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Using Envision to Assess the Sustainability of Groundwater Infrastructure: A Case Study of the Twin Oaks Aquifer Storage and Recovery Project

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Abstract: The ISI (Institute for Sustainable Infrastructure) Envision rating system is designed to be a comprehensive sustainability assessment that can be applied to a wide range of infrastructure projects, including water supply. With water supply resiliency, a prominent concern in many arid and semi-arid regions, the implementation of a water sustainability metric would be beneficial to both regulators and planners. This review seeks to assess the merit of applying Envision to water infrastructure projects specifically designed to enhance supply resiliency by retroactively rating the San Antonio Water System (SAWS) Twin Oaks Aquifer Storage and Recovery (ASR) project. In this review, we find that the novelty and innovation inherent in ASR is largely overlooked by Envision, which often does not evaluate sector-specific concepts. Furthermore, the project-oriented focus of Envision does not analyze water supply systems, or any infrastructure system, as a whole. This paper proposes that a water specific sustainability index be used in conjunction with Envision, to more specifically address concerns for water supply.

Keywords: groundwater management; rating systems; sustainability index; managed aquifer recharge; water supply

1. Introduction

The general concept of sustainability emerged in research in the 1980s and has since been applied to concepts in water management [1]. Mays [2] defines water sustainability as "the ability to use water in sufficient quantities and quality from the local to the global scale to meet the needs of humans and ecosystems for the present and the future to sustain life, and to protect humans from the damages brought about by natural and human-caused disasters that affect sustaining life".

Long-term sustainable-use water supply is a major challenge in arid and semi-arid areas that have limited precipitation and high rates of reservoir evaporation. The scarcity of surface water leads to groundwater exploitation and mining, especially during times of drought [3]. Despite progress in groundwater research, aquifer depletion has not slowed [4,5]. Mays [6] attributes these difficulties to a confusion of safe yield and sustainable yield, assured water supplies, sustained growth, and a lack of consideration of climate change. Misconceptions of safe yield alone have led to what Bredehoeft [7] called the "water budget myth". It will likely take the combined usage of traditional knowledge and modern technology [6] in conjunction with improved understanding to prevent water sustainability crises.

To better quantify and understand water sustainability, various indices have been developed. However, there are inherent challenges associated with creating an index which must simultaneously: quantify subjective criterion, be broadly applicable, mitigate controversial subject matter, and avoid arbitrary valuations [8]. Sandoval-Solis *et al.* [9] have developed a water sustainability index based on management policies and mostly focus on technical aspects of sustainability; however, no environmental, social, or economic criteria are included [10]. In groundwater, different methods have been used to overcome the challenges associated with creating a water sustainability index and have included: analytic hierarchy processes in conjunction with information entropy theories [11], fuzzy logic [12], groundwater footprints [4], and an unweighted composite index [13].

Despite their existence, no groundwater sustainability indices have achieved wide acceptance or usage [11]. For this reason, using a previously established comprehensive sustainability index could provide a needed solution. A popular index for rating environmental sustainability is Leadership in Energy and Environmental Design (LEED) [14]. However, LEED was designed as a building rating system and is inappropriate for rating large-scale infrastructure. It also does not incorporate important aspects of social sustainability [15] or life-cycle analysis [16] and is criticized as "incorporating greenness as a way to increase profit" [17] (p. 631).

Envision, created by the Institute for Sustainable Infrastructure (ISI), has been designed to provide a broad sustainability framework capable of being used for rating the sustainability of a variety of infrastructure projects. The goal of Envision is to increase sustainable performance within the "three pillars of sustainability": social, environmental, and economic. Ratings are assessed in five major categories with 60 different credits designed to cover all aspects of sustainability with a holistic approach [18]. Because not all credits are intended to apply to all projects, a fairly low percentage of points are required to receive an Envision award, as shown in Table 1. Only 50% of points are required to receive the highest award in Envision [19], which is low compared to the LEED requirement of over 80% [20].

Table 1. Comparison of Envision and LEED award levels [19,20].

Envision Award	% Required	LEED Award	% Required
Bronze	20	Certified	40
Silver	30	Silver	50
Gold	40	Gold	60
Platinum	50	Platinum	80

Envision allows for flexibility and adaptation by design. However, such a broad focus may also be a liability. A number of conference proceedings have been published on Envision [21–23], the most detailed of which was done by the ASCE (American Society of Civil Engineers) Task Committee on Sustainable Design of Pipelines [24]; however, none of them offer a broad evaluation of Envision's merit. The objective of this paper is to assess the merit of using the Envision rating system for a certain class of projects related to groundwater and water supply infrastructure. To this end, Envision was used to retroactively rate the San Antonio Water System (SAWS) Twin Oaks Aquifer Storage and Recovery (ASR) Facility completed in 2006. This case study allows an assessment of what aspects of groundwater sustainability are included in Envision as well as what it may be lacking.

