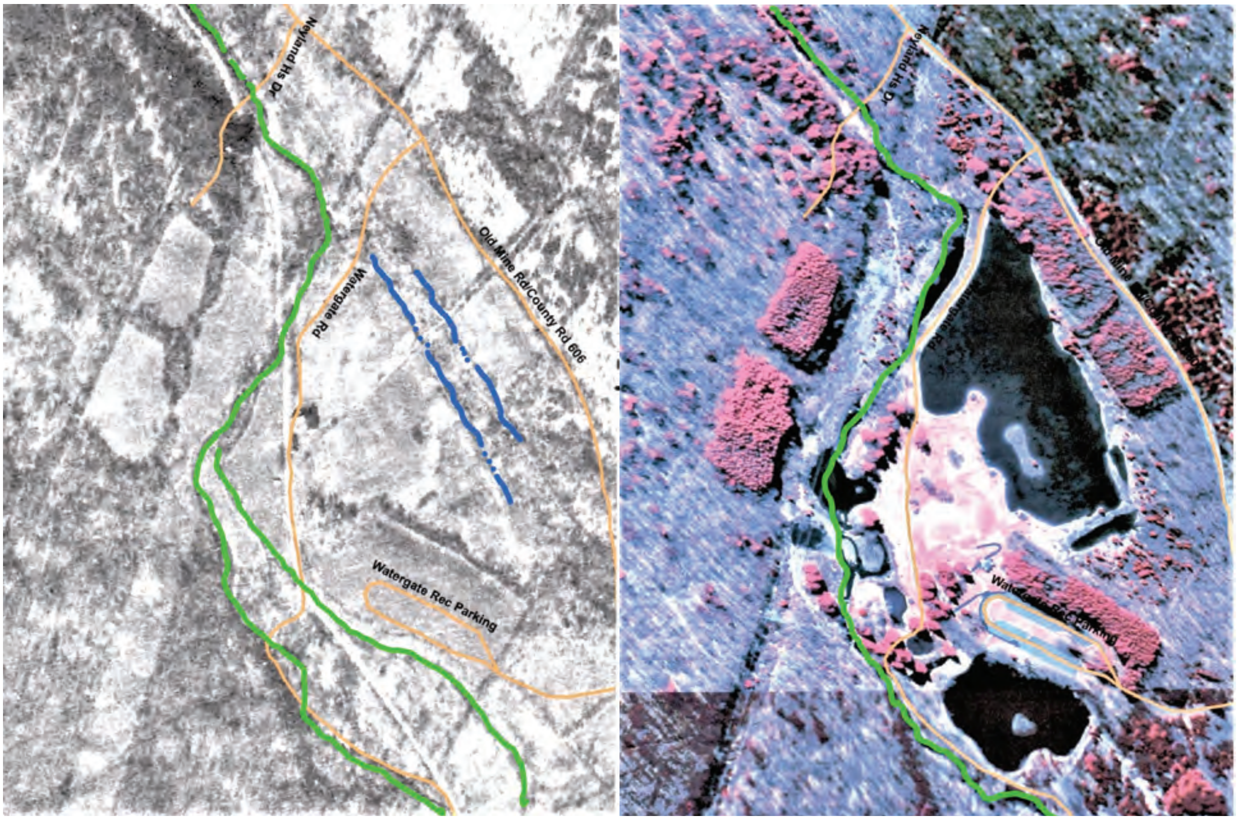

FIGURE 1. Aerial views of the restoration area from (left) 1939 and (right) 2002 (post-1960s disturbance). Note the wetland meadows, with drainage ditches (blue) that were converted to lakes in the 1960s. Van Campens Brook is depicted in green. Source: DEWA park archives.

season. Most models predict that there may be fewer days per year that reach below freezing and a greater number of days above 35°C (95°F). Staudinger et al. (2015) report that Pennsylvania and northern New Jersey may have 20–21 fewer days per year with a minimum temperature below freezing, and 6–9 days per year with a maximum temperature above 35°C (95°F). Gonzalez (2016) reports that the greatest increases of temperatures within the subject watershed will occur in September through November.

