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基于区域多中心治理模式的生态恢复——以吐鲁番地区坎儿井水利系统的再生利用为例

ECOLOGICAL RESTORATION BASED ON A REGIONAL POLYCENTRIC GOVERNANCE MODEL — REGENERATION OF THE KAREZ WATER SYSTEM IN TURPAN REGION

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摘要

快速的人口增长及工农业发展加剧了吐鲁番地区水资源供应不足的问题，现代水利工程使坎儿井形成的独特生态系统逐渐失衡，与坎儿井相伴而生的绿洲文明和特色文化景观也逐渐丧失活力。本文以坎儿井为切入点，以当下气候变化为契机，在分析吐鲁番地区水资源现状的基础上，提出基于区域多中心治理模式的规划、设计和实施途径，以探寻能够协调社会各方利益的公共环境治理新思路。具体策略包括：1）建立水账户管理体系；2）建立生态农业节水、控水机制；3）构建“农－牧－渔”循环发展模式；4）挖掘废弃空间的潜在价值。通过重新梳理场地的供需关系，重置现状资源与区域发展之间的平衡参量，发挥景观作为生态基础设施的功能性作用，上述策略可在各方利益达成共识的基础上形成公共利益，以实现韧性景观的构建及资源的可持续利用。

关键词

多中心治理模式；吐鲁番；坎儿井；水账户；生态农业；废弃空间

ABSTRACT

With the population boom and the rapid industrial and agricultural development, regional water demand has exceeded the supply capacity in Turpan. Modern water infrastructure not only made the unique ecosystem formed by the Karez out-of-balance, but also devitalized the oasis civilization and the indigenous cultural landscape associated with the Karez. Taking the Karez system as an example, this article proposes planning and design schemes and roadmaps based on a regional polycentric governance model to explore a new path of public environmental governance which coordinates the interests of all stakeholders. Four strategies are proposed: 1) establishing the water account management system; 2) establishing an ecological agriculture water saving and control mechanism; 3) introducing an agriculture-husbandry-fishery circular development mode; and 4) revitalizing abandoned space. By re-identifying water supply and demand, rebalancing the existing resources and regional development, and encouraging the role of landscape as ecological infrastructure, resilient landscape and sustainable resource utilization could be realized to maximize the public interest.

KEY WORDS

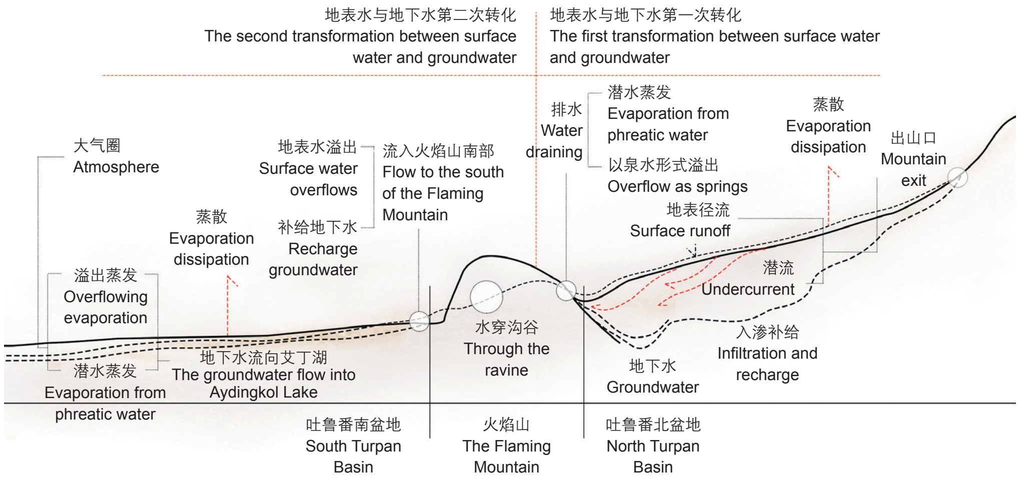
Polycentric Governance Model; Turpan; The Karez; Water Account; Ecological Agriculture; Abandoned Space

翻译 张健 田晓劼
TRANSLATED BY Angus ZHANG TIAN Xiaojie

1 吐鲁番地区水资源现状

中国吐鲁番地区素有“火洲”之称，这里地面蒸发量巨大，且多为沙性土壤，地表水下渗严重[1]；该地区水资源的补给完全依靠冰川融水和山区季节性降水[2]。由此，被称为“地下长城”的坎儿井应运而生。坎儿井大致由竖井、明渠、暗渠、涝坝四部分组成，采用人工手段，在地表以下开挖水渠引流地下水。其优点包括蒸散耗水量小、不易被风沙侵袭、四季水量稳定、工程材料易获取，且无需依靠外部动力便可将浅层地下水引至地面，是吐鲁番地区人畜饮水、农牧业生产、工业用水的主要水源之一（图1）。

自20世纪70年代以来，快速的人口增长及工农业发展使得吐鲁番地区的需水量逐渐超出了坎儿井的供水量。取而代之的现代水利工程不但使坎儿井形成的独特生态系统逐渐失衡，亦使与坎儿井相伴而生的绿洲文明和特色文化景观逐渐丧失活力。水资源过度开采及利用引发了土壤盐渍化与次生盐渍化问题，阻碍了干旱区的农业发展；在气候变化的影响下，当地以冰川融水补给为主的径流将难以为继[3]，进一步加剧了水资源供应不足的问题，并可能引发水资源权限边界划分方面的冲突（图2，3）。



