Constructed Wetlands for Brine Water Management

A CASE STUDY OF BULLARD REGULATING WETLAND (GOODYEAR, AZ)

Global Institute of Sustainability
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Goodyear, Arizona

A Case Study of the Bullard Wetland

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INTRODUCTION

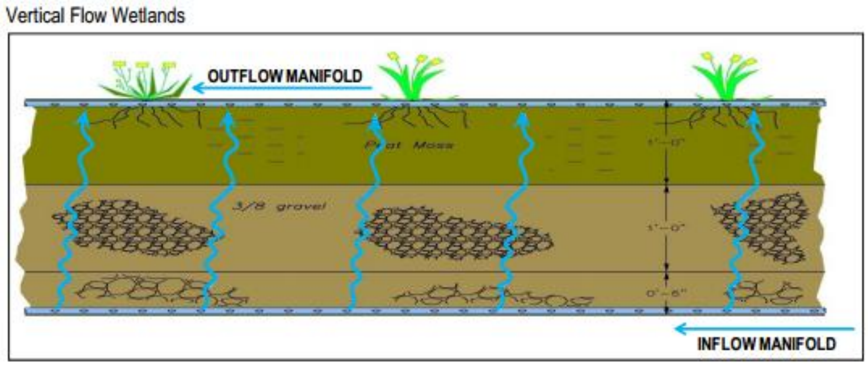
What is presented in this report? | One

With a projected increase in population of 115,300 total residents by 2020 and 167,700 residents by 2030 (City of Goodyear, 2014), the city of Goodyear will need to meet the demands of potable water for its growing community. Given that the city currently depends solely on groundwater to meet this demand and will remain heavily reliant, future pressures of limited supply will require innovative and effective means of treating and reusing this supply throughout the city. In light of these challenges, the City of Goodyear has embarked upon an experimental wetland system as a potential means to treat brine concentrated wastewater to be discharged into surface waters. This brine wastewater is a byproduct of treating salty groundwater for potable water purposes for Goodyear residents through the process of reverse osmosis (RO). Given the challenges for alternate means of treatment such as thermal driven evaporation processes or deep well injection, a constructed wetland presents an innovative, effective method for not only treating such brine wastewater, but providing a myriad of economic and social additional benefits as well.

With a projected increase in population of 115,300 total residents by 2020 and 167,700 residents by 2030 (City of Goodyear, 2014), the city of Goodyear will need to meet the demands for potable water for its growing community. Given that the city currently depends solely on groundwater to meet this demand and will remain heavily reliant, future pressures of limited supply will require innovative and effective means of treating and reusing this supply throughout the city.

The City of Goodyear's Bullard Water Campus pilot wetland, constructed in 2010, utilizes vertical flow to treat RO concentrate. In such a system, water is piped to the wetland using a vertical inflow pipe, flowing horizontally across the wetland through "a matrix of emergent vegetation" (see Figure 1 below) (City of Goodyear, n.d.). As the water flows across this matrix, the wetland plants extract toxins such as arsenic and selenium. Microbial communities attached to both the plants and soil mediums also support the extraction and transformation of nutrients and pollutants throughout the process. Finally, after extraction by microbial communities, soil mediums, and plants, the emergent water byproduct exits through an outflow pipe at the top of the wetland treatment area and is transported to its final destination (in the case of the Bullard Wetland project, into the sewer system (with the potential hope of being piped into the Gila River in the future)).

Figure 1. Diagram of a vertical flow wetland (CH2M Hill 2012)



This case study was developed as an initial report to inform the "scaling up" of the Bullard Wetland pilot project into a fully implemented wetland system. We present here an overview of the social, ecological, and economic components of such a system. In addition to presenting such analyses to inform full scale implementation, we have also developed an initial list of "social" indicators and sustainability targets to help the city assess the current state and track the future progress of its green systems and infrastructure as well as provide an overview of how such a full scale implementation can impact these systems. Finally, using these analyses, we present an initial recommendation of next steps to help the full scale implementation in the future.

Methodology | Two

The evaluations and assessments presented in this report were developed using an extensive literature review of scholarly sources, state and city documents, and additional organizational reports and publications. In addition, the data for the current state of green systems in Goodyear presented in the social assessment was developed using secondary statistical data analysis of data from city reports and databases. A full list of original sources for such data can be found in the References at the end of this report.

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ANALSYSIS OF THE WETLAND

Ecological Analysis |One

For our ecological assessment of using wetland for brine management in Goodyear, we will focus our examination on the following three ecological aspects that would be affected by wetland establishment: 1) the expected water quality of wetland outflow, 2) the potential vegetation biodiversity outcomes of treatment wetland establishment, and 3) the possible impacts that treatment wetlands can have on local wildlife.

Water Quality

As a part of the wetland pilot project conducted on the Goodyear Bullard Water Campus (GBWC), US Bureau of Reclamation (USBR) and City of Goodyear staff have been measuring the water quality outcomes of different wetland test bins to identify what combinations of wetland media and vegetation would best achieve brine treatment targets, as well as to estimate full implementation performance. While there are a wide variety of water quality parameters measured, the treatment parameters of primary concern have been Total Dissolved Solids (TDS), Arsenic, Chromium, Selenium, and Nitrates. Specific water quality targets were set for the parameters according to Arizona Department of Environmental Quality (ADEQ) surface water quality standards, although no specific quality target was set for TDS (Poulson et al., 2012). The selected water quality targets are shown in the figure below.

