综合教学与实践：
绿色基础设施规划和绿色屋顶绩效
在美国半干旱校园环境中的应用

INTEGRATED TEACHING AND
PRACTICE:
GREEN INFRASTRUCTURE
PLANNING AND GREEN ROOF
PERFORMANCE IN A SEMI-ARID
CAMPUS ENVIRONMENT, USA

1 引言

美国环境保护署一直倡导将绿色基础设施（GI）设计作为一种雨水管理的生态可持续方法，尽管鲜有研究对美国西部半干旱地区的GI绩效进行评估^{[1]-[4]}。气候变化的不确定性会影响GI系统的绩效。为了填补这一知识空白，并使设计师、决策者及公众意识到GI系统可能存在的不确定性，有必要对GI最佳实践的实际建成效果进行展示^{[5][6]}。特别需要强调的是，大学教育是传播这些知识的首重途径，尤其是景观设计学这个有资格设计此类GI系统的学科。

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摘要

本文介绍了一个鼓励校园内外利益相关者广泛参与的综合性教育和研究计划。这个设计方案旨在加强人们对于水的关注，推动了位于美国西部半干旱山区的犹他州立大学校园内实现有效的雨水管理。犹他州已经采用各种各样的“绿色”雨水管理措施，例如，大部分校园中的径流被用于补给地下水。然而，这其中并没有哪个方案全面地展示出可持续实践的内容，且极少对设计绩效进行定量评估。根据2011年制定的《犹他州立大学校园总体规划》及《校园可持续发展规划（2013-2020）》，本文提出了一系列以雨水为资源的绿色基础设施策略来弥补上述空白，并制定了校园实施计划的三个阶段。其中第一阶段总体规划包括一个建成的绿色屋顶项目，研究对该绿色屋顶表面与作为实验参照的相邻沥青屋顶在削减雨水径流和降低温度方面的绩效数据予以了记录。总而言之，本研究提供了一种整体性的绿色基础设施设计方法，不仅为目前相关研究较少的半干旱气候地区贡献了绿色基础设施绩效评价数据，其本身也成为了一个在设计过程中进行研究的案例。

关键词

气候适应性；犹他州；绿色基础设施；雨水管理；教育体验；教学创新

ABSTRACT

This paper presents an integrated education and research program that involves extensive participation from stakeholders on campus and beyond. The resultant water conscious design proposal promotes efficient stormwater management on Utah State University’s campus, situated in the semi-arid Intermountain West. Utah State has adopted various “green” solutions for stormwater management, such as directing most campus runoff to recharge groundwater. Yet, there is no comprehensive plan that lays out its sustainable practices, and little quantitative assessment of the design performance has been performed. In accord with the University Campus Master Plan of 2011 and Campus Sustainability Plan 2013-2020, this paper addresses this gap and proposes a series of green infrastructure strategies that make use of rain as a resource, and that can be implemented across campus in three phases. A built green roof project is part of the Phase I master plan. Pilot performance data are presented regarding stormwater runoff and temperature reduction on a green roof surface versus an adjacent test-bed asphalt roof. In summary, the paper provides a holistic approach toward adopting green infrastructure designs and assessing green infrastructure performance in the less evaluated semi-arid climatic conditions, and it serves as an example of research through design process.

KEY WORDS

Climate Resilience; Utah; Green Infrastructure; Stormwater Management; Educational Experience; Pedagogical Innovation

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1. 1 教学创新

在校园中建设可持续发展项目已被证明是倡导最佳实践和推动未来设计师进行相关实践的有效方法^{[7]~[9]}。例如，在犹他州（美国最为干旱的地区之一），许多公民和政策制定者都对雨水管理问题不甚理解，因为“犹他州不太下雨”。然而，在气候变化的大背景下，如何采用创新性的方法使干旱地区宝贵且稀缺的水资源得到充分利用变得至关重要^{[10][11]}。教育在培养环境管理文化方面发挥着重要作用，学生在学校里习得的GI实践将使得他们在工作后更加可能倡导类似的可持续实践。

传统课堂教学法的一个劣势是其无法为学生提供理解和应用相关信息的情景化语境^{[12]~[14]}。对真实案例的学习主张的理念是“学习需源自真实课题（现实问题和针对研究课题的模拟训练）”^{[15][16]}。基于项目的学习和基于问题的学习（POPBL）是两种广泛应用于真实案例学习中的方法^[17]。在实践中，运用真实项目才是POPBL方法的核心，为学生提供剖析现实状况和获得一手实践经验的机会^{[7]~[9]}。

本研究通过运用创新性的方法，制定了一系列旨在解决现实设计问题（例如绿色屋顶的设计和建造）的景观设计学课程。受过此类课程教育的学生表现出更高的参与度和实践水平，且展现出了更好的批判性思维和解决问题的能力^[18]。来自景观设计学、流域科学和土木工程学的跨学科团队通过与10余所校园内外的院校/机构密切合作，制定了

1 Introduction

Green infrastructure (GI) design has been advocated by the U.S. Environmental Protection Agency as an ecologically sustainable approach for stormwater management, although few studies have assessed the efficacy of GI in the semi-arid U.S. West^{[1]~[4]}. Climate change poses further uncertainties about the performance of GI systems. To bridge this knowledge gap and to make designers, policy makers, and the general public aware of the possible uncertainties in GI performance, it is imperative to demonstrate best practices with tangible outcomes^{[5][6]}. In particular, college education would be an important first step to disseminate these knowledge components, especially in Landscape Architecture, a discipline well qualified to designing this type of GI system.

1.1 Pedagogical Innovation

Adopting campus sustainability projects have been demonstrated to be an effective approach to advocate best practices and to promote projects by the next generation of designers^{[7]~[9]}. For instance, in the United States’ second driest state of Utah, stormwater management issue is not easily understood by many citizens or policy makers because it “never rains in Utah.” However, adoption of innovative approaches that take advantage of the valuable, yet scarce, water resources in arid regions is critical in face of the changing climate^{[10][11]}. Education can play an important role in fostering a culture of environmental stewardship because students who learn about the GI practices at their schools are likely to champion the same type of sustainable practices when they join the work force.

One shortcoming of traditional classroom pedagogy is that it fails to provide students with contextual features that enable them to understand and apply information^{[12]~[14]}. Authentic learning is based on the idea that learning is sparked by authentic tasks — real-world problems and simulations that stem from the subject under study^{[15][16]}. Project-based learning and problem-based learning (POPBL) are two authentic learning approaches in broad use^[17]. In practice, the use of real projects is at the core of the POPBL approach, providing students with the opportunities to analyze real-life situations and gain hands-on experiences^{[7]~[9]}.