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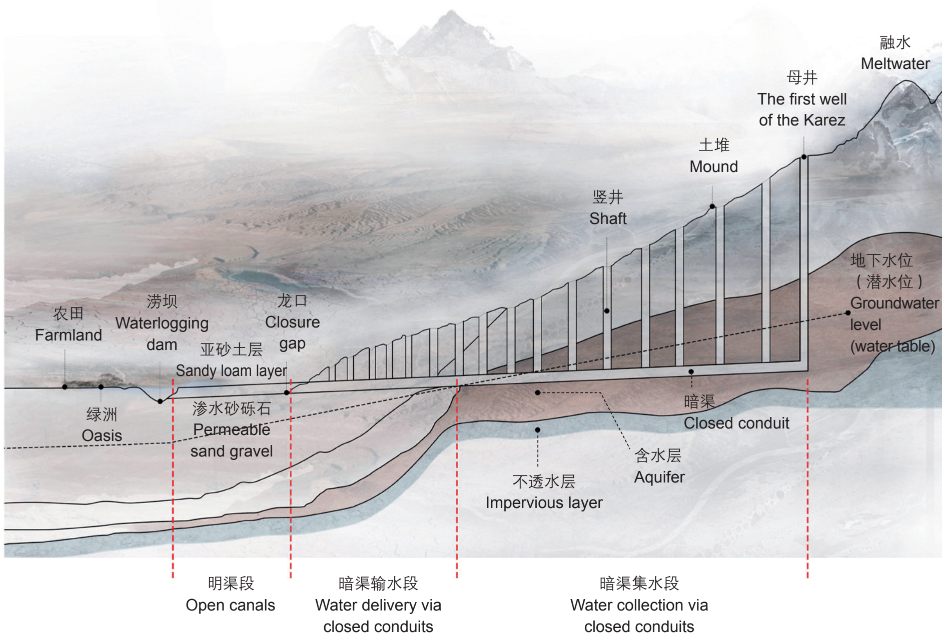


1-2

1-1. 自然条件下吐鲁番盆地的水资源转化模式
1-2. 坎儿井纵剖面示意图

1-1. Turpan Basin's natural water circulation
1-2. Profile of the Karez

2 多中心治理模式

吐鲁番地区的可持续发展是涉及生态环境、技术手段、经济需求与社会认同等多方面的复合性问题。其中，水资源的可持续性不仅与天然水资源的储备量、获取途径、分配成本及经济风险有关，还应考虑社会意愿与资源支付能力。据此，本文提出了基于区域多中心治理模式的规划、设计和实施途径。为了打造良性的“水—土—人”生态系统，本文力求在区域水土综合治理的基础上，探寻出一条能够协调社会各方利益的公共环境治理新思路，为开展相关生态恢复工作提供策略及实施路径（图4，5）。

2.1 建立水账户管理体系

在当前全球变暖的背景下，吐鲁番地区众多小冰川消融正盛，短期内能够持续补给河流；但从长远来看，这部分固态水资源对河流的补给作用终将减弱。资料显示，为天山南麓吐鲁番—哈密盆地内径流提供水源的面积小于2km^{2}的小冰川预计将于2050年前基本消融殆尽，而规模较大的冰川也终将萎缩成小冰川，逐渐丧失对于气候变化的抵御能力。[4]因此，该地区的水资源短缺问题将日趋严重。

融水、降水如同大自然存入水账户中的“收入”，全球变暖则导致“存款”被提前支取。一旦人们毫无节制地“透支消费”水资源，水账户将面临“赤字”危机。我们必须以可持续的方式管理水账户，在对水资源的“存储”“支出”进行精确计算的同时，还需制定“开销计划”并学会“理财”。作为公共环境治理的主导者，政府应积极从源头蓄水并补充地下水，以实现水资源的可持续利用（图6）。具体策略包括：