Figure 7. Water Quality Targets (Poulson et al., 2012)

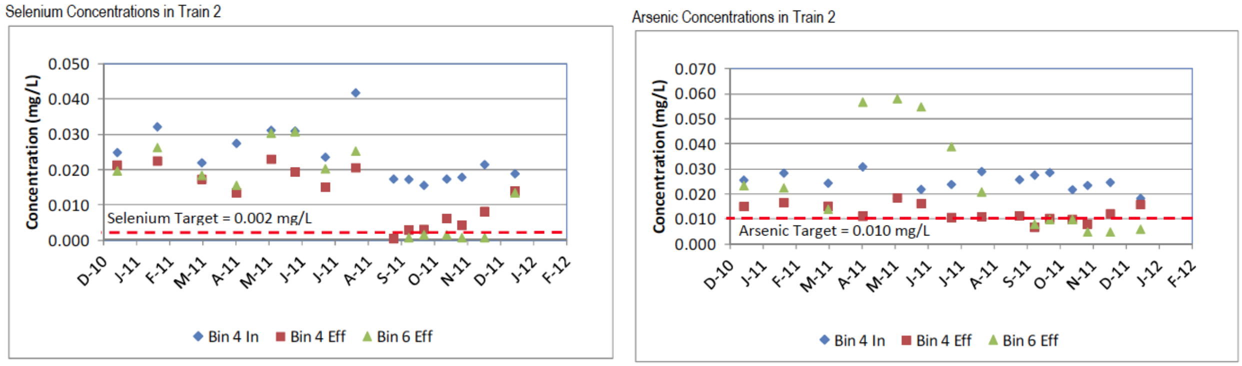
Water Quality Targets

Parameter	Unit	Limit	Standard*
Arsenic	µg/L	10	Domestic Water Source
Chromium (Total)	µg/L	100	Domestic Water Source
Selenium	µg/L	2	Aquatic and Wildlife Effluent Dependent Water
Nitrate	mg/L	10.0	Domestic Water Source

Notes:
*The standard with the lowest limit was selected for target values

After over a year of measurements, three wetland bins (Bins 2, 4, & 6) were identified as achieving superior treatment results. The bins, either separately or in combination, were able to achieve the desired water quality targets, although each bin's effectiveness varied over time according to seasonal and biological cycles. Examples of bin water quality measurements are provided below.

Figure 8. Selenium and Arsenic Concentrations (Poulson et al., 2012)



One issue which has been identified by the water quality measurements is that wetland treatment will not only be unable to reduce brine TDS levels, but also that wetland outflow will most likely be have higher TDS than incoming brine. This is due to the fact that the wetland treatment achieved negligible removal of salts (i.e. sulfates and chlorides) and evaporation rates were typically high (especially during summer months), resulting in an outflow with lower volume and consequently higher TDS values than the incoming brine. However, this is not considered a major obstacle for wetland establishment, as it has been determined that desired TDS levels can be achieved by mixing wetland outflow with wastewater effluent from the 157th Ave Water Reclamation Facility in a "mixing" pond or surface water wetland (Poulson et al., 2012).

More recent testing has focused on trying different combinations of the successful wetland bins to compensate for each bin's treatment variability in order to provide consistent year-round brine treatment outcomes. This additional testing has shown promising results, indicating that it is possible for a full-scale wetlands to achieve desired water quality targets year-round (D. Tosline, personal communication, November 17th, 2014). Based on the initial results from Bins 2, 4, and 6, a scenario model was created to project the performance of a full-scale wetland implementation. The results of this model are provided in the figure below.

Figure 9. Projected Wetland Performance (Poulson et al., 2012)

Projected Wetland Performance

Parameter (units)	Summer			Winter		
	Concentrate	Effluent	Removal	Concentrate	Effluent	Removal
Selenium (µg/L)	41.9	0.6	98.5%	19.0	2.0	89.4%
Arsenic (µg/L)	29.1	8.4	71.1%	18.4	9.2	50.1%
Chromium (µg/L)	43.0	6.0	86.0%	33.0	4.4	86.7%
Nitrate (mg/L)	56.0	0.5	99.2%	54.0	1.3	97.6%
TDS (mg/L)	7,450	14,534	N/A	7,840	9,629	N/A
Flow (mgd)	0.50	0.26	48.7%	0.50	0.41	18.6%

Vegetation

Natural wetlands are generally characterized by high levels of plant abundance and biodiversity, and constructed treatment wetlands usually prove to follow this trend as well. Even when initially constructed with only a limited set of plant species, new species often quickly find their way into and establish themselves in treatment wetlands. As an example, one constructed wetland in Florida which started with just 21 species reached a total of 185 plant species in just one year. However, there are also cases when vegetation has not fared well in treatment wetlands. In their third year after start-up, the Tres Rios Wetlands of Phoenix experienced the sudden die off of almost all their existing vegetation and experienced difficulties establishing replacement vegetation, with the exact cause remaining unclear (Kadlec and Knight, 2008; City of Phoenix, 2014). Due to these types of emergent outcomes with wetland vegetation, it is effectively impossible to fully know or fully control what the exact vegetation outcomes will be for a Goodyear wetland, although it can be posited that the high salt content of the brine inflow will act as the most significant barrier to vegetation establishment. However, the wetland pilot study on GBWC has identified multiple plant species that have survived quite successfully on brine inflow, including alkali sacaton, salt grass, cattails, and Olney's three-square rush, which suggests that the establishment of a diversity of vegetation is likely for a full-scale wetland (Poulson et al., 2012).

Wildlife

A wide variety of wildlife species from all taxonomic orders either frequently visit or completely rely on wetlands as habitat, so it is almost guaranteed that a certain degree of wildlife habitat provision will be an outcome of establishing a Goodyear wetland. However, the degree of this habitation can be significantly affected by the overall design of the wetlands. Various possible constructed design features can be used to encourage or discourage wildlife, and among treatment wetlands there are examples of both philosophies, with some attempting to attract wildlife and others trying to exclude wildlife (Kadlec and Knight, 2008). Depending on which design philosophy Goodyear followed in constructing their wetland, the amount of wildlife habitat provided could vary greatly. But even if Goodyear chose to try to exclude wildlife from the treatment wetlands itself, a certain amount of additional riparian wildlife habitat would still likely be facilitated from outflow being surface discharged into the Gila River, the current intended destination for wetland outflow.

While the positive impact of habitat provision is the most likely outcome that a Goodyear treatment wetland would have on wildlife, there are also possible negative impacts as well. One of course is the displacement of existing wildlife by the construction of the wetlands. But another far more concerning potential impact is the poisoning of wildlife by toxins that have accumulated within the treatment wetlands, which can and has occurred. An example of this took place in the treatment wetlands of California's Keterson Marsh, where bio-accumulated selenium ended up poisoning wildlife, causing birth defects, stillbirths, and deaths among multiple species (Lemly & Ohlendorf, 2002). However, such undesirable outcomes are the exception and not common among treatment wetlands, and can be avoided with proper ecological risk assessment and treatment wetland design.