In this study, an innovative approach is used to develop Landscape Architecture courses that focus on real-world design problems (e.g., design and installation of a green roof). Students who experience project-based education demonstrate higher levels of engagement and performance and they present better critical-thinking and problem-solving skills^[18]. An interdisciplinary team of students from Landscape Architecture, Watershed Science, and Civil Engineering worked closely with colleagues from more

表1：犹他州北部的绿色屋顶项目和项目绩效研究
Table 1: Green Roof Projects in Northern Utah and Research on Project Performance

项目名称 Project Name	所在地 Location	建成时间 Built-up Year	绿色屋顶研究 Green Roof Research	参考文献 References
犹他自然历史博物馆 Utah Natural History Museum	盐湖城 Salt Lake City	1963	未进行 N/A	无 N/A
马瑞奥特图书馆 J. Willard Marriott Library	盐湖城犹他大学校园 University of Utah campus, Salt Lake City	1968	蒸腾（ET）监测 （2013年至今） Evapotranspiration [ET] monitoring [2013-]	参见参考文献[22][23] See Refs. [22][23]
耶稣基督后期圣徒教会 （LDS）会议中心 Church of Jesus Christ of Latter-Day Saints (LDS) Conference Center	盐湖城 Salt Lake City	2000	未进行 N/A	无 N/A
幼儿教育大楼 Early Childhood Education Building	洛根市犹他州立大学校园 Utah State University campus, Logan	2010	未进行 N/A	无 N/A
自然资源大楼 Natural Resource Building	洛根市犹他州立大学校园 Utah State University campus, Logan	2017	径流量和温度监测（2017年 至今） Runoff volume and temperature [2017-]	初步数据在本文中有体现 Preliminary data presented in this paper

一个大学校园的综合性GI规划。此外，他们还设计和建造了一个绿色屋顶展示项目，作为该GI规划第一阶段的示范性项目。

1.2 犹他州的绿色屋顶实践

作为一种受欢迎的GI策略，绿色屋顶在减少雨水径流、提高水质、节约能源、创建栖息地、提升生活品质等方面的效益已得到广泛证实^{[19]-[21]}。但在美国西部半干旱山区，特别是犹他州，GI实践并不多——虽然一些显要建筑也设置了绿色屋顶，但其应用仍明显少于其他州（参见《美国国家低影响开发图集》）。

由于缺乏相关数据，绿色屋顶的绩效无法评估，因此在犹他州和其他西部干旱地区迟迟没有广泛推广绿色屋顶。在犹他州北部的几个绿色屋顶项目案例中（表1），犹他大学主图书馆绿色屋顶项目可能是唯一一个收集了绩效数据的项目，但其仅重点记录了绿色屋顶植物的蒸散率^{[22][23]}。目前在犹他州立大学（USU）进行的这项研究对绿色屋顶另外两个重要的绩效指标（径流量和温度）进行了记录，并将研究与教学/教育活动相结合。

USU因其在可持续发展方面所作出的积极努力被视为美国“最环保”的校园之一。USU校园通过利用遍布校园的干井实现了近100%的雨水径流收集，并实施了一系列最佳水质管理项目（如生态洼地）。

than ten colleges / units on and beyond campus to develop a comprehensive GI plan for a university campus^①. In addition, as a demonstration project for the first phase of the GI plan, a green roof display was designed and constructed by the same group of students and colleagues.

1.2 Green Roof Adoption in Utah

Green roofs are a popular GI strategy whose widely reported benefits include stormwater runoff reduction, water quality enhancement, energy conservation, habitat creation, and improvement on quality of life^{[19]-[21]}. In the semi-arid Intermountain West, and specifically in Utah, only a few examples exist. Although some of these have been installed in prominent buildings, application of green roofs has been noticeably higher in other states (e.g., see National LID Atlas^②).

One hesitation of adopting green roofs in Utah and other parts of the arid west is uncertainty about their performance due to a lack of performance data. Among these few green roof project examples in Northern Utah^③ (Table 1), the project at University of Utah’s main library is perhaps the only one that collects performance data, but its main focus is to understand the evapotranspiration rates of green roof plants^{[22][23]}. This

① 来自犹他州立大学（USU）和犹他州其他参与该研究的院校/机构包括：犹他州农业和应用科学学院、犹他州自然资源奎尼学院、USU公共设施部、USU水资源拓展计划项目组、犹他州农业实验站、国家自然科学基金会iUTAH计划小组、USU可持续发展委员会、犹他州水质监管部、犹他州水质特别工作组，以及犹他州水质扩展部。
② 更多信息请访问<http://lidmap.uconn.edu/>。
③ 犹他州北部是指从洛根（犹他州立大学的所在地）到普罗沃从北到南的城市链，盐湖城（州首府）也位于其间。超过80%的犹他州居民居住在盐湖城及周边地区^[63]。

① Participating colleges / units from Utah State University (USU) and in the state of Utah include: College of Agriculture and Applied Sciences, Quinney College of Natural Resources, USU Facilities, USU Extension Water Initiative, Utah Agricultural Experiment Station, iUTAH program (NSF), USU Sustainability Council, Utah Division of Water Quality, Utah Water Quality Task Force, and Utah Water Quality Extension.
② For more information, please visit <http://lidmap.uconn.edu/>.
③ Northern Utah refers to the chain of cities running north to south from Logan (home of Utah State University) to Provo, with Salt Lake City (state capital) in between. More than 80% of Utah residents live in Salt Lake City and the surrounding areas^[63].

1. 犹他州立大学GI总体规划第一阶段试点绿色屋顶项目将研究、教学与公共教育相结合。

1. Integrated research, teaching, education and outreach program for GI master plan with a phase I, pilot green roof project at Utah State University.

虽然《校园可持续发展规划（2013-2020）》^[24]对USU校园提出了更高的绩效目标，但未制定实现这些目标的总体规划。

研究包括两个目标：1）为USU主校区制定GI总体规划，以雨水管理为重点，分三个阶段实施；2）在第一阶段建立一个绿色屋顶展示项目，并将相邻的沥青屋顶作为参照，评估二者在削减雨水径流和降低温度方面的绩效。该计划鼓励校园内外利益相关者广泛参与；它不仅将教学和实践相结合，其本身也成为了一个在设计过程中进行研究的案例^[25]（图1）。

2 雨水管理的背景和当前实践及挑战

2.1 区域背景和气候变化影响

西部各州是美国最干旱的地区，也是发展最快的地区之一。1990~2000年，西部地区的人口增长占美国人口增长总数的50%，其中犹他州位列前五^[26]。犹他州人口的快速增长和城市化激发了对有效雨水管理的巨大需求。一方面，预计到2050年时，犹他州人口将增加100~250万人^[27]，届时供水压力将空前巨大。另一方面，在降水稀缺的环境下，犹他州正面临着如何利用不断减少的水资源来应对城市发展的挑战。目前，犹他州大部分的降水都以降雪的形式集中发生在高海拔地区。这些水资源通过高海拔水库和运河系统被输送至全州。据预测，未来50年中，犹他州西南部的降雨量将减少，而北部低海拔地区的降雨量将增加^[28]。如此一来，现有水库和运河系统的有效性将大大减弱，从而导致灌溉用水和生活用水供水量减少。

current study at Utah State University (USU) assesses two other important indicators of green roof performance — runoff volume and temperature, as well as integrating research with teaching / education components.

USU has been considered as one of the “greenest” campuses in the United States for its sustainability initiatives. It recharges nearly 100% of its stormwater runoff through dry wells across campus and has installed a series of water-quality best management practices (e.g., bio-swales). Although the campus Sustainability Plan 2013-2020^[24] has lofty goals toward higher performance, there is no holistic master plan in place to achieve these goals.