1）在山前设置生态挡水低坝，通过降低洪水流速、增加洪水下渗总量，以提升地下水水位，涵养坎儿井水源，缓解山前雨洪对中下游绿洲区的潜在威胁；

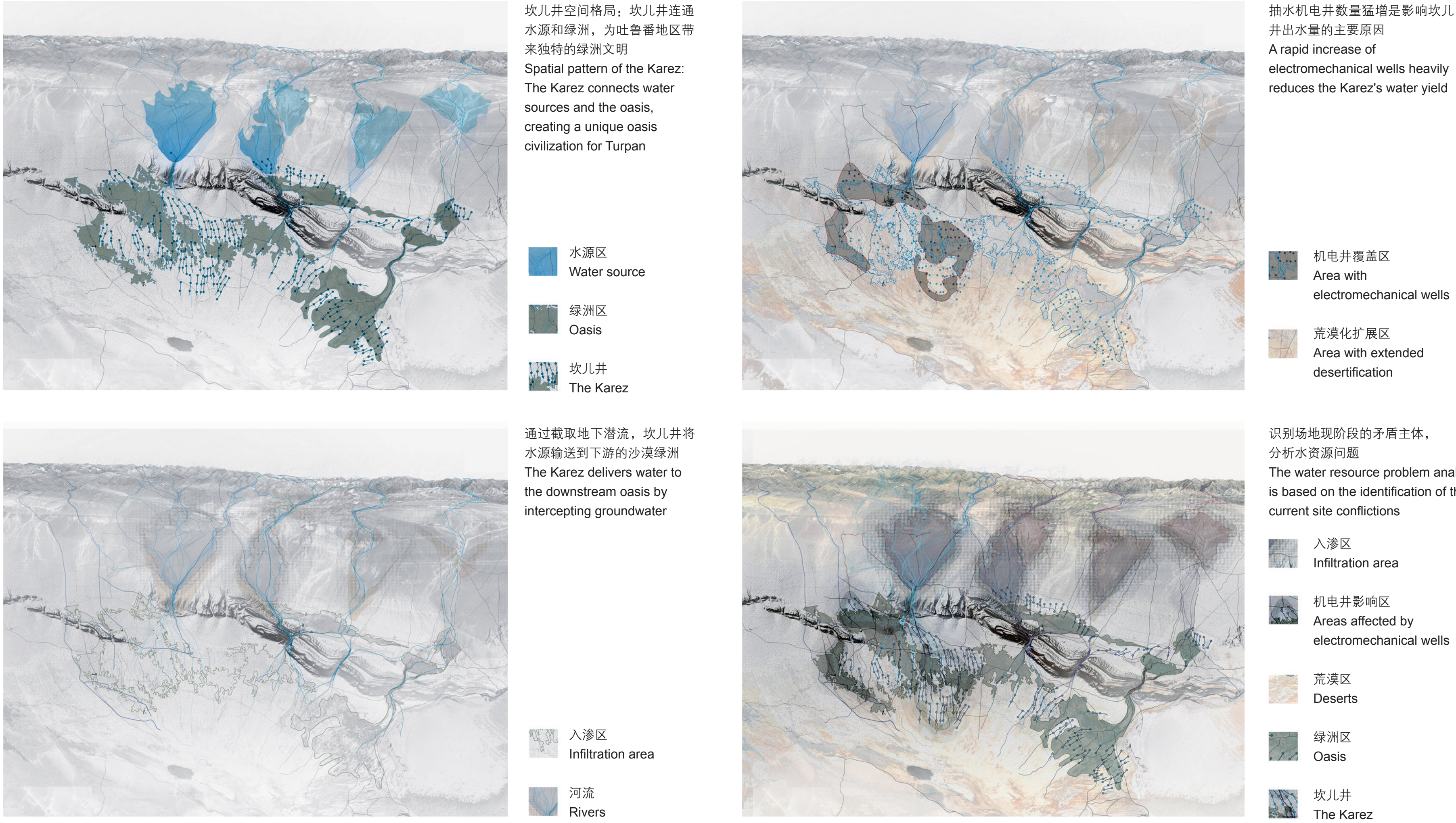
2）建立地下水动态监测站与低坝滞洪入渗监测站，从源头节水、控水，实现水资源的合理利用。

2.2 建立生态农业节水、控水机制

由于长期使用大水漫灌等粗放灌溉方式，当地的土壤盐碱化情况不断加剧，严重影响了农业发展。作物的生长需要土壤，合理的节水技术可以调节土壤水、热、盐及养分状况，改善耕作层土壤环境，并对土壤盐碱化起到一定的防治作用。因此，建立长效的农业节水、控水机制显得尤为重要。具体策略包括：

1）政府应对生态农业节水技术的创新给予政策支持和资金资助，并进行监测评估；营利性组织除定期举办公益性新技术培训及宣传活动外，还可联合企业研发机构，建立生态农业示范区，提供服务与技术指导，推广相关节水设施；

2）土壤状况及土壤微生物是培育作物时的必要考量因素，作物的生长需要整个土壤群落系统的共同作用。通过构建作物和土壤微生物



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的“合作关系”，打造水—土—作物相协调的绿洲农业系统；

3）建立科学节水、控水管理制度，完善投资政策、水价政策和灌溉政策，统筹政府、企业、示范区管理者、种植户及资源环境之间的共利关系。

2.3 构建“农—牧—渔”循环发展模式

坎儿井孕育了吐鲁番地区的绿洲文明，是当地生态、社会、经济和文化共同的物质基础，也是多中心治理模式的纽带。当地居民不仅是坎儿井的受益者，更是坎儿井的创造者与维护者。通过更新传统的坎儿井掏挖与修复工艺、运行和管理方式，结合现代监测技术，定期、定点监测水位、水质变化，可使相关治理工作逐步实现标准化。本文建议构建“农—牧—渔”循环发展的新型农业生产与经营方式，充分利用当地已有的冷水资源，建立水资源储备与分流体系。具体策略包括：

1）在提高地下水水位之后，对原基地已坍塌的坎儿井和废弃的涝坝蓄水空间进行整合，以恢复部分涝坝蓄水空间的生态价值；

2）坎儿井中的地下水在夏季可保持较低温度，故可利用冷水资源开展虹鳟（*Oncorhynchus mykiss*）、金鳟（*Salmo aguabonita*）等冷水鱼与鲢鱼（*Hypophthalmichthys molitrix*）、鳙鱼（*Aristichthys nobilis*）等滤食性经济鱼类的生态养殖。由于滤食性经济鱼类对水质的要求较低，因此可重复利用冷水鱼养殖区的水资源，以充分发挥水体中剩余营养物质的作用（图7）。此外，还需对鱼苗进行定期放流；通过在池塘内放置“泡沫浮岛”实现水质净化，并定期回收其中的吸附碳，作为农作物肥料再次投入使用，由此实现循环经济学定义下的闭环流动模式，使水体中剩余的物质和能量得到最大化的梯次利用；