Economic Analysis | Two

Ever since wetlands began gaining widespread recognition in the 1970s for providing valuable ecosystem services and possessing the capacity for wastewater treatment, economic evaluation methods for natural and constructed wetlands have experienced substantial development (Kadlec and Knight, 2008). One such method is found in the International Union for the Conservation of Nature's (IUCN) Wetland Assessment Toolkit, which provides a framework for identifying and categorizing the economic costs and benefits of wetlands, with primary categories of Direct Values, Indirect Values, Existence Values, Option Values, Management Costs, Costs to Other Activities, and Opportunity Costs (IUCN, 2009). However, for the sake of brevity, we will narrow our focus to just three aspects for our economic evaluation of wetlands for brine management in Goodyear: 1) the estimated direct capital and O&M costs of wetlands compared to alternatives, 2) the opportunity costs that might result from using wetlands, and 3) some potential risks factors that could cause additional secondary costs to arise during wetland establishment and operation.

Direct and O&M Costs

There is a considerable amount of existing data available for estimating the costs of implementing wetlands for water treatment, including research directly catered to Goodyear's specific regional context. As the amount of concentrate produced by RO water treatment plants in the Valley of the Sun is projected to increase dramatically in the coming decades, research has been conducted by the US Bureau of Reclamation (USBR), as a part of their Central Arizona Salinity Study (CASS), exploring various options for disposing the aggregate concentrate of these RO plants (including brine from Goodyear's Bullard Water Campus). These studies included detailed cost analysis comparisons of six concentrate management options that could be implemented in the region, with wetlands being one of the potential options. The result of these cost comparisons displayed strong evidence that wetlands would be the most economical choice for management as wetlands had the lowest annualized cost estimate, as well as the 2nd lowest estimates in both the capital and O&M cost categories, among the considered options. The following table and charts summarizes the cost analysis findings from CASS research assuming the processing of 10 million gallons per day of concentrate (Poulson, 2010).

Table 1. Cost of 10 MGD Concentrate Management (Poulson 2010)

Cost of 10 MGD Concentrate Management (millions of dollars)						
10 MGD	Regulating Wetlands	Yuma pipeline	Injection wells*	Soften/2nd RO/VSEP/EP	Evaporation ponds (EP)	Brine concentrator/EP
Capital	$150.22	$266.11	$114.46	$286.56	$651.69	$ 272.71
O&M	$1.75	$0.62	$11.31	$6.9	$3.5	$29.75
Annualized (50 years)	$10.37	$14.92	$17.46	$22.30	$40.26	$44.40

* No known site in central Arizona that meets criteria for concentrate injection.
Note. Adapted from Poulson, 2010.

Figure 2. Capital Cost of 10 MGD Concentrate management (Adapted from Poulson, 2010)

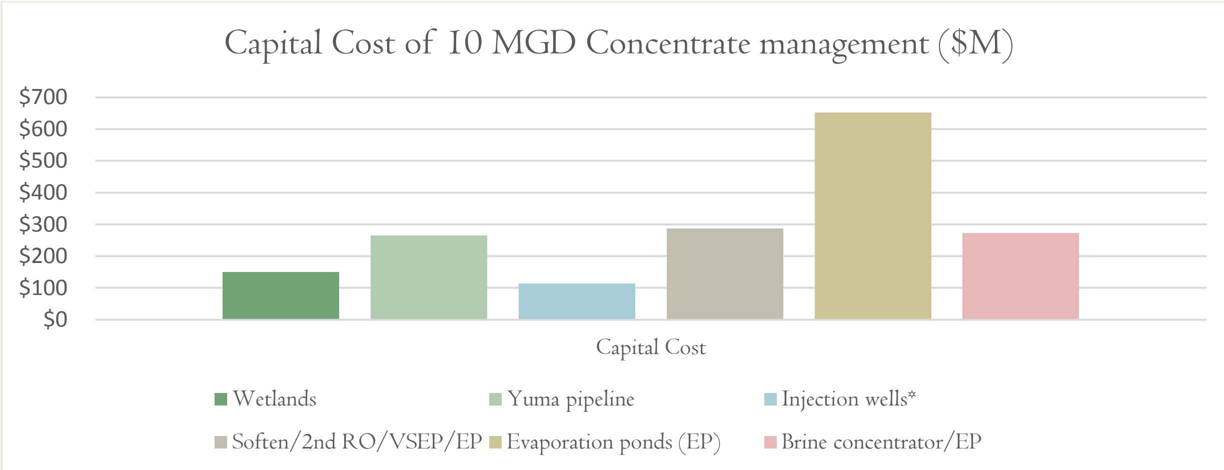


Figure 3. O&M Cost of 10 MGD Concentrate management (Adapted from Poulson, 2010)

