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低影响开发绩效评估：

德克萨斯州康罗市易干旱景观地下水涵养方案

Performance Evaluation of Low Impact Development:

Groundwater Infiltration in a Drought Prone Landscape in Conroe, Texas

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摘要 ……

由于地下水极度短缺，美国德克萨斯州正经历着严峻的水资源匮乏挑战，为了防止此情况继续恶化，该项目对整合低影响开发的替代性设计方法予以了探讨与研究。其采取的设计方法是通过对拟建的雨水基础设施可能带来的环境和经济绩效的衡量，来决定它的设计，包括其概念与项目安排。其重点在于尽量提升文化和水文系统之间的关联性。

关键词 ……

干旱；地下水；涵养

项目地址： 美国德克萨斯州康罗市
项目面积： $2hm^2$
项目委托： 孤星地下水保护区
景观设计： 德克萨斯州A&M大学景观设计硕士课程组
首席设计师： 盖伦·纽曼
项目负责人： 孙源敏
设计团队： 大卫·丹尼尔森、郭芮丝、李之凰、宁思曼、苏晓甜、王宇骋、杨碧彤、姚越、张祎珣、赵靖琳
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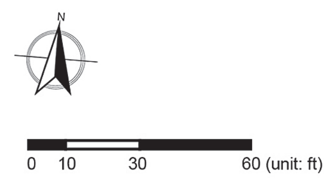
Abstract ...

Texas, USA is undergoing critical water challenges due to immense groundwater deficiencies. Alternative methods to integrating design with Low Impact Development need to be explored to stymie this condition. This projectapplies an approach to design whose concept / program is reinforced by projected environmental and economic performance measures of proposed stormwater infrastructure. The focus is to maximize the relationship between cultural and hydrological systems.

Key words ...

Drought; Groundwater; Infiltration

Location : Conroe, Texas, USA
Area (size): $2\ hm^2$
Client: Lone Star Groundwater Conservation District
Landscape Architecture: Texas A&M University, Master of Landscape Architecture Program
Chief Designer: Galen Newman
Project Leader: Won Min Sohn
Project Team: David Danielson, Ruisi Guo, Zhihuang Li, Siman Ning, Xiaotian Su, Yucheng Wang, Bitong Yang, Yue Yao, Yixun Zhang, Jinglin Zhao
Award: 2014 Texas American Society of Landscape Architecture Merit Award



Stormwater Management 雨洪管理
1. Dry creek 旱溪
2. Rain garden 雨水花园
3. Bio-swale 生态洼地
4. Detention pond 滞留池
4-1. Upper platform 上层平台
4-2. Lower platform 下层平台
5. Retention area 滞留区
5-1. Green terrace 绿色台地
5-2. Stone pathway 石径
5-3. Rock seat 石凳
6. Berm pocket levee and depression 小型防波堤与洼地

Parking space 停车场
7. Entrance 入口
8. Pixelated parking lot 嵌草停车位
9. Curb-cut 路缘坡

Landscape 景观
10. Phyto-remediation grassland 植物修复草地
11. Private garden 私人花园
12. Xeriscape garden 旱生花园
13. Successional plant growth area 植物生长演替区

Rainwater harvesting 雨水收集
14. Homestyle rain barrels 家用雨水收集器
15. Rainwater harvesting simulation 雨水收集模拟
16. Rain symphony 雨幕

Rest area 休息区
17. Lid plaza 雨棚广场
17-1. Reflection waterway 倒影水道
17-2. Underground cistern 地下蓄水池
17-3. Water wall and living wall 水景墙与垂直绿化墙
18. Outdoor classroom 露天教室
19. Pergola 格架
20. Weather station 气象站

Pathway 路径
21. Permeable sidewalk 透水人行道
22. Elevated walkway 抬升通道
23. Permeable carpet 透水铺装
24. Unpaved pathway 未设铺装的小径

1. 总平面图。大部分设计的景观元素旨在过滤并将雨洪径流导至滞留池中。
1. Master Plan. Most proposed landscape elements function to filter and distribute runoff to the detention pond.

背景

为了使非渗透性土地覆盖的影响最小化，强调雨水管理——如低影响开发（LID）的土地规划策略，越来越常被应用于设计领域中。LID采用场地设计技术以“保存和重建自然景观特色；最小化非渗透性效果以创造其功能性用途，并呼吁场地排水，将雨水视为一种资源而非无用之物[1]”。LID应用范围广泛，它同时也是一种土地规划实践，可以维持或修复流域的水文和生态功能[2]。

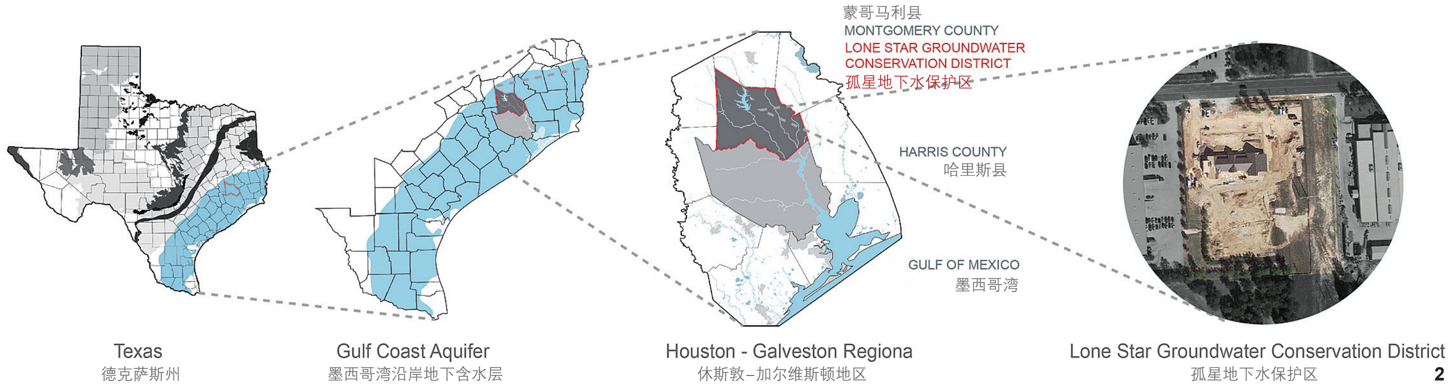
现有的一些设计准则/手册可以用来推断LID的应用潜力以及区分LID设施的显著特点[3]-[5]，但是基于LID的设计的绩效评价方法却并不常见。此外，虽然如德克萨斯运输局等州立机构根据1972年的《净水法案》[6][7]努力开发工程技术以减少城市径流，小规模的水管理基础设施系统（例如生物洼地及滞留池等）仍需被进一步地体验以衡量其影响。

德克萨斯州康罗市内的孤星地下水保护区（LSGCD）办公室，负责保护水资源并监测依赖其地下水资源的蒙哥马利县内的用水情况（图2）。由于墨西哥湾沿岸地区含水层[8]内地下水被过度抽取，康罗市正面临着多重水资源挑战。保护区所面临的艰巨任务是如何使该地区快速增长的人口，摆脱对地下水的依赖。目标是截至2016年实现较2009年的地下水抽取量降低30%[9]。同时，该县市政供水区也积极争取新的基础设施的兴建许可权，提供替代性水源，如面积约8 $100hm^2$的康罗湖。由于责任所在，该机构自身也成为潜在的教学设施，展示最新的地下水资源保护技术。

LSGCD办公室项目总规划意在将其地区总部转变为一个能够让人们学习地下水资源知识，并了解到保护水资源的解决方案同时也能实现视觉美的享受。此外，该项目把对于拟建的LID技术的绩效评估列入设计过程的一部分。本文撰写时，总计划评估目前处于分阶段实施过程中的初始阶段。

