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论文

景观绩效：
湿地治理系统和自然化景观的量化效益与经验总结

Landscape Performance:
Quantified Benefits and Lessons Learned from a Treatment Wetland System and Naturalized Landscapes

摘要 ……

根据景观设计基金会的定义，景观绩效是一项“衡量景观解决方案在实现其预设目标的同时满足可持续性方面的效率的指标”。景观绩效在近些年成为了一个非常热门的研究焦点，其理论框架建立在可持续性的三元体系之上：环境、经济和社会。建成景观设施的绩效可通过其环境、经济和社会效益的量化结果得到体现。本文记述了一项对一个范围约1 300hm^2、采用了湿地治理系统和自然化景观的总体规划性社区所进行的景观绩效调查，并对其中的经验进行了总结。研究团队确定了环境、经济和社会衡量标准，收集了能够反映出该系统绩效成果的数据，并对水质、土壤肥力和草本植物多样性进行了调查。此外，研究团队还对潜在和实际利益进行了量化，包括固碳，以及通过减少草坪修剪、肥料施用和用于灌溉的饮用水而节省成本。文中对环境、经济和社会方面的效益成果进行了讨论，并对建设过程中和建成之后各个阶段的管理和维护事项的相关经验进行了总结。

关键词 ……

雨洪；水质；景观维护；草原；景观感知

Abstract ...

Landscape performance, as defined by the Landscape Architecture Foundation, is "the measure of efficiency with which landscape solutions fulfill their intended purpose and contribute toward sustainability." It is becoming a popular research focus in recent years; and its theoretical framework is built upon the sustainability triad: environment, economy and society. Through the quantification of environmental, economic and social benefits of a built landscape, its performance can be determined. This paper presents results from a landscape performance investigation and the lessons learned from a 3,200-acre master planned community that employs a treatment wetland system and naturalized landscapes. The research team identified environmental, economic and social metrics, and then collected data that reveals the performance results of the installed systems. Water quality, soil fertility, and herbaceous plant diversity were investigated. In addition, the research team quantified potential and actual benefits, including sequestration of carbon dioxide, and cost savings through the use of reduced mowing, fertilizer use, and reduction of irrigation with potable water. Environmental, economic and social benefit results are discussed. Lessons learned from management and maintenance issues during and post construction phases are summarized.

Key words ...

Stormwater; Water Quality; Landscape Maintenance; Prairie; Landscape Perception

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1 调查背景

根据景观设计基金会（LAF）的定义，景观绩效是一项“衡量景观解决方案在实现其预设目标的同时满足可持续性方面的效率的指标”。景观绩效在近些年成为了一个非常热门的研究焦点，其理论框架建立在可持续性的三元体系之上：环境、经济和社会。建成景观设施的绩效可通过其环境、经济和社会效益的量化结果来体现（图1）。

LAF从2010年起通过一系列“案例调查”征集活动来推动景观绩效的研究。LAF不断将这些案例调查的简要介绍发布在其网站上[①]，旨在提供“一个在线的互动资源集合，向设计师、政府机关和支持者展示景观绩效的意义并提供衡量途径，使他们能够对景观绩效进行评估，创造出新的可持续景观解决方案案例”。2012年，LAF选择了德克萨斯州A&M大学作为研究团队之一，对已建成的景观项目的景观绩效效益进行调查。LAF要求必须从环境、经济和社会这三个领域对景观绩效效益进行量化反

① 详细信息请登录http://www.lafoundation.org/research/landscape-performance-series/。

Article

1 Introduction

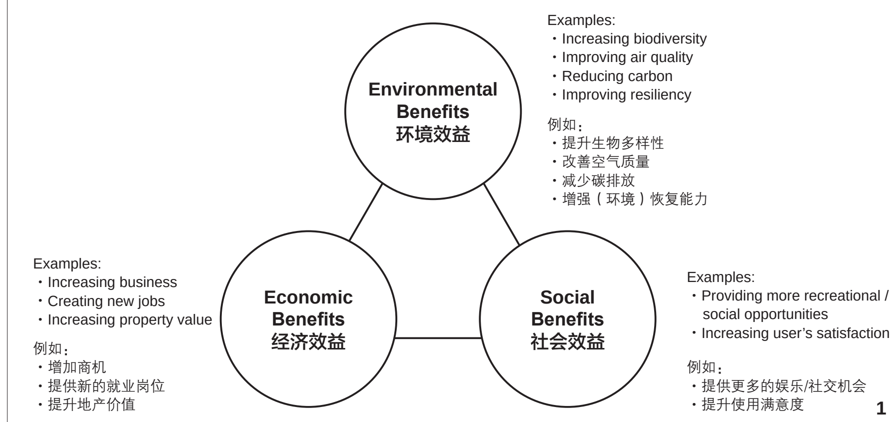
Landscape performance, as defined by Landscape Architecture Foundation (LAF), is "the measure of efficiency with which landscape solutions fulfill their intended purpose and contribute toward sustainability". It is becoming a popular research focus in recent years. Its theoretical framework is built upon the sustainability triad: environment, economy and society. Through the quantification of environmental, economic and social benefits of a built landscape, its performance can be determined (Fig. 1).

LAF has been promoting landscape performance research since 2010 through a series of calls for "Case Study Investigations". This effort has been producing case study briefs published by LAF on its web site[①]. The intent is to provide "an online interactive set of resources to show value and provide tools for designers, agencies and advocates to evaluate performance and make the case for sustainable landscape solutions". In 2012, LAF selected Texas A&M University as one of the research teams to investigate landscape performance benefits of built landscape projects. LAF required that three areas of the landscape performance benefits must be quantified, including environmental, economic and social areas. The timeframe of the study was limited, which began in May 2012 and ended in August 2012. Texas A&M University partnered with SWA Group to explore the landscape performance of a master planned community named Cross Creek Ranch designed by SWA Group.

Master planned communities in the United States started in the 1960s following the housing boom. The development of master planned community is strong in the Sunbelt stateswhich include the state of Texas[1]. In Texas, the popularity of master planned communities influenced suburban growth, in which several communities were created starting in the 1970s, including Las Colinas in the 1970s (near Dallas), The Woodlands in the 1970s (North of Houston), Cinco Ranch in the 1990s (West of Houston), Cross Creek Ranch in the 2010s (near Houston), and so on.

Cross Creek Ranch is a residential community located approximately 20 miles west of Houston, Texas that promotes the use of a treatment wetland system and naturalized landscapes as continuous landscape infrastructure (Fig. 2, 3). Throughout the community, wetlands, native grasses and reforestation are employed as essential components of wastewater and stormwater management systems, interconnected wildlife corridors, and biologically diverse passive recreation systems are used in part to educate homeowner's attitudes and appreciation of naturalized and native landscaping in their backyard.