3）节余下的水可用于荒漠生态草业发展，既可提高地表的植被覆盖率，也可促进自主管理式家庭小牧场的发展。执行整体生态放牧养殖计划，收集牲畜粪便为农田提供有机肥料，并开展淡水鱼养殖，有助于恢复自然生态的良性循环。

2.4 挖掘废弃空间的潜在价值

坎儿井在维持当地生物多样性方面也发挥着重要作用：沿线地表的土丘为穴居动物提供了栖息地，竖井内壁为鸟类提供了庇护所，涝坝为鱼类和两栖动物提供了生存环境。通过整合、改造废弃的机电井与坍塌的坎儿井，我们力求赋予它们更多的空间价值和生态价值（图8）。具体策略包括：

1）对无法恢复使用的坎儿井、废弃蓄水池等进行整合重构，以形成当地居民和游客进行集会、交往、娱乐、休憩的公共空间；

2）基于当地住户、商户、农户对空间环境的了解，鼓励其积极参与废弃公共空间的改造，并减少新建构筑物对当地生态环境的干扰；

3）构建在线公共空间数据库，尽可能从多方面掌握使用者对空间使用的满意程度和期望值，从而更加合理地指导空间整合工作。

尽管上述4项适应性策略的决策重心和适用规模各不相同，但却相互关联、相互制约。唯有同步推进这些策略，才能解构自上而下式的单向管理模式，进而促生良性循环的多中心治理机制。

3 多中心治理模式下的景观韧性构建

在当前资源环境和社会制度背景下，景观逐渐被赋予了一种主动适应发展需求的期望（图9）。本文探讨了如何通过坎儿井这种具有地域特色的信息传递与物质交换媒介构建多中心治理模式，以促进吐鲁番地区生态环境与经济运营的良性发展。本文提出，在将坎儿井的资源、功能、体系相互交叠整合，并嵌入更大尺度生态系统的过程中，景观不仅要实现生态价值，更要体现人文、技术、经济及政策因素的融合，形成多元化的、具有持久效益的韧性系统，以加强应对未来突发事件的能力。

当前，新技术、新事物的涌现在推动社会不断发展并创造高额利润的同时，也加剧了资源开发的不可持续性，而传统的治理方式与平衡策略势必难以应对未来的诸多不确定因素。本文旨在引导各利益相关方在共同参与、达成共识的基础上，通过运用多中心治理模式，实现景观效益最大化。正如巴里·康芒纳所定义的生态学第一定律——“凡事皆相关”[5]一样，加勒特·哈丁认为“我们的任何行为都将产生连锁效应”[6]。LAF

致谢

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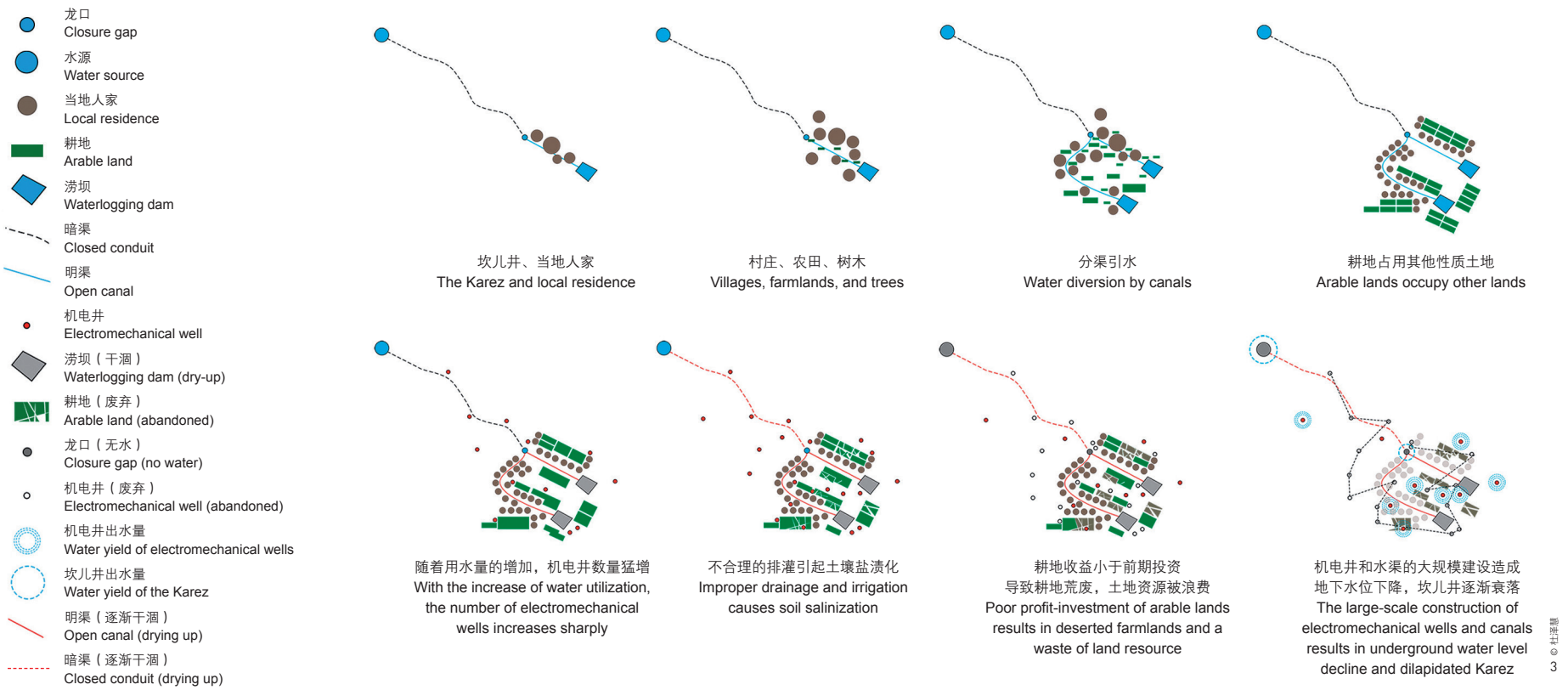
注释