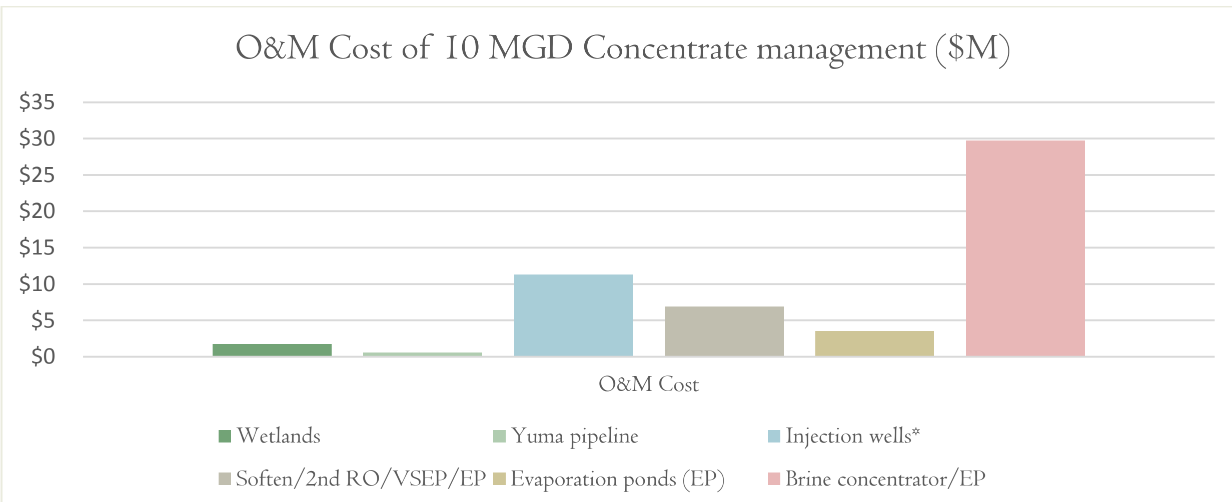
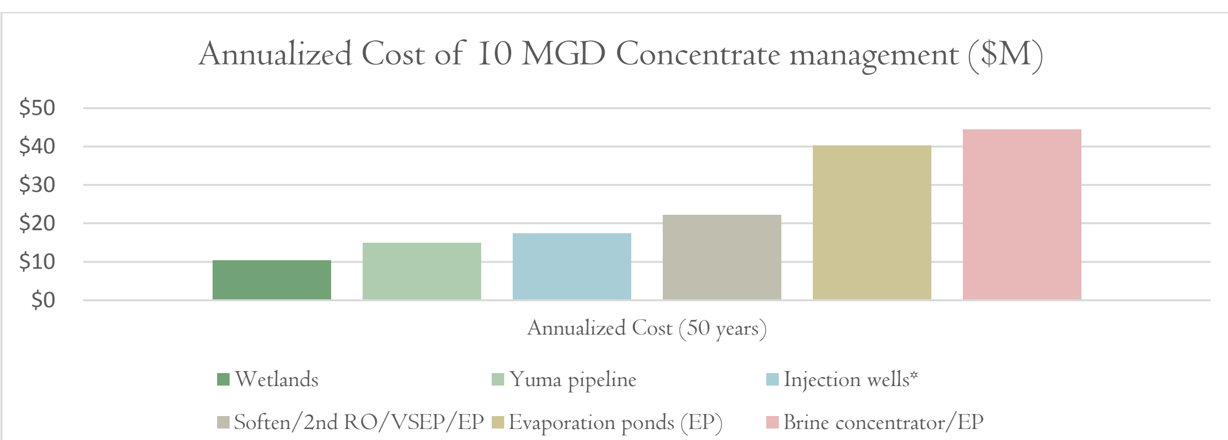


Figure 4. Annualized Cost of 10 MGD Concentrate management (Adapted from Poulson, 2010)



In addition to the CASS research, a wetland pilot study project report for Goodyear made by USBR and CH2M Hill, using standard cost equations for wetland construction derived from meta-analysis of already constructed wetlands (Kadlec and Knight, 2008), provided a preliminary cost estimate of $6,350,000 for a 19.5 acre regulating wetlands that could process the current max concentrate output of 0.5 MGD by the Bullard Water Campus, which is detailed in the table below (Poulson et al., 2012).

Table 2. Preliminary capital cost estimate for Goodyear regulating wetland (Poulson et al. 2012)

Preliminary capital cost estimate for Goodyear regulating wetland*	
Description	Cost
Media bed Subsurface flow wetlands (17.5 acres)	$4,200,000
Surface flow wetlands (2 acres)	$150,000
Sub-total	$4,350,000
Engineering and Permitting (15%)	$700,000
Contingency (30%)	$1,300,000
Total	$6,350,000
*Cost estimate does not include costs for siting or land acquisition. Note. Adapted from Poulson et al., 2012.	

Comparing the above capital cost with evaporation ponds, the most common brine management method for small quantity concentrate flows, a USBR model for the capital costs of an evaporation pond (which excludes costs of land and land clearing) to manage a 0.5 MGD concentrate flow estimates a capital cost range between a low of $1,419,000 to a high of $6,578,000. As for comparing land costs, an equation for determining evaporation pond size using concentrate flow rate suggests that around 70 acres of land would be needed to evaporate 0.5 MGD of concentrate (Mickely, 2006; Ahmed et al, 2000). The charts below provides a visual comparison of the capital costs and land area required of wetlands and evaporation ponds for managing 0.5 MGD of concentrate.

Figure 5. Capital Cost of 0.5 MGD Concentrate management (Adapted from Poulson et al., 2012; Mickely, 2006)

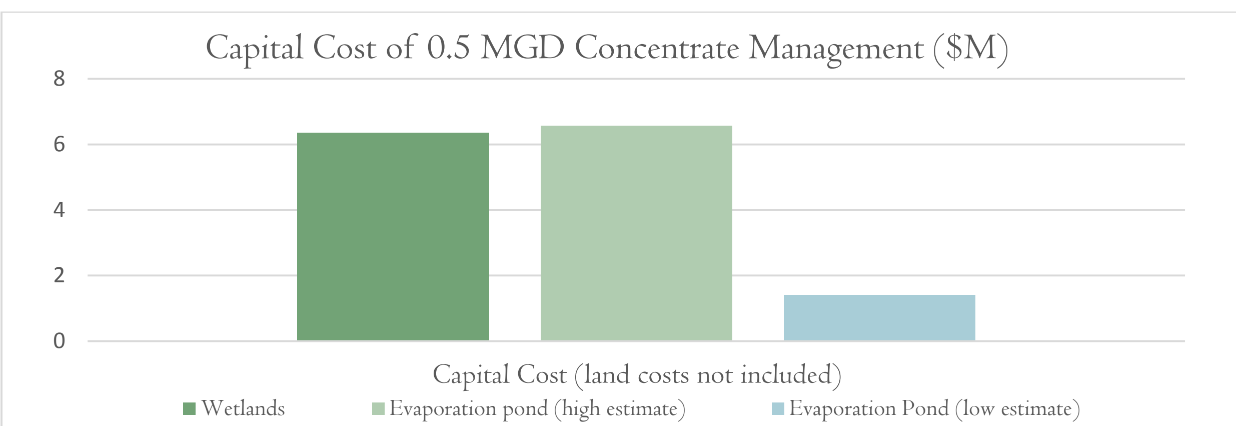
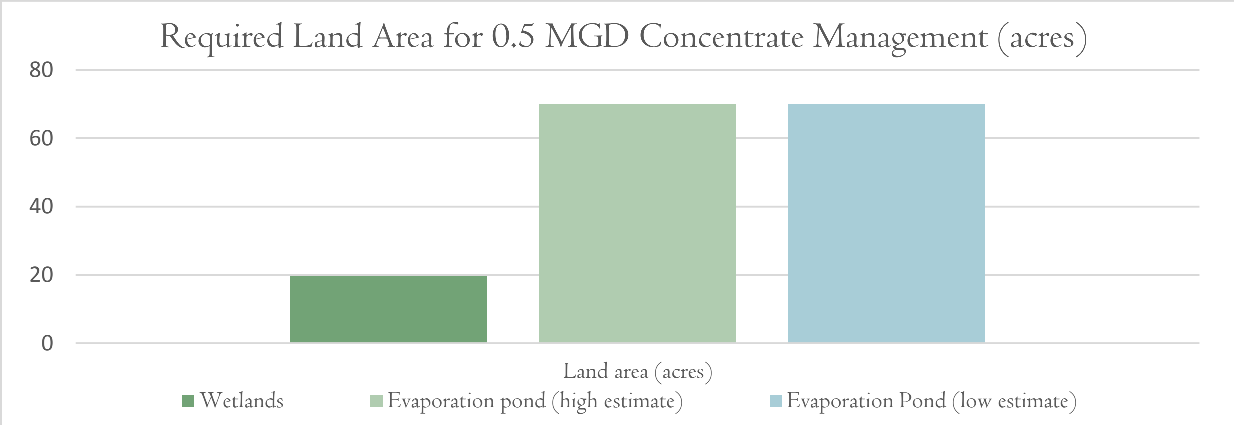