The purpose of this paper is to present the results of landscape performance investigation, as well as lessons learned from the designer's perspective. The intent of landscape performance investigation is to raise the awareness of a cutting edge research area for the landscape architecture discipline and profession. The lessons learned can help practitioners, educators and students revisit management and maintenance strategies when designing similar large-scale landscapes



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① For more information, please visit: http://www.lafoundation.org/research/landscape-performance-series/.


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1. 景观绩效效益框架
2. 越溪牧场社区中的污水治理湿地

1. Landscape performance benefit framework
2. Treatment wetland in Cross Creek Ranch

映。研究于2012年5月开始，同年8月结束，时间非常有限。德克萨斯州A&M大学与SWA集团进行了合作，对由SWA集团设计的、名为“越溪牧场”的总体规划性社区的景观绩效开展了调查研究。

20世纪60年代，随着住宅建设的快速发展，美国的总体规划性社区开始涌现。总体规划性社区的开发在美国南部包括德克萨斯州在内的“阳光地带”非常兴盛[1]。在总体规划性社区日益普及的影响下，德克萨斯州的城郊地区逐步扩张。自20世纪70年代开始，一些总体规划性社区纷纷建立，包括20世纪70年代的拉斯科利纳斯社区（位于达拉斯附近）、20世纪70年代的伍德兰兹社区（位于休斯顿北侧）、20世纪90年代的辛科牧场社区（位于休斯顿西侧），以及21世纪10年代的越溪牧场社区（位于休斯顿附近）等。

越溪牧场是一个位于德克萨斯州休斯顿市以西约32km处的居住社区。该社区将湿地处理系统和自然化景观作为连续的景观基础设施进行推广应用（图2，3）。在整个社区内，湿地、原生草种草地，以及再造林成为了构成废水和雨洪管理系统的基本要素。纵横交错的野生动植物廊道和具有高度生物多样性的被动休闲系统也在某种程度上有助于培养业主对其后院中自然化的乡土景观形成积极的欣赏态度与观念。

本文旨在呈现景观绩效调查的结果，并以设计者的视角对从中获得的经验予以总结。景观绩效调查的目的在于提高人们对景观设计学科及其业界中前沿研究领域的认识。从调查中获得的经验能够帮助执业人员、教育者和学生们在设计类似的紧邻人居住宅的大尺度景观时重新审视管理和维护策略，并突出在项目的初期阶段就对管理和维护进行通盘考虑的重要意义。

2 调查方法

2.1 环境效益

研究工作主要集中于2011年建成的越溪牧场社区一期部分。因为研究团队面临着时间的制约（只有三个月）和有限的预算，所以采用了一种快照式的横向对比方法来对环境效益进行量化分析。研究团队就治污湿地和复育后的河流/滞留湖系统的绩效进行了评估，并将自然化景观和人工化景观的绩效进行了比对。

社区的污水处理站能够有效地处理来自社区一期部分的生活污水（图4）。从污水处理站排出的水已在很大程度上得到了净化，随后被抽送至治污湿地的起点以得到进一步的处理。我们所分析的污染物质指标包括总氮量（N）、总磷量（P）、总钾量（K）、总钙量（Ca）、总镁量（Mg）、总钠量（Na）、总锌量（Zn）、总铁量（Fe）、总锰量（Mn）和总悬浮固体量（TSS）。

根据治污湿地和弗莱沃伦溪的流向选定了7个采样地点（图4）。采样步骤遵循德克萨斯州A&M大学土壤、水及饲料检测实验室的指导原则[2]。研究团队在每一个采样地点各收集了10份约227ml的水体子样本，然后在一个空筒中将这些子样本进行混合，接着将混合后的水倒入一个约454ml的空瓶中，注入量约为瓶容量的一半。为了避免漂浮物对测量结果造成影响，子样本的采集深度至少在水面下15cm。样本的采集日期为2012年7月9日，并于同一天运输到实验室进行分析[3]。

为了对比自然化景观和人工化景观，研究团队收集了土壤标本，并对pH值、N、P、K、Ca、Mg、硫（S）、Na、土壤结构和有机物进行了分析。根据至河流/滞留湖系统的距离和所种植植物的种类选定了5个采样地点（图5）。采样步骤遵循德克萨斯州A&M大学土壤、水及饲料检测实验室的指导原则[4]。研究团队在每一个采样地点各采集了10份土壤子样本（采样深度为15cm），然后将这些子样本倒入清洁的塑料空筒中进行混合，清除可见的植物根茎，并取454~510g混合样本置于可再封口的厚塑料袋中[4]。

3. 越溪牧场社区中复育溪流两岸的自然化景观设计和再造林

3. Naturalized landscape design and reforestation along a restored creek in Cross Creek Ranch

that are immediately adjacent to human dwellings, and to emphasize the importance of management and maintenance that is integrated in the early phases of a project.

2 Methods

2.1 Environmental Benefits

The research effort focused on the Phase I of Cross Creek Ranch completed in 2011. Because the research team was faced with the constraints of time (only three months) and limited budget, a snapshot cross-sectional method was used to quantify environmental benefits. The research team evaluated the performance of the treatment wetland and restored creek / detention lake system, and naturalized versus. cultivated landscapes.

The community's sewage treatment plant was in operation and treating residential sewage water from Phase I (Fig. 4). Effluents from the treatment plant are mostly purified, and pumped to the beginning point of the treatment wetland for further processing. Analyzed pollutants include total nitrogen (N), total phosphorus (P), total potassium (K), total calcium (Ca), total magnesium (Mg), total sodium (Na), total zinc (Zn), total iron (Fe), total manganese (Mn) and total suspended solids (TSS).

Seven sampling locations were selected based on flow directions of the treatment wetland and the Flewellen Creek (Fig. 4). The sampling procedure followed the guideline by the *Soil, Water and Forage Testing Laboratory of Texas A&M University*[2]. At each sampling location, ten 8-ounce subsamples were collected, mixed in a large bucket and then poured into a 16-ounce bottle with about 50% headspace. In order to avoid floats, subsamples were collected at least 6 inches below the water surface. The samples were taken on July 9th, 2012 and transported to the laboratory on the same day for analysis[3].

For the naturalized versus. cultivated landscapes, the research team collected soil samples for analyses on pH, N, P, K, Ca, Mg, sulfur (S), Na, soil texture and organic matter. Five sampling locations were selected based on the distance to the creek / detention lake system and the type of vegetation planted (Fig. 5). The sampling procedure followed the guideline by the *Soil, Water and Forage Testing Laboratory of Texas A&M University*[4]. At each sampling location, the research team collected 10 subsamples by cutting the ground surface 6 inches deep into the soil, mixed subsamples in a clean plastic bucket, removed visible roots / plants, and placed 16 ~ 18 ounces of soil in a re-sealable heavy gauge plastic bag[4].