Study Site: SAWS Twin Oaks ASR

The SAWS service area includes all of San Antonio, the majority of Bexar County, and parts of Medina and Atascosa counties in Texas, and provides water to 1.65 million people, shown in Figure 1. In 2012, residents used water at a rate of 0.54 m^3 per day per person, combining to use 8.9×10^5 m^3 per day. With population within the service area expected to grow 70% to 2.80 million by 2070, SAWS has a continuing need to expand its water supply and mitigate anticipated droughts [25]. The Trinity, Carrizo, and Edwards aquifers, in conjunction with multiple surface reservoirs, are the source for the water supply.

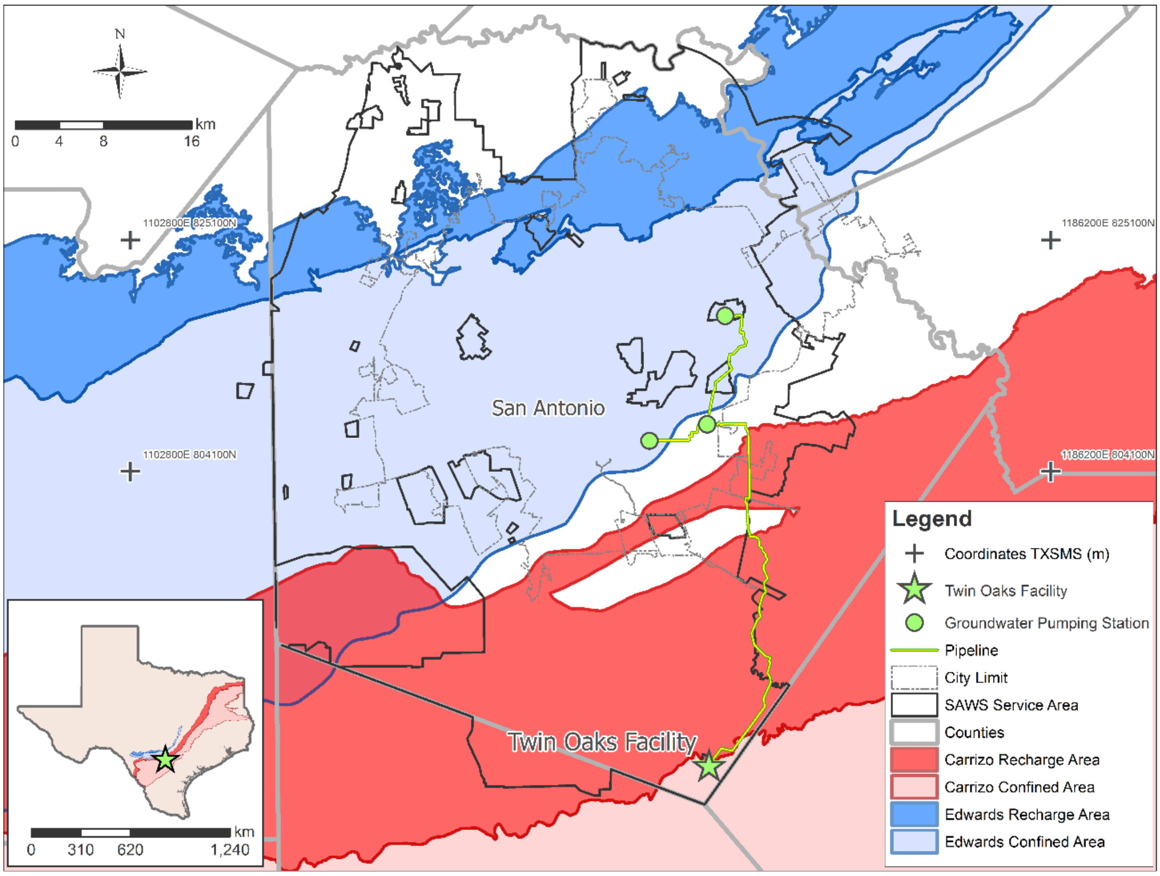

Figure 1. The Twin Oaks Facility in Bexar County, Texas. Data courtesy of SAWS, Texas Natural Resources Information System (TNRIS), Texas Parks and Wildlife Department (TPWD).

In the past, San Antonio has relied entirely on the Edwards Aquifer for its water supply [26]. The Texas Senate established the Edwards Aquifer Authority (EAA) in 1993 and mandated a reduction in pumping [27]. By 2012, SAWS reduced its dependence on Edwards Aquifer water to just 46% of its total, or approximately 140 million cubic meters [25,28,29].