Figure 6. Required Land Area for 0.5 MGD Concentrate management (Adapted from Poulson et al., 2012; Ahmed et al., 2000).



As the charts show, wetlands do not compare as favorably to evaporation ponds in terms of capital costs at a 0.5 MGD concentrate flow rate; however, evaporation ponds require significantly larger amounts of land area than wetlands. This could, depending on the cost of land per acre, result in wetlands still being the cheaper option over evaporation ponds even with higher capital costs.

Opportunity Costs

When examining opportunity costs, there are indications that wetlands potentially have much lower opportunity costs on land and economic activity than other brine management alternatives. This is due to the fact that wetlands can potentially be constructed on land that would not be viable for use by other brine management alternatives due to environmental concerns, such as areas next to riparian zones, on floodplains, and within nature parks or reserves. Siting wetlands in such areas requires additional planning and regulatory approval, but there are already several existing cases where wetlands have been successfully built in such areas (Kadlec and Knight, 2008), and doing so would allow the wetlands to avoid occupying land could otherwise be used for more economically valuable activities. However, it is likely that wetlands would have higher opportunity costs in terms of time and human resources. As wetland design, construction, and operation involves carefully combining both biological and mechanical processes, it may require additional personnel, expertise, and time before the wetlands are completed and operational than in the case of other more straightforward alternatives.

Risk Factors

The following example risk factors which could bring about additional secondary costs were identified by reviewing available case studies and literature detailing wetland operations across the United States. Particular attention was paid to the experiences of existing Arizona wetland projects, specifically the Tres Rios Wetlands of Phoenix and the Sweetwater Wetlands of Tucson. These risks are not comprehensive nor guaranteed to manifest, and only serve as a short list of potential factors that were ascertained to be of possible concern to Goodyear.

The first risk factor is vector control, which is a common issue arising with open surface water wetlands as they can become spawning grounds for disease carrying insects such as mosquitoes. Both Tres Rios and Sweetwater have had to implement mosquito control measures to manage this risk (Kmiec & Thomure, n.d.; City of Phoenix, 2014; City of Tucson, 2014). However, vector control may not be as much of a concern for Goodyear, as the proposed vertical flow design for the Goodyear wetlands would likely minimize mosquitoes, as the majority of water would remain subsurface, although vector control issues may not be eliminated completely.

The second identified risk factor is extensive vegetation management to sustain optimal wetland function and conditions. As vegetation can play a significant role in water treatment as well as greatly affect mobility within wetlands, careful management is often required. These management activities can include clearing to maintain accessibility to wetland maintenance points, removal and replacement after unexpected die offs, and controlled burns to manage overgrowth. Both Tres Rios and Sweetwater have had to carry out various vegetation management measures in order to maintain desired wetland efficacy (Kmiec & Thomure, n.d.; City of Phoenix, 2014; City of Tucson, 2014).

The third risk factor is managing invasive species and wildlife activities which can disrupt the treatment functions of wetlands. As there sometimes needs to be a specific combination of structural and biological wetland components to achieve water treatment goals, any species and activities that can drastically modify these components can undermine treatment effectiveness (Kadlec and Knight, 2008). Tres Rios personnel have had to deal with both an invasive tree species displacing preferred wetland species as well as excessive beaver activity interfering with wetland operations (City of Phoenix, 2014). As the Goodyear wetlands will most likely be located not far downstream from Tres Rios, it is possible similar issues will arise. Although, once again, the proposed vertical flow design of the Goodyear wetlands might reduce this risk factor to a certain degree, as subsurface water is less likely to attract disruptive wildlife like beavers.

The fourth risk factor is liabilities that can arise when legally protected wildlife is threatened by wetland operations. Even if constructed wetlands are not intended for wildlife habitation, wetland owners are still legally responsible for impacts on wildlife and can be prosecuted under laws such as the Migratory Bird Treaty Act and the Endangered Species Act. One example of this occurred at Keterson Marsh in California, where accumulated selenium from water treatment poisoned wildlife and resulted in the wetland becoming designated as a contaminated landfill and a new wetland having to be constructed in order to offset lost wildlife habitat (Lemly & Ohlendorf, 2002). Another example is in Florida, where stormwater treatment wetlands have had to modify their operations in order to avoid disturbing protected birds that nested in the wetlands (SFWMD, 2008).