该项目曾获第14届全国高校景观设计学生作品展——LA先锋奖研究创新类综合奖，本文基于该获奖作品撰写。



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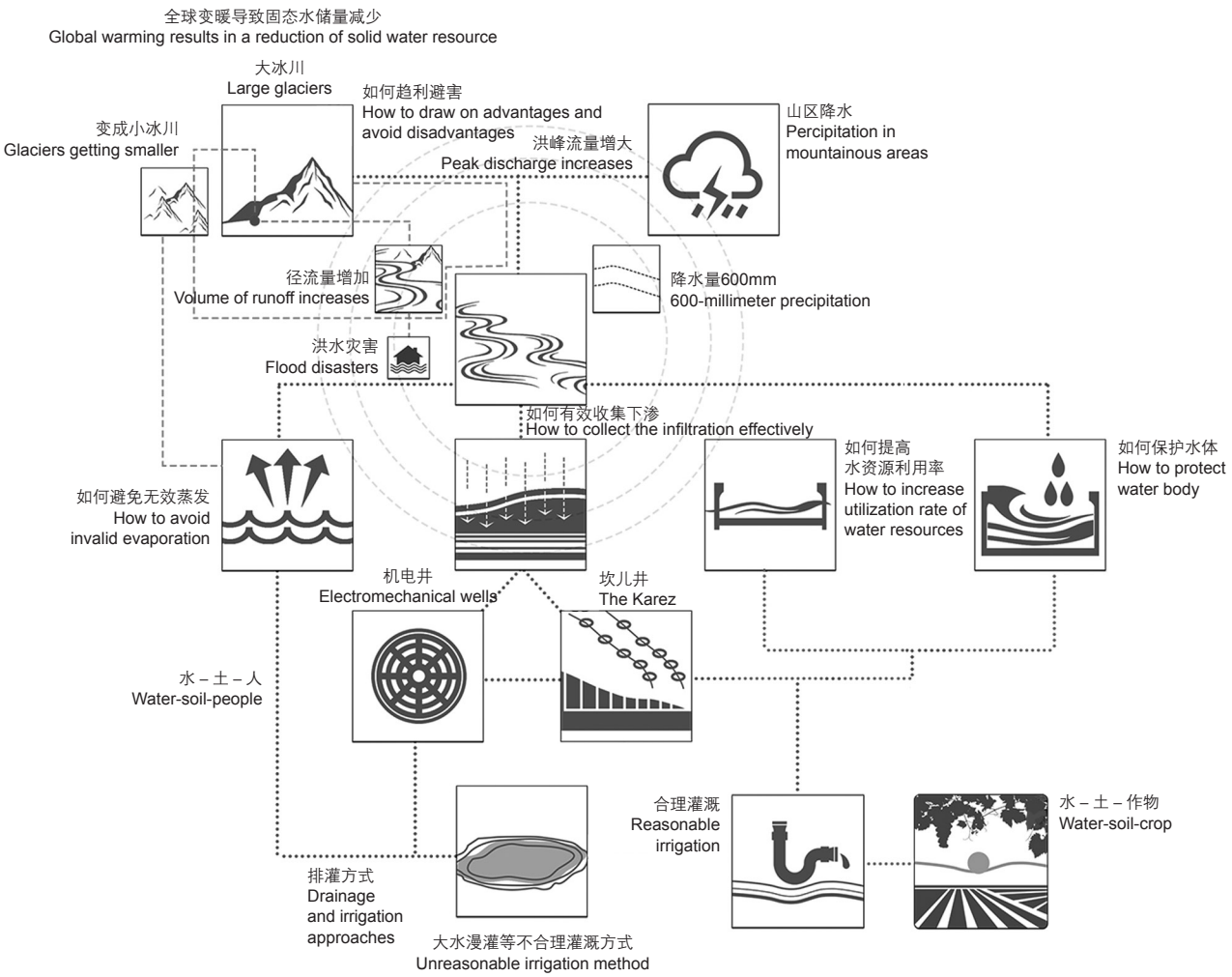

4. 当地生态系统改进策略
5. 场地平面图

4. Local ecosystem improvement strategies
5. Master plan of the site

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4

1 Water Resource in Turpan

Turpan has historically been called “the land on fire.” With an extremely strong evaporation and a serious infiltration of surface water due to the sandy soil[1], the water supply in the Turpan Basin depends entirely on glacial melting and seasonal precipitation in mountainous areas[2]. As an indigenous response, the Karez, which is called “the underground Great Wall,” came into being. Generally, it consists of four parts: shafts, open canals, closed conduits, and waterlogging dams, composing an underground canal system constructed manually to transport water from an aquifer or water wells to surface for drinking and irrigation. While delivering water to the ground without any external forces, the Karez is superior in reducing evaporation loss, being resilient to sandstorm and seasonal changes of water resource quantity, and easily obtaining construction materials. The Karez therefore has supplied water for Turpan’s human and livestock living, agricultural production, and industrial uses for years and years (Fig. 1).