问题与挑战

由于地下水极度短缺，德克萨斯州正经历着严峻的水资源挑战，这也使得水文



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学敏感设计日趋重要。德克萨斯州境内都正面临着水供给减少和需求激增的问题。预计2010~2060年间，全州供水量将下降10%，其需求量则将上升22%，这主要归因于德克萨斯人口预估将增长至4 600万。一旦出现类似于1947~1957年间发生的旱情，德克萨斯的用水需求量将超过其可供应量。

随着极端干旱事件的日益频发及强度增大，德克萨斯州经历着地下水补给和地表水供应的严重减少的危机[12]。据德克萨斯州蒙哥马利县估测显示，预计到2040年，该区域的人口将增加一倍，地下水抽取量将超出墨西哥湾沿岸地区含水层补给能力[13]（图3）。蒙哥马利县的供水几乎全部来自淡水含水层，而其目前被消耗的速度远快于其补给速度。地下水的过度消耗还会造成抽水亏空与地表下降。例如，据估计，休斯顿-加尔维斯顿都市统计区的部分地区由于过度抽取地下水，地平面在未来一个世纪可能下沉达3m，受洪涝事件影响的可能性也会随之增加。

为了应对这一挑战，可以有效增强场地雨水渗透的LID成为一项突出可行的设计解决方案。为了使非渗透性土地覆盖的影响降至最小，LID技术通过集成软、硬质工程来加强雨水径流管理[14]。这形成了新的设计形式，该设计立足于项目的量化测量，展现雨水基础设施的环境和经济绩效，使文化和水文系统之间的关联达到最大化。因此预期影响成为设计项目安排的决定性工具。

设计策略及原则

在这一项目中，设计决策主要基于方案能否促进地下水补给和对现存雨水排放问题做出积极回应。自然的地下水枯竭源自很长一段时间内的补给减少，而这一情况往往因人类活动而加剧[15]。场地总体规划提出了众多的设想，策略性地引导雨水使其能够渗透到地下，而非从场地上排出（图1）。开发者一向试图以让雨水迅速排出场地的方式处理雨水，这种做法不利于该地地下水的补给。设计方案通过实践运用LID，强化场地入渗性和地下水补给。设计项目由17个LID设施组成，根据其水文功能可分为获取、输送及净化三种类型；然后设施可根据材料组成分为两组：硬质工程设施，主要由需要构建工程的结构组件所组成；软质工程设施则仰赖非结构性组件，如植物修复过程等，使植被在减少污染物和减缓水流方面的作用达到最大化。

例如，该设计要求滞留池保留收集场地及周边区域的溢流雨水，使其得以渗入地下；停车场采用渗透性材料，使雨水能直接下渗；花园的台地系统使水在流经该地时得以过滤；屋顶的配备使雨水流入水箱进行保存用以灌溉（图4）。设计项目中的其他节水特性包括：

- 略微抬升的人行道（非地平面的人行道）
- 非渗透性的铺装和路缘坡
- 大型蓄水池和民用集雨桶
- 配有绿色屋顶和垂直绿化墙体的信息亭
- 用以收集雨水的温室和花园
- 空调冷凝收集系统
- 注重耐旱和低维护的植物景观配置

基于耐旱能力和水处理能力的考虑，植物选取旱生和植物修复品种。旱生植物能够在减少水灌溉需求方面发挥作用，具有修复功能的植物可以作为天然过滤器，净化被污染的径流。设计具体运用了两种类型的修复功能植物：植物提取修复和根系过滤。具有提取修复功能的植物在吸收重金属方面发挥重要作用；同样的[16]，根系过滤植物能够吸收土壤水分中及流过根部区域[17]的水中的金属和疏水性有机物。

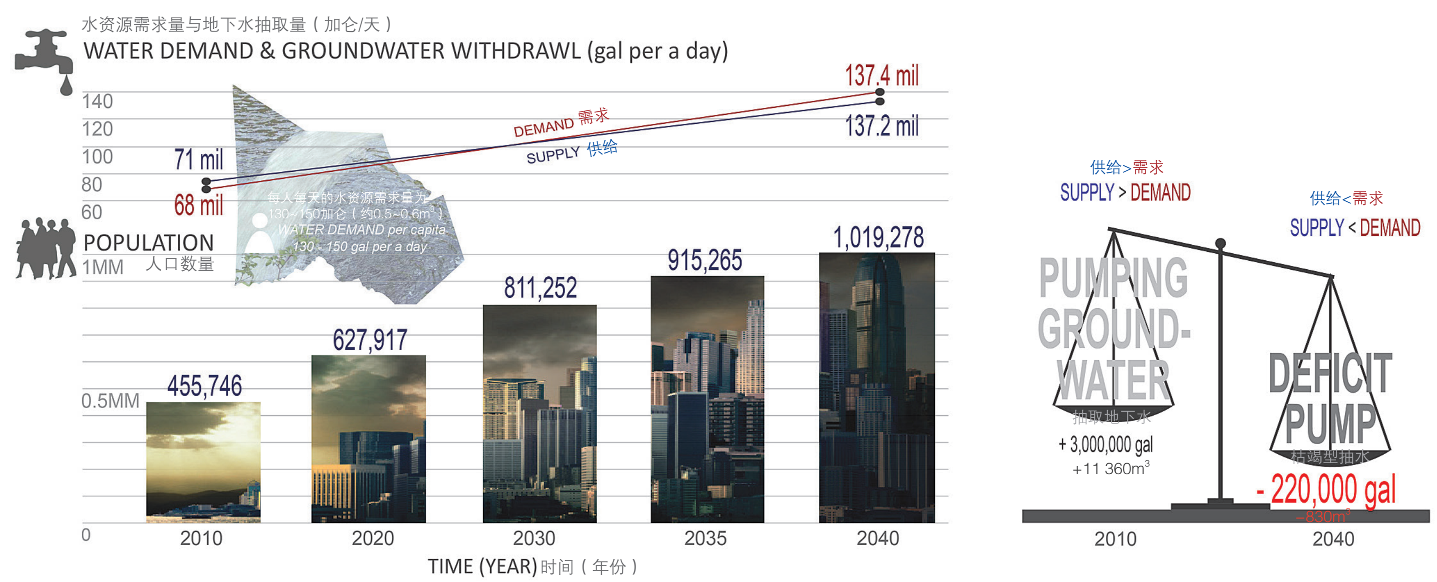
设计绩效

要检验地下水补给潜力，需要透过整合每月降雨量数据、每月蒸散量数据、植物系数和设计后表面材料径流系数，来测定每一设施的渗透量占总降雨量的比率。然而传统的设计往往主要采用混凝土覆盖的基础设施，其缩短了径流时间，在径流流经时减少了地下水补给；而每个LID设施都增加了径流的场地渗透能力（图5，6）。此外，基于其水文功能（获取、输送及净化）设施间的关系和战略布局能够使它们在自然过程中净化污染的径流。

我们根据水文影响和整体绩效对这一设计进行评估。评估方面包括：1）雨水收集量和再利用量；2）径流减少量；3）用水需求减少量；4）雨水水质改善情况。通过年降雨量、区域面积和对比常规设计与LID设计的复合径流系数，可计算出径流量的减少量，而使用月降雨量、屋顶面积和屋顶系数数据，则可计算出回收雨水量与再利用量。此外，旱生植被、年度参照作物蒸散量、作物系数和灌溉效率用于估测减少的水需求量。最后，土壤污染物浓度、植物提取系数、种植密度和植物覆盖中污染物浓度用于衡量水质的改善程度。