The final risk factor addressed here (which is not drawn from other wetland examples, but from Goodyear wetland pilot study research) is the frequency of wetland media saturation and replacement. The proposed design of the Goodyear wetland revolves around water passing through an organic media that will act as the primary filtration mechanism for removing water contaminants. However, pilot study research shows that the media will eventually reach a saturation point and would require replacement to maintain water treatment. It is currently unclear what the time frame would be for such media saturation. If further research shows that the media would require frequent replacement, then the cost of wetland maintenance could rise significantly.

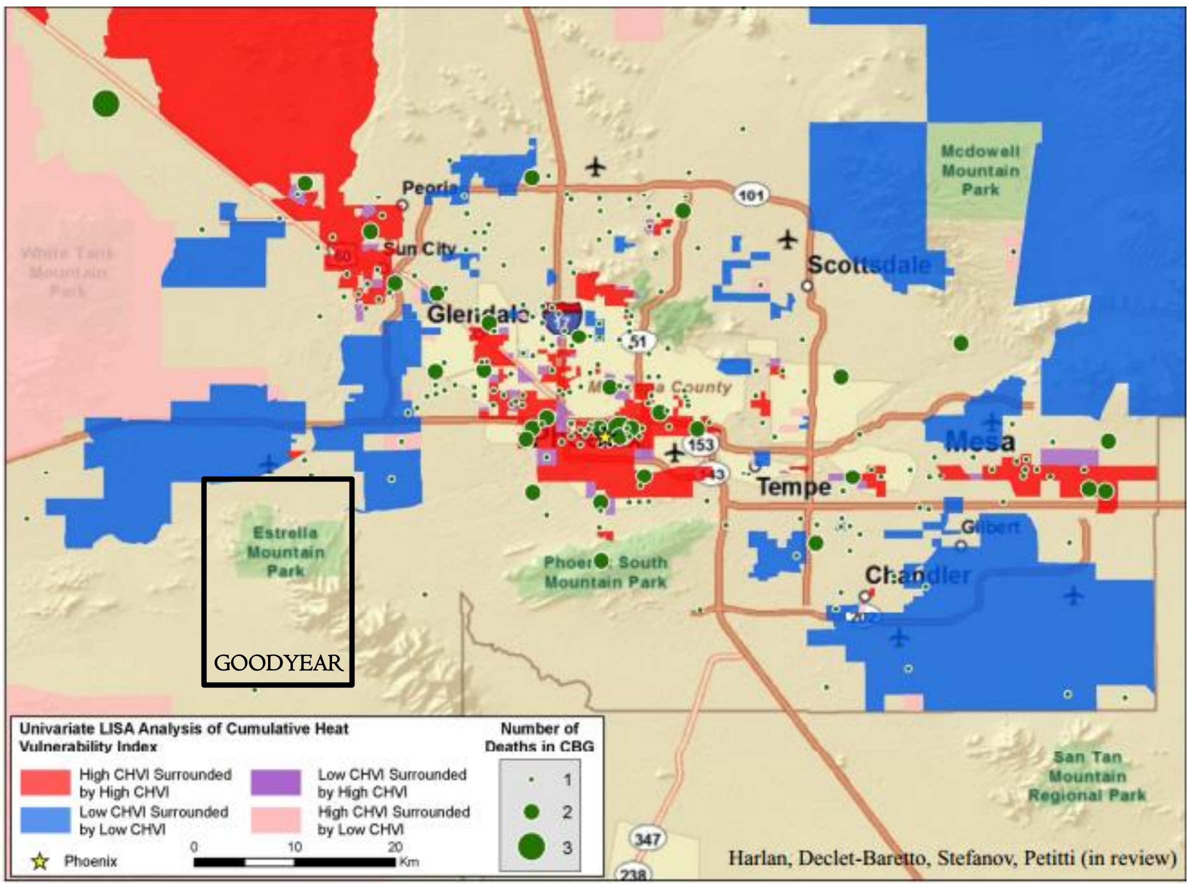
Social Analysis | Three

Quantifying the social benefits for an ecological asset such as a wetland can be challenging. However, we provide here a compilation of indicators, targets, and current city data to assess the current state of "sustainability" for green systems in Goodyear. The assessments of Goodyear against these indicators and targets is also used to provide context in which the construction of a full scale wetland could help to meet or exceed these sustainability thresholds in the future. Assessment of the sustainability/unsustainability of the current state of Goodyear is based on comparison of current state data (for each indicator) to the identified targets drawn from literature and best practices from around the world (distance-to-target analysis). If the city meets or exceeds the sustainability threshold, the assessment is labeled with a green box. If the city does not meet the threshold, it is labeled with a red box. Data that is unavailable for the city of Goodyear is labeled with a NA and a grey box. Finally, these indicators can also be used in the future to assess the social impact of the constructed wetland as a best practice in desert cities.

Urban parks, open space, and green elements in living environments have multiple social benefits for physical and mental health (Ulrich, 1984; DeVries et al., 2003). Parks and open space give people opportunities for outdoor recreation and activity, improving health and overall wellbeing. The integration of wild or semi-wild nature into cities supports biodiversity (Beatley, 2010; Faeth et al., 2011), which is essential for human health and our ability to flourish as a species (Chivian & Bernstein, 2008). For Goodyear, the percentage of parks and green open space currently exceeds the identified sustainability threshold based on literature (Kuchelmeister, 1998; Wang, 2009; Beatley, 2011). However, with the projected population growth of the city for 115,300 total residents by 2020 and 167,700 residents by 2030 (City of Goodyear, 2014), these percentages are predicted to drop to an unsustainable threshold by 2030. In addition, the city also sits well below the sustainable threshold for miles of walking and biking trails per 1,000 people. In order to provide equitable access to parks and green open spaces for their residents in the future, Goodyear must look to increase these public spaces to match this population growth. The addition of a 15 acre wetland alone for the city would, by no means, allow the city to meet the sustainability threshold (Wang, 2009; Beatley, 2011) by 2030 (this would increase the projected rate to 88 ft^2/person versus 85 ft^2/person, still well below the minimum threshold of 97 ft^2/person), but it would provide augmented public space as an approach to meeting both the green spaces and walking/biking trails targets. In addition, although the city provides well above the threshold for nature preserves for residents to hike, run, and bike, a public wetland could only serve to increase this level and situate the city as one of the most attractive places for recreation in the Valley. Finally, the construction of a wetland can help to meet most, if not all, objectives of the Goodyear Parks, Recreation, Trails and Open Space Master Plan.