The objective of this paper is two-fold: 1) to provide a GI master plan for the USU main campus, with a focus on stormwater management, to be implemented in three phases; and 2) to present a Phase I pilot project of a green roof display with quantitative performance assessment of stormwater runoff and temperature compared with an adjacent conventional asphalt roof. The program involves extensive participation from stakeholders on campus and beyond. It integrates teaching and practice, and serves as an example of research through design process^[25] (Fig. 1).

2 Context and Current Practices in Stormwater and Challenges

2.1 Regional Context and Climate Change Impacts

The Western States are among the fastest growing areas in the United States. From 1990 to 2000, population growth in the West, including the driest states in the nation, accounted for 50% of the nation’s growth, with Utah being one of the top five^[26]. Utah’s rapid population growth and urbanization result in a great need for effective stormwater management. On one hand, water demands are projected to increase at an unparalleled level given a forecasted population increase between 1 ~ 2.5 million by 2050^[27]. On the other hand, Utah is faced with the challenge of how to use the diminishing water resource to accommodate the urban growth in a state where rain is an uncommon occurrence. Most rain currently falls in Utah as snow at high elevations. A system of high elevation reservoirs and canals deliver this water throughout the state. Climate models for the next 50 years project less rain in the southwestern parts of Utah, and rain at lower elevations in the northern areas of the state increases^[28]. These outcomes would reduce the effectiveness of the existing reservoir and canal system, resulting in reduced water available for irrigation and domestic consumptions.

USU位于洛根市（犹他州最北端的城市之一）。洛根市位于卡什河谷，海拔约1 370m，当地居民约4.8万人。这所由政府划拨土地的公立研究型大学拥有约1.5万名学生，占地面积约136hm²（图2）。由于卡什河谷独特的流域地形和寒冷的气候条件，洛根市的空气质量较差——这由冬季时车辆尾气排放造成，并由于当地高压、地形，以及畜牧业产生的化学物质等因素不断加剧^[29]。

2.2 雨水管理的当前实践及挑战

目前，USU通过在可持续发展方面的积极探索，在校园内建造了各类GI，包括幼儿教育大楼的绿色屋顶和楼前两个约49m长的雨水花园；位于波谱大楼南侧、远程教育大楼、犹他州科学技术研究中心（USTAR）的坡道绿地；远程教育大楼和塔格特学生中心的透水道路铺装；景观设计和环境规划学院（LAEP）大楼的雨水收集设施；以及LAEP实践课程中各种正在进行的GI示范性项目。特别是，USU主校区通过利用近20口干井（排水井）实现了近100%的雨水径流地下水补给。本文将重点介绍位于自然资源大楼附近的新近建成的绿色屋顶展示项目。

但是，现有的GI系统并未被重视或利用为一种教育性资产（例如，幼儿教育大楼的绿色屋顶不为公众可见）。另一个挑战是公众对GI系统知之甚少，他们几乎没有见过多少雨水管理设施。雨水减缓技术的应用对提升社会对于GI的认知至关重要，可以激发社区将雨水利用融入他们的日常生活^[30]。第三个挑战来自于降雨量不断变化所导致的不确定性。

新的GI规划旨在提升现有和新建GI的可见性，加强相关监测，并最终为USU校园内外现有和新建的GI提供绩效数据。特别值得关注的是干井系统，其将收集地表和屋顶径流以补给地下水（图3）。根据《犹他州行政法典（R317-7）》，水源保护区内的补给区域应符合V类井水注入规定。该规则还要求对地表径流进行额外的水质监测。但USU不受此规则限制，因为其地表径流（例如来自停车场的径流）已实现了就地处理。

USU is located in Logan, one of the most northern cities of Utah. Located within Cache Valley, Logan sits at about 1,370 m in elevation with a population of approximately 48,000 residents. The land-grant, public research university, with around 15,000 students, encompasses approximately 136 hectares (Fig. 2). Due to Cache Valley's unique basin topography and cold climatic conditions, Logan faces challenges in poor air quality, which are caused by vehicle emissions released during winter months and trapped due to high atmospheric pressure, topography, and chemicals produced by livestock^[29].

2.2 Current Practices in Stormwater Management and Challenges

USU's sustainability program currently boasts a variety of GI projects for stormwater installed on campus, including a green roof and two 160-foot long rain gardens in front of the Early Childhood Education Building, curb cuts at the south of the Spectrum Building, the Distance Education Building, and the USTAR Building, porous pavement installations at the Distance Education Building and the Taggart Student Center, rainwater harvesting at the Department of Landscape Architecture and Environmental Planning (LAEP)'s House, as well as various undergoing GI demonstration projects in the LAEP Field Studio. In particular, there are nearly twenty dry wells (drainage sumps) on USU main campus that infiltrate almost 100% of stormwater runoff generated on-site and recharge groundwater. This paper focuses on a new green roof display project that is recently installed outside of the Natural Resources Building.

However, existing GI systems are not highlighted and utilized as an educational asset. The green roof on the Early Childhood Education Building, for example, is not visible to the public. Another challenge is the lack of knowledge that ordinary people have concerning GI. There have been few visible stormwater management systems in general. Stormwater mitigation techniques are crucial for a community outreach component to inspire the community to follow in using stormwater as an amenity^[30]. The third challenge lies in the uncertainties in performance in the face of the changing rainfall regime.

The proposed GI master plan capitalizes on increased visibility of existing and new GI, paired with monitoring capabilities. This will eventually provide performance data for existing and proposed GI on USU campus and beyond. Of particular concern are the dry well systems, which capture and infiltrate surface and rooftop runoff to replenish groundwater (Fig. 3). According to Utah Administrative Code R317-7^④, a recharging area within a Water Source Protection Zone is subject to Title V Injection Well regulations. This rule requires additional water quality monitoring of runoff. USU is exempt

2. 犹他州立大学远景照片
3. 干井系统示意图
2. Aerial photo of Utah State University
3. Diagram of dry well system

- ④ 更多信息请访问<https://rules.utah.gov/publicat/code/r317/r317-007.htm#T4>。
- ⑤ 斜屋顶是洛根市和北洛根市地区的一种重要的建筑特色^[59]。
- ④ For more information, please visit <https://rules.utah.gov/publicat/code/r317/r317-007.htm#T4>.
- ⑤ Pitched roofs are commonly found in the City of Logan and North Logan City as an important architectural feature^[59].

该USU原校园总体规划^[31]由Sasaki景观设计事务所制定。在该总体规划之下，USU公共设施部及校内其他单位都制定了各自的雨水管理计划。在查阅干井技术资料时，我们几乎没有发现关于系统总容量和整体设计策略的信息，也缺乏将雨水管理规划与校园规划（和扩展规划）相协调以提升水源管理的举措。

3 GI总体规划和预期的绩效效益

3.1 USU的可持续发展愿景

《校园可持续发展规划（2013-2020）》旨在将USU创建一个更加可持续的校园。设计团队通过与USU公共设施部、规划部和可持续发展委员会的讨论，列出了运用GI策略的当前环境条件和所面临的设计挑战（表2），以及运用的GI策略及可能带来的相关效益（表3）。

基于一系列设计方案研讨会，设计团队制定了对现有场地进行GI改造的若干标准：建议将平屋顶改造为绿色屋顶（不包括那些坡度陡峭的斜屋顶），且需考虑建筑年代、结构的稳固性和承载能力；优先选择校园内那些易于看到、开放可达的屋顶；对于那些不适宜改造的建筑物，可以在建筑周边设置种植了低需水量植物的雨水花园；在那些学生很少使用的地区，可以引入需水少且低维护的乡土植被；最

from this rule because its surface runoff (e.g., from parking lots) has been properly treated on-site.