A challenge inherent in using the Edwards Aquifer has become the variability of allowed withdrawals. During wet years, SAWS is permitted to use more water than it may immediately need to supply its users [30]; any unused allocations are then lost. During dry years, water allocated for SAWS use may not be available due to pumping restrictions. Therefore, the reliability and long-term sustainability of a water supply system dependent on using the Edwards Aquifer is dramatically improved by the Twin Oaks ASR facility, shown in Figure 2. Twin Oaks takes water from the Edwards Aquifer and stores it in the more stable Carrizo sandstone aquifer [31] for seasonal recovery during peak demand [32]. With storage at Twin Oaks, SAWS is able to store unused Edwards Aquifer allocations for later access. This storage acts to buffer against seasonal fluctuations or even future policy changes for the Edwards aquifer.

The high hydraulic conductivity in the Edwards leads to a wide fluctuation in aquifer discharge from wet to dry periods, much like a river [33,34]. Pumping of the Edwards Aquifer is controlled by the EAA which is required by Texas law to maintain specified spring discharge rates and groundwater levels in index wells [27]. The purpose of such monitoring is to preserve multiple endangered species [35] that rely on Edwards Aquifer spring flow for habitat [36]. Thus, the SAWS permitted withdrawals of 363 million cubic meters per year are reduced if water levels or spring flows cross critical thresholds and then increased again when water levels rise [25,28].

The Edwards Aquifer is a highly karstified confined aquifer that has high conductivity of up to 305 m/d [33]. The Edwards formation has a depth 260 to 290 m below the water extraction sites and has a maximum thickness of 165 m [37]. The aquifer is a dissolution-modified and faulted limestone [38] consisting of the Kainer and Pearson formations of the Edwards group in addition to the overlying Georgetown limestone [26,39,40]. Aquifer flow is predominantly from west to east and is fed by direct infiltration and streamflow seepage within the recharge areas [40]. The Edwards Aquifer has high water quality and often can be consumed without treatment. A major source of potential water contamination is urban runoff, leaks, and spills associated with urbanization [41], which would be exacerbated by macropores and the aquifer's high conductivity [40,42].

Figure 2. An aerial photograph of The Twin Oaks facility. Pictured are storage tanks, cascade aerators, dual media filters, solids contractors, and settlement ponds. Much of the surrounding farmland around Twin Oaks is also owned by SAWS (Imagery and Map Data, [43]).

The Carrizo formation is 60 to 125 m below the site and forms a confined aquifer with a thickness of 213 to 244 m [32]. The Carrizo also has a lower hydraulic conductivity than the Edwards, 3×10^{-3} to 43 m/d [44], making it suitable to keep stored water on-site [32]. Water from the Carrizo aquifer is considered lower quality than the Edwards aquifer with a pH of 5.5 and high levels of iron, hydrogen sulfide, and manganese and so must be treated before consumption [32]. For cases when the Edwards water mixes with the native Carrizo water, Twin Oaks includes cascade aerators to oxidize iron and hydrogen sulfide, lime softeners for hardness and pH, flocculation and sedimentation tanks for dissolved solids, and dual media filters to treat water.

ASR has numerous sustainability benefits beyond providing a reservoir for storage of water. For example, ASR can reverse declining groundwater levels [45,46], which have previously been an issue for the Carrizo–Wilcox Aquifer [31]. In addition, water stored in the subsurface is also subject to less leakage than surface reservoirs and has no evaporative losses [47,48]. In the San Antonio–Nueces coastal basin, mean evaporative losses amount to 148 cm per year, thus storage of water without evaporation losses would preserve a large quantity in Texas.

The Twin Oaks facility has 29 injection/recovery wells and 112 million cubic meters of storage, making it the third largest ASR facility in the nation [25]. Maximum injection since construction has been 2.2 $\times$ 10^5 cubic meters in a single day with a maximum single day recovery of 1.4 $\times$ 10^5 cubic meters. Twin Oaks' size in conjunction with the challenging water sustainability issues faced by San Antonio (see [49]) make it an ideal candidate to for a sustainability study. Twin Oaks is extremely important to the overall framework of San Antonio's water supply and will account for 23% of the city's water storage by 2030 [25]. Furthermore, the fact that Twin Oaks was specifically designed to increase San Antonio's sustainability makes reviewing it with a sustainability index a compelling proposition.

It is important to note that sustainable practices were not expressly sought during the design and construction of Twin Oaks. Beyond water supply sustainability and garnering public acceptance for the project, no major steps were taken to enhance the facilities social, economic, or environmental sustainability.

2. Materials and Methods

Envision rates the sustainability of a project based on 60 criteria, called credits, in five categories: Quality of Life, Leadership, Resource Allocation, Natural World, and Climate and Risk. Each credit is ranked by level of achievement, and the various ranks, from lowest to highest scoring, are: no added value, improved, enhanced, superior, conserving, and restorative. Credits that are not applicable to the particular project can be rated N/A, and the credit is effectively not included. The ability to remove credits from the overall scoring is, in part, what allows Envision to be so broad and adaptive. By creating a wide range of criteria and then using only those that apply to each individual project, Envision can, in theory, adequately rate any type of infrastructure. In addition, Envision also has innovation and exceedance credits for innovative design practices or exceeding performance requirements of a particular credit. The innovation and exceedance credits serve as a form of "bonus" points, allowing a reward for exceptional levels of sustainability performance or pioneering innovations [18].