Furthermore, the research team collected herbaceous plants at locations corresponding to soil sampling locations. Herbaceous plant diversity was determined by the identificaiton of dominant species of plants found within a 15-foot radius of the soil sampling sites identified in Figure 5. The intent was to investigate the correlation between soil fertitiliy and plant species. The research team also quantified the potential carbon sequestration using the National Tree Benefit Calculator[5] with the tree data provided by the design firm.

2.2 Economic and Social Benefits

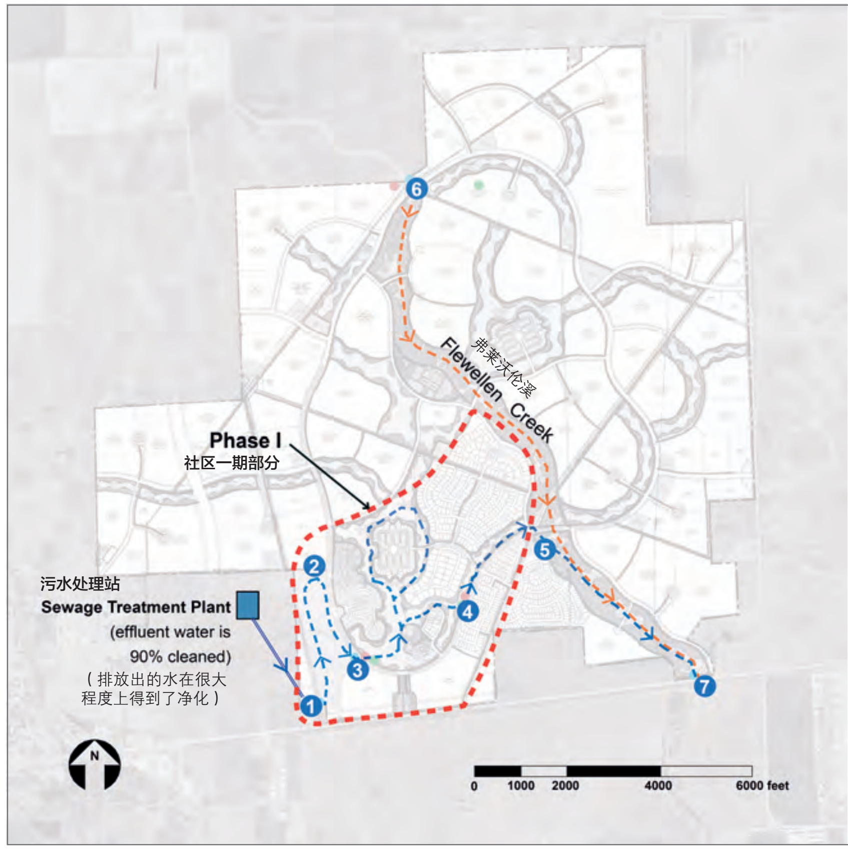
Economic benefits were estimated for three types of cost-savings, including reduced mowing, fertilizer use, and potable water use for irrigation. Each cost-saving was based on the comparison between traditional practices and Cross Creek Ranch's sustainable practices. Detailed estimation procedures are presented in the Results section.

Social benefits were estimated by two indirect measures: the percent of homes adjacent to green spaces / trails, and the number of educational signs per acre. Studies on the proximate principle suggest that abutting or fronting a passive recreation park area would have positive impacts on property values[6], as well as enhance human welfare.

3 Results

3.1 Environmental Benefits

The results of water quality analysis are presented in Table 1. The pollutant removal efficiency was calculated based on the water quality between Location 1 (beginning of the treatment wetland) and Location 5 (ultimate drainage outlet of Phase I of Cross Creek Ranch) (Fig. 4). The results reveal that the treatment wetland and restored creek / detention lake system



1. Beginning of the treatment wetland into which the mostly cleaned sewage water pumped
采样地点1：沿污湿地起点，已在很大程度上得到净化的废水被抽送至该湿地中
2. Mid-point of the treatment wetland
采样地点2：沿污湿地中间点
3. End of the treatment wetland
采样地点3：沿污湿地终点
4. Mid-point between 3 and 5
采样地点4：采样地点3和采样地点5的中间点
5. Ultimate outlet of the treatment wetland and creek / detention lake system of Phase I into the creek
采样地点5：一期中的沿污湿地和溪流/滞留湖系统的终端排水口，净化过的水在此流入弗莱沃伦溪
6. Influent location of Flewellen Creek into the Cross Creek Ranch site
采样地点6：弗莱沃伦溪流入越溪牧场的起点
7. Outlet of the two water systems (wetland and creek / detention lake system & Flewellen Creek)
采样地点7：两个水系统（湿地和溪流/滞留湖系统，以及弗莱沃伦溪）的排放点

4

1. Represents soil sampling locations within a naturalized landscape near the treatment wetland
采集地点1：沿污湿地附近的一处自然化景观内的土壤样本
2. Represents soil sampling locations within a naturalized landscape near thedetention lake system.
采集地点2：滞留湖系统附近的一处自然化景观内的土壤样本
3. Represents soil sampling locations within a naturalized landscape where the site's water exits the property
采集地点3：住宅区排水口附近的一处自然化景观内的土壤样本
4. Represents soil sampling locations within Bermuda turf
采集地点4：狗牙根草地内的土壤样本
5. Represents original site soil conditions that were disturbed by cattle grazing
采样地点5：受到牛群放牧影响的原始场地土壤样本

5

4. 水体样本采集地点
5. 土壤样本采集地点
4. Locations of water samples
5. Locations of soil samples

improved water quality as the concentration of nutrients and metals decreased along the direction of the flow (from Location 1 down to Location 5). Except for TSS, the pollutant removals were effective.

The analysis of soil fertility and herbaceous species are presented in Tables 2 and 3, respectively. The results do not indicate a strong correlation between soil organic matter and plant species count (correlation coefficient is –0.57). The weak correlation can be attributed to the fact that the community is still new (less than three years old) and the planting and management practices have not yet changed the soil fertility. Future study and long-term monitoring is needed for further understandings.

According to the plant information provided by the design firm (Table 4), about 24,420 trees were planted in Phase I, in which most are a pine and oak mix. Using the National Tree Benefit Calculator[5], 787,545 lbs of CO_2 in the trees planted per year was estimated. The projected total number of trees to be planted for the entire community is 51,525. When the entire project is completed, an estimated 1,661,644 lbs of CO_2 will be sequestered.