根据现有建筑物的情况，每年该区域通过屋顶收集可以获取近1 250m³的雨水[18]（足以填充大约半个奥运会标准泳池）（图7）。所收集的雨水通过回收方案成为了户外灌溉存储。所收集雨水量仅占总降雨量率的5%左右。虽然回收率偏低，但大部分留存的水被收集在拟建的滞留池中，实现减低径流量，并提高雨水下渗率的目标。

假设常规设计的典型径流系数是0.65（轻工业区），基于LID的设计每年能够通过增加场地渗透（图8）减少近7 200m³的地表雨水。这一设计极大地减少了径流（减少44.5%的径流），其不仅成功地将非渗透区域面积降至最低，同时也改进



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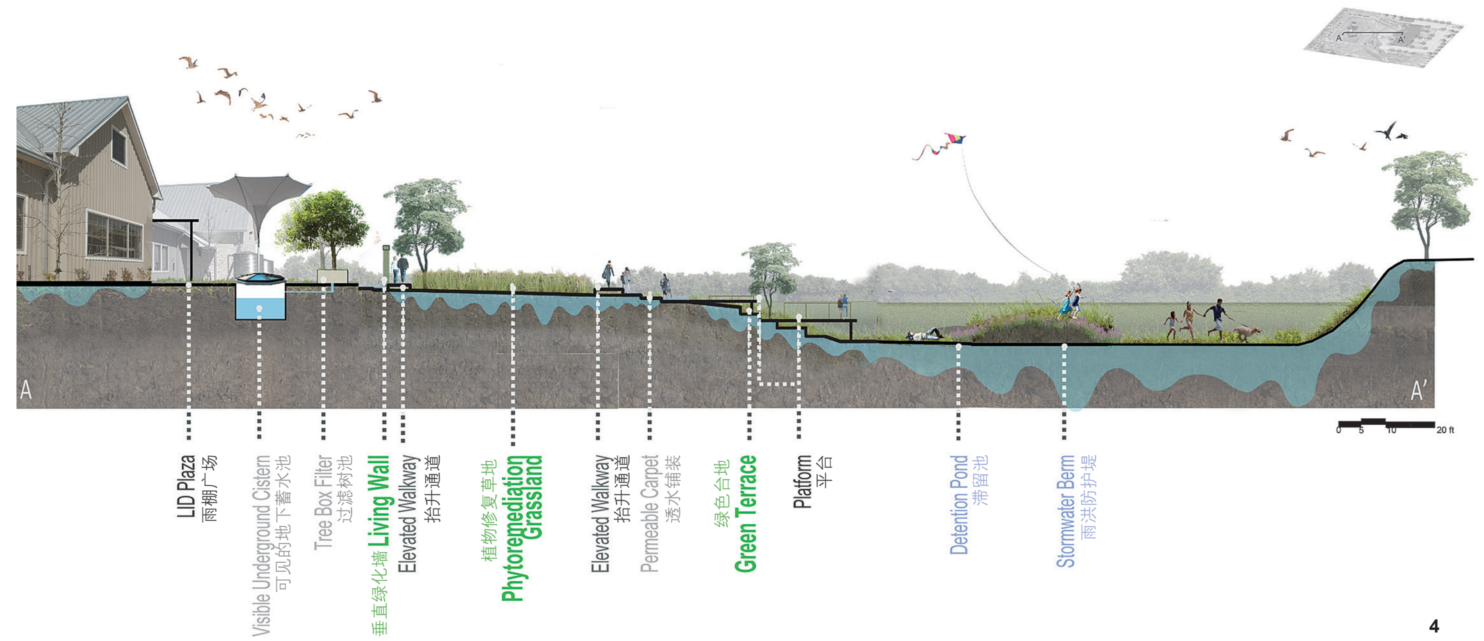

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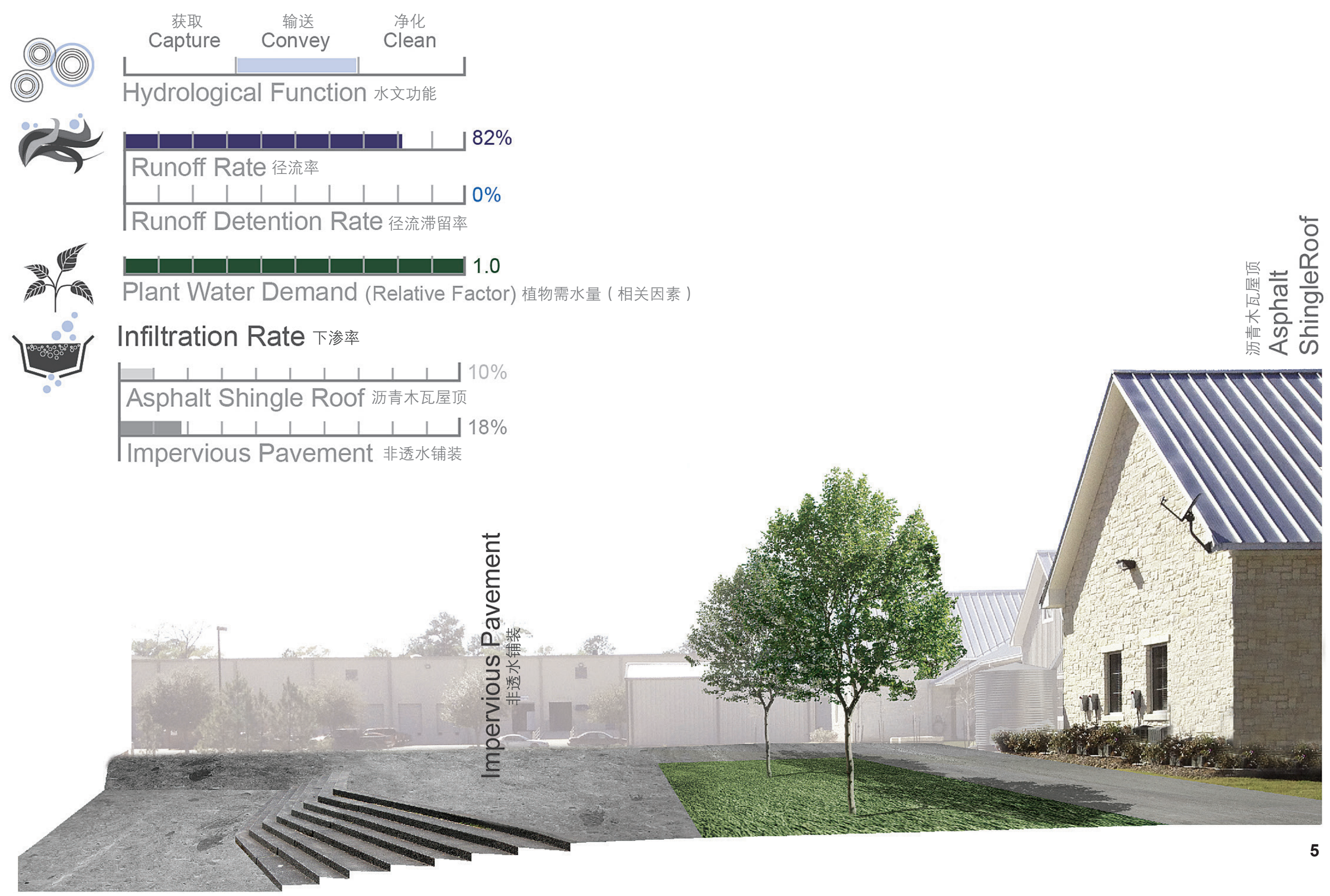
2. 孤星地下水保护区区位图
3. 增长的人口与水需求量。至2040年，当地人口将会达到100万人。这将导致非透水地表的大幅增加，并由此产生雨水下渗减少问题。水需求量将超过墨西哥湾沿岸含水层供给能力，并导致严重的地下水短缺危机。
4. 设计将透水地表直接或间接地串联在一起，以将雨洪径流疏导至人工滞留池。

2. LSGCD site area
3. Increasing population and water demand. By 2040, populations will reach 1,000,000, resulting in increased impervious lands and decreased rainwater infiltration. Water demand will exceed the supply capacity of the Gulf Coast aquifer, leading to serious shortages of groundwater withdrawal.
4. Proposed pervious surfaces directly or indirectly connect to convey stormwater runoff to the constructed detention pond.