Increasing precipitation. Precipitation amounts in the Northeast region are expected to increase and be the largest increases in heavy precipitation events in the country. The Northeast region is likely to experience a greater increase in the number, intensity, and interannual variability of extreme precipitation events. Precipitation totals are projected to increase over winters, and summers will be drier (Staudinger et al. 2015). Given modeled results, there will be a shift toward higher winter stream flows and lower spring flows because runoff will be highest during winter months.

Overall, precipitation amounts and frequency of extreme events on mountain slopes adjacent to the restoration site are likely to increase in winter months and shift from snow to rain under warming climate conditions (Staudinger et al. 2015). Gonzalez (2016) found that the frequency of 20-year storm events in the Van Campens Brook watershed could double or even triple. Precipitation was projected to be highest in June and September and could be lower than historical amounts during July, October, and February (Gonzalez 2016). Summers are projected to be drier which suggests that droughts will occur in between the higher intensity precipitation events.

Specific climate-change effects

Rising temperatures. Projected summer warming and less frequent precipitation events may produce more frequent heat waves and droughts lasting 1–3 months. Growing seasons (total freeze-free days) will start sooner and extend longer, i.e., shorter winters and longer summers. Changes in the length of the growing season, and daylight conditions in temperatures above freezing, can adversely influence life cycle stages of plant species, including leafing, flowering, and seeding. Vegetation biomes should shift from southern latitudes northward as temperatures rise (Staudinger et al. 2015). Vegetation species that cannot survive the changes may provide increased opportunity for aggressive pioneer annuals and nonnative species. Higher temperatures would increase evapotranspiration and reduce soil moisture content. High temperatures during breeding, feeding, and migration of herpetofauna and invertebrates will likely cause increased expiration due to warmer water temperatures or desiccation stress (Staudinger et al. 2015).

Stream temperatures. Data from Van Campens Brook showed a significant increase in stream temperatures in the period 1950–2010 (Tzilkowski 2019). Increased precipitation would contribute to higher infiltration, lower below-ground water temperatures, higher groundwater elevations, and greater contribution of warner ground water to the stream's hyporheic zone and baseflows. The predicted decreased precipitation input during the spring could adversely affect stream temperatures and thermal requirements for trout survival. Warming water temperatures could influence activity levels, consumptive demands, growth rates, and the amount of suitable habitat for aquatic species. Changes in timing (late winter instead of spring snowmelt input) and the decreased magnitude of snowmelt could impact stream flows and may also adversely affect the life history and life cycles of aquatic species.

Stream erosion. Stream flows will increase and intensify around storms causing increased erosion and bedload movement. Increased scouring could smother eggs of fish and other aquatic species and invertebrates. High flow velocities over short periods of time can also impede the natural displacement of small fish, invertebrates, and other aquatic organisms. Staudinger et al. (2015) mentions that vulnerability of the wood turtle species (*Glyptemys insculpta*) found in the restoration area could increase with the increase in bank habitat scouring from extreme storms. The increased bank erosion of the stream, trying to move laterally to accommodate the increased flows, may disturb the hibernacula and breeding grounds of the turtle.

Increasing precipitation. Greater precipitation in the winter months may increase surface runoff, potential flooding, and erosion. During wetter winter months, some soils will become wetter as the groundwater elevations rise. Some soils will become drier in the increased summer heat and reduced precipitation. The loss of intolerant plant species will create an opportunity for nonnative plant species to become established.

Lake evaporation rates. Lake ice minimizes evaporation from lakes. As ice cover diminishes and the waters warm, increases in lake evaporation are expected. Lake evaporation rates will increase as the total number of ice-cover days decreases.