Since the 1970s, with the population boom and the rapid industrial and agricultural development, regional water demand has exceeded the supply capacity of the Karez system. The replacement of the Karez by modern water infrastructure not only made the unique ecosystem formed by the Karez out-of-balance, but also devitalized the oasis civilization and the indigenous cultural landscape associated with the Karez. The overexploitation of water resource has caused problems like soil salinization and secondary salinization, which are adverse to the agriculture in arid regions. Climate changes would make the dominated regional meltwater-streams unsustainable[3], further aggravating the existing shortage of water supply and probably triggering more conflicts in boundary division of water resources (Fig. 2, 3).

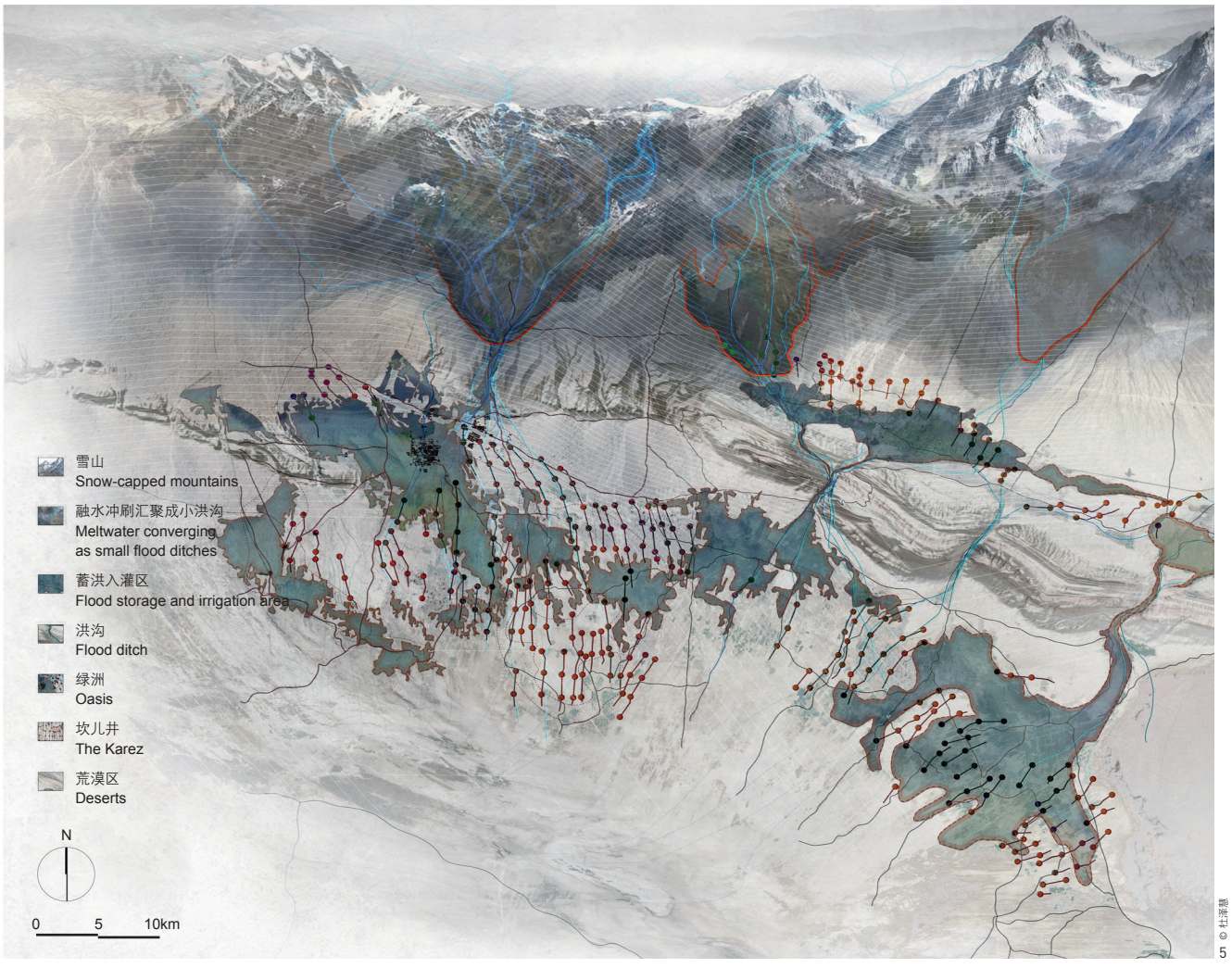
2 Polycentric Governance Model

The sustainability of the Turpan region is a complex issue associated with ecological environment, technical means, economic needs, and social identification. With regard to the water resource, its sustainability not only relates to the reserve margin, source access, distribution costs, and economic risks of natural water resource, but also depends on the public will and the resource affordability. Therefore, this article proposes planning and design schemes and roadmaps based on a regional polycentric governance model. In order to coordinate the interests of all stakeholders and create a sound water-soil-people ecosystem, this article explores a new path of public environmental governance through comprehensive management of water and soil, providing strategies and methods for ecological restoration projects in the future (Fig. 4, 5).