3.2 Economic Benefits

Economic benefits in terms of cost-savings were estimated at 35,192 USD annually, approximately 10,055 gallons of gas, and 100,550 USD in labor through the creation of no-mow zones, for a 64% reduction in overall maintenance costs (Table 5). For the fertilizer cost, native naturalized planting area in the community is about 636 acres, which requires no fertilizer usage, could save 1,454,250 USD annually by reducing fertilizer use by 831 ton.

For landscape irrigation, reclaimed water from the treatment wetland was used to supplement the potable water usage. Since 2009, about 121,671,400 gallons of potable water has been saved through the usage of reclaimed water for irrigation. Assuming that the water rate is the City of Fulshear's 4.96 USD/1,000 gallons (the nearest municipality), cost savingsare about 603,490 USD (121,671,400 ÷ 1000 × 4.96).

3.3 Social Benefits

Social benefits were explained by two indirect measures. First, 42% of resident homes are adjacent to native naturalized landscape, designated trails, and parks, which have a positive impact on property values. Approximately 25 ~ 30 miles of trails in the community are to be built. Second, 154 outdoor education signs (Fig. 6) had been installed. This equals one sign per 4 acres or 180 persons per sign.

4 Lessons Learned

The research team documented the designer's lessons learned from management and maintenance issues during and post construction phases. These lessons were learned from field observations and

表1 水样本中的污染物浓度
Table 1 Pollutant concentration in water samples

Sampling Location 采样地点	Total N 总氮量 ppm	Total P 总磷量 ppm	Total K 总钾量 ppm	Total Ca 总钙量 ppm	Total Mg 总镁量 ppm	Total Na 总钠量 ppm	Total Zn 总锌量 ppm	Total Fe 总铁量 ppm	Total Cu 总铜量 ppm	Total Mn 总锰量 ppm	TSS 总悬浮固体量 mg/L
1 (start) 起始点	5.45	3.78	26.06	56.13	7.02	137.2	0.014	2.25	0.015	0.238	32
2	3.63	1.88	23.33	36.06	7.19	115.5	0.001	2.37	0.043	0.174	17
3	2.91	0.74	20.99	30.27	6.37	92.8	0.013	1.33	0.010	0.105	5
4	0.96	0.11	7.76	25.87	3.52	22.3	0.001	1.06	0.056	0.038	45
5 (end) 终点	0.83	0.10	11.14	25.81	3.40	20.8	0.013	0.07	0.001	0.117	116
6	1.27	0.16	12.70	44.70	7.30	33.6	0.014	2.76	0.016	0.112	26
7	0.85	0.13	13.26	29.36	5.19	46.5	0.006	1.32	0.012	0.031	39
Pollutant Removal Efficiency* 污染物去除率*	85%	97%	57%	54%	52%	85%	7%	97%	93%	51%	-263%

*Removal efficiency between Location 1 and Location 5 = (Value of 5 – Value of 1) / (Value of 1) X 100%.
*采样点1和采样点5之间的去除率=（采样点5的数值 — 采样点1的数值）/（采样点1的数值）X 100%。

除此之外，研究团队还在土壤采样点的位置进行了草本植物的采集工作。如图5所示，草本植物多样性由土壤样本采集点半径约4.6m范围内的优势物种来决定。这一工作的目的是研究土壤肥力和植物物种之间的相关性。研究团队还通过使用国家树木效益计算器[5]并依照由设计公司提供的树木数据，对潜在的碳吸收量进行了量化。

2.2 经济和社会效益

经济效益包括对由减少草地修剪、肥料施用和用于灌溉的饮用水这三类举措所节约的成本进行评估，每一类成本节约举措都将在传统社区和越溪牧场社区所采取的可持续实践之间进行比较。详细的估算步骤将在后文结果章节进行呈现。

社会效益通过两个间接指标来体现：临近绿色空间/步道的住宅比例，以及每英亩范围内教育性标牌的数量。相关领域的研究指出，临近或正对被动休闲公园区域能够拉动房地产价值的增长[6]，同时也能增加人民福利。

3 调查结果

3.1 环境效益

如表1所示，在水质分析结果中，污染物去除率是依据采样点1（治污湿地起始点）和采样点5（越溪牧场社区一期部分的最终废水排出点）（图4）之间的水质数据计算得出的。结果显示，营养物质和金属元素的浓度沿着水流方向（即从采样点1至采样点5）逐渐下降，表明治污湿地和复育后的河流/滞留湖系统改善了水质。除了TSS之外，污染物的去除率较高。

如表2及表3所示，在土壤肥力和草本植物种类的分析结果中，我们并未发现土壤有机质含量和植物种类数量之间存在很强的关联性（关联系数为-0.57）。得到这一微弱关联数据的原因可能是因为该社区为新建社区（不满3年），以及种植和管理活动还没有改变土壤的肥力。若想对此问题有进一步的理解，则需要更深入的研究和长时期的监测。

根据设计公司提供的植物信息（表4），该社区一期部分共种植约24 420棵树木，其中大多数地区为松树和栎树混种。经由国家树木效益计算器[5]的计算，这些树木每年能够吸收约357 224kg的CO_2。该项目计划在整个社区中共种植51 525棵树木，当整个项目完工之后，则能够吸收753 718kg的CO_2。

3.2 经济效益

相较于传统社区，越溪牧场社区每年因成本节约举措带来的经济效益约为35 192美元，每年可节省近10 055加仑汽油，还包括因不再需要修剪草地的区域所节省下来的100 550美元人工费用（总维护费用下降了64%）（表5）。在肥料成本方面，越溪牧场社区内的乡土自然化种植区域约为636英亩，这些区域全都不需要施用肥料，每年可通过减少754吨的肥料用量节省1 454 250美元。

在景观灌溉方面，从治污湿地中回收再利用的水可用于补给饮用水灌溉。从2009年开始，通过在灌溉中使用循环利用的水源，共节省了约121 671 400加仑饮用水。假设富舍尔市（距该社区最近的自治市）的水费为4.96美元/1 000加仑，大致可节省成本603 490美元（121 671 400 ÷ 1000 × 4.96）。

3.3 社会效益

社会效益通过两个间接指标进行衡量。首先，

表2 土壤肥力分析结果
Table 2 Results of soil fertility analyses

Sampling Location 采样地点	pH	N ppm	P ppm	K ppm	Ca ppm	Mg ppm	S ppm	Na ppm	Texture 土壤质地				Organic Matter 有机质
									Sand 沙土	Silt 粉土	Clay 粘土	Class 分类	
1	7.9	0	10	50	1569	178	12	107	58%	24%	18%	Sandy Loam 沙质壤土	0.91%
2	7.9	2	14	82	2005	124	13	54	62%	20%	18%	Sandy Loam 沙质壤土	0.95%
3	6.1	1	13	61	708	125	11	40	62%	24%	14%	Sandy Loam 沙质壤土	1.44%
4	8.2	0	6	108	1622	333	29	345	68%	10%	22%	Sandy Clay Loam 沙质粘壤土	1.03%
5	6.0	4	14	37	834	96	12	9	56%	32%	12%	Sandy Loam 沙质壤土	1.69%

investigation into practices rather than formal research. They will help practitioners, educators and students revisit management and maintenance strategies when analyzing and designing similar large-scale landscapes that are immediately adjacent to human dwellings, and to emphasize the importance of management and maintenance that is integrated in the early phases of a project. Integration of analysis, design, management and maintenance is more likely to create high-performing landscapes.