Application of the wetland restoration adaptation design process

The adaptation design process described here is relatively simple:

1. Identify the quality of the existing physical and biological conditions of the degraded system, and develop tactics to restore the degraded conditions to desired predisturbance conditions. Traditional tactics for restoring wetlands include reestablishing physical and biological conditions based on current and historical data (e.g., grade artificial dams and fill in lake areas in order to restore predisturbance wetland meadow conditions).
2. Understand the regional and local climate change historical trends, future projections, and potential adverse impacts to the planned system restoration (e.g., precipitation events will increase in the Northeast, which will likely lead to greater flooding).
3. Modify tactics to restore physical and biological systems to predisturbance conditions. Synthesize the potential effects of climate change on the degraded wetland system. Develop tactics to encourage adaptation of the degraded system to future changes, and mitigate adverse impacts (e.g., raise the restored wetland meadow's capacity to handle an increase in flood waters by setting elevation grades to allow the floodplain meadow to accept large quantities of stream overflow).

On-the-ground restoration design tactics

On-the-ground restoration tactics, for returning a disturbed wetland to predisturbance condition, are well established and are based on historical descriptive, hydrologic, and hydraulic data. These tactics will be implemented in this project to create baseline conditions. A 1939 aerial photograph (see Figure 1) of the restoration site shows areas comprised of wet meadows (with drainage ditches) and a meandering stream system. Implementing traditional on-the-ground tactics will restore physical and biological conditions that will quickly adapt to current climate conditions. "Climate change-related tactics" are referred to as any modifications to the traditional tactics that will facilitate adaptation and increase the capacity to survive climate change impacts in the future. The traditional and climate change-related tactics are described below.

Design the groundwater hydrology in the restoration site to support plant species common to the surrounding area. The traditional restoration design objective would be to replicate the same hydrologic regime (fluctuation in groundwater elevation), and plant those species that will grow in that hydrologic regime as determined in a reference area. Reference sites were chosen to represent the range of wetland plants that currently occur in hydric soils in the area. Data from shallow groundwater wells in nearby reference sites are typically used to identify hydrologic regimes over the past three growing seasons. The well data also allow us to identify locations where specific hydric plant species (those which grow in hydric soils), will survive. In other words, we determine the unique fluctuation in groundwater elevations for specific species, replicate the same soil elevations relative to the groundwater elevations in the restoration area, and plant the identified species.

Replant the restoration site with native species that have adapted to warmer climate zones. Since warmer conditions are predicted, plant species that are only adapted to the Northeast region will likely be displaced by species from warmer climate zones. The National List of Plant Species that Occur in Wetlands (Reed 1988) identifies how frequently a species occurs in wetlands within 12 regions of the US. All wetland plant species in the reference area intended for planting in the restoration site are identified. From that list, only those species that are common to the Northeast, Southeast, and South Plains regions of distribution are selected for the project.

The idea is that if a species is adapted to both cooler current and warmer future temperatures, then it should be able to adapt to the warmer temperatures that evolve on the restoration site and not be displaced by other species. Some believe that, for those species that grow both in warmer and cooler climate zones, the genomes differ between the two populations, with the result that the species would be unable to adapt to different conditions. Therefore, some test plots may be established where the species adapted to the current restoration site conditions will be planted adjacent to plots containing the same species imported from warmer climate zones. However, this tactic of planting test plots is still under debate. The current National Park Service policy is to plant only “native” species. Consensus has not been reached on whether or not the same species has different genomes that facilitate survival in different climate zones, nor on whether a species that is found in another climate zone can be considered native to a different climate zone.

To facilitate adaptation of plant species to an increase in groundwater elevations over time, species that prefer drier soil conditions are selected so long as their preferred groundwater fluctuation is no less than 10 inches from the soil surface during the growing season. This provides room within the plant-root zone for the groundwater elevation to rise and still remain below the soil surface as precipitation increases.