A flourishing urban forest is critical for the social, economic, and environmental health of a city. Elements such as green spaces and vegetation are utilized to create comfortable and cool spaces throughout a city. Wherever exposed and non-shaded pavement and rooftops exist, there will be higher surface temperatures in the warmest part of the day (Stone et al., 2001; Carlson et al., 2008; Houston Advanced Research Center, 2009). This is known as the Urban Heat Island Effect. Although data for surface temperatures in the city is unavailable, past research on the UHI Phoenix has revealed dangerous temperatures throughout the Valley (Baker et al., 2012). The map in Figure 7 (see below) provides an overall analysis of the current Cumulative Heat Vulnerability Index (CHVI) as well as the number of heat-related deaths throughout Maricopa County from 2000-2008. Although Goodyear is designated with a mostly low CHVI (with a small area of high CHVI) and only two heat-related deaths within the city for this time period, this is projected to increase as development throughout Goodyear increases (Harlan, 2012). If the city of Goodyear aims to combat the UHI and protect its residents from its dangerous effects, Goodyear must look to increasing shade through various means, especially through an increased urban forest or tree coverage. The city of Goodyear does not meet the identified sustainable threshold of 25-40% total tree coverage (American Forests, 2002; City of Phoenix, 2008), sitting at a 1.4% for the entire city (Jones et al., 2014). The sustainability threshold of 25-40% of tree coverage presents a conflict between water conservation (as discussed below) and landscaping: lower water use is good for water conservation, whereas higher water use improves the local landscape and thermal comfort. This trade-off must be carefully analyzed for project implementation in the future. However, despite this conflict, urban forests improve the quality of urban life in many ways (Kuchelmeister, 1998). Goodyear recognizes the importance of investing in urban forest, and notes in their Preliminary Tree Plan (Jones, 2014) that such investment can clean the air, increase biodiversity, address UHI, decrease energy costs, increase property values, and reduce stormwater runoff and Goodyear's carbon footprint. However, the current rate of 1.4% tree canopy has significant implications for health and biodiversity throughout the city. Without tree coverage, shade is minimal throughout Goodyear, magnifying the UHI effect and creating areas of high surface temperatures. These high temperatures have significant impacts on heat-related illness and air quality in the city. The lack of tree coverage greatly reduces the amount of natural habitats for additional plant and animal species, reducing overall biodiversity potential for the city. The construction of such a wetland in the city would not only be beneficial in increasing the amount of vegetated land that can contribute to lower surface temperatures (as compared to asphalt surfaces), but provide an environment in which trees conducive to a wetland environment could contribute to a growing tree canopy for the city. In addition to increasing shade, these wetland trees can also provide habitats for birds and other wildlife to be enjoyed by visitors year-round.

Figure 7. Spatial clustering of Cumulative Heat Vulnerability Index and heat-related deaths in Maricopa County census block groups of decedents' residence (2000-2008) (Harlan, 2012)



Finally, Goodyear has recognized the threat of water scarcity throughout the city (Sakal 2014). Currently, residential water use both indoor and outdoor sits at 92.8 gallons per day per person (with an indoor water use rate of 50 gallons per day per person) (Sandra Rode, personal communication, December 1, 2014). Although the city meets the AZ Department of Water Resources efficiency targets, these water use rates (60/31.5 gal/day/person respectively) sit far above the identified sustainability thresholds (Soyocool et al., 2001; U.K. Department for Environment, Food and Rural Affairs, 2008). In addition, in the 2085 Goodyear Water Master Plan, with the city's projected build-out of 800,000 residents in the future, the city is expected to experience a shortfall of 100,000+ acre-feet per year (afy) for both potable and non-potable water as ground-pumping increases and CAP resources are used for potable water supply only (M. Holmes, personal communication, October 21, 2014). In the Master Water Plan, the city proposes a reduction of waste brine as a potential strategy for meeting the demands for potable supply. However, with the projected population increases as well as the projected increases in brine wastewater of 1 million gallons of brine in the Goodyear area, this strategy may not be feasible. In addition, to meet the growing demand for water, Goodyear will have to tap into the Rainbow Valley supply given that the maximum water available to pump in Goodyear is only 8,700 afy. With approximately 10,000 acre-feet per year available for Goodyear use in Rainbow Valley, treating this groundwater supply will likely result in an additional 1.77 million gallons per day of waste brine that needs to be treated before it can be returned to surface water (Brown and Caldwell 2014). Additional build-out water may need to come from, for example, additional Colorado River contracts, leases with Native American entities, exportation from other basins, and field fallowing in Yuma, AZ., etc. Water originating from these sources may or may not need to be treated using RO. In light of these projections, a decrease in brine outflow appears to be impossible. Thus, the scaling up of the wetland project would produce a feasible option for treating and re-using this water for irrigation and landscaping purposes, reducing the overall demand for pumping groundwater to meet the growing demand for potable water for the city.

Constructing the Goodyear wetland, if opened to the public for use, can provide a myriad of other social benefits to the Goodyear community. The ecological, biochemical, and hydrological functions of this type of wetland directly supports important social components for the city. Hogan et al. (n.d.) identify that wetlands, in addition to the primary ecological benefits of reducing pollutants in wastewater (or in this case, brine), can provide areas for wildlife conservation. The use of native flora and fauna as well as the protection of biodiversity within the wetlands can supply a myriad of educational opportunities for local schools. Arizona currently boasts a total of two wetlands, one being the Tres Rios wetland project. With the limited number of wetlands in proximity to Goodyear residents, the construction of a wetland would provide valuable access for schools to expand on-the-ground, applied, and project-based educational opportunities for students and expose these students to a diversity of ecosystems.