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了初始排水模式，增加了径流流经时间（图9）。

为了计算运用旱生景观后（与传统景观相比）水需求的减少量，采用了传统景观的植物系数的中间值，旱生景观的灌溉效率为95%来进行估算。结果表明旱生景观缩减了约600m³的灌溉需求，节约了50%~83%的灌溉用水，有效地缓解了城市供水压力。由于在美国所取用的地下水70%是用于户外灌溉[19]~[21]，旱生景观对地下水供应缺乏问题可以有极大帮助（图10）。

为了促进通过植物修复去除土壤中的重金属，印度芥菜（*Brassica juncea*）被选为主要植物品种（每英亩净重3吨）[22]，因其是在过去研究中所发现的最有效的具备提取功能植物之一。假设现有土壤中的污染物浓度低于美国环境保护署的标准，则其最多可以从该场地吸收160kg金属[23]~[25]（图11）。

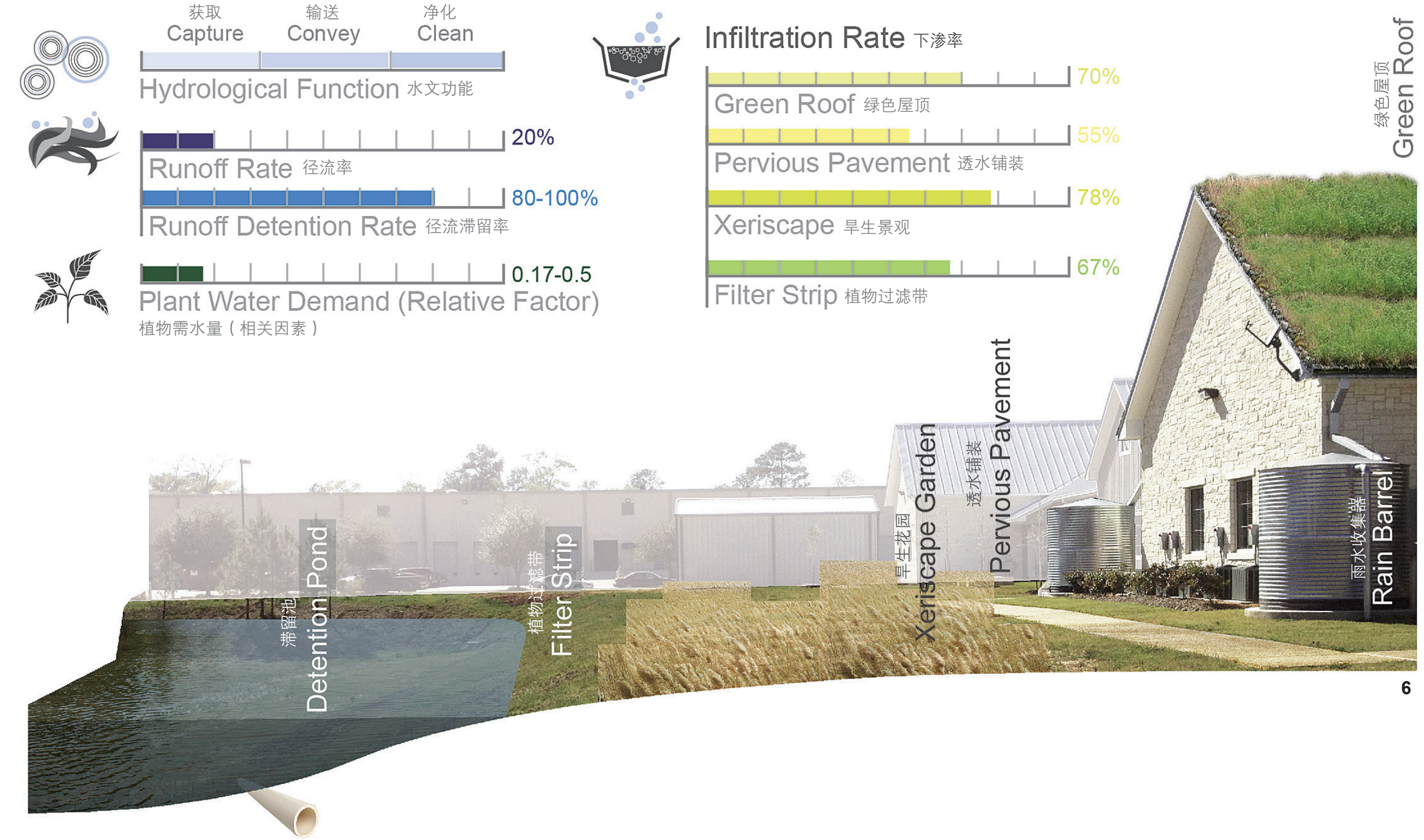
基于水文性能测量的雨水收集量、品种耐旱度以及场地渗透率增加量，结果显示雨水用量和水质改善可直接节约成本。根据当前城市的供水和水处理费用的花销（图12），该项目每年可产生7 300美元的利润。相比其他周边城市，由于地下水枯竭的问题[26]，康罗市的非住宅土地用水量较高。相较于其他同样面临水供给量和水处理量缩减的城市，这一设计有助于康罗市免于产生超额经济支出。

结论

此项目阐述了基于LID设计的重要性，并强调了其发展后绩效评估的意义。环境和经济评估结果显示LID技术在节约用水和地下水补给方面做出的显著贡献。然而，减少洪涝风险等间接因素需要以货币量化价值评估出那些本可消免的环境损害所需的代价，从而避免低估成本节约。伴随着成本分析的绩效衡量过程也将有助于明确项目实施的影响。

基于LID的设计有助于产生更为客观的设计，是整体设计和运用定量测量为基础的规划决策时的有效工具。该方法不仅可以应用于住宅/商业设计等微观项目，也可以应用于区域影响评估等宏观规划和环境政策，同时会给业主、开发商和地方政府带来诸多益处。通过将上述结构进一步开发为不同权重的详细指标，该系统将不断强化，其框架可能会在未来应用到多个案例研究和设计中。LAF

5. 惯常设计。缺乏雨洪滞留设施的混凝土铺装导致雨水直接排放到场地的低势区域。
6. 基于LID的设计。滞留池作为临时性储水空间，增加了下渗率。
5. Conventional design. Concrete pavement without detention facilities directly moves stormwater to the lower level of the site during stormwater events.
6. LID-based design. The detention pond functions as a temporary storage space to increase infiltration rates.



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Background

In an effort to minimize the impact of impervious land cover, land planning strategies emphasizing stormwater management, such as Low Impact Development (LID) have become increasingly utilized in the design fields. LID employs site design technologies such as "preserving and recreating natural landscape features, minimizing effective imperviousness to create functional and appealing site drainage that treat stormwater as a resource rather than a waste product[1]." Applied on a broad scale, LID is also a land planning practice that can maintain or restore a watershed's hydrologic and ecological functions[2].

While several design guidelines / manuals exist which infer potentialities of LID applications and differentiate the distinctive features of LID facilities[3]-[5], not many approaches evaluate the performance of LID based designs. Furthermore, while state agencies such as the Texas Department of Transportation have shown efforts to develop engineering techniques in reducing urban runoff under the *Clean Water Act of 1972*[6][7],small-scale water management infrastructure systems (for example, bio-swales, detention ponds, etc.) need farther examination to gauge impact.