The Envision guidance manual has a list of evaluation criteria and required documentation for verification. It also provides benchmarks for each credit to help determine a project's performance. For the purpose of this study, credit ratings were produced by reviewing documentation on SAWS and the Twin Oaks ASR facility in conjunction with interviews held with SAWS representatives working at the facility.

Because of the retroactive nature of the review process, the verification documentation requirements for many of the Envision credits required a certain number of assumptions for this analysis. For example, many simple and inexpensive tasks such as reports containing minutes for all Twin Oaks' stakeholder meetings were not provided for the Provide for Stakeholder Involvement credit; however, a suitable review of stakeholder involvement was done with what resources were available. Other simple tasks were scored as if the necessary documentation had been submitted. In this review, the authors want to focus on what SAWS actually did and the intentions behind its decision making rather than on Envision's required documentation.

3. Results

The following presents a brief description of how each Envision category was scored for the review of the Twin Oaks ASR. All categories, ratings, and credits are according to the 2015 Envision manual [18]. Ratings for each credit are shown in Tables 2–6 with ratings of conserving or better shown in bold. As a reference, points for credits rated N/A are shown in parentheses. These points are not factored into the overall Envision score or counted for award verification.

Table 2. Twin Oaks Envision ratings in Quality of Life in the Quality of Life category.

	Criteria	Rating	Points Earned	Points Possible
Quality of Life	Improve community quality of life	Superior	10	25
	Stimulate sustainable growth and development	**Conserving**	**13**	**16**
	Develop local skills and capabilities	Improved	1	15
	Enhance public health and safety	**Conserving**	**16**	**16**
	Minimize noise and vibration	Improved	1	11
	Minimize light pollution	No added value	0	11
	Improve community mobility and access	N/A	-	(14)
	Encourage alternative modes of transportation	N/A	-	(15)
	Improve site accessibility, safety and wayfinding	No added value	0	15
	Preserve historic and cultural resources	N/A	-	(16)
	Preserve views and local character	No added value	0	14
	Enhance public space	N/A	-	(13)
	Innovate or exceed requirements	N/A	-	-
		Total	**41**	**123 (181)**

Table 3. Twin Oaks Envision ratings in Leadership.

	Criteria	Rating	Points Earned	Points Possible
Leadership	Provide effective leadership and commitment	Improved	2	17
	Establish a sustainability management system	Superior	7	14
	Foster collaboration and teamwork	Enhanced	4	15
	Provide for stakeholder involvement	**Conserving**	**14**	**14**
	Pursue by-product synergy opportunities	N/A	-	(15)
	Improve infrastructure integration	Enhanced	3	16
	Plan for long-term monitoring and maintenance	**Conserving**	**10**	**10**
	Address conflicting regulations and policies	**Conserving**	**8**	**8**
	Extend useful life	Enhanced	3	12
	Innovate or exceed requirements	N/A	-	-
		Total	**51**	**106 (121)**

Table 4. Twin Oaks Envision ratings in Resource Allocation.

	Criteria	Rating	Points Earned	Points Possible
Resource Allocation	Reduce net embodied energy	Improved	2	18
	Support sustainable procurement practices	No added value	0	9
	Use recycled materials	No added value	0	14
	Use regional materials	Improved	3	10
	Divert waste from landfills	No added value	0	11
	Reduce excavated materials taken off-site	**Conserving**	**6**	**6**
	Provide for deconstruction and recycling	No added value	0	12
	Reduce energy consumption	Improved	3	18
	Use renewable energy	No added value	0	20
	Commission and monitor energy systems	**Conserving**	**11**	**11**
	Protect fresh water availability	**Conserving**	**17**	**21**
	Reduce potable water consumption	Improved	4	21
	Monitor water systems	**Conserving**	**11**	**11**
	Innovate or exceed requirements	N/A	-	-
		Total	**57**	**182 (182)**

Table 5. Twin Oaks Envision ratings in Natural World.