Sasaki Associates Inc. developed an early version of the campus master plan^[31]. The USU Facilities Department and other units on campus developed stormwater management plans to align with the master plan. In reviewing the technical documents of dry wells, little information can be found regarding the total capacity of the system and the holistic strategy for design. Also lacking is the coordination of stormwater management plan and campus plan (and expansion plan) for better water resource management.

3 GI Master Plan and Expected Performance Benefits

3.1 University’s Vision for Sustainability

The Campus Sustainability Plan 2013-2020 has ambitious goals to create a more sustainable campus. Table 2 summaries the existing environmental information and design challenges for adopting GI strategies, followed by the design team’s discussions with the campus Facilities Department, Planning Department, and Sustainability Council. Table 3 provides a list of GI strategies and possible benefits that they can bring for campus.

Based on a series of design charrettes and meetings, the design team suggested several criteria when retrofitting existing sites / locations using GI strategies. Green roof retrofit is recommended for flat roofs but acceptable for pitched ones without steep slopes, depending on the building age, structural soundness, and load bearing capacity^⑤. Priorities would be given to highly visible or accessible roof locations on campus. Rain

表2：犹他州立大学主校区内与绿色基础设施运用相关的现有环境条件和设计挑战
Table 2: Existing Environmental Information and Design Challenges for Adopting GI on Utah State University’s Main Campus

现有环境条件 Existing Environmental Conditions	设计挑战 Design Challenges
土壤 Soils	砂质壤土 ^[39] ；高渗透性，难以用于他用 Sandy loam soil ^[39] : high permeability, challenging to retain for other uses
种植用水 Planting water use	高用水量植物占94.2%，低用水量植物占5.8% 94.2% high water-use, 5.8% low water-use
建筑的水和能源利用 Building’s water and energy use	（GI规划一期项目中）米利尔-卡泽尔图书馆的耗能和用水量最高：分别为每年200万千瓦时和3 785m ³ (For GI Plan Phase I) Merrill-Cazier Library has the highest energy and water use on campus: 2,000,000 KWH and 1,000,000 gallons per year
校园栖息地 Campus habitat	目前的原生栖息地面积仅为7.9hm ² ，占校园内植被区域总面积（59.5 hm ² ）的13% Current native habitat only covers 7.9 hm ² (or 13%) of 59.5 hm ² of vegetation on campus
空气污染程度 Air pollutant level	逆温现象及其他因素导致空气质量危机 ^[25] Inversion and other factors cause air quality crisis ^[25]

表3：犹他州立大学校园GI设计策略及潜在环境效益
Table 3: GI Design Strategies for Utah State University Campus and Possible Benefits

GI类型 GI Type	介绍 Description	效益 Benefits	参考文献 References
雨水花园和种植池 Rain gardens and planter boxes	在不透水区域的雨水汇入河流之前，通过创建生物滞留区域与现有的雨水系统相隔 Rain water from impervious areas disconnect existing stormwater systems by using bioretention areas before flowing toward the creek area	缓解场地的雨水冲刷和高能耗问题，保护生态系统的完整性，增加校园生物多样性，通过蒸散作用促进水循环 Reduces problems associated with onsite erosion and high levels of flow energy; protects ecosystem integrity; adds to biodiversity on campus; and, treats water through evapotranspiration	参见参考文献 [40]–[42] Refs. [40]–[42]
雨水收集设施 Rain harvesting	雨水收集系统收集屋顶径流并将之输送到蓄水池，以用于非饮用水用途并促进了场地下渗 Rain harvesting systems collect runoff from rooftops and convey it to a cistern tank where it can be used for non-potable water uses and on-site infiltration	促进雨水回收并在校园景观中得以循环利用；减少用水成本；节约水资源 Allows water to be recycled and reused in campus landscapes; cuts back water use costs; conserves water resources	参见参考文献 [43]–[45] Refs. [43]–[45]
生态洼地 Bioswale	生态洼地通常设于道路和人行道之间，以收集两者的地表径流；其优势包括减少峰值流量、减少污染物负荷、增强生物多样性 Bioswales are usually found between a road and sidewalk, collecting runoff from both; benefits include lessening peak flows, reducing pollutant loads, and enhancing biodiversity	生态洼地可以应用于整个校园中目前那些通过路缘将水排走的区域。当尺度较大时，其功能类似于生物滞留池 Bioswales can be incorporated throughout campus where curbs currently direct water into drains. When the size is large, it functions similarly to a bioretention	参见参考文献 [46]–[48] Refs. [46]–[48]
透水路面 Permeable pavement	通过开挖现有路面并铺设多孔混凝土、沥青，或透水块状铺装材料，形成透水路面，以使雨水能够通过路面进入砾石储水层 Permeable pavement systems are excavated areas paved with porous concrete, asphalt or permeable block pavers to allow rainfall to pass through into the gravel storage layer	在校园中原先为不透水路面的区域，水以自然速率下渗至场地的原生土壤中 Slows infiltrate at natural rates into the site's native soils on previous impervious surface areas on campus	参见参考文献 [49]–[51] Refs. [49]–[51]

4

后，改造停车场时应基于坡度和雨水排放分析，选择那些坡度和排水条件都适宜建造坡道绿地和/或植被过滤带的场地。

研究对于GI在缓解场地地表径流方面的现状和潜在成效进行了三组分析评估。首先，不透水路面面积决定了雨水径流量和水质状况^{[32][33]}。通过对地球探测器 获得的分辨率精度为1m的图像进行分析，发现大约56%的校园面积被不透水铺装覆盖（共计76.89hm²）。尽管USU的地表径流通过地下水补给实现了就地收集利用，但不透水路面的减少将进一步改善水质并减缓径流流速。

其次，研究对展示GI理念的教育性项目的选址进行了评估。为了使项目被更多的人看到并将设计与当前的校园生活相整合，研究于

gardens with low water-use plants surrounding the building would be created where retrofit is not appropriate. In areas that are seldom used by students, employ native species that require minimum water and maintenance. Last, parking lot retrofit should be based on a slope and storm drain analysis. Design for areas where slope and drain locations are suitable for curb cuts and / or vegetated filter strips.

Three sets of analyses were performed to assess the current conditions and potential outcomes of GI in mitigating on-site runoff. Impervious surface is an important variable that defines the amount of stormwater runoff and water quality conditions^{[32][33]}. Using a 1-m resolution image acquired from the Earth Explorer[®], an analysis determined that roughly 56% of the campus was covered by impervious surfaces, which equates to about 76.89 hectares. Although USU's surface runoff is retained on site through groundwater recharge, additional reduction of impervious surface areas would further contribute to water quality and reducing runoff rates.