Lone Star Groundwater Conservation District (LSGCD) office in Conroe, Texas, USA is charged with monitoring and conserving water in groundwater-dependent Montgomery County (Fig. 2). The City of Conroe has experienced many water challenges due to excessive groundwater withdrawal from the Gulf Coast aquifer[8]. The conservation district faces a daunting task of weaning the area's fast-growing population off of groundwater, targeting by 2016 a 30 percent reduction in groundwater pumping from 2009 levels[9]. In the meantime, the county's municipal water districts are racing to acquire rights and build infrastructure needed to provide water from alternative sources, such as the 20,100-acre Lake Conroe. Because of its duties, the agency supplants itself as a potential educational facility for demonstrating the latest groundwater conservation techniques.

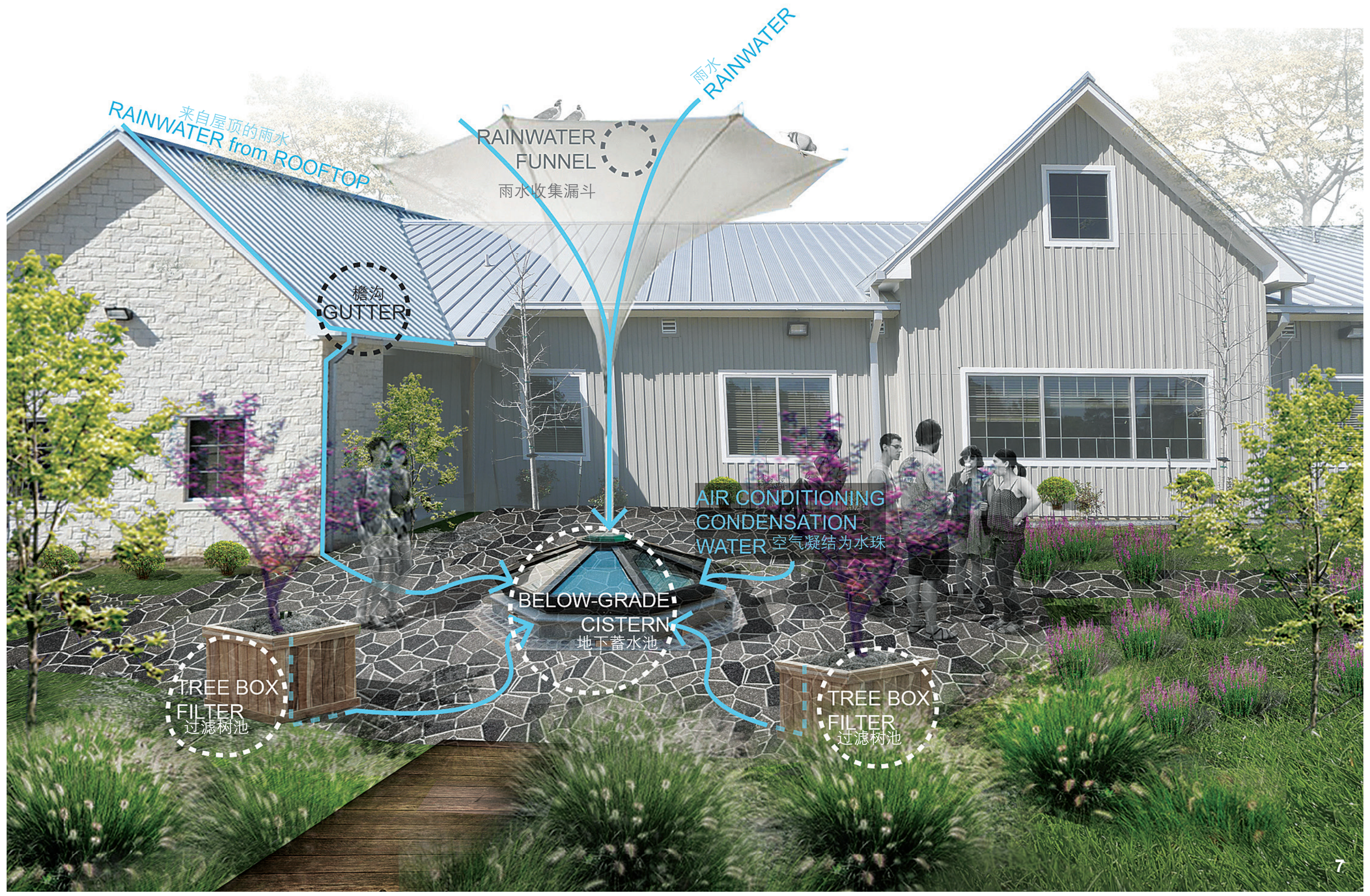
The purpose of the master plan project for the LSGCD office is to transform the district's headquarters to become a site where people learn about groundwater and see that conservation solutions can be aesthetically pleasing. Additionally the project included performance evaluation of the proposed LID techniques as part of the design process. The master plan evaluated in this article is currently beginning the process of phased implementation.