	Criteria	Rating	Points Earned	Points Possible
Natural World	**Preserve prime habitat**	**Conserving**	**14**	**18**
	Protect wetlands and surface water	N/A	-	(18)
	Preserve prime farmland	Superior	6	15
	Avoid adverse geology	N/A	-	(5)
	Preserve floodplain functions	Improved	2	14
	Avoid unsuitable development on steep slopes	N/A	-	(6)
	Preserve greenfields	No added value	0	23
	Manage stormwater	No added value	0	21
	Reduce pesticide and fertilizer impacts	**Conserving**	**9**	**9**
	Prevent surface and groundwater contamination	Superior	9	18
	Preserve species biodiversity	**Conserving**	**13**	**16**
	Control invasive species	No added value	0	11
	Restore disturbed soils	No added value	0	10
	Maintain wetland and surface water functions	N/A	-	(19)
	Innovate or exceed requirements	N/A	-	-
		Total	**53**	**155 (203)**

Table 6. Twin Oaks Envision ratings in Climate and Risk.

	Criteria	Rating	Points Earned	Points Possible
Climate & Risk	Reduce greenhouse gas emissions	No added value	0	25
	Reduce air pollutant emissions	No added value	0	15
	Assess climate threat	No added value	0	15
	Avoid traps and vulnerabilities	Improved	2	20
	Prepare for long-term adaptability	**Conserving**	**16**	**20**
	Prepare for short-term hazards	Improved	3	21
	Manage heat islands effects	No added value	0	6
	Innovate or exceed requirements	N/A	-	-
		Total	**21**	**122 (122)**

Twin Oaks scores high for the credit Enhance Public Health and Safety. During the planning phase, substantial research was done to ensure that no public risk was generated by building the Twin Oaks facility. This research included a geochemical assessment of water compatibility for the mixing of Edwards and Carrizo groundwater in addition to numerous cycle tests. Twin Oaks also received high marks in the credit for Improve Quality of Life and Stimulate Sustainable Growth and Development. Ultimately, providing a more reliable water supply provides long-term stability for San Antonio's growing population.

Some credits in the Quality of Life category highlight the fact that sustainability was not an explicit objective in the design process for Twin Oaks. No extra measures were taken to minimize light pollution and noise pollution is only reduced minimally. Furthermore, for security reasons, site access, mobility, wayfinding, and public transportation to the site are intentionally limited. Twin Oaks could increase its score in the Quality of Life category by producing a view plan of before and after construction for the credit Preserve Views and Local Character. With over 95% of the land purchased for Twin Oaks remaining as farmland, much of the natural character was preserved.

In the Leadership category, Twin Oaks scored highly in Provide for Stakeholder Involvement because of the high level of input allowed from all concerned parties including SAWS, the farming community around Twin Oaks, and public consumers in San Antonio. In addition, Twin Oaks was given the highest possible points for its remarkable long-term maintenance and monitoring program as well as addressing conflicting regulations and policies present during planning.

Twin Oaks received points in every Leadership credit applicable. However, for the credit Provide Effective Leadership and Commitment, Envision requires sustainability as a prime goal during design to receive highest marks. Twin Oaks leadership is effective; however, not all aspects of sustainability were intentionally considered during Twin Oaks design. Furthermore, other than for economic reasons, Twin Oaks did not investigate ways to extend the useful life of the ASR system or the facility.

In the Resource Allocation category, Twin Oaks was given the highest ratings for Commission and Monitor Energy Systems. The facility is equipped with a monitoring system to detect unnecessary losses and inefficiencies. These were primarily installed to prevent economic losses caused by leaks; however, they also serve to increase the overall sustainability of the facility. Twin Oaks also scores well for Reduce Excavated Materials Taken Off-site for the manner in which grading and excavation was handled.

In Resource Allocation, rating Twin Oaks on the Protect Fresh Water Availability credit was particularly challenging. In this instance, the application of the credit is subject to uncertainty. For a superior rating, a project should demonstrate "wise water management" and planners should:

> *"Design the project to solely access water that can be replenished in quantity and quality. Control water usage over average maximum conditions, with plans to offset peak withdrawals during lower water need periods. Determine impacts of fresh water withdraw on receiving waters current and historic aquatic species." [18] (p. 94)*

To earn the conserving rating, "total water management" is necessary. Planners should:

> *"Design delivery and operations maintained such that there is no net impact on water supply volumes, including managing runoff to recharge local groundwater and surface water supplies in a manner that offsets withdrawals. Freshwater supplies are replenished at source. Discharges to receiving waters meet quality and quantity requirements of historic high value aquatic species. Methods may include closed loop recycling of water within the project." [18] (p. 94)*

The challenge in interpreting the text arises because Twin Oaks actually allows San Antonio to pump more water annually from the Edwards Aquifer, albeit during periods of adequate flow. Ultimately, San Antonio uses the same net amount of water, but the ASR approach conserves more water than a traditional surface reservoir. This conservation of water comes from the lack of significant evaporation in the subsurface, which saves substantial amounts of water in Texas when compared to surface reservoir evaporation (see [50]). Nevertheless, water use from the Edwards Aquifer may be at the expense of surface water and spring flow [36]. Therefore, using any Edwards aquifer water makes it unavailable elsewhere. Ultimately, a conserving rating was given in Protect Fresh Water Availability because the use of the Edwards Aquifer is done in a sustainable manner.