The second analysis was to evaluate an optimal location for

⑥ 更多信息请访问<https://earthexplorer.usgs.gov/>。
⑥ For more information, please visit <https://earthexplorer.usgs.gov/>.

4.

犹他州立大学米利尔-卡泽尔图书馆及周边地区的人流情况
5.

犹他州立大学GI分阶段规划（详细地图请参见：<http://youth.usu.edu/events/pdfs/MapLayoutUBW.pdf>）
4.

Behavior analysis of Merrill-Cazier Library and surrounding area at Utah State University.
5.

GI phasing plan for Utah State University (detailed map available at <http://youth.usu.edu/events/pdfs/MapLayoutUBW.pdf>)

2016年10月实施了为期一周的行为测绘，以评估位于校园中心的米利尔-卡泽尔图书馆及周边地区的人流情况（图4）。图书馆北侧的现有条件和高人流量使之成为了绿色屋顶展示项目的理想场所。目前，图书馆附近有一个配有解说标识的教育性乡土花园。这一位于该区域的绿色屋顶展示项目于2017年春季开展了建造工作。

第三组分析评估了径流减少量和植被增加比率。根据自然资源保护协会（NRCS）的曲线数值法^[34]，研究使用了如下公式：

$$Q = ((P - 0.2S) ^ 2) / (P + 0.8S) \quad (1)$$

$$S = 1000 / CN - 10 \quad (2)$$

$$Ia = 0.2S \quad (3)$$

其中，P指设计降雨重现期24小时降雨深度（以英寸为单位）；S指最大储水量（以英寸为单位）；Q指总径流深度（以英寸为单位）；CN为曲线数值；Ia指不计算在内的初期降雨量（以英寸为单位）。

3.2 总体规划和阶段性计划

GI总体规划提出了三个相互关联的目标（表4）。当前的GI总体规划明确了设计挑战（表2），基于社会行为模式创建了解说性和教育性展示项目，并试图为教育工作者和公众提供正规和非正规教育机会。

a green display for educational purposes. In order to increase visibility and integrate the design into current campus life, a week-long behavior mapping was conducted in October, 2016 to evaluate the distribution of users at the centrally-located Merrill-Cazier Library and surrounding area (Fig. 4). Existing conditions along with high pedestrian traffic made the north side of the Library an ideal location for a green roof display. An educational native garden with interpretative signage currently exists adjacent to the library. The green roof display was constructed in this area in Spring 2017.

The third set of analysis was performed to evaluate the runoff reduction volume and vegetation percentage increase. Natural Resources Conservation Services’ Curve Number method^[34] was used, as expressed in Equations 1-3 below.

$$Q = ((P - 0.2S) ^ 2) / (P + 0.8S) \quad (1)$$

$$S = 1000 / CN - 10 \quad (2)$$

$$Ia = 0.2S \quad (3)$$

where P is the 24-hour rainfall depth for a storm of a selected frequency in inches; S is the potential maximum storage of the site in inches; Q is the total runoff depth in inches; CN is the curve number; and Ia is the initial subtraction of rainfall in inches.

3.2 Master Plan and Phasing Plan

The proposed GI master plan has three interrelated goals, as presented in Table 4. The current GI master plan addresses the design challenges (Table 2) and highlights interpretative and

表4：犹他州立大学GI规划目标和阶段性计划
Table 4: Goals and Phasing Plans for the Utah State University's GI Plan

目标 Goal	阶段 Phasing	示范性/试点项目 Sample / Catalyst Project	时间跨度 Year Span
目标1：通过GI实践和解说标识进行雨水管理的教育，鼓励公众参与 Goal 1: Educate and engage the community on stormwater management through GI practices and interpretive signage	第一阶段：教育 Phase I: Education	米利尔-卡泽尔图书馆和周边建筑被选为第一阶段的试点项目地点 The Merrill-Cazier Library and surrounding buildings were selected for the Phase I	5年 5 year
目标2：创建和恢复栖息地。第二阶段建造绿色屋顶和雨水花园，充分利用校园内收集的雨水 Goal 2: Create and restore habitat. Phase II also implements green roofs and rain gardens. Take advantage of stormwater that is already retained on campus	第二阶段：创建栖息地 Phase II: Habitat creation	用低用水量乡土植被取代高用水量植被，在校园内建立城市栖息地 Replacing high water-use vegetation with native low water-use vegetation and creating urban habitat on campus	5~10年 5 ~ 10 years
目标3：实现雨水收集，并循环利用为景观用水 Goal 3: Implement stormwater harvesting to reuse water for landscaping	第三阶段：转变 Phase III: Transformation	通过在艾奇林荫道（校园内的主要交通走廊）创建GI，赋予其教育、可持续和美学功能 Focus on Aggie Boulevard, USU's main transportation corridor, using GI to transform it into an educational, sustainable, and aesthetic highlight	10~15年 10 ~ 15 years

此外，GI总体规划不仅基于USU规划部提出的目标、预算和阶段性计划，还体现了《USU可持续发展使命和计划》的目标：“通过促进可持续性运营、学术研究及服务，来提高个人和社区的生活品质”，并“通过制定适当的系统来管理具有明确目标的环境、社会和经济可持续性计划”。

此外，新的总体规划是一个时间跨度为15年的计划，共分三个阶段，每个阶段各为5年（图5），且每个阶段的预计性增长都由校园规划和公共设施部制定，并综合考虑了在实施阶段哪些要素的投入最具成本效益。

第一阶段：教育。目标是促进教育和鼓励社区参与。解说性、教育性展示是该阶段的重点之一。米利尔-卡泽尔图书馆及周边建筑被选为第一阶段的实施场地。该图书馆是校园的教育枢纽，且由所有学科的学生所共享。在获得额外资助后，此处将加建一个绿色屋顶。该区域还将创建一条基于雨洪GI的犹他州栖息地解说导览线路（图6-1）。第一阶段旨在尽可能激发全社会各个群体（包括USU扩展计划、当地中学学生、校内师生等）对于GI的认知。该设计展现了犹他州多样化的景观和栖息地（图6-2）。基于场地环境、气候条件和行为分析，通过GI和解说性展示项目来激活场地“死角”，并充分利用高人流量区域来激发人们对于解说性展示项目的关注，并作为GI的潜在实施场地。

第二阶段：创建栖息地。该阶段的重点是用低用水量的乡土植被

educational displays based on social behavioral patterns, and seeks to create formal and informal educational opportunities for educators and the public. In addition, the proposed GI master plan complements the USU’s Planning Department’s goals, budgetary considerations, and phasing plans. It is also aligned with USU’s Sustainability Mission and Plan: to “enhance the quality of life for individuals and communities by promoting sustainability in its operations and academic and service missions,” and “develop appropriate systems for managing environmental, social, and economic sustainability programs with specific goals and objectives.”^⑦

In addition, the proposed master plan is a 15-year plan with 3 phases and a five-year increment for each phase (Fig. 5). Each phase reflects planned growth anticipated by campus Planning and Facilities Departments, and considers which elements are most cost-effective for implementation.

Phase I: Education. The goal is education and community involvement. Interpretative educational displays are one of the focus areas. The Merrill-Cazier Library and surrounding buildings were selected for the Phase 1. The library is the educational hub for campus which serves students of all disciplines. It was also built with the intention of adding a green roof when additional funds become available. This area also includes a signage tour of Utah habitats using stormwater GI (Fig. 6-1). Phase I is designed specifically for community outreach in mind geared toward various users, such as USU’s Extension programs, local high schools, and the campus community. The design reflects Utah’s diverse landscapes and habitats (Fig. 6-2). Based on site surroundings, climate conditions, and behavioral analysis, GI and interpretative displays were placed where site conditions permit to make use of

⑦ 更多信息请访问<https://sustainability.usu.edu/>。

⑧ 目前关于绿色屋顶坡度对雨水径流滞留能力的影响研究得出了差异化的结果^[52]：一部分研究表明，如果有影响的话，影响也非常微弱^{[53][54]}；另一些研究提出了不同的结果^{[55]-[57]}，特别是克里斯汀·格特等人^[55]对4种不同的屋顶坡度（最大坡度为25%）的相关影响进行了研究。在本研究中，我们建议将30%作为绿色屋顶改造的阈值，因为校园内许多建筑物的屋顶坡度都大于这一坡度^{[58][59]}。

⑦ For more information, please visit <https://sustainability.usu.edu/>.

⑧ Mixed findings are reported on the influence of green roof slope on runoff retention capacity^[52]. Some studies suggested little, if at all, influence exist^{[53][54]}, while other studies suggested otherwise^{[55]-[57]}. In particular, Getter and colleagues^[55] study assessed four different slopes, with 25% being the steepest. In this current study, we suggested 30% as the threshold for green roof retrofit, understanding the fact that many buildings on campus have slopes that are more than 30% with examples in^{[58][59]}.

6-1

6-1. 犹他州栖息地解说导览
线路：犹他州立大学GI
总体规划第一阶段
6-2. 犹他州立大学米尔-卡
泽尔图书馆GI项目实施
后效果图
6-1. Reflection of Utah Tour:
Phase I of GI master
plan for Utah State
University.
6-2. Perspective of GI
adoptions in front of
Merrill-Cazier Library
at Utah State University

取代高用水量植被，并在校园内建立城市栖息地。该阶段将对坡度不超过30%且基础结构足够坚固的，或者仅需要少量改造便可创建大面积或集约型绿色屋顶的屋顶进行改造。对于那些不符合上述条件的建筑，可以通过建立雨水花园的方式减轻雨水影响。经过10年的积极努力，规划将重新引入卡什河谷丰富多样的乡土植物、昆虫和动物品种，以加强校园内的生态系统服务（包括营建原生栖息地）。这一阶段还考虑了10年后的新的开发建设方向，规定所有新的开发项目都需使用乡土植物或低需水量植物。

第三阶段：转变。第三阶段通过实施GI来解决校园内所有停车场的雨水管理问题。停车场及道路改造包括：在校园内车流量高、占地面积大的道路和停车场区域引入坡道绿地以及设置（使用低用水量的乡土植物的）植被过滤带和采用透水性路面铺装。随着USU校园的变化和发展，规划部预测车辆和行人的流通将发生巨大变化。此阶段试图将艾奇林荫道（USU的主要交通走廊）转变为一条兼具教育性、可持续性和美学功能的靓丽的风景线。

3.3 校园雨水地表径流的预期绩效

校园内的主要标识展示了GI具有的效益，包括：改善被城市化进程影响的水文环境；在城市化地区创建自然栖息地，以增加生物多样性和野生生物数量；保护并提升城市化地区的水质；使用相较于传统草坪和目前高使用率的其他观赏植物需水量更低的乡土植物。

dead zones, and to maximize use in high traffic areas as viable locations for interpretative displays, and implement GI.

Phase II: Habitat creation. This phase focuses on replacing high water-use vegetation with native low water-use vegetation and creating urban habitat on campus. Phase II also implements green roofs on buildings where no steep slope presents (e.g., less than 30%) and the infrastructure is robust enough, or needs little retrofitting to hold extensive or intensive green roofs.[®] Rain gardens are incorporated on buildings that currently do not meet this criterion to mitigate stormwater. After ten years of the initial implementation efforts, the plan is to reintroduce various species of plants, insects, and animals native to Cache Valley to enhance ecosystem services on campus, including creating native habitats. This phase considers new developments that would be built after ten years and focuses on all new developments using native or low water-use vegetation.

Phase III: Transformation. This last phase addresses stormwater management on all parking lots on campus through implementing GI. Parking lot and roadway transformations would take place with the implementation of the following GI practices: curb cuts along selected high traffic, high surface area streets on campus and parking lots, vegetated-filter strips (with native, low water-use plants), and pervious pavements. As USU campus changes and grows, the Planning Department anticipates that vehicular and pedestrian circulations will drastically change. Phase III focuses on Aggie Boulevard, USU’s main transportation corridor, transforming it into an educational, sustainable, and aesthetic highlight.

3.3 Projected Performance of Stormwater Runoff from Campus

Main signage for this part of campus will include information on the benefits of GI, including changes in stream hydrology associated with urbanization; creation of a natural habitat in urbanized areas to increase biodiversity and wildlife; protection and improvement of water quality in urbanized areas; and increased native plants that use less water than traditional lawns and other ornamental plants currently in high use.

6-2

表5: 实施GI计划后径流深度（流量）减少量
（设计降雨重现期降雨量数据由犹他州洛根市的北犹他州与南爱达荷州新闻无线电台提供）^[35]
Table 5: Runoff Depth (Volume) Reduction after Adopting the GI Plan
(Rainfall Depths for the Design Frequencies Were Collected at the KVNU Radio Station, Logan, Utah)^[35]

设计降雨重现期 (24小时降雨量) Design Frequency (24 hour)	降雨量 (mm) Rainfall Depth (mm)	径流深度 (mm) (当前径流指数为73) Runoff Depth (mm) (CN=73, Existing Condition)	径流深度 (mm) (GI建成后径流指数为65) Runoff Depth (mm) (CN=65, Proposed GI Plan)	径流减少量 (mm) 及减少比例 (%) Runoff Reduction (mm) (%)
两年一遇 2-year	37.1	3.0	0.8	2.3 / 78%
10年一遇 10-year	51.8	8.6	3.8	4.8 / 57%
25年一遇 25-year	61.2	13.2	6.6	6.6 / 49%
50年一遇 50-year	68.8	17.3	9.7	7.6 / 45%
100年一遇 100-year	76.7	22.1	13.2	8.9 / 41%

7. 犹他州立大学GI总体规划成果
8. 绿色屋顶（右）与沥青屋顶（左）绩效对比

7. Outcomes of the GI master plan for Utah State University
8. Green roof (right) in comparison with a conventional asphalt roof (left)

第三阶段将减少主校区内22%的不透水地表面积（约30hm²）。根据广泛用于对城市化项目评估的NRCS曲线数值法^[34]计算，不透水地表区域的减少使得整个校园的径流指数将从73减少至65。此外，根据洛根市最新的应对不同风暴重现期及持续时间的LID/GI设计标准^[35]，作者评估了在径流指数降低后，5种不同设计降雨重现期的径流深度（流量）的减少幅度（表5）。总体而言，在实施GI计划后，预计将减少超过40%的径流。