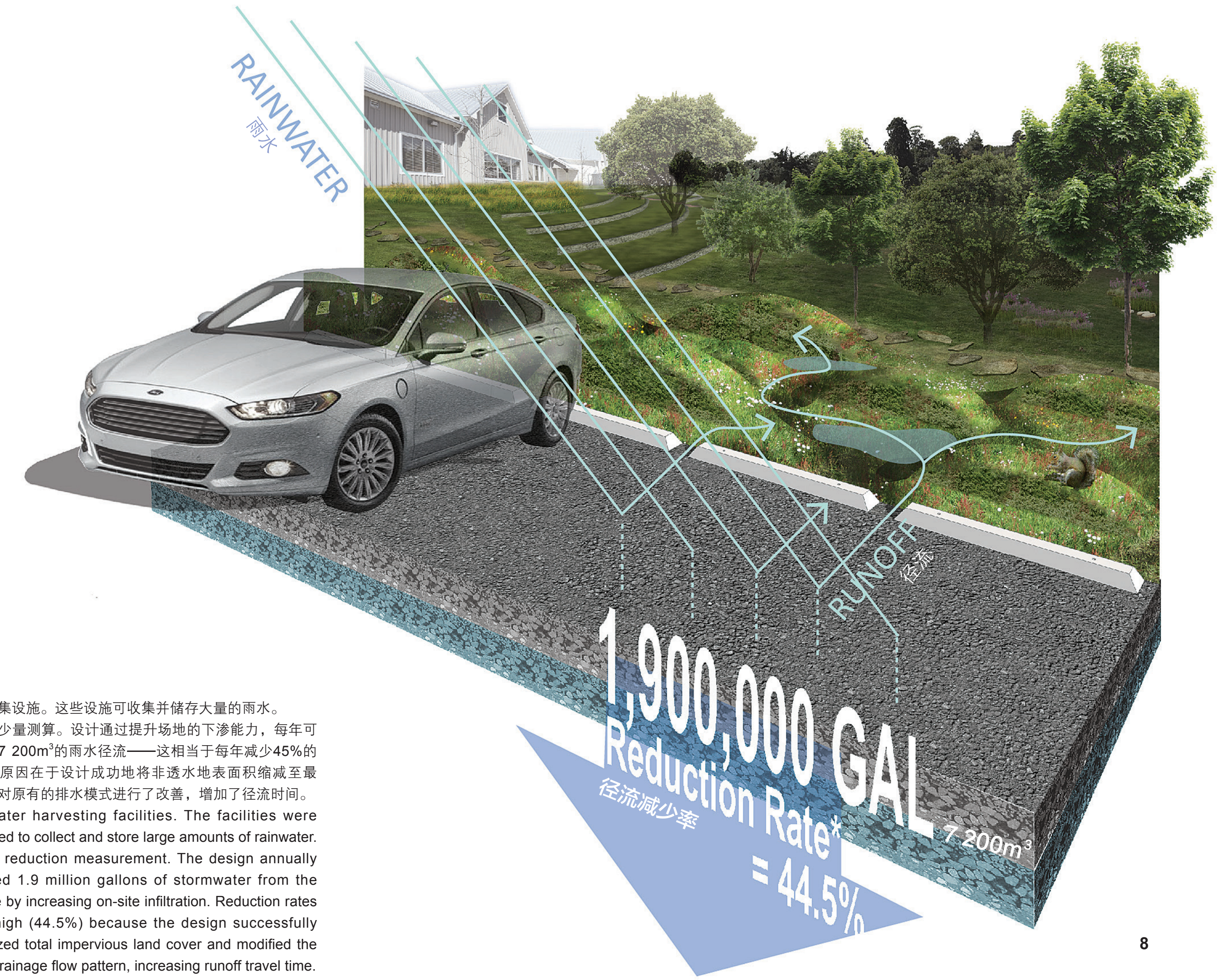
Issues and Challenges

Texas is undergoing critical water challenges due to immense groundwater deficiencies, rapidly increasing the significance of hydrologically sensitive design. Statewide, Texas is faced with dwindling water supplies while demand is growing rapidly. A 10% drop in the statewide water supply is projected between 2010 and 2060, while water demand is expected to rise 22%, due mostly to a projected population increase to 46 million people[10].Should a drought similar to the dry spell occurring between 1947 and 1957 occur, the demand for Texas water will exceed the supply[11].

With a growing frequency and increased intensity of extreme drought, Texas has experienced severe reduction in groundwater recharge and surface water supplementation[12]. Montgomery County, Texas projections suggest as the population forecasts to double, groundwater use by humans will exceed the capacity of Gulf Coast aquifer recharge by 2040[13](Fig. 3). Montgomery County's water supply comes almost exclusively from freshwater aquifers that are being depleted faster than they can recharge. Excessive withdrawals of groundwater consequently have caused deficit-pumping and land subsidence. For instance, it is estimated that some ground levels in the Houston-Galveston Metropolitan Statistical Area, couldsink as much as ten feet in the next century due to excessive groundwater use, also increasing vulnerability to flood events.

In response to this challenge, LID serves as a salient design solution by increasing on-site infiltration of stormwater. In an effort to minimize the impact of impervious land cover, LID technology emphasizes stormwater runoff management by integrating hard and soft engineering[14]. The result is a new form of design which bases its program upon quantitative measures exposing the environmental and economic performance of stormwater infrastructure, thereby maximizing the relationship between cultural and hydrological systems. Projected impacts can then become a decision making tool for design programming.





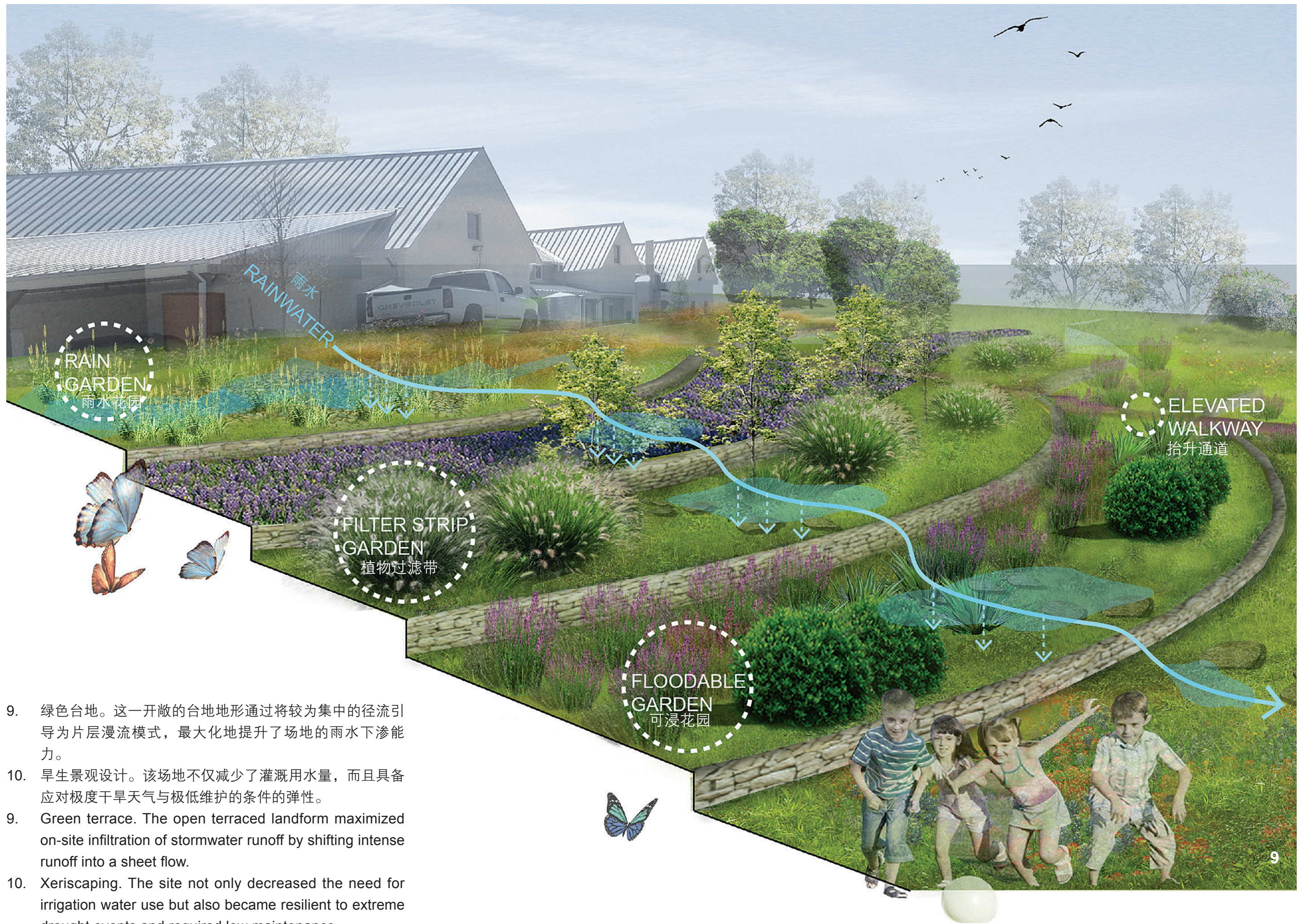
7. 雨水收集设施。这些设施可收集并储存大量的雨水。
8. 径流减少量测算。设计通过提升场地的下渗能力，每年可减少约7 200m^{3}的雨水径流——这相当于每年减少45%的径流，原因在于设计成功地将非透水地表面积缩减至最低，并对原有的排水模式进行了改善，增加了径流时间。
7. Rainwater harvesting facilities. The facilities were proposed to collect and store large amounts of rainwater.
8. Runoff reduction measurement. The design annually reduced 1.9 million gallons of stormwater from the surface by increasing on-site infiltration. Reduction rates were high (44.5%) because the design successfully minimized total impervious land cover and modified the initial drainage flow pattern, increasing runoff travel time.