Twin Oaks received no points for credits such as Use Renewable Energy, Support Sustainable Procurement Practices, Provide for Recyclable Materials and Deconstruction, Divert Waste from Landfills, and Use Recyclable Materials in Resource Allocation. It is possible that some of the procurement practices were sustainable, that the facility uses renewable energy, or was even constructed with recyclable materials; however, not enough documentation on these matters was available to support a high rating at the time of writing.

In the Natural World credit, Reduce Pesticide and Fertilizer Impacts, the Twin Oaks facility receives a high score because it uses no pesticides or fertilizer. Furthermore, because the facility is substantially far away from known rare, threatened, or endangered species habitat, Twin Oaks was awarded a high rating for the Preserve Prime Habitat credit. Envision received a superior rating in the Preserve Prime Farmland credit because over 95% of the site will remain farmland, which includes areas with prime farmland soils. In addition, Twin Oaks was given a conserving rating in Preserve Species Biodiversity because it does not adversely impact endangered species and is part of a program to preserve these species during droughts [51]. Twin Oaks ensures that San Antonio can get Edwards Aquifer water without impairing these species during dry periods. However, the facility missed points in several natural world credits such as Preserve Greenfields, Control Invasive Species, and Manage Stormwater. Envision often requires planners to go above and beyond what is required. While Twin Oaks has met regulatory requirements in these areas, it did not exceed the requirements with respect to many Natural World credits.

In the Climate and Risk category, Twin Oaks received a significant number of points in the Prepare for Long-term Adaptability credit. A high rating was given because of the adaptability afforded by the water storage provided in conjunction with the facility's highly adaptable and resilient management plans. In addition, project designers were mindful of the potential for clogging in the storage aquifer, although no issues have been detected as of this writing. However, of the five rating categories, Twin Oaks Scores lowest in Climate and Risk, earning only 17% of available points. The low score in the Climate and Risk category is because most climate and risk credits require forethought and a sustainability focus that was not sought at the time of construction.

Table 7 and Figure 3 show the ratings given by the authors for the Twin Oaks facility in each category. Twin Oaks did best in Leadership, with 48% of points earned. Comparatively, Envision scored 33% in Quality of Life, 31% in Resource Allocation, and 34% in Natural World. Climate and Risk, as stated above, is the exception to Twin Oaks' high ratings.

Table 7. Total Envision ratings for Twin Oaks by Category.

Credit Category	Points Given	Total Applicable Points	Percentage of Total Applicable Points	Overall Points per Category	Percentage of Overall Points Applicable
Quality of Life	41	123	33%	(181)	68%
Leadership	51	106	48%	(121)	88%
Resource Allocation	57	182	31%	(182)	100%
Natural World	53	155	34%	(203)	76%
Climate & Risk	21	122	17%	(122)	100%
Total	223	688	32%	(809)	85%

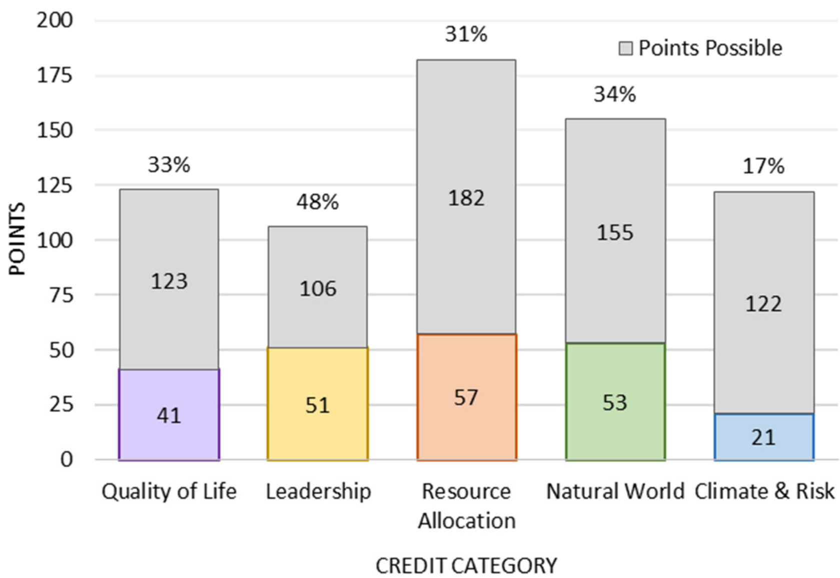

Figure 3. Total points earned in the category are shown in the colored section of columns while total points available are in the gray portion. Points earned as a percentage of the total are shown on top of the columns.