2.1 Establishing the Water Account Management System

Impacted by global warming, many small glaciers in the Turpan region are melting away and cannot supply rivers for a long run. Data shows that the small glaciers with an area less than 2 km^2 providing water resources for Turpan-Hami Basin, located to southern Tien Shan Mountains, will disappear by 2050, and the existing larger glaciers will eventually melt into small ones, continuously weakening the region's resistance to climate change.[4] At a regional scale, the water shortage will be severer and severer.

If meltwater and rainfalls are the "income" we get from the nature, then we have to "withdraw" them in advance due to the global warming. If humans continue to "overdraw" immoderately, they will face a crisis of "deficit." We must manage the water account in a sustainable way. While having a clear awareness of savings and expenditures, people also need



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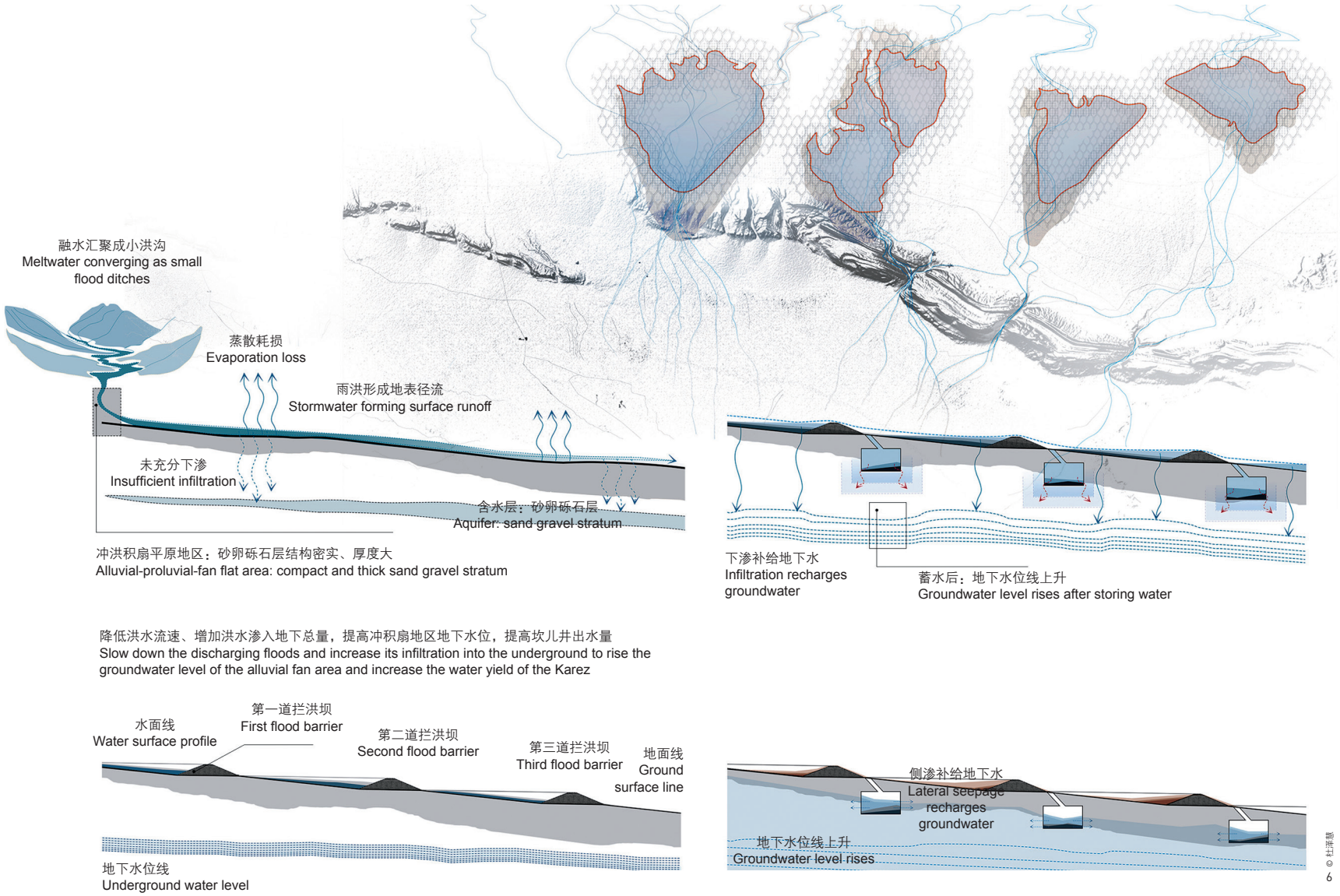


to develop “expenditure plans” and learn management methods for a “financial sustainability.” Playing the leading role in public environmental governance, the government should proactively conserve water from the source and recharge groundwater for a sustainable utilization of water resources (Fig. 6). Specific strategies include:

1) Setting up low ecological dams in front of the mountains to slow down the speed of flood and increase infiltration, thereby to recharge the groundwater, conserve water for the Karez, and alleviate the potential threat of stormwater and flood to the oasis in the middle and lower reaches;