Design Strategy and Schematics

In this project, design decisions are made based primarily on their ability to assist in groundwater recharge and respond favorably to the existing stormwater issues. Natural groundwater droughts originate from reduced recharge over a prolonged period of time and these droughts are often enhanced by human activities[15]. The master plan developed for the site includes numerous schemes to strategically guide stormwater in an effort to allow it to infiltrate the ground rather than be forced off the property (Fig. 1). Developers have traditionally attempted to deal with rain by allowing it to run off the property, to the detriment of recharging the groundwater on site. The design strategy emphasized on-site infiltration and groundwater recharge through the application of LID practices. The design program consisted of 17 LID facilities which were categorized into three typologies depending on their hydrological function: capture, convey, and / or clean. The facilities were then divided into two groups based on the materials composing them. While hard engineering facilities were mainly comprised of structural components requiring engineered construction, soft engineering facilities were reliant upon non-structural components such as phyto-remediation processes, maximizing the use of vegetation in mitigating pollutants and dissipating the energy of water flow.

For example, the design called for a detention pond to hold overflow rainwater collected from the site and tangential properties for subsequent infiltration; parking areas constructed from permeable materials that allow rainwater to pass through; a tiered system of gardens to filter water as it traveled across the site; and rooftops outfitted to route rain into cisterns where it is held for irrigation purposes (Fig. 4). Other water-saving features in the design program included:

• Slightly elevated walkways (rather than ground level sidewalks)
• Impervious paving and curb cuts
• Large scale cisterns and residential-style rain barrels



9. 绿色台地。这一开敞的台地地形通过将较为集中的径流引导为片层漫流模式，最大化地提升了场地的雨水下渗能力。
10. 旱生景观设计。该场地不仅减少了灌溉用水量，而且具备应对极度干旱天气与极低维护的条件的弹性。
9. Green terrace. The open terraced landform maximized on-site infiltration of stormwater runoff by shifting intense runoff into a sheet flow.
10. Xeriscaping. The site not only decreased the need for irrigation water use but also became resilient to extreme drought events and required low maintenance.

• Informational kiosks equipped with green roofs and living walls

• A greenhouse and garden using harvested rainwater

• An air conditioning condensation collection system

• A plant palette emphasizing drought tolerance and low maintenance

Plant selection was chosen using xeriscape and phyto-remediation specimen, based on drought tolerance and water treatment capacity. While xeriscape plants functioned to reduce the water demand of irrigation, phyto-remediation plants served as natural filters in cleansing contaminated runoff. Two typologies of phyto-remediation plants were specifically used: phyto-extraction and rhizo-filtration. Phyto-extraction plants play a significant role in heavy metal uptake; similarly[16], rhizo-filtration plants are capable of taking in metals and hydrophobic organics from soil water or from water flowing through the root zone[17].

Design Performance

To verify the potential of groundwater recharge, the rate of stormwater infiltration out of total rainfall for each facility was measured by integrating monthly rainfall data, monthly evapotranspiration data, plant coefficients, and post-design runoff coefficients of surface material. While conventional design calls for predominantly concrete-covered infrastructure which shortens the travel time of runoff and reduces groundwater recharge by channeling runoff, each LID facility made high contributions to increase on-site infiltration of runoff (Fig. 5, 6). Furthermore, the relationship and strategic placement of facilities based on their hydrological function (capture, convey, and/or clean) allowed contaminated runoff to be cleansed by natural processes.

The design was evaluated according to its hydrological impact and overall performance. Variables include 1) rainwater collection and reuse, 2) runoff reduction, 3) water demand reduction, and 4) stormwater quality improvement. Monthly rainfall, roof size, and roof coefficient data were used to calculate the volume of rainwater collection and reuse, while annual rainfall, property size, and composite runoff coefficients comparing conventional design and LID design computed the rate of runoff reduction. Also, xeriscape plant cover, annual reference evapotranspiration, crop coefficients, and irrigation efficiency were employed to estimate the volume of reduced water demand. Finally, pollutant concentration in soils, phyto-extraction coefficients, plant densities, and plant cover were used as measures to determine the extent of water quality improvement.

On the basis of the condition of existing buildings, the site could capture 330,000 gallons of rainwater annually[18] through rooftop harvesting (enough to fill roughly half of an Olympic-sized swimming pool) (Fig. 7). This collected water resulted in outdoor irrigation savings through reuse strategies. The total collection rate of rainwater from the total rainfall was only around 5%. Although the rate was low, much of the remaining water was collected in a proposed detention pond resulting in runoff volume reduction and high infiltration.

Under the assumption that the typical runoff coefficient of conventional design is 0.65 (light industrial area), the LID based design annually reduced 1.9 million gallons of stormwater from the land surface through increasing on-site infiltration (Fig. 8). The reduction rate was high (44.5%) as the design not only successfully minimized total impervious area but also modified the initial drainage flow pattern to increase the travel time of runoff (Fig. 9).

To calculate water demand reduction through xeriscaping (compared to conventional gardens), it was assumed conventional gardens had a medium value of plant coefficients and the irrigation efficiency of a xeriscape garden was 95%. The result suggested that xeriscaping reduced irrigation needs by 160,000 gallons, saving 50% ~ 83% of irrigation water and alleviating the strain on the city water supply. Since 70% of withdrawn groundwater is used for outdoor irrigation in the U.S. [19]-[21], xeriscaping can contribute greatly to solving the lack of groundwater supply (Fig. 10).

To encourage removal of heavy metals from the soil through phyto-remediation, *Brassica juncea* (Indian Mustard), one of the most effective phyto-extraction plants found in previous studies[22], were selected as a primary plant specimen (3 tons dry weight per acre). With an assumption that the pollutant concentration in the existing soil is below the U.S. Environmental Protection

Agencystandard, a maximum 160 kg of metals could be taken up on site[23]–[25](Fig. 11).