According to ISI guidelines, the Twin Oaks project would receive a bronze award in Envision if the above scores were given. The facility earned 32% of available points suggesting that SAWS has not only built an adequate groundwater sustainability project but also designed and built it in a reasonably sustainable manner. Since the facility was not designed with sustainability or the Envision rating system in mind, any awarded achievements are unexpected.

4. Discussion

Using the Twin Oaks Envision rating as an example, it was clear that five important aspects of the Envision system may need more consideration. They are highlighted here and discussed below:

(1) Conflation of project purpose and project design
(2) No weighting of points based upon local needs
(3) Project-oriented focus omits systems scale
(4) Uneven weighting of three sustainability pillars
(5) Positive scoring overlooks negative aspects of projects

In Envision, the sustainable nature of the ASR concept itself is never directly addressed. Indirectly, credits such as Improve Community Quality of Life or Stimulate Sustainable Growth and Development (or even innovation and exceedance credits) can be used to assign points for ASR in the quality of life category. In the resource allocation category, there is a credit for protecting fresh water availability. However, the text in this credit seems more concerned with the infrastructure facility's consumption rates than storage or banking of supply. As such, it is questionable whether this rating should be directed to the Twin Oaks facility or the ASR system that the facility runs. At least in the case of Twin Oaks, Envision also often looks at the facility being designed instead of the designed facility's purpose.

In addition to the above, it was noted that there is no mention of protecting water availability for environmental purposes (e.g., in-stream environmental flows, soil water available to plant roots) in the credit for protecting fresh water availability, which is an oversight of an important environmental issue.

Envision, and many other green or sustainability ratings systems, do not weigh critical needs of a specific geographic area [52]. For example, in Texas, where protecting water quantity is important to the sustainable development of the state, it would be more appropriate to give higher scores to designs that better protect freshwater availability. In Maryland, where water quality within the Chesapeake Bay is the main concern [53,54], infrastructure that protects water quality could be scored higher. Credit values could be adjusted both temporally and geographically to address the most pressing sustainable needs of a given time and place.

Envision also has a project-oriented focus, which prevents it from looking at groundwater systems, or any system, as a whole. Despite its credit for integrating with existing infrastructure, a systems-level perspective is lacking, potentially encouraging approaches that enhance sustainability at a local level while detracting from it at a more regional scale. While system scale management may not be important to all infrastructure sectors, it is paramount to water resources [55–57]. Unfortunately, Envision is similar to other environmental and sustainability indices in this regard, many of which have limited scopes (e.g., LEED, Energy Star, the Green Building Initiative, BE^{2}ST-In-Highways, GreenLITES (Green Leadership in Transportation Environmental Sustainability), and Greenroads). Notably, the federal Highway Administration's INVEST (Infrastructure Voluntary Evaluation Sustainability Tool) proves to be a rare exception to the above as it includes modules for planning transportation systems at state and regional scales [58].

As with LEED [59–61], the difficulty and cost of documentation may be an economic barrier with Envision. Every credit requires some form of documentation, and many require extra plans and analysis, which can add to the complexity and cost of seeking Envision certification. These additional costs, plus the price of having an Envision rating verified for award, seem to go against Envision's goal of seeking economic sustainability in unison with social and environmental sustainability.

Environmental sustainability is the focus for 57% of points available in Envision. This means it is entirely feasible for a project to receive Envision's highest award, which only requires 50% of applicable points, while neglecting two of the three pillars of sustainability. Most infrastructure projects already have ample incentives for providing for economic sustainability in the form of project budgets and limited capital. However, the often neglected considerations of social sustainability [62] need more encouragement from rating tools such as Envision and LEED [15].

In the Envision system, no points are ever taken away from the overall score for poor performance in a credit. Because the Envision system never penalizes by subtracting points, overtly negative aspects of certain projects will never be reflected with a low overall score in Envision. Not taking points away for negative aspects of projects means that an exceptionally negative performance in one Envision credit never needs to be offset by a positive performance elsewhere. This adds a type of systematic error that may give Envision a positive bias that rates projects with poor performance higher.

In addition, some negative aspects of ASR, such as its considerable energy consumption, are not accurately reflected in the Envision rating. For example, in order for the ASR system to be used, water first has to be pumped from the source to the ASR site, then pumped into the aquifer—in Twin Oaks' case, an aquifer under pressure. It is then re-pumped back to the surface and to the consumer during subsequent periods of demand. Compared to a hypothetical surface reservoir located the same distance from the consumer, we estimate that Twin Oaks requires 479 watt hours more energy per cubic meter, assuming a temperature around the San Antonio average of 21 °C, standard pipe roughness, pump efficiency of 75%, and evaporative losses of 50% from a surface reservoir. Thus, the high energy demand is a critical drawback of using ASR, whereas energy generation is a potential benefit of a surface reservoir.