In addition, the Goodyear wetland can open up access to recreational activities such as bird watching, hiking, and fishing if opened to the public. Other than Tres Rio, Goodyear residents have no areas in the vicinity for bird watching activities. In the 2014 National Citizen Survey for Goodyear residents, 89% of residents identified that improving green space was essential to their quality of life (City of Goodyear 2014). In addition, a 2006 US Fish and Wildlife Service report identified over 1,000,000 birdwatchers in the state of Arizona, 25% of which are tourists (US Fish and Wildlife Service, 2006). Constructed wetlands to treat municipal wastewater in both ShowLow and Pinetop, AZ have shown diverse benefits in attracting birds such as Stellers jay and western bluebird as well as other wildlife such as coyotes and various kinds of amphibians. Both wetlands boast a high number of visitors as well as educational opportunities. In addition, Ghermandi (n.d.) identifies that land value increases when the land is integrated with recreational activities in nearby water resources. Mosaic patterns of vegetation, open water, and wildlife can create an attractive landscape enhancement that can increase the value of nearby urban development sites (Ghermandi, n.d.). The proposed Goodyear wetland, if opened to the public, could not only provide a direct source of revenue for the cities due to increased visitors for recreational purposes such a bird watching, but could foster future development throughout the city given its attraction from this type of amenity.

Finally, wetlands can also provide sites of not only landscape enhancement, but cultural importance (Hunt et al. 2011). Nassauer (2004), in her work evaluating the success of a wetland restoration project in Minnesota in terms of the cultural and ecological functionality, found that cultural significance of such an amenity was directly related to the perceived attractiveness (plant species and bird species richness) of the natural landscape context. A wetland for Goodyear that incorporates planned design for such richness can contribute to engraining such an amenity into the cultural context of the city and contributing to an overall distinct and unique sense of place. However, this case study is designed as a beginning to analyzing such social components of such a proposed wetland. It is recommended that the city conducts a series of workshops and/or contingent valuation surveys to provide an evaluation of social values such as cultural significance of such an amenity for Goodyear residents and the city overall.

Table 3. Indicators and Targets for Green Systems in Goodyear, AZ (Adapted from Golub et al. 2014)

Indicator	Definition	Target	Goodyear Data	Assessment
Water Consumption				
Potable water	Average indoor residential use	>31.5 gals/day/person	37-50 gals/day/person	
	Average person residential	>60 gals/day/person	92.8 gals/day/person	
	Average industrial and commercial use	NA	92.6 gals/day/person	
Urban Heat Island				
Surface Temperatures	Percentage of District >130°F Percentage of District <105°F	<1% >10%	NA	
Asphalt surface parking	Percentage of District that is asphalt surface parking	<20% of off-street parking	<20%	
Quantity and Quality of Green Systems				
Urban forest	Percentage of District covered by trees	25—40%	1.4%	
Parks and green open space	Ft²/person of parks and green open space	97—215 ft²/person	~195 ft²/person	
			By 2020: 124 ft²/person	
			By 2030: 85 ft²/person	
Native natural environment	Percentage of District that is nature preserves	10% (Phoenix: 10.15%)	31-62%	
Walking and biking trails	Mi of walking trails/1,000 people	1 mi/1,000 people	0.65mi/1,000 people	

Sources: (Soyocool et al., 2001; Bryan, 2001; U.S. Green Building Council, 2008; Houston Advanced Research Center, 2009; Beatley, 2011; Land Use Law center, 2013; Kuchelmeister, 1998; American Forests, 2002; City of Phoenix, 2008; Wang, 2009; Beatley, 2011; Bithas, 2007; Todd Engineers 2010; City of Tucson 2014; Brown 2011)

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RECOMMENDATIONS

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Moving forward, the city of Goodyear would be best suited to pursue a phased, full scale implementation of the wetland project. Given the ecological success of the pilot project, a full scale wetland would provide the city an effective means of treating increasing volumes of brine wastewater due to projected increases in water demand. Given the additional ecological risks of invasive species, risks of toxins to wildlife, and eventual saturation of soil medium, it is recommended that the city conduct a series of scenario-based ecological assessments and designs in order to anticipate and overcome/address any challenges.

Economically speaking, with the projected increase in population, water demand, and brine wastewater volume in the coming years, the use of a full scale wetland provides the best financial option. If the city's wastewater output were to remain at the current levels of 0.5 MGD, evaporation ponds would potentially be a viable, if not less expensive option for Goodyear. However, these levels will undoubtedly increase in the future and at or above a level of 1.0 MGD per day, evaporation ponds or any other treatment alternatives become exponentially more expensive when compared to a wetland. The city may experience additional costs associated with a full-scale wetland implementation such as vector control and invasive species, but further scenario-based economic evaluations for the city would provide a pathway to anticipate and develop coping strategies for such barriers.

Finally, not only would the construction of a wetland help to meet most, if not all, objectives of the Goodyear Parks, Recreation, Trails and Open Space Master Plan, a public space such as this would provide additional amenities for hiking, biking and walking for both residents and visitors. Siting a full scale wetland in order to capitalize on existing infrastructure and foster a connected green system can benefit Goodyear in several ways. For example, implementing the project in locality to the Estrella Mountain Park in Goodyear would not only expand the recreational opportunities for the area, but would attract a large amount of visitors (both local and tourists) and could provide additional areas for educational and family-oriented activities and programs. Additionally, linking a wetland to the park could build a connected habitat thoroughfare for wildlife and encourage a diverse range of birds and other animals, attracting additional economic activities such as bird-watching. This amenity could also help increase land and home values surrounding the Estrella Mountain Park area as well as attract additional economic activity in the vicinity.

Moving forward, it is recommended that the city not only conduct additional economic and ecological assessment and evaluations, but evaluate the social benefits of the specific Goodyear wetland project using a series of workshops and/or contingent valuation surveys. These types of surveys and workshops should be designed to assess how open the community is to such a project, what types of recreational activities associated with the wetland residents and visitors would be interested in, and their willingness to pay for such an amenity. This type of assessment could be used to inform design and strategy implementation for the wetland in the future.

Despite the presence of additional risks such as the unintentional creation of a legally protected habitat for wildlife, implementing a wetland that is designed for both wildlife and recreational activity provides benefits that perhaps far outweigh the costs associated with such risks. The possibility of a full scale constructed wetland provides exciting opportunities for the city of Goodyear. If designed carefully, this wetland could help define the city as a top destination in Arizona and help create a unique sense of place for Goodyear.

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