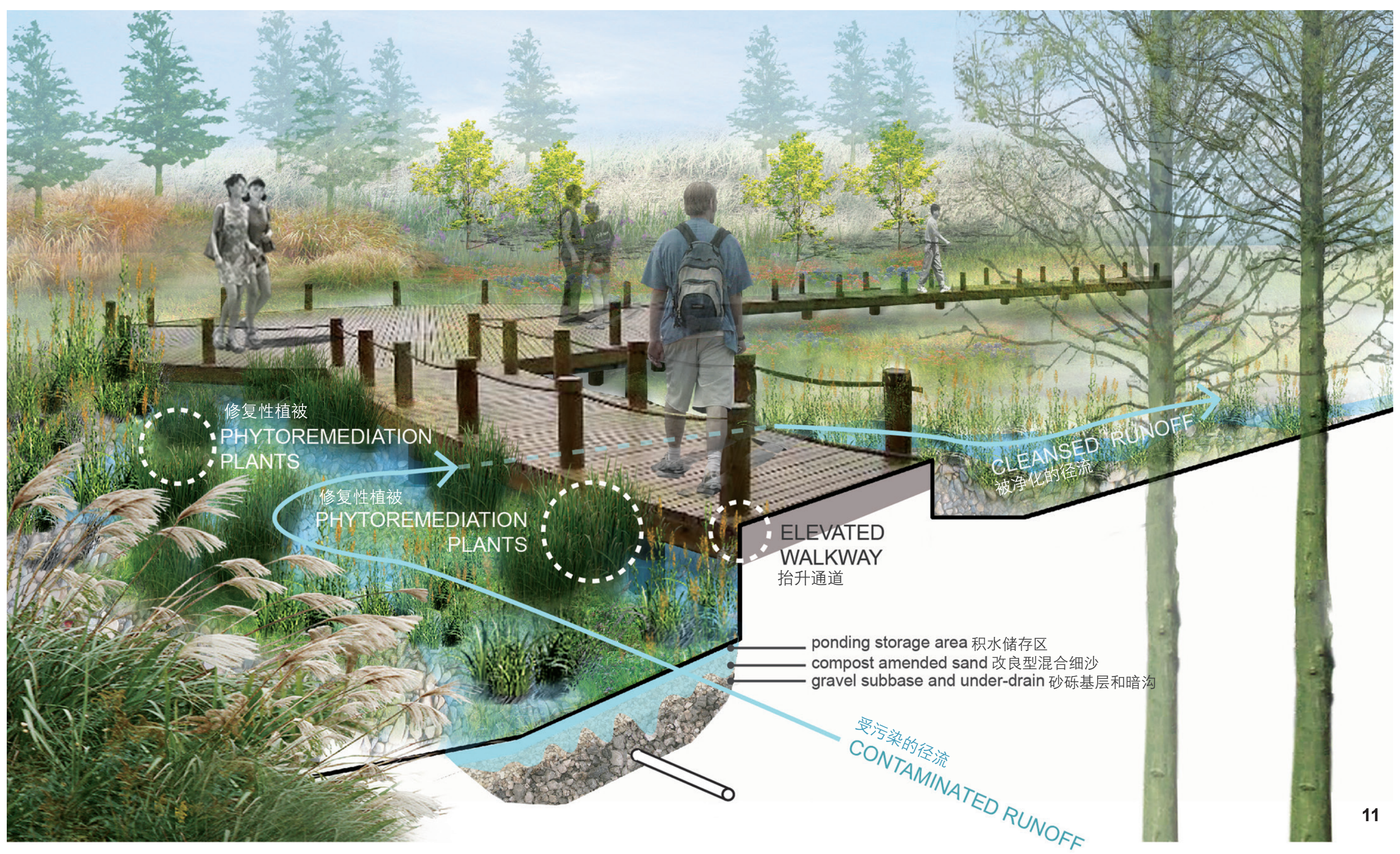
Based on the hydrological performance measurement of rainwater harvesting amounts, specimen drought tolerance, and increased on-site infiltration, the result was a direct cost savings of water use and water quality. The project generated an annual profit of USD 7,300 in savings based on current city water supply and water treatment costs (Fig. 12). The City of Conroe had a higher water rate for non-residential land than other surrounding cities, due to the issue of groundwater depletion[26]. The design helped avoid excess economic charges compared to other cities for the same amounts of water supply and treatment reduction.

Conclusions

This project emphasized the significance of LID based design and its projected performance evaluation post-development. Results of the environmental and economic assessment implied significant contributions of LID techniques to water conservation and groundwater recharge. However, indirect factors such as reduced flooding risk needed to be quantified in dollar values to assess the avoided environmental damage cost, thus preventing underestimated cost savings. The process of performance measurement accompanied by cost analysis will also help determine the impacts of project implementation.

LID based design could be an effective tool in the decision making process for holistic design and planning based on the utilized quantitative measurements, producing more objective designs. The approach could be applied not only to micro scaled projects such as residential / commercial design but also to macro scaled plans and environmental policies such as regional impact assessments and would bring a wide range of benefits to property owners, developers, and municipal governments. By further developing the aforementioned structure into detailed indicators with varied weights, the system would be strengthened and the framework could be applied to multiple case studies and designs in the future. LAF

11. 植被修复过程。大量修复性植被被广泛种植在主要污染源附近（例如停车场和工业区周边）。通道被轻幅抬升，以不影响植被修复过程与水流。
12. 成本节约。一年可在城市水供给与水治理方面节省7 300美元。康罗市在非住宅用地用水方面要高于周边其他城市，该设计为这座城市节约了经济开支。
11. Phyto-remediation process. High densities of phyto-remediation plants were widely placed near major sources of pollution (such as parking lot and adjacent industrial area). Walkways are slightly elevated not to interrupt this process and water flow.
12. Cost saving. An annual profit of USD 7,300 can be generated in saving city water supply and water treatment costs. Conroe had a higher water rate for non-residential land than surrounding cities and the design helped avoid excess economic charges.



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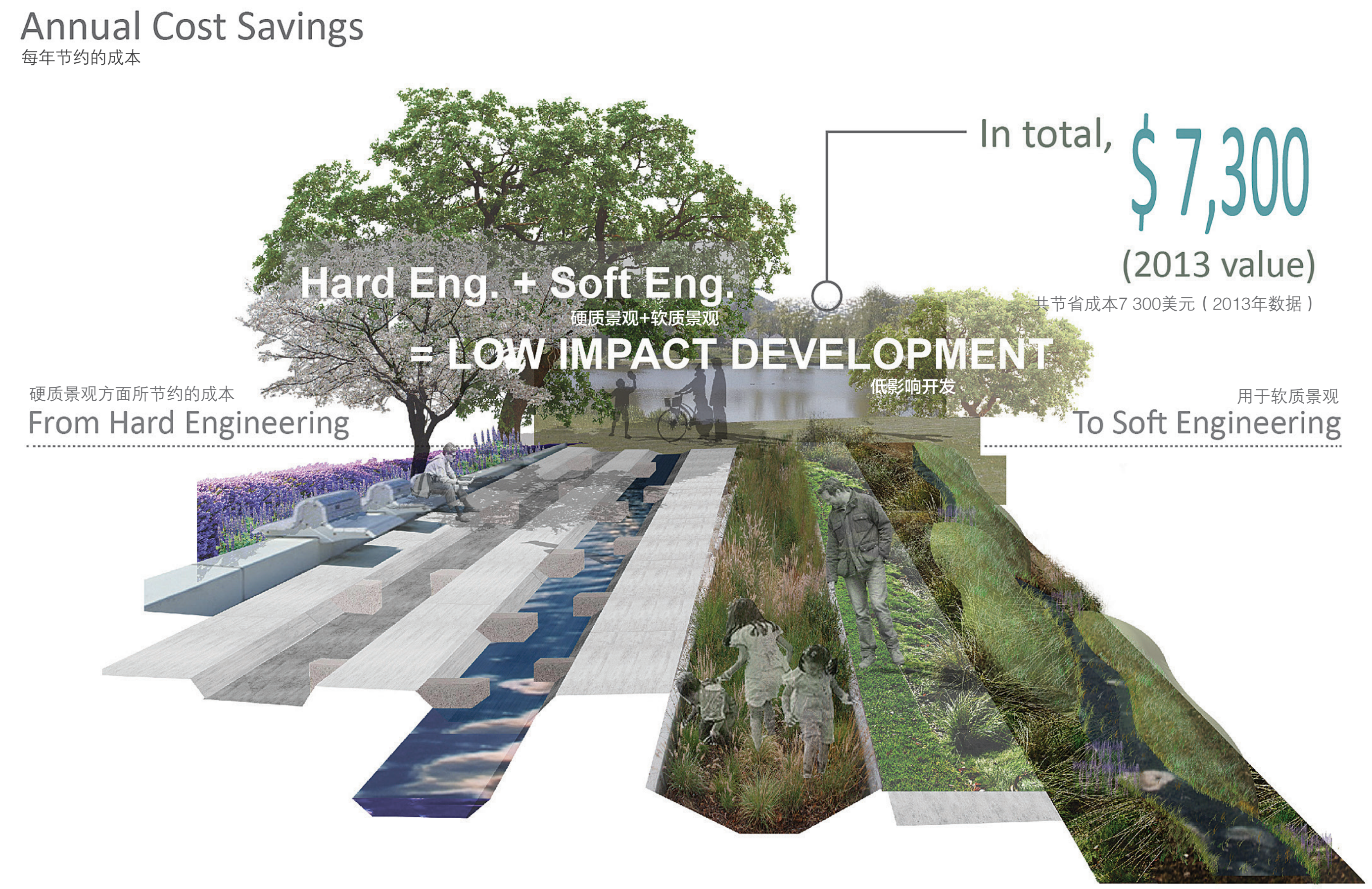

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