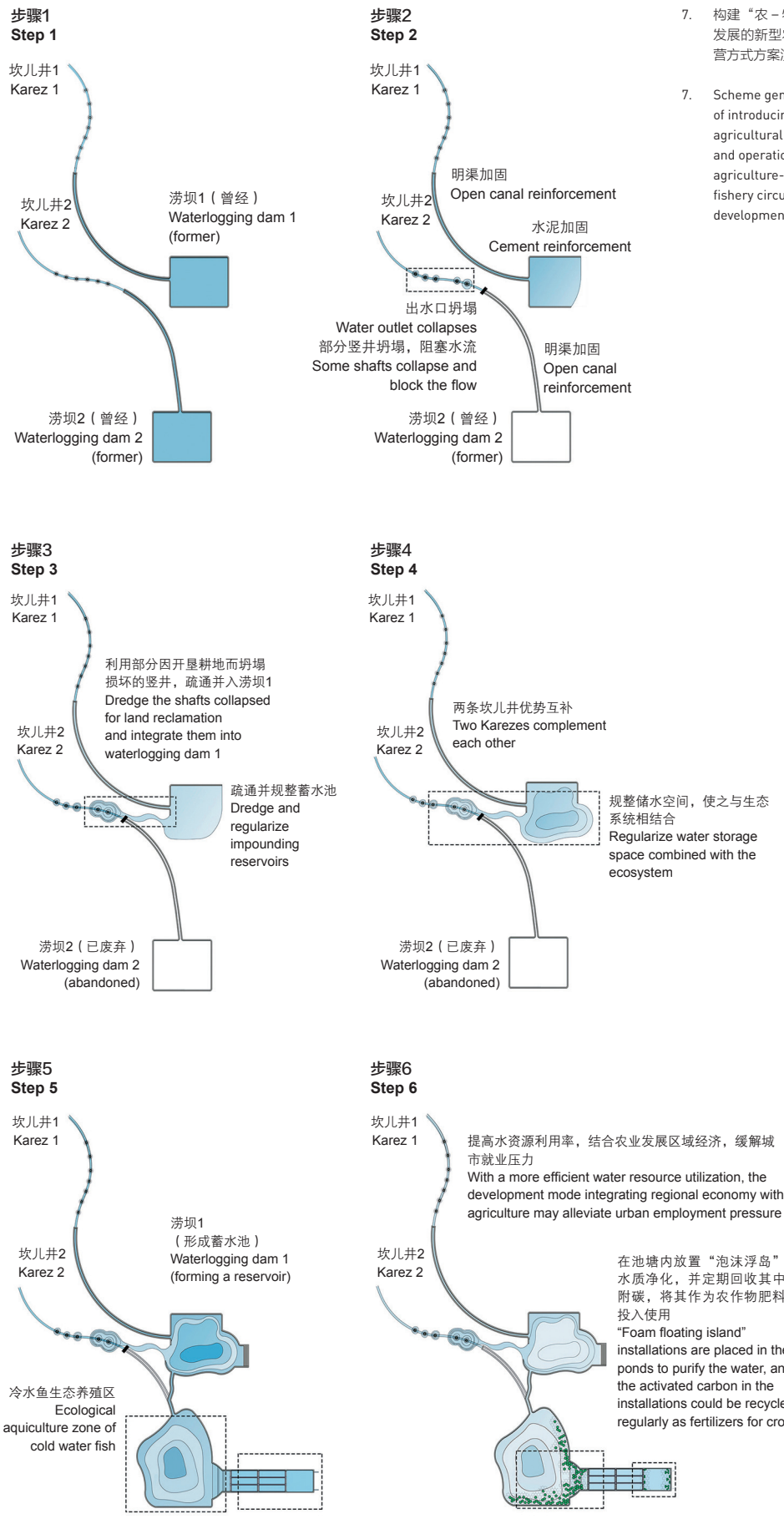
2) Establishing stations to monitor the groundwater and the flood detention and infiltration by low dams to inform wise conservation and utilization of water resource.

2.2 Establishing an Ecological Agriculture Water Saving and Control Mechanism

The long-term application of flood irrigation has somehow aggravated soil salinization in the region and increasingly affected Turpan’s agriculture development. Since water-saving technology can help regulate the moisture, heat, salinity, and nutrient condition of the soil and improve the quality of topsoil, it is significant to establish a long-term agricultural water saving and control mechanism. Specific strategies include:

6. 蓄洪入渗地下水，提高地下水水位，涵养坎儿井水源，缓解山前雨洪对中下游绿洲区的潜在威胁。

6. The strategy of storing the stormwater and increasing its infiltration, thereby to recharge the groundwater, conserve water for the Karez, and alleviate the potential threat of the stormwater to the oasis in the middle and lower reaches.



7. 构建“农－牧－渔”循环发展的新型农业生产与经营方式方案演进图。

7. Scheme generation of introducing a new agricultural production and operation mode for agriculture-husbandry-fishery circular development.

1) The government is expected to provide policy and financial support to innovative efforts of ecological agriculture water-saving technology and conduct monitoring and evaluation. In addition to regular public training programs and promotion events of new technologies, profit-making organizations can cooperate with enterprise-based research and development institutes to establish eco-agriculture demonstration zones, provide service and technical guidance, and popularize water-saving facilities;

2) Soil condition and microbiota impