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土壤：水系统中被忽视的向度
Soil: the Unseen Layer of Water

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摘要

健康的土壤在水文中扮演着调节水量与控制水质的重要角色，对于水与土之间相互影响的忽视，往往是造成水系统设计失败的原因。例如，土壤过度夯实或结构遭到破坏，会在雨洪管理中影响土壤的渗透率与保水力，因而增加地表径流；土壤中有机质的流失，会降低土壤的净水效能，破坏营养物质与沉积物，从而导致水污染。为了将土壤知识纳入景观设计工作中，本文建议在设计过程中增加土壤管理专项。其中与水系统相关的最佳实践包括：1）保护既有的土壤以保持原有水文；2）避免及改善土壤夯实以增加保水率；3）保存及重建土壤有机质以改善水质。

关键词

健康土壤；土壤夯实；土壤有机质流失；雨洪管理；土壤保护；土壤管理

Abstract

Healthy soil performs important functions in regulating water volume and controlling water quality. However, overlooking such dynamics between soil and water often leads to design misassumption and water system failure. For instance, the compacted soil and disturbed soil profile result in poor water retaining capacity and increased surface runoff. The organic matter loss decrease soil's effectiveness at binding and breaking down nutrients and sediments, which further pollute the water system. To incorporate soil sciences in design and construction processes, implementing a soil management plan is suggested. The best soil practices for water system includes 1) Protecting soil structure to conserve hydrological performance; 2) Avoiding and amending soil compaction to increase water retaining capacity; 3) Conserving and restoring soil performance in water cleansing.

Key words

Healthy Soil; Soil Compaction; Soil Organic Loss; Stormwater Management; Soil Conservation; Soil Management

美国西北部沿岸的广大流域，是北美太平洋鲑鱼的重要繁殖地。由于野生鲑鱼自海洋回游河川得以完成繁衍、生长所牵涉的范围广阔，而多道回游路线遭到了水库、水坝，以及边坡硬化的破坏，致使野生鲑鱼数量锐减。为了拯救日益缩减的鱼群，极大的资源投注在了重建回游路线鱼梯、水体边坡整治，以及产卵地生态修复等方面。理论上而言，随着水路回复畅通，鱼群数量应该渐渐得以恢复，但是多年来的成效却是非常有限——鱼群总量要么依旧维持在较低水平，要么呈缓慢的持续下降趋势[1]。长期的追踪与观测发现，只关注水体本身是不够的，造成鲑鱼数量减少的更深层原因之一在于都市化与农林开发使得水文过程遭到了改变，包括降水无法渗透到地下，土壤保水力下降，造成雨季与非雨季的水量极端化；地表径流产生的冲刷导致土壤流失，并将农业污染物带入水中，严重影响其水域的生态环境与生态循环。由于鲑鱼对水文循环的各项指数尤为敏感，这些由集水区内的土地所引发的水量与水质的改变[①]，才是导致鲑鱼锐减而复育不易的“看不见”的主因。

人们可能难以想象鲑鱼与土壤之间存在怎样的直接关系，正如当我们看到一条清澈的溪流，也难以意识到这只是区域水系统的极小一部分。土壤是地表水的载体，同时也是地下水的容器和地下径流的滤芯，其系统覆盖整个集水区（图1）。由于水系统与土壤系统的关系难以直观显现，对土壤的不重视往往成为水系统治理失败的主因。有美国研究者感叹，花费在火星土壤上的科研经费，甚至多于研究我们脚下的土地所花费的经费[②]。同时，站在实践一线的景观设计师大多能够对土方和排水较有认识，而对于地表以下的世界则知之甚少。但如果要让我们的实践能够更贴近自然的作用与过程，了解土壤与水量、水质之间的基本互动关系应该是第一步（图2）。

1 土壤过度夯实对水量调节的影响

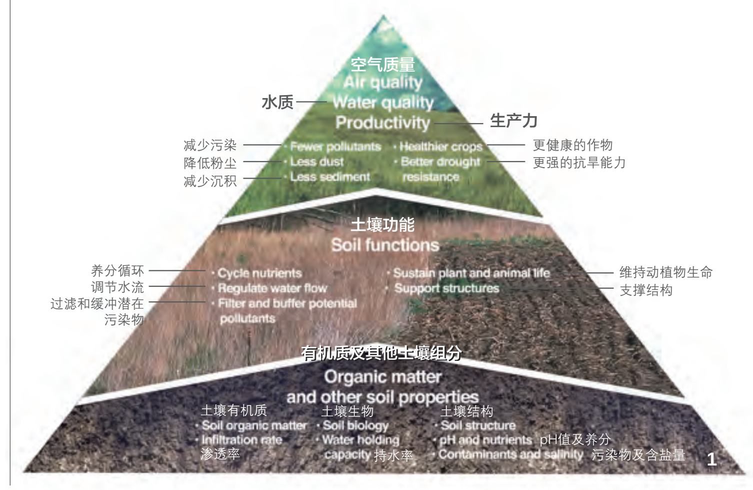
随着城市建设的推进，地表构筑物与硬质铺装不断增加，地表径流也随之倍增，为缓解由此而造成的影响在雨洪管理中是非常重要的课题之一。最直接的解决方法就是尽量减少不透水面

In the vast watersheds of Pacific Northwest in the United States lie important spawning grounds for pacific salmon stocks. Despite public support and their enormous cultural and economic value, the wild salmon population has declined remarkably over the decades. Because of the anadromous life cycle, where salmon return each year to the same breeding grounds, many migration routes are threatened by damming and habitat lost. To restore the stocks and their passages, heroic efforts were invested in the establishment of fish ladders and riverbank habitat restoration. Theoretically, with waterways secured, the population should have recovered substantially. To the disappointment of many, they remained at overall low levels or continue to decline in spite of costly efforts[1]. With further studies and monitoring, the focus has shifted from the waterway to the land beyond: urbanization, logging, and farming have altered the original hydrology, leading to increased surface runoff and erosion. The runoff then carries pollution and sediment, damaging habitat essential to aquatic life. Not only are winter peak storm flows much higher, but summer stream flows are also much lower due to a lack of recharged groundwater. Wild salmon is highly sensitive to changes in water quality and levels, and therefore it is nearly impossible to restore their habitat without looking at the soils in the watersheds[①].

It may be difficult to see the direct linkages between salmon and soil, just as it is difficult to see the larger watershed while viewing a clear stream. Soil is the vessel of surface water, the container of ground water, and the filter of underground flow. These roles work together to regulate regional hydrology (Fig. 1). Because soil exists beneath the surface, it is often an unseen layer of the water system. Ignoring such a layer usually leads to design misassumptions and water system failures. Even in the United States, researchers have noted that the money spent on studying the soil of Mars is more than that spent on the study of soil

1. 土壤质量金字塔：健康的土壤是干净的水与空气的基础。© National Resource Conservation Service: Soil Publications
2. 土壤是水系统中看不见的基底：水牛湾公园将原本水岸边的工业棕土改造为城市示范湿地。项目设计将原有的地表径流引导至一系列的水塘，运用整地与湿地的技术，去除细菌、养分与有害物质后，再将水排入水湾中。项目地点：美国德克萨斯州休斯顿市。© SWA Group

1. Soil quality pyramid: Healthy soil is the base for clean water and clean air. © National Resource Conservation Service: Soil Publications
2. Soil is the unseen layer in water systems: Buffalo Bend Park is a conversion of waterfront and industrial brownfield into an urban wetland demonstration project. The project diverts urban runoff into a series of connected wetlands before returning the flow to the bayou, removing bacteria, nutrients, and toxic materials from water on the way. Project location: Houston, Texas, USA. © SWA Group



积，增加软质铺装的比例。但是软质铺装也并不能保证土壤具有较高的排水率和渗透率。笔者曾考察过一个公园，完工后的硬质铺装面积所占比例不到1/10，但其地表径流量与汇集速度都非常惊人，远高于1/10的增幅，为什么会出现这样的情形呢？

在健康的土壤中，其物理组成除了固态矿物质与有机物外，还包括约1/4的空气和1/4的水。空气与水在重力的作用下在土壤的大孔隙（Marcopores）中循环增减；还有一部分的水游走在小孔隙（Mircopores）中，这一过程由水的表面张力与毛细作用维持。大雨时，当土壤中所有空隙都被水渗入而占满后，达到土壤水饱和，也就是该土壤的最大容水量；当大雨退去，大孔隙中的水缓慢渗透完毕，空气再度回到土壤，植物的根系还能从小孔隙中吸取水分，此状态称为一般保水量（Field Capacity）。如果持续干旱，直至根系无法从土壤吸收水分时，才达到枯萎点（Wilt Point）。健康且未受压实的土壤，其饱和状态与枯萎点间的承水幅度较大；反之，过度夯实缺乏大小孔隙的土壤，其承水幅度很小，极易达到饱和状态而无法吸水，或是非常容易流失水分而致使植物枯死，这样的恶性循环往往会加速土壤流失与植被死亡。

土壤在整地与施工阶段非常容易被过度夯实。尤其在常规工程中，重型机械以构筑物或硬质铺地的夯实标准在场地上反复运行，虽然满足了建构基础的要求，却压缩了原本可容纳水与空气的孔隙，从而导致植物根系难以建立，雨水无法渗透，保水力大幅下降，地表径流倍增[2]。如果不加以处理，极易引发一系列的土壤衰败。

另一个影响雨水渗透率的原因则是土层结构的破坏。土壤层的剖面是岩石风化/沉积过程的缩影，逐层的渐变代表了其与空气、水的长期互动，各有不同的物理性质与土层顺序。无章法的整地往往是对土层的粗野翻动，原本渗水、保水率最好的表土不是流失掉，就是被错置到了下层；次层土或是更深的土层反而被挖至上层。土壤被翻动后，不同土质之间的突变边界（Abrupt Boundary）会形成一个隔水层，在上层土壤没有达到完全饱和的情况下，水往往不会向下层顺畅渗透，土壤的整体透水率自然会受到影响。当土壤的透水率与渗水率都因过度夯实或结构遭破坏而下降后，其表现就与硬质铺装无异，无法实现整个集水区的水量调节与地下水补给。

2 土壤有机质流失对水质控制的影响

土壤与砂石的不同之处在于土壤是有生命的。除了无机质之外，土壤中的空气、水、腐殖质，植物根系及附着其上的真菌等微生物，以及生活在土壤中的小动物等，共同组成一个强大而富有韧性的生物圈。这个生物圈的结构越复杂、其有机粘性越大、表面积越广，与其他化学物质的离子交换能力也就愈活跃。例如，腐殖层的离子交换能力是沙壤土的10倍以上[3]。这个特征在农业中，代表土壤保持养分以及提供养分给植物的能力旺盛，即保肥力强。从水质控制的角度而言，则代表该土壤能将多余养分与悬浮物保持在固态表面上，不会轻易流失到地表水中，这对水质的稳定及改善尤为重要。

湿地及水生植物能够改善水质已在近几十年之内得到科学证实和普遍理解。但较不为人知的是，其净水过程大部分发生在植物根系与土壤交界处的广大活性表面[4]。这一过程也利用了土壤离子的交换原理，由于生物化学的代谢旺盛，过度的养分能受到分解，过多的悬浮物得到固定，经过水体缓慢的流动，进而整体改善水质。

但是在一般的建成环境中，表土中生物化学活性最强的腐殖层，往往没能得到应有的重视。园艺养护刘除落叶腐殖层，切断了养分的自身循环，如果再加上表土流失、保水力下降等问题，土壤生态系统则难以维持。如果一块土地由于长期流失大部分有机物而衰败，再强施肥料也是无用的。因为衰败的土壤无法有效地吸附和分解肥料、碳氢化合物以及其他污染物。这些原本可以供植物生长的有益物质反而流失到水体中，造成水体的污染以及水中食物链的失衡。

3 最佳实践的建议

景观设计是一个结合科学与美学的专业，身为景观设计师，这个职业赋予我们极大的机会在既有的知识系统中寻找最佳的执行方法，在实践中改善人类的生活环境。随着景观设计学日益强调多学科性，土壤无疑将会是下一个在实践中被重视的领域。因此，在常规的设计过程中增加土壤管理专项（Soil Management Plan）则显得极为必要③。土壤管理能够成为科学知识的融入、设计推演、业主沟通、施工程序协调，以及养护与检测的最佳平台。由于各地条件不同，土壤管理需要因地制宜并且时时调整，以下列举几个方面作为建议：

3.1 保护既有的土壤就是保护原有水文

健康土壤生成不易，却极易流失，而且难以复原。所以场地

3. 保存场地与区域土壤：保存场地内现有的土壤，并与四周开发后的多余土壤混合，经由仔细的土方推敲后，确保利用自然重力集水取代原本破碎的水文，创造一个连贯的水系以重建当地生态系统。项目地点：中国宁波市。© SWA Group

3. Conserving on-site and off-site Soils: Conserving and incorporating the on-site and surrounding soil, the eco-corridor is carefully graded to create hills and valleys that direct the flow of water across the site, replacing the existing disconnected canals with a series of free-flowing rivulets, streams, ponds, and marshland that will support the re-establishment of the indigenous ecology. Project location: Ningbo, China. © SWA Group

on Earth②. In our daily practice, landscape architects are proficient with site grading and drainage, but when it comes to soil and water dynamics that exist under the finished grade, our knowledge is usually woefully insufficient. To link this gap, the first step is to understand how soil performs in regulating water volume and controlling water quality (Fig. 2).

1 Soil Compaction in Stormwater Management

With increasing areas of impervious surface in urbanized centers, tackling the corresponding surface runoff in an altered urban hydrology has been a difficult challenge in stormwater management. The direct solution is to reduce the paved area and preserve more softscape areas. However, softscape does not always guarantee infiltration and drainage performance. I have seen a newly graded site with only 10% hardscape suffer from a more than 10% increase in stormwater runoff and erosion. How did this happen?

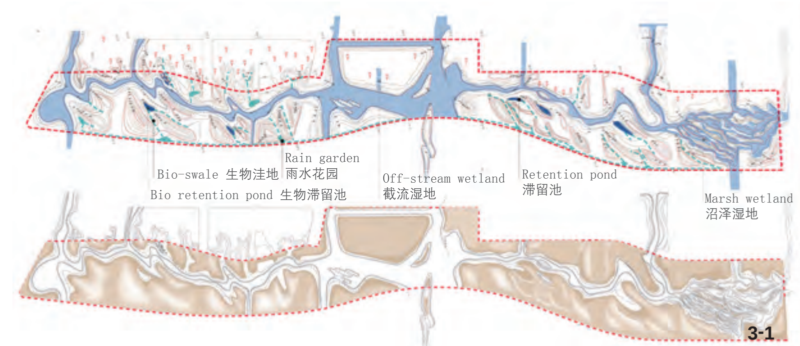
Healthy soil, other than the mineral component and organic matter, is composed of roughly 25 percent air and 25 percent water. Two types of passages allow air and water to travel through the soil: the large passages are called macropores and are large enough to be governed by gravity; smaller passages between particles are called micropores, inside which the water is held by surface tension and capillary action. When water fills in all macro and micropores, the soil reaches “Saturation”, which is the largest capacity a given volume of soil can hold. After the water in the macropores has been drained by gravity, the soil reaches a state called “Field Capacity”, and the air returns to the passage while water in the micropores are still available for the roots. When a drought occurs and roots are no longer capable of pulling remaining water from the micropores, the state is called the “Wilt Point”. Healthy, non-compact soil has a larger range from saturation, field capacity, to wilt point, while compact soil has much smaller range of taking in and storing water in its property.

Soil can very easily become overly compacted during construction. In standard practice, heavy equipment for building roads and structures compact the soil to an engineered hardscape standard, which seriously damages soil structure by shrinking the spaces between soil particles available for air and water. This process reduces infiltration rates, which increases the runoff volume and flooding potential[2]. If not restored immediately, compacted soil can start a spiral of degradation.

Another factor affecting infiltration and percolation is damage to soil structure and horizons. Soil horizons are horizontal layers of soil at different stages of weathering and accumulation. Each horizon sequence has a different structure and performs differently in drainage relative to the surface. If the original soil profile is disregarded or disturbed during site grading, for example, the displaced soil horizons will lose their original performance standards. Furthermore, the disturbed soils sometimes form an abrupt boundary between two dramatically different horizons. Roots and water may have difficulties crossing layers that have different levels of porosity. These effects contribute to poor infiltration or percolation, and result in poor drainage performance and poor water retaining capacity.

2 Organic Matter Loss and Water Quality Control

The difference between soil and dirt lies in soil’s ability to form a living medium and support life. Other than mineral components, the air, water, humus, roots and the attached fungi, micro-organisms, and fauna that constitute soils, form a strong and complex ecosystem. The more established the system, the more organic connections exist with larger surface areas, allowing for a stronger Cation Exchange Capacity (CEC). In the humus layer, for instance, its CEC range is about ten times more



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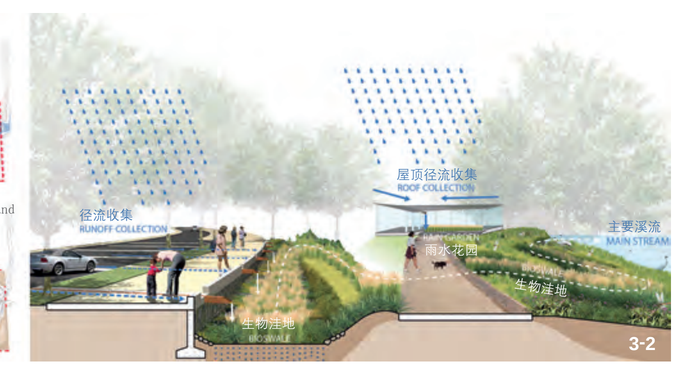


3-2

设计与施工的第一步，就是对现有的土壤作详细调查，并确定值得保护的植被与土壤区划（VSPZ）④。在设计阶段就应将对现有土地的保护纳入考量（图3），并在施工阶段严格实施。如果在不得已的情形下需要移动土方，较好的做法是依调查所确定的表土深度分层开挖并将其堆放保存，保存的过程中应确保温湿条件不变，以及实施防止风雨冲刷等措施。待硬质铺装与粗整地完成后，再将保存在一旁的表土覆盖回填。在所有的施工步骤中，皆须设立拦沙围篱与滞洪池，以实现现有资源的保留并且不污染邻近环境。

3.2 避免及改善土壤夯实以增加保水率

土壤的物理结构与密度，深深影响着土壤的性能与演化。在设计与施工中，应该同时考虑机械在场地上的作业空间，例如将无可避免需要被夯实的施工通道设计为未来的硬质铺装，而在预定的种植区中则尽量避免重型机械的碾压。但对于已经受到夯实而衰败的土壤——例如大部分的棕土场地——的复原工作相对困难。轻微的表面夯实，可采用表面增肥、种植深根性植被等自然方式来解决。但是如果夯实程度比较严重，仅处理表面也无济于事。最有效的方法还是借助机械。如果夯实的程度中等，可以采用一般的农业翻耕机来松土；如果土壤紧实的深度比较深，就需要借助特殊的机械深切壕沟，强行创造缝隙让空气、水与根系可以伸入。机械在场地的作业流线需要仔细规划，以免松动过的土壤被再度压实。在操作的过程中，可以适度加入有机质、膨胀页岩、多孔陶粒等碎材来改良土壤结构。但是切勿以添加细砂的方式来改善密实的粘土的排水性，细砂非常难与现有粘土搅拌均匀，反而会与土块表面结合，形成封闭的结构[5]。

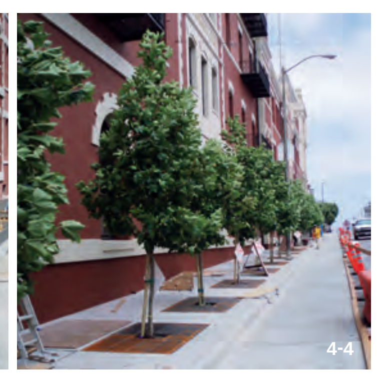
在都市化程度非常高的区域，软硬铺装彼此交织得比较紧密——例如广场与行道树——难以清晰地界定夯实基础与不需夯实的渗透区域之间的界限。近几年在此方面也涌现了许多创新的手段，例如采用结构土壤（图4）及地底支架系统等（图5），其目的都是在满足铺装所需荷重标准的同时，也能为水、空气、根系保有足够空隙。

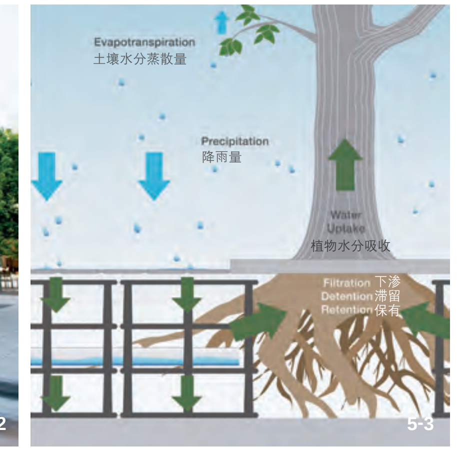
3.3 保存及重建土壤有机质以改善水质

在某些长期恶劣的环境中，土壤本身已经失去有机质与肥力，仅留下矿物成分。设计师能做的，是参考场地附近的参照土壤（Reference Soil）⑤，尽力还原有机质的性质与比例，并立即引入当地的深根性植物，借由植被根系来诱导并重建土壤中的生化反应。一般而言，堆肥种类的选择也可以依照原始土壤或植被设计而定。例如改善土壤质地，以及改造木本植物附近的土壤，可用松木屑等高木质素堆肥；而对于表土修复，以及针对草本植物的土壤改造，则施用草叶类苗圃堆肥。增加有机质除了能够帮助恢复土壤生物化学活性，某种程度上也在重建养分链的循环；有机堆肥在一定时间内会慢慢消失，其空间被植物根系取代，取而代之的植物也将在未来变成腐殖质。一旦土壤的健康与功能循环得到重建，其对养分的附着力、对悬浮物的吸附力，以及稳定酸碱质等方面都将变得更加强劲，这对水质的控制将产生长远的益处。

同理，只要土壤与植物根系健康，在任何地点都可以利用土壤本身吸附养分与悬浮物的生物净化性能，发挥改善水质的功

4. 结构土壤：由特选级配碎石、粘壤土与少量的水凝胶组成的特殊结构骨料，在基础施工阶段使用泡棉预留出树池位置。完工后，该结构不仅能够满足荷重要求，还能保证土壤的通透性，并且能够使根系横向生长。项目地点：美国旧金山市。© SWA Group
5. 地底支架系统：支撑硬质铺装并将荷重传导至基础底部，保证土壤不被过度夯实，并为大树根系预留生长空间，其间土壤的大小孔隙也能发挥雨洪管理中控制水质与水量的作用。项目地点：美国伯克利市。© DeepRoot
4. Structural soil: Uniformly graded angular gravel, clay loam, and hydrogel form this uniquely designed medium, which can meet or exceed pavement design and installation requirements while remaining root penetrable and supportive of tree growth. Project location: San Francisco, USA. © SWA Group
5. A modular suspended pavement structural cell supports hardscape and transports structural loads to the base. The system was developed to provide soil volumes that support large tree growth and powerful on-site stormwater management. Project location: Berkeley, USA. © DeepRoot





than that found in the same amount of sandy loam[3]. This character, in terms of agriculture, refers to the soil's ability to hold nutrients and make them available to the plant and therefore more fertile. From the perspective of water quality control, soils rich in organic matters contain micro-organisms that demobilize or degrade pollutants and keep them from entering the surface water.

In the recent decades, the use of treatment wetlands to clean surface water has been proven effective and gained substantial public support. Less well know are cleaning processes that occur at the interfaces between soil and roots[4]. Wetland environments, with large amounts of organic matter and aquatic root systems, provide an excellent setting for cation exchange, a process similar to the ways healthy soil helps in nutrient break-down.

In the regular built environment, the humus layer of topsoil often does not get the attentions it deserved. Foliage litter, dead twigs, and other debris collected in the soil are usually removed, if they existed in the first place, by site maintenance. This practice breaks the nutrient cycle and keeps the plants from becoming replenished with organic matter. Over time, the loss of organic matter and problems of moisture loss will slowly diminish the capacity of cation exchange. Degraded soils suffering from organic matter loss have a decreased ability to maintain biological activity and provide nutrients to the plants. Poor soils are less effective at binding and breaking down fertilizers, hydrocarbons, and other urban pollutants. When entering the aquatic food chain, these excessive nutrient and urban toxins significantly degrade water quality and damage the aquatic food chain over short and long term time periods.

3 Soil Best Practices

Landscape architecture is a profession that brings art and science together. Landscape architects are privileged to be in a position that finds solutions and potentially makes the world a better place. With the expanding base knowledge of landscape architecture, soil is undoubtedly the next frontier to be incorporated in our regular practice. Adding a "Soil Management Plan" ③ into the standard deliverable might be a good start. It will provide a platform for scientific involvement, design intervention, owner's commitment, construction coordination, maintenance and monitoring. The following are some very brief suggestions for soil best practices that pertain to water systems:

3.1 Protect Soil Structure to Conserve Hydrological Performance

It takes hundreds of years to develop soil horizons and topsoil, but it does not take very long to irreversibly damage them. Conservation of existing soil structure should be a priority in site design and construction, because it has the most vernacular character and a performance that is almost impossible to replicate. In another word, protecting soil on-site, is protecting the site hydrology. The first step is to conduct an overall soil survey and identify valuable Vegetation and Soil Protection Zones (VSPZ)④. Soil conservation should be an important site constraint during the design process (Fig. 3), and the designed plan should insure minimal disturbance during construction. If existing site conditions need to be modified, soil removal and stock piling is the next best practice to ensure soil quality is maintained. Evaluate the conditions and extents before stripping topsoil and subsoil, protect soil stockpiles and storage from water and wind erosion, yet

能——净化可以在一道草沟、一个树池，或是一片雨季花园中发生（图6）。在许多场地的景观设计中，我们无法直接控制整个水文过程，但是我们绝对可以经由设计来控制土壤，让土壤成为水的载体，成为雨洪的容器，成为地下水的滤芯，让自然系统静静地提供水系控制的服务。这些土壤是承载景观的基底，更是绿色基础建设的根本。

4 一条鱼值多少钱？

以上所有的实践建议都会带来设计更困难、总体经费更高昂、施工条件更多限制、工期更长等挑战，然而如此付出的回报——例如形成健康的本土植物群落、降低雨洪风险、减少灌溉成本、改善水质等——往往无法在短期内体现。为了一条洁净的河流，为了水中有鱼，为了一片净土，我们到底愿意付出多少？

这个问题或许需要整个社会来共同回答。但景观设计师必须率先认识到土壤与可持续的水系统之间的密切关联，充分理解土壤性质，从而使每个图纸细部与工程管理都获得科学知识的支持。这些科学知识将有助于我们成为更好的设计师，帮助我们在关键时刻更具创新力。LAF

注释

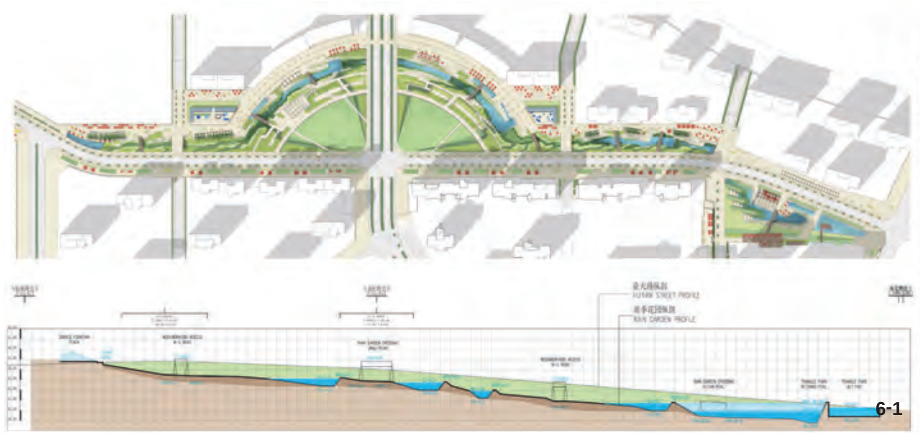
① 1999年，华盛顿有机循环局实施了一项名为“还鲑鱼以净土”的项目，旨在呼吁增加对于土壤改良的重视，从而促进鲑鱼以及其他物种的复育。相关网站：http://www.soilsforsalmon.org/。
② “火星上铺满金钱，地球上铺满尘埃。”援引自：Baskin, Y. (2006). Under Ground: How Creatures of Mud and Dirt Shape Our World. Washington, DC: Island Press.
③ “土壤管理计划”的更多内容可以参见“可持续场地倡议”所制定的“导则与表现标准2009”中的导则4.3。相关网站：http://www.sustainablesites.org/
④ 更多关于“植被与土壤区划”的内容可以参见“可持续场地倡议”所制定的“导则与表现标准2009”中的导则4.4。相关网站：http://www.sustainablesites.org/
⑤ 参照土壤是指在场地被扰动之前的土壤信息样本。设计师可以参考美国自然资源保护中心土壤调查局的资料，以及（或者）本土植被群落所在的土壤状况。

provide constant moisture to maintain its biological activity, and provide fencing and sediment control throughout the construction period to avoid off-site pollution.

3.2 Avoid and Amend Soil Compaction to Increase Water Retaining Capacity

Physical structure and bulk density of soil has a direct influence on soil performance, such as infiltration, percolation, and overall water retaining capacity. During the design phase, designers should set up the hardscape layout corresponding to potential construction staging areas. Contractors should limit heavy equipment routes and staging areas in future planting zones to prevent unnecessary compaction. For the areas inevitably disturbed during construction, or in brownfield sites where the soil has already been compacted, a soil amendment plan should be in place. Slight surface compaction can be treated by adding topsoil amendment with deep root plating. For deeper compaction, making changes in the top layer of soil will do little to improve the soil if nothing is done to correct problems in the layer below. Using mechanical treatments might be helpful in such compaction: traditional tilling can be ideal for thin layer compaction, while trench sub-soiling might be necessary to bring air and water back to deeply compacted soils. When applying soil compaction reduction techniques, sequencing and routing is critical in preventing a second round of compaction from the equipment's load. Adding organic matter or material, such as expanded shale or calcine clay, to the soil during turning or tilling will introduce an artificial structure and help reduce the tendency toward recompaction. Do not add small amounts of sand to improve texture and drainage in the clay. It is difficult to mix sand into clay or silt, and if insufficiently mixed, the sand will surround the soil peds and form a coating, resulting in worse drainage[5].

In highly urbanized areas, such as plaza canopies and street trees, hardscape and softscape are so closely interwoven it can be difficult to set a clear boundary between compacted and non-compacted soils. In this situation, there are several innovative solutions, such as structural soil (Fig. 4) and suspended pavement structural cells (Fig. 5), for designers' and builders' references. Both of these methods provide alternative solutions to load requirements; yet preserve passages for aeration, water storage, and root development.



3.3 Conserve and Restore Soil Performances in Water Cleansing

Long term degradation and organic matter loss turns soil into lifeless dirt with little capacity for holding nutrients. To restore the lost organic property, compost is an ideal material for amendment. Use the reference soil⑤ to determine a reasonable composition of the original soil profile, as well as potential deep root pioneer plants for the first succession. Types of compost vary greatly and designers should select the appropriate according to the original soil profile or future planting material. For areas around trees or general soil texture improvement, use high-lignin compost such as pine bark or coconut husks. These have greater longevity in soil and decompose slowly, thus holding soil particles apart longer. For restoring topsoil or the humus layer, well-aged compost from locally produced yard waste made up of leaves and grass is more ideal. Apply the appropriate amount of yard waste compost; lightly tilling it into the top several inches of soil will improve the organic content of the soil and create conditions for improvements in the soil food web. Organic restoration is the final step in soil improvement. The goal during this phase is to reintroduce and reconnect the damaged link of the original nutrient circle. The proposed organic matter should eventually disappear and be replenished by plant litter on site. Once the organic functions are restored, the soil will be more resilient to environmental, chemical, and PH changes while at the same time contributing to better water quality.

In summary, as long as a design can provide an environment that facilitates bio-remediation, water cleansing can happen anywhere — a swale, a tree pit, or a rain garden (Fig. 6). In most sites, we cannot directly control the hydrology, but we can control the soil within these sites, and enable natural processes to work in our favor. In thoughtful and sustainable design, let the soil be the vessel, let the soil be the container, and let the soil be the filter. It is the unseen layer of landscapes and the foundation of green infrastructure.

4 How Much Does a Fish Cost?

The best practices outlined previously, make projects more challenging to design, higher in overall cost, more restrictive during construction, and more complicated to coordinate. With all these additional efforts, however, the benefits — healthier native flora and fauna, lower risk of flooding, reduced irrigation costs, and improved water quality — are often unseen in the short term. How much does a salmon cost? The bigger question might be, how far would we go to return land to a pristine condition that harbors clean streams and sustainable eco-systems?

It may take a whole society to answer this question. But before that, it is essential for landscape architects to understand that soils are woven into the entire fabric of sustainable water systems. We must understand soil sufficiently so that each design detail and specification is informed by what impact it will have on basic soil concepts and requirements. That knowledge will also require us to be better designers and allow us to pursue greater design innovations. LAF

NOTES

① In 1999, Washington Organic Recycling Council (WORC) established a project call "Soils for Salmon" designed in increasing the awareness of soil improvement as a means to support salmon and other species recovery. The website: http://www.soilsforsalmon.org/.
② "Money is on Mars, Dirt is on Earth." quoted from: Baskin, Y. (2006). Under Ground: How Creatures of Mud and Dirt Shape Our World. Washington, DC: Island Press.
③ For more information of Soil Management Plan, please refer to "Guidelines and Performance Benchmark 2009" from Sustainable Site Initiative. Prerequisite 4.3. The website: http://www.sustainablesites.org/.
④ For more information of VSPZ, please refer to "Guidelines and Performance Benchmark 2009" from Sustainable Site Initiative. Prerequisite 4.4. The website: http://www.sustainablesites.org/
⑤ Reference Soil is the sample soil profile before disturbance. Designers can refer to NRCS Soil Surveys and / or native vegetation communities are present.

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6. 生态基础建设：健康的土壤是都市环境中最好的净水介质。经由细致的设计研究与整地，利用开发区内的雨季花园来取代市政雨水管。项目地点：中国合肥市。© SWA Group

6. Sustainable green infrastructure: Healthy and functional soil is the best medium in cleansing surface runoff in urban settings. With careful grading and hydrological study, a series of rain gardens replace storm pipes and become the green infrastructure of a new development. Project location: Hefei, China. © SWA Group