此外，总体规划实施后，乡土植物群落的面积将增加约10hm²，雨水花园的面积将增加3.5hm²，绿色屋顶的面积将增加11.5hm²，而高用水量植被的面积将减少25%（图7）。在提升植物多样性和传粉媒介的多样性方面，设计特别引入了一些能够吸引犹他州本地蜜蜂的植物（表6），其中一些植物仅应用于图书馆绿色屋顶项目。

For the main campus, the authors anticipate a 22% reduction in impervious area (about 30 hectares) after Phase III is completed. The NRCS Curve Number method is widely used in assessing urbanizing project sites^[34]. Using the changes in impervious surface areas, the Curve Number of the entire campus would reduce from 73 to 65. In addition, according to the latest storm event frequency and duration requirements for LID / GI design standards of the City of Logan^[35], the authors assessed the reduction in runoff depth (volume) for five different design storms as a result of the Curve Number reduction (Table 5). Overall, more than 40% of reduction in runoff would be anticipated after the implementation of the GI plan.

⑨ 详情请访问<http://extension.usu.edu/waterquality/>

⑨ <http://extension.usu.edu/waterquality/>

4 绿色屋顶试点项目（总体规划第一阶段）

4.1 绿色屋顶项目概述

绿色屋顶展示项目是实施总体规划第一阶段的开始，其将不透水表面与植被表面的绩效进行比较，并收集可量化的数据。USU的学生可以通过解说标识和“USU水质提升网站”来了解最佳管理实践。

绿色屋顶展示项目于2017年6月完成，并已开始收集雨水及记录表面温度数据。展示项目由两个并排的面板构成，每个面板的面积为1.2m×1.6m，坡度为5%。其中一块面板采用传统的沥青屋顶，另一块上面则铺满了0.3m×0.6m、带有排水系统、种植了景天属植物的绿色屋顶模块（图8）。这个展示项目设在USU自然资源大楼东南角的高人流行人道旁边的一个原先被忽视的小空间中。解说标识对GI的效益予以了介绍，并对绿色屋顶和沥青屋顶在径流率、径流量和温度等方面的绩效进行了数据对比。

表6：可以吸引本地蜜蜂的犹他州原生传粉植物^{[60]–[62]}
Table 6: Pollinator Plants Native to Utah that Attract Native Bees^{[60]–[62]}

传粉植物 Flower Species			蜜蜂种类 Bee Genus						
植物种类 Species	常用名 Common	植物属性－类型 Code-Form	蜜蜂属 <i>Apis</i>	熊蜂属 <i>Bombus</i>	隧蜂属 <i>Halictus</i>	壁蜂属 <i>Osmia</i>	芦蜂属 <i>Ceratina</i>	回头蜂属 <i>Habropoda</i>	切叶蜂属 <i>Megachile</i>
醉蝶花属 <i>Cleome</i>	Bee Plant	GUW-A	○	○					
翠雀花属 <i>Delphinium</i>	Larkspur	GU-AP		○					
天人菊属 <i>Gaillardia</i>	Blanket Flower	GUW-P	○	○	○	○			○
向日葵属 <i>Helianthella</i>	Sunflower	GU-AP	○		○				
马薄荷属 <i>Monarda</i>	Bee Balm	G-P		○					
吊钟柳属 <i>Penstemon</i>	Firecracker Penstemon	GUW-P	○	○		○	○		
风箱果属 <i>Physocarpus</i>	Ninebark	GUW-S							
茶藨子属 <i>Ribes</i>	Currant	GUF-S	○	○		○			
景天属 <i>Sedum</i>	Autumn Joy	GUW-P	○				○		○
百里香属 <i>Thymus</i>	Lemon Thyme	GWF-P	○		○				○

注：
植物属性：G——在犹他州生长；U——犹他州乡土植物；W——节水植物；F——生产食物的植物
植物类型：A——年生植物；P——多年生植物；S——灌木
Notes:
Codes: G — Grows in Utah; U — Utah Native; W — Water Wise; F — Food Producing
Forms: A — Annual; P — Perennial; S — Shrub

In addition, implementing the master plan should result in an additional approximately 10 hectares of native plant communities, 3.5 hectares of rain gardens, an increase of 11.5 hectares of green roof area, and a reduction of high water-use vegetation by 25% (Fig. 7). The design would increase plant diversity and pollinator diversity by adding plants that specifically attract native bees in Utah (Table 6). Some of the plants are included specifically for the Library green roof.

4 Green Roof Pilot Project (Phase I of Master Plan)

4.1 Green Roof Project Overview

The green roof display is the start of implementing Phase I of the master plan and compares impervious surfaces with vegetated surfaces and collects quantifiable data. USU students are informed on best management practices through interpretive signage and through USU’s Water Quality Extension website^⑨.

The green roof display was completed in June 2017 and has been collecting stormwater and surface temperature data. The display is constructed of two side by side panels that are 1.2 m × 1.6 m each. The panels are set at a 5% slope. One of the panels is constructed with traditional asphalt roofing as the surface. The other panel is lined with green roof of 0.3 m × 0.6 m modules with drainage and sedum plants (Fig. 8). This demonstration is installed in a small space once unused next to a high traffic sidewalk (southeast corner of USU’s Natural Resource Building). A display sign describes the benefits of GI and compares runoff rate and volume and temperature data between the green roof and the adjacent asphalt roof.

展示项目中的自动洒水装置每天会分别在三个预定时间（上午9时、中午12时和下午3时）进行小型降雨模拟。在暴雨模拟中，喷头会持续喷水10分钟。每个面板上的“雨水”都排入各自的雨水收集槽，再汇入各自的翻斗式收集桶中（此处采用的是“HyQuest Solutions”牌TB6/0.01型号的翻斗式雨量计），以测量径流率和径流量。在最初几个月内，研究人员对数据进行了手动记录，并在此之后定期（如在解说游览线路或教学演示时）进行数据收集。校准型翻斗式收集桶的测量结果为研究这两种表面的径流参数（速率和流量）差异提供了实证数据。降雨模拟中的径流被导流到一个小型雨水花园中，以作为该展示项目的一部分。

4.2 综合性教育和公众参与

绿色屋顶展示项目通过在校园中的显眼地方设置展示项目，为学生和教职员工提供了一个了解GI的教育机会（图9）。这不仅是一处美观的景观设计，还使参观者通过观察整个降雨模拟过程及水量测算，直观地了解到（相较于沥青屋顶）绿色屋顶在削减雨洪径流方面的显著效益^{[36][37]}。此外，设计团队一直在教学活动中对此进行推广^[38]（图10）。在LAEP为本科生和研究生开设的GI课程（课程编号4940/6940）中，学生们还为这两种“屋顶”绘制了水文图。

这种绿色屋顶展示项目为在校园中创建一个真实的、通过POPBL等方法研究环境的机会，并为更多的实践学习及研究提供了机遇^[37]。

A sprinkler system delivers a small “rain event” at three scheduled times every day at: 9:00 am, 12:00 am, and 3:00 pm, respectively, as demonstrations. During a “rainstorm,” sprayers stay on for 10 minutes. Each panel drains into separate collection gutters that feed separate tipping buckets (HyQuest Solutions Model TB6/0.01 Tipping Bucket Rain Gauge) to measure runoff rate and volume. The data were collected manually during the first few months after installation and periodically (e.g. during tours or classroom presentations) after that. Data from calibrated tipping buckets provide empirical evidence of the differences in runoff parameters (rate and volume) from these two surfaces. Runoff from these events was distributed to a small rain garden installed as part of the display.