Envision cannot directly address the energy consumption drawback of ASR because the guidance manual requires a comparison to similar projects and "industry norms", which in this case would be other ASR facilities. This means a comparison to alternative solutions, like a surface reservoir for the Reduce Energy Consumption credit, is not permitted by Envision. If a comparison to alternative solutions were allowed, Twin Oaks would score lower for this credit because it would be compared to the energy production of a surface reservoir. Thus, Envision could be a more effective sustainability metric for water infrastructure if all possible storage solutions are compared, instead of just those analogous to the facility under review.

The Twin Oaks case study also highlights how Envision advocates competing interests within sustainability. While Envision maintains that sustainable infrastructure needs to be secure, as identified in the credit Prepare for Short-Term Hazards in Climate and Risk, it also suggests that projects be open, visible, and publicly accessible as detailed in the credits Improve Site Accessibility, Safety and Wayfinding and Encourage Alternative Modes of Transportation. However, public access and high visibility create security challenges that Twin Oaks intentionally avoids. Envision does not address conflict between credits, or within sustainability, in any way, thus leaving interpretation and mitigation to verifiers.

Though the Twin Oaks Facility rates very well with the Envision system, a number of sustainable practices could have been implemented to make the facility more sustainable. Aspects of sustainability examined in the Quality of Life category of Envision would have offset some negative impacts of development. Noise and vibrations from pumping could have been reduced, light pollution minimized, and the view shed could have been less impacted had sustainability been explicitly considered. Envision's Leadership credits would have guided SAWS to extend the facilities useful life and look for long-term benefits of sustainability management. In Resource Allocation, it was noted that the Twin Oaks site has enough space for solar panels. If the solar panels averaged 5 kWh/m^2 per day, Twin Oaks could power its average daily recovery of 58,000 m^3 with only 232 m^2 of panels. If Envision were being used during project design, renewable energy, recyclable materials, and waste diversion would have received greater attention. Furthermore, environmental impacts listed in the Natural World category could have been minimized by improving storm water management, abating floodplain alteration, and restoring disturbed soils. Twin Oaks could gain points in Climate and Risk by performing simple assessments of greenhouse gas emissions, heat island effects, and pollutant emissions.

The findings in this study support those of the ASCE [24]. The ASCE Task Committee suggests local and sector based weightings for credits in addition to more strongly emphasizing economics in the credit topics. An additional point they make is that duplicative elements addressed by multiple credits in Envision may be inconsistent or unfair.

5. Conclusions

The review presented here serves the dual purpose of rating the SAWS Twin Oaks facility and provides a critical evaluation of Envision. The vague wording of some credits make a 3rd party review of Envision difficult. In practice, professional Envision verifiers interpret the guidance manual for project stakeholders and dictate how credits are scored while providing feedback throughout planning and development. A key feature of Envision is how it provides direct access to sustainability experts throughout the lifespan of an infrastructure project.

Twin Oaks success in leadership and management should be an example to future water management projects. SAWS receptiveness to review and input from all affected parties, and even this study, showcases the organization's desire for broad satisfaction and accountability. The Twin Oaks ASR facility provides resiliency to San Antonio's water supply by increasing its diversity. In order to complete this project, SAWS had to be open to new ideas and challenge traditional views while maintaining focus on long-term supply goals.

It is clear that Envision can enable designers and planners to think more broadly and creatively about specific aspects of sustainability that otherwise may be overlooked. If Envision would have been used in the actual design of the Twin Oaks facility, it is likely that a significant portion of the planning and construction would have occurred in an even more sustainable manner. The Envision guidelines would have given a sustainability framework on which to base numerous decisions and provide additional accountability. If this were the case, it is probable that Twin Oaks would have an even higher Envision rating. One of the flaws of this retroactive analysis, then, is that the incentives present during normal Envision usage were not present during the project's construction.

Envision's broad infrastructure focus would make it unsuitable for supporting water sustainability without additional consideration of water-specific topics. Important aspects of groundwater sustainability Envision omits are aquifer-wide monitoring programs, sustainable yield, groundwater regulations, and public awareness of water resource limitations. An effective water resource sustainability index would also include system principles and simultaneously assess both surface and subsurface water supplies.

Envision's focus is on project implementation and less on what a project does on a large scale. If Envision were used in conjunction with a groundwater specific sustainability index (such as [4,10–13]), both the water system and the individual water project could be reviewed together in a truly holistic manner. A combination of both types of indices would provide the most integrated and thorough view of sustainability in groundwater.

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Abbreviations

The following abbreviations are used in this manuscript:

ASCE	American Society of Civil Engineers
ASR	Aquifer Storage and Recovery

EAA	Edwards Aquifer Authority
GreenLITES	Green Leadership in Transportation Environmental Sustainability
INVEST	Infrastructure Voluntary Evaluation Sustainability Tool
ISI	Institute for Sustainable Infrastructure
LEED	Leadership in Energy and Environmental Design
SAWS	San Antonio Water System

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