Fill all open water features. To facilitate long-term adaptation or resilience from effects of warmer temperatures on stream baseflows, all impoundments that are in the Van Campens watershed will be filled. Stream water temperatures are rising in Van Campens Brook and it is likely that the numerous artificial ponds are major contributors to rising brook temperatures. All impoundments or lakes in the upper watershed, not just at the restoration site, will be replaced with wetland meadow floodplains and/or restored stream channels. The objective of this tactic is to eliminate the exposure of the lake water to accelerated evaporation rates and heat absorption from the atmosphere as climate change effects increase. The groundwater will remain below the soil surface and will maintain cooler temperatures as it migrates down the valley and into the Van Campens Brook hyporheic zone.

Reconnect the stream to the floodplain. Properly designed channel connections allow for the diversion of floodwater flows onto floodplains. This requires grading the wetland meadows adjacent to the stream and the stream banks to allow for backwater flow into the meadow detention areas. This minimizes high-energy flows both in and out of the wetland meadow floodplains. The meadow detention floodplains will be graded to very shallow gradients to detain as much water as possible during storms.

Restore the Van Campens Brook geomorphology. Properly designed stream restoration will maintain a more desirable transfer of bed loads and suspended solids as climate change increases precipitation in the valley. Properly designed channel width-to-depth ratios should accommodate current flows with room to handle increased flows in the future, which will result in reduced erosion and bank scouring. This means that the channel dimensions should have built-in excess channel water transfer capacity.

Unstable bank slopes and bank erosion can have deleterious effects on some wildlife species. Stream channels will also be planted with herbaceous and woody shrub cover, which will help maintain stable-bank breeding ground and hibernacula for wood turtles and other herpetofauna as they adapt to future increased flows.

All concrete structures in the stream will be removed and the geomorphology of the locations will be restored. If grade-change structures are necessary to prevent channel incision, then the structures will be designed to accommodate grade changes that handle flows that may eventually become significantly higher than at present.

Enhance the biological components of Van Campens Brook. In addition to filling in the open water features in the watershed, restoring the lakes to floodplain wetland meadows will help increase infiltration and groundwater flows that contribute to the brook and cool downstream baseflow temperatures. Cooler waters will reduce the threat of increasing temperatures beyond the thermal tolerance of the resident brook trout population and other aquatic organisms, and discourage the dominance of nonnative rusty crayfish, which prefer warmer waters. A diverse mix of broadleaf and evergreen tree and shrub species with broad thermal tolerance, high dispersal capabilities, and high fecundity will be planted adjacent to streams and wetlands. Planting a dense cover of shrubs and trees along the stream banks will help reduce sun exposure and water temperatures, and minimize the effects of predicted heat-waves. To create thermal refugia for aquatic organisms, overhanging shade structures will be placed along the stream banks, and riffles with deep pools will be designed into reaches of the stream. Nonnative trout will be eradicated to reduce competition with native species.

Conclusions

The foundation for all restorations is the implementation of traditional tactics to restore the wetland to predisturbance conditions. The approach recommended in this paper is to modify the traditional restoration tactics with those that will accommodate potential climate change effects that may occur in the future. Wetlands restored using only traditional tactics would not have the same opportunities to accommodate effects of climate change in the future. They would have the same opportunities as all existing natural or undisturbed wetlands that lack modifications to adapt.

The traditional on-the-ground design tactics that are meant to restore the physical and biological conditions of wetlands to predisturbance or natural conditions have been implemented for many years, and we can measure the success of these approaches. However, modifications of the physical and biological aspects of the traditional tactics aimed at facilitating adaptation and increasing resilience capacity to predicted adverse effects of climate change are currently based on unsubstantiated conjecture and best professional judgement. Without testing the cause-and-effect relationships between the climate change-related tactics and the actual progression of the adverse impacts, we may discover that the modifications end up being ineffective. Or, if the climate change effects fail to evolve as predicted, the climate change-related modifications could end up being ineffective. However, failure of some or all of the implemented climate change-related tactics would not adversely affect the evolving conditions of the restored wetland.

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