4.2 Integrated Education and Public Engagement

The green roof display has been providing an educational opportunity for students, faculty, and staff through illustrating a model that is easily accessible (Fig. 9). They not only appreciated the visually appealing landscape design, but were also impressed with the substantially reduced runoff amount from the green roof versus the asphalt roof, as the display allows them to observe the entire simulation-runoff process and count the water amounts measured^{[36][37]}. Also, the design team has been promoting this in college classrooms^[38] (Fig. 10). The LAEP 4940 / 6940 Green Infrastructure class was offered to undergraduate and graduate students. Students produced hydrographs for the test-bed “roofs” simultaneously during the demonstration.

This green roof display offers a real opportunity to create an authentic learning environment on campus through approaches such as POPBL, and it opens the door for many more hands-on learning and research opportunities^[37].

9.

绿色屋顶展示项目为学生和教职工提供了一个了解GI的教育机会。
10.

在LAEP为本科生和研究开设的GI课程（课程编号4940/6940）中，学生们对两种“屋顶”的降雨及径流进行了模拟。
11.

绿色屋顶与沥青屋顶径流对比图
12.

15分钟降雨模拟中绿色屋顶与沥青屋顶的径流温度变化对比图
9.

Educational experience for college students, faculty, and staff.
10.

Demonstration of simulated rainfalls and runoff from different "roof" materials in LAEP 4940/6940 GI class offered to undergraduate and graduate students.
11.

Runoff from green roof display compared to adjacent asphalt roof
12.

Comparison of temperature of runoff from green roof and adjacent asphalt roof during a 15 minute "rain event."

4.3 绿色屋顶绩效试点评估

在校园中建立绿色屋顶示范性项目并非首创，但该绿色屋顶项目对于犹他州和西部半干旱地区来说，是独一无二且非常宝贵的，因为此前鲜有此类实践，相关绩效数据资料也少之又少。作为总体规划第一阶段的试点项目，这个质朴的绿色屋顶展示项目将成为推动USU校园内绿色屋顶研究，以及犹他州其他地区在更大尺度上进行绿色屋顶研究的起点。

图11显示了绿色屋顶与沥青屋顶在暴雨模拟中的径流数据。降雨初期，绿色屋顶的径流流速增长较缓，且径流峰值低于沥青屋顶。这些更趋于自然状态的地表径流将缓解水土流失问题；降雨末期，绿色屋顶的径流逐渐减少，并在暴雨结束后一小时内继续以低速流动，此过程将促进雨水下渗，从而补给地下水并使河水在夏末免于干涸。

在犹他州的公共数据库中，污染物负荷数据通常非常有限且难以获得，尽管先前对犹他州生态洼地绩效的研究已证实悬浮土壤、总氮、总磷和某些重金属的减少率可达80%~90%^[4]。USU校园的GI策略也将会促进水质改善。

4.3 Green Roof Performance Pilot Assessment

Green roof demonstrations are not unique to campus, but this green roof project is unique and valuable to the state of Utah and the semi-arid West, because its application has been rare in this region and rarely are performance data collected. As a pilot project in Phase I of the Master Plan, this modest green roof display would be the starting point of green roof research conducted on USU campus and other initiatives to further green roof research on larger scales in Utah.

Figure 11 shows runoff data from a sample "storm" in the green roof versus that from the adjacent asphalt roof. At the beginning of the storm, runoff from the green roof increases at a slower rate and never reaches the same peak flow as the asphalt roof. These more natural storm flows would protect land and stream banks from erosion. Besides, at the end of the storm, runoff from the green roof declines gradually and continues at a low rate up to an hour after the "rainstorm" ends. During this period, water is able to soak back into the ground, restoring groundwater and late summer flows.

Pollutant load data are generally limited and difficult to obtain in public databases in Utah, though a previous study on bioswale performance in Utah suggests reduction rates of suspended soils, total nitrogen, total phosphorus, and certain heavy metals to be within the ranges of 80% ~ 90%^[4]. GI strategies incorporated to USU campus would suggest similar improvements in water quality.

同样，图12显示了绿色屋顶与沥青屋顶的温度变化。研究使用HOBO微型防水温度记录仪（型号：UA-001-08）每3分钟记录一次屋顶温度，发现绿色屋顶的温度始终低于沥青屋顶。绿色屋顶可以缓解校园内的城市热岛效应，这反过来也有助于减少蒸发造成的水损失。

5 讨论与结论

GI总体规划的实施旨在提升人们对于GI实践和犹他州所面临的独特的水资源危机的认知，包括改善水质、储蓄水源以循环利用，以及通过恢复植物和野生动物自然群落来增强生态完整性。在USU的案例中，GI总体规划和相关实践为校园带来了多种环境、社会和经济效益。在大学环境中进行GI应用可以使未来的设计师和居民从这些实践活动中了解GI实践。

此外，GI总体规划将作为在半干旱气候环境下的校园中探索GI的教育性和韧性分析模型。绿色屋顶在减缓雨水径流和降温方面的显著绩效，为在犹他州开展GI实践提供了实证经验。未来的GI应用可以大大改善校园内乃至整个卡什河谷的水体和空气质量，这将为USU节省财政资源——目前的绿色屋顶展示项目是实现这一美好愿景所迈出的第一步。**LAF**

Likewise, Figure 12 provides an example of temperature attenuations that green roof can provide when comparing with the same asphalt roof in adjacent. HOBO Miniature, Waterproof Temperature Recorders (Part Number: UA-001-08) were used to collect temperature data at 3-minute interval. The green roof is consistently cooler than the asphalt roof. Green roofs could reduce the urban heat island effect on campus, which in turn could reduce water losses due to evaporation.

5 Discussion and Conclusion

The implementation of the GI Master Plan expects to educate members of the community about GI practices and Utah’s unique water challenges, improve water quality, increase water retention for reuse, and improve ecological integrity by restoring natural communities of plants and wildlife. The GI Master Plan and the associated GI practices provide multiple environmental, social, and economic benefits on university campuses as demonstrated by USU’s case. Applying GI strategies at university settings offers additional benefits that future designers and residents learn from these activities and are informed of GI practices.

In addition, the GI Master Plan will serve as an educational and resilience analysis model of GI development for a campus setting in semi-arid environments. The successful demonstration of green roof’s performance in stormwater runoff mitigation and temperature reduction provides evidence of its efficacy in Utah’s environment. Future GI installations would be organized to save the university financial resources, which potentially greatly improve water and air quality not only on campus but for the Cache Valley where the campus resides. Finally, the current green roof demonstration serves as the first step to educate students and faculty on campus and the general public. **LAF**

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