4.1 The Lifecycle of Prairie Grasses

Fire is known to have a positive and regenerative influence on establishing prairies[7]. Because we were not allowed to burn the prairie, two factors had a negative influence on the establishment of the prairie: a narrow time when seeding could take place and the absence of prescribed burning. The best time to plant native grass is during the fall and spring. However, the development of the housing community does not wait for the best time to seed, but when prospective home buyers would be available. As new houses were built and the need for the landscape to remain attractive throughout the year, a strategy of establishing temporary erosion control was devised. Bermuda grass grows in the summer in areas where future native grass will occur. During native grass seeding windows the temporary Bermuda is scalped and tilled and the native grass mix is hydro seeded.

With regard to fire, the community context and ability to use fire is limited. Fire adjacent to homes and the region's air quality pollution regulations prevent all burning. Thus, all tall grasses are trimmed to 6 inches tall once a year during winter. In initial phases the grasses did not establish themselves quickly enough for the developer. As a result, the grasses were continually mowed and their lifecycle and ultimate peak establishment delayed. After much debate and contractor's error a dedicated effort for patience was agree upon. By eliminating the frequent mowing, grasses were able to quickly establish themselves in less than a year and were visually striking. After the first year and first mowing, the case for patience was solidified and prospective home buyers appreciated the aesthetic. These implementation compromises allowed

表3 5个采样点鉴别出的草本植物物种
Table 3 Herbaceous species identified at five locations

Non-native Species 非乡土物种	Location 采集地点				
	1	2	3	4	5
朱樱花属 *Calliandra spp.*		√			
积雪草 *Centella asiatica*		√			
刺儿菜 *Cirsium mexicanum*		√			
球状石竹 *Dianthus barbatus*					
高大鸢尾 *Iris giganticaerulea*					
蔓马缨丹 *Lantana montevidensis*		√			
含羞草 *Mimosa pudica*		√			
绿萝 *Scindapsus aureus*		√			
狗尾草 *Setaria viridis*		√			
草原鼠尾粟 *Sporobolus heterolepis*				√	
Native Species 乡土物种	**Location 采集地点**				
	1	**2**	**3**	**4**	**5**
美丽鹧鸪豆 *Chamaecrista fasciculata*	√	√			
三叶金鸡菊 *Coreopsis tripteris*				√	
水竹 *Cyperus alternifolius*					
节沙草 *Cyperus articulatus*					
莎草属植物 *Cyperus pseudovegetus*		√	√		
刺杆莎草 *Cyperus surinamensis*					
莎草科植物 *Dulichium arundinaceum*					
紫锥菊 *Echinacea purpurea*				√	
牛志毡 *Eleocharis montevidensis*					
加拿大披碱草 *Elymus canadensis*				√	
木贼属 *Equisetum spp.*					
异叶刺芹 *Eryngium heterophyllum*		√			
犊牛儿草 *Eryngium leavenworthii*		√			
天人菊 *Gaillardia pulchella*		√	√	√	
向日葵属植物 *Helianthus maximiliani*				√	
铜钱草 *Hydrocotyle umbellata*		√			
龙须草 *Juncus effusus*					
李氏禾 *Leersia oryzoides*		√			
千金子 *Leptochloa dubia*	√				
金叶麦秆千屈菜 *Lythrum alatum var. lanceolatum*					
线叶千屈菜 *Lythrum lineare*		√			
毛马松子 *Melochia tomentosa*					
沙滩含羞草 *Mimosa strigillosa*		√			
毛芒乱子草 *Muhlenbergia capillaris*					
日本乱子草 *Muhlenbergia lindheimeri*				√	
墨西哥羽毛草 *Nassella tenuissima*				√	
美丽月见草 *Oenothera speciosa*		√	√	√	
过江藤 *Phyla nodiflora*		√			
北美梭鱼草 *Pontederia cordata*	√	√			
大花毛茛 *Ranunculus macranthus*		√			
草原松果菊 *Ratibida columnifera*		√		√	
黑心金黄菊 *Rudbeckia hirta*		√	√	√	
北美小须芒草 *Schizachyrium scoparium*		√			
含羞草 *Schrankia nuttalli*		√			
泽芹 *Sium suave*					
西洋蒲公英 *Taraxacum officinale*					√
宽叶香蒲 *Typha latifolia*		√			

42%的住宅与乡土的自然化景观、指定的小路及公园相邻近，这对房地产价值产生了积极的影响。社区内还将建造长约40~48km的步道。第二，154块室外教育标识牌（图6）已经安装完成，合每4英亩或每180个人就设有一块标识牌。

4 经验总结

研究团队记录了设计师们从正在进行和已经完成的建设阶段的管理和维护事项中所吸取的经验。这些经验是从现场观察和调查以及实践中获得的，而非源自于那些正式的研究。它们能够帮助执业人员、教育者和学生们在分析和设计类似的、紧邻人居住宅的大尺度景观时重新审视管理和维护策略，并突出在项目初期就将管理和维护纳入考虑的重要性。对分析、设计、管理和维护进行整合将更有可能创造出高绩效的景观。

4.1 草原草种的生命周期

众所周知，火对形成草原具有积极的、促进草种再生的作用[7]。但由于政策不允许燃草，因此存在着两种对草原的形成具有负面影响的因素：一是播种时间有限，二是缺乏明确的烧荒计划。种植乡土草种的最佳时间是秋季和春季。然而，在住宅区的开发中，并不会等到最佳时间才进行草种播种，而要求在潜在买主到来时就呈现出草坪景观。随着新住宅的不断建造和景观在一年四季始终保持美观的需求，人们设计出了一种建立临时性侵蚀防控的策略。在夏季，那些原本计划种植原生草种的区域种上了狗牙根草。而在原生草种的种植期前，这些临时性的狗牙根草被铲去，并在土地翻整的过程中喷播混合的原生草种。

该社区的环境背景及明火的使用权限为烧荒带来了局限性。住宅附近严禁明火的规定和当地的空气质量污染条例明令禁止所有的焚烧行为。因此，所有的高草都在每年冬季被修剪到15cm。在初期阶段，草地的自发生长速度无法满足开发商的要求，结果导致草地被不断修剪，其生命周期和最终的成型效果也被拖延。经历过许多争论及承包者意识到错误之后，人们在为了形成精美的景致而必须付出等待这件事上达成了一致。通过终止频繁的修剪，草地在一年之内迅速得到自建，并在视觉上取得令人意想不到的效果。在一年后的景致和第一次修剪后的情形相比之下，人们终于对这份等待予以了肯定，那些潜在买主也非常欣赏这里的美景。草地修剪的让步使得自然景观的建立成为了可能。

4.2 景观维护的变化

我们所学到的最为重要的经验之一，就是对治污湿地和自然景观之间的边界的维护和认识方式上所作出的一个微小但却至关重要的变化。在引入修剪草带之前，潜在居民普遍对“自然化”景观较为喜爱。尽管湿地或草地不仅具有净化水体的作用，还能够提供被动休闲和观赏野生动植物的空间，但对于那些居住在与草地相邻的住宅中的居民们来说，对这种自然化景观的美好印象在他们真正入住之后“一落千丈”。为了消减他们的不满，修剪草带被引入进来。所有临近人行道、道缘和住宅篱笆的区域都设立了一条修剪草带，道路修剪草带的宽度为道路两侧各约50cm（图7），篱旁修剪草带为篱笆周边约152cm。这个方法在改善人们对居住环境中的自然景观的认知方面非常有效，因为修剪草带能够给人带来“草地是经过精心打理的，所以能够令环境更漂亮”的暗示作用[8]。这些考虑迫使设计团队对整个社区的草甸修剪模式做出重新评估，同时要尽量减小景观碎片化，并为今后负责维护的承包商创造能够形成高效维护的环境条件。最终，设计团队不得不就维护操作和自然化景观的边缘的最终效果问题，对大量的工作人员进行培训。

4.3 原生草地维护成本

在无需修剪草种的种植方面，存在一个被广泛认可的理论：虽然这些草的初期维护成本较高，但是从长远来看，终将会带来成本的节约。在越溪牧场社区中，虽然修剪草地和耗油的费用有所降低，但维护工作仍略为繁琐。在表土的收集、存放和重新利用的过程中，可能会使土壤混入不合乎要求的植物的种子，因而需要进行大量的拔草工作。根据草地维护的效率来看，一个人使用割草机的作业需要5位拔草者才能完成。因此，虽然通常的耗油和污染问题减轻了，但支付给维护公司的费用却大致相同。

4.4 植树

为了表现出再造林区在生态演替、生态多样性和生态弹性上获得的成功，设计中采用了不同大小、不同物种的混合种植方法。因为在资金相同的情况下，相比单一种植大型树木，采用不同规格树木混植的方法能够带来更多的经济效益。虽然初

the natural landscape to become established.

4.2 Changes in Landscape Maintenance

One of the critical lessons learned regarded a minor, but critical change to how the edges of the treatment wetland and natural landscape was maintained and perceived. Prior to the introduction of mowing strips, prospective residents' often had a positive perception of the "natural" landscape. For residents who moved into homes adjacent to prairie, even though the wetlands and prairie had a positive influence on cleaning the water and provided space for passive recreation and viewing wildlife, perceptions of these landscapes became negative after residents moved in. To alleviate these concerns, mowing strips were introduced. All areas adjacent to walks, curbs, and residential fences received a mow strip ranging from 18 inches wide at all walk edges (Fig. 7) to 5 feet wide along the reserve side of residential fences. This approach has been effective in improving the perception of natural landscapes in residential settings because mow strips can imply that the meadow is cared for and thus improves acceptance[8]. These considerations forced the design team to re-assess mowing patterns throughout and create less fragmentation and greater efficiencies for the maintenance contractors. As a result, the design team had to train numerous parties regarding maintenance practices and what the natural landscape edges should look like.

4.3 Native Grass Maintenance Costs

A commonly accepted theory for the planting of no-mow grasses is that they have higher maintenance costs at first, but will eventually result in a cost reduction over time. At Cross Creek Ranch, mowing and gasoline use has been reduced, but the maintenance issue is a bit more complicated. A great deal of weed pulling has been necessary to eliminate undesirable species whose seeds were in site topsoil that was scraped, stored and reused. Due to the rate of weed maintenance, the normal scheme of one person on a mower is equal to the requirement of five weed pullers. Therefore, while typical gasoline and pollution problems are reduced, the costs to maintenance companies are essentially equal.

4.4 Tree Planting

In order to achieve some semblance of ecological succession, diversity, and resilience in the reforestation areas, a tree species mix was used with a variety of sizes and species. Using differing sizes has created an economic advantage as more trees have been planted with funds that would have equated to many fewer large specimen trees. While having a smaller initial visual impact, the tree masses still created planting areas of substance and have quickly grown into successful shade areas. It has also been noted that larger transplanted trees have experienced more shock while the smaller installed trees seem to adapt more easily.

4.5 Erosion Control by Bermuda Grass

When designing the creek, a primary need was to establish turf immediately for erosion control purposes. Germination rates of the native grasses and wildflowers were deemed to be too slow and risky given the large area and hydrology of the creek. Thus, the native grass mix included 25% Bermuda seed because of its quick germination period. The hope was that it could be allowed to grow long and match the future character of the native grasses. The greatest fear was that the Bermuda grass would out-compete the native grasses and create a monoculture with little diversity and native character. For the first few years, this was the case. However, as the project matures, the native grasses and wildflowers have been competing quite well and are now very well established if not out-competing the Bermuda grass. This approach helped prevent soil erosion, preserve water quality and maintain visual

表4 社区一期部分种植的树木与项目完工时的预计树木
Table 4 Planted and estimated trees in Phase I and project completion

Tree species 树种	Percent 种植比例	Size 苗木胸径	Planted trees in Phase I 一期部分种植树木量	Planted trees in project completion 项目完工时种植树木量
Pine 松树	25%	2.5” / 5.08 cm	6,105	12,881
Oak mix 栎树混交林	65%	2.5” / 5.08 cm	15,873	33,492
Live oak 常绿橡树	10%	4” / 10.16 cm	2,442	5,152
Total 树木总量			24,420	51,525

Table 5 越溪牧场社区与传统社区的草地修剪成本节约情况详细比较

Table 5 Detailed comparison between Cross Creek Ranch and conventional community in estimating cost-savings of mowing

<table>
<tr><td rowspan="6">Conventional community
传统社区</td><td>a.typical frequency of mowing (times / year)
常规的修剪频率（次/年）</td><td>b. average speed of mowing (acre / h)
平均修剪速度（英亩/小时）</td><td>c. total area of a conventional community (acres)
一个传统社区的总面积（英亩）</td><td>d. average gas consumption for mowing (gallon / h)
修剪所需平均耗油量（加仑/小时）</td><td>e. gas price (USD / gallon)
汽油价格（美元/加仑）</td><td>f. average labor cost for mowing (USD / h)
修剪平均人工费用（美元/小时）</td></tr>
<tr><td>38</td><td>1.54</td><td>636</td><td>1</td><td>3.5</td><td>10</td></tr>
<tr><td colspan="3">Gas cost for mowing (USD / year) 因修剪所需的耗油费用（美元/年）
c ÷ b × a × d × e</td><td colspan="3">54,929</td></tr>
<tr><td colspan="3">Labor cost for mowing (USD / year) 因修剪所需的人工费用（美元/年）
c ÷ b × a × f</td><td colspan="3">156,940</td></tr>
<tr><td colspan="3">Total maintenance cost (USD / year)
总维护成本（美元/年）</td><td colspan="3">211,869</td></tr>
<tr><td colspan="6"></td></tr>
<tr><td rowspan="5">Cross Creek Ranch
越溪牧场社区</td><td colspan="2">g. gas consumption for mowing (gallon / year)
修剪所需耗油量（加仑/年）</td><td colspan="2">h. average gas consumption for mowing (gallon / h)
修剪所需平均耗油量（加仑/小时）</td><td>i. gas price (USD / gallon)
汽油价格（美元/加仑）</td><td>j. average labor cost for mowing (USD / h)
修剪平均人工费用（美元/小时）</td></tr>
<tr><td colspan="2">5,639</td><td colspan="2">1</td><td>3.5</td><td>10</td></tr>
<tr><td colspan="3">Gas cost for mowing (USD / year) 因修剪所需的耗油费用（美元/年）
g × i</td><td colspan="3">19,737</td></tr>
<tr><td colspan="3">Labor cost for mowing (USD / year) 因修剪所需的人工费用（美元/年）
g ÷ h × j</td><td colspan="3">56,390</td></tr>
<tr><td colspan="3">Total maintenance cost (USD / year)
总维护成本（美元/年）</td><td colspan="3">76,127</td></tr>
</table>

Total cost saving:
Annual gas saving: 15,694 – 5,639 = 10,055 gallons / year
Total cost saved in gas: 54,929 – 19,737 = $35,192
Total cost saved in labor: 156,940 – 56,390 = $100,550
Percent of maintenance cost saved: (211,869 – 76,127) ÷ 211,869 = 64%

总节约费用：
每年节约耗油量：15 694 – 5 639 = 10 055 加仑/年
每年节约耗油费用：54 929 – 19 737 = 35 192美元
每年节约人工费用：156 940 – 56 390 = 100 550美元
每年维护费用节约百分比：(211 869 – 76 127) ÷ 211 869 = 64%

论文

期的视觉效果较弱，但这些树木依然构成了种植区域，并且已经快速成长为非常理想的遮蔽区域。同时应该注意到的是，较大的移植树木受到的创伤也会更多，而较小的树木适应能力则更强。

4.5 利用狗牙根草进行侵蚀防控

在设计溪流时，一个主要目的就是为了建立一片能够起到侵蚀防控作用的草坪。考虑到区域的面积和溪流的水文条件，设计团队认为原生草种和野花的出芽率过低且具有风险性。因此，在混合的原生草种中加入了25%的狗牙根草种子，因为它的出芽期非常短。设计团队最大的担忧是狗牙根草将成为优势种并影响原生草种的生长，从而变成缺乏多样性和当地特色的单一草地。在最初的几年中，情况确实如此。但随着项目的逐渐成熟，原生草种和野花也形成了良好的竞争力——现在即便没有淘汰掉狗牙根草，其生长情况也非常好。这个方法有助于防止土壤侵蚀，保护水质并维持居民的视觉效果。

4.6 灌溉策略

在发生水管破裂时，滴灌系统的维护难度非常高，并且会在美观度上带来负面效果。根据原始计划，预计在两年的生长期之后先不拆除这些灌溉系统，而是原样保留作为备用。但最终发现全部使用喷灌系统和使用滴灌系统的成本差异非常小，而且乡土/自然化区域的灌溉管理非常简单，只需要在植物群落建成之后将喷灌系统关闭，或因物种生存需要再将其开启。这样一来，缺乏美观的滴灌管线不再是问题，同时自然景观的外观也得到了提升。

4.7 标识牌

室外自然标识牌作为一种教育工具，能够有效地提高居民对于自然化景观的接受程度。而设计团队面临的问题是如何处理这些标牌的树立时间、高度及地点。它们的安置需要在栎树草地和再造林区的种植完成之后、达到成熟株高之前进行。标识牌同时也以宜人的尺度被设立在种植区域中（图8）。当植物成熟之后，标识牌将被高草或浓郁的树荫所遮蔽，变得模糊。改善的方案是，应考虑标识牌的高度和与植株成熟株高的比例，并在植物群落适度形成后以及一年中合适的时间内添设新的标识牌。

5 结论

在此次研究中，研究团队对德克萨斯州休斯顿

acceptance by residents.

4.6 Irrigation Strategy

The drip systems were difficult to maintain when water line breaks occurred and were found to be aesthetically unappealing. The original intent was not to remove the system after the two-year growing period, but to leave it in place as a backup. Eventually it was determined that the cost between full spray systems and the drip system were minimal and irrigation to the native / naturalized areas could easily be managed by turning the spray system off once plants were established or turned back on for species survival. Unsightly drip irrigation lines were no longer an issue, and visual acceptance of the natural landscape was improved.

4.7 Signage

Outdoor nature signage was used as an educational tool, which effectively enhances residents' acceptance of naturalized landscapes. One issue was the timing, height and placement of the signs. Their installation occurred right after oak savannah and reforestation zones were planted and not yet fully reached their mature height. The signs were also designed to be human scale and embedded in the planting zones (Fig. 8). As the plantings matured, signs became obscured by tall grass and or deep shade from trees. A better approach would have been to consider sign height and proportion for planting maturity and to add signs after reasonable plant establishment and during the correct time of year.

5 Conclusion

In this study, the research team investigated landscape performance of a 3,200-acre master planned community near Houston, Texas that employs a treatment wetland system and naturalized landscapes. Through the quantification of environmental, economic and social benefits of the installed systems, the research team concluded the following:

1) Uses a treatment wetland and a creek / lake system to improve water quality, which reduces concentration of nitrogen by 85%, phosphorous by 97%, potassium by 57%, calcium by 54%, magnesium by 52%, sodium by 85%, zinc by 7%, copper by 93%, and manganese by 51%.

2) Sequesters an estimated 787,545 lbs of CO_2 in the trees of the community per year and will sequester an estimated 1661,644lbs of CO_2 when the community is at build-out.

3) Saves annually 35,192 USD and about 10,055 gallons of gas, and $100,550 in labor through the creation of no-mow zones, for a 64% reduction in overall maintenance costs.

4) Saves 1,454,250 USD annually by reducing fertilizer usage by 831 tons in naturalized planting areas.

5) Saves 603,490 USD by reducing potable water usage for irrigation by 121,671,400 gallons from 2009 to 2012 through usage of reclaimed water in the treatment wetland for irrigation.

6) 42% of resident homes are adjacent to native naturalized landscape, designated trails, and parks which might help increase property values.

7) Creates 25 ~ 30 miles of trails.

8) Creates 154 outdoor education signs, 1 every 4 acres, 180 people per sign.

Although the above quantified benefits are concluded, this study used the snapshot observation method due to time / budget constraint. Thus, the

6. 越溪牧场社区中的标识牌
7. 步行道沿线约50cm宽的修剪草带
8. 调整高度之后的高草区域标识牌
6. Signage example in Cross Creek Ranch
7. Mowing strip of 18 inches along sidewalk
8. Signage in tall grass zone after height modification

Article

市附近占地面积约1 300hm²、采用了湿地处理系统及自然化景观的总体规划性社区的景观绩效进行了调查。通过对该系统环境、经济及社会效益的量化分析，研究团队得出了以下结论：

1）使用治污湿地及小溪/湖泊系统以改善水质，共计降低了85%的氮含量、97%的磷含量、57%的钾含量、54%的钙含量、52%的镁含量、85%的钠含量、7%的锌含量、93%的铜含量，以及51%的锰含量。

2）社区中的树木每年预计吸收$CO_2$357 224kg，在社区完工后可预计吸收$CO_2$753 718kg。

3）每年节省35 192美元及10 055加仑汽油，通过创建无刈区可节省人工费用100 550美元，总体维修费用减少64%。

4）自然栽植植被区域每年可减少化肥施用量754吨，节省费用1 454 250美元。

5）从2009~2012年通过利用经治污湿地处理后的再生水进行灌溉，减少了用于灌溉的饮用水121 671 400加仑，节省费用603 490美元。

6）42%的居民住宅与乡土自然化的景观、指定的步道及公园毗邻，能够提升其房地产价值。

7）创建了40~48km的步道。

8）创建了154块户外教育标识牌，合每4英亩或每180人就设有一块标识牌。

尽管得出了上述量化效益结果，本研究因时间/预算有限，采用了快照式观察方法。因此，调查团队仅选择了适于横向分析的度量标准。如果要进行更加透彻的效益定量分析，应当考虑进行长期的纵向分析。另外，研究小组建议将效益量化的数据收集工作在建设之前开展，并在建设及建成后持续进行。这将有助于形成具有说服力和更具针对性的景观绩效数据库和设计指导准则。这不仅将会提升景观设计学在跨学科实践中的地位，同时也有利于执业人员、教育者、研究者及公众等各方的利益。

最后，研究团队对从景观管理及维护实践中获得的经验进行了总结。在景观维护方面的变化举措是基于实地观察的，同时也为设计与居民住宅相毗邻的自然化景观提供了指引——这不仅间接提升了景观的绩效，也印证了景观感知体验的重要性。**LAF**

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research team only chose metrics that are suitable for cross-sectional analysis. For a thorough quantification of benefits, long-term longitudinal analyses should be considered. Furthermore, the research team suggests that data collection for benefit quantification should begin prior to construction and continue the process post construction. This enables the development of convincing and liable landscape performance database and design guides. Such an effort will not only elevate the stature of the landscape architecture profession in multidisciplinary practices but also benefit all, including practitioners, educators and researchers, as well as the general public.

Finally, lessons learned from landscape management and maintenance practices are provided. Landscape maintenance changes were based upon field observations and will provide guidance on strategies when designing naturalized landscapes that are immediately adjacent to human dwellings, which should indirectly enhance landscape performance and confirm the importance of perceived care of the landscape. **LAF**

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观点与评论
View and Criticism

“水系统生态设计”这个主题可以从4个层面来理解。首先是对于“水”的理解，水以三种形态存在于自然界中，包括液态的江河湖海、云雨雾露，固态的冰雪霜雹，以及气态的水蒸汽。景观设计中，我们通常关注的仅仅是液态的“水流”，如何将水的所有形态纳入设计考量中是我们思考的第一个层次。其次是对于“系统”的理解，一方面，我们所讨论的并不仅限于如何对某一“水景观”进行单纯的设计，而是要将其置于一个系统中来思考。这个系统既包含水自身的系统性——水体的循环、增减，也包含水系统与诸如土壤、生物、大气等其他系统之间的联系及相互影响；另一方面，水体还与我们的城市人居环境、城市乃至区域形象/特色的营造息息相关。第三个关键词是“生态”，我们希望跳出仅对于水景的审美考虑，而将生态性作为首要的考量因素。第四个层面，则是将上述所讨论的“水”、“系统”、“生态”的问题转化为具体的、可操作的设计语言和设计过程，即如何将理论转化为实践。

“水系统生态设计”这一主题相当宏大，本期杂志难以囊括与之相关的方方面面，但我们意在激发设计师意识到与水相关的各种或有形、或无形的联系，从而以更广阔的视野、更丰富的维度来思考“水”这一问题。

The “Ecological Water System Design” can be interpreted in its four aspects. The first one is our understanding of “water”, which exists in the nature in three states. The liquid form exists as streams, rivers, lakes, seas, plus clouds, raindrops, fog and dew; the solid form occurs as ice, snow, frost and hail, while the gaseous state can be seen as vapor. In landscape architecture, we usually focus only on liquid water. Thus the first dimension is how to bring all forms of water into design consideration. The second one is our understanding on “system”. We are not merely talking about how to design a single waterscape, but to put it into a system, which includes not only water itself, but also the greater system of its interaction with soil, biology, atmosphere and other systems. Water is also closely bound up with our urban living environment and the city. Waterscapes play a significant role in place making and to many city's identity and branding. The third one is “ecological”. Beside the aesthetic value, ecology should be seen as a priority factor in design processes. Last but not least, we wish to transform the above mentioned issues into an operable design language and process, which means turning theory into practice.

“Ecological Water System Design” is too vast a theme to be fully discussed in this single issue. Our intention is to remind designers the myriad water related connections, whether visible or not, and to think about water in a broader sense, entailing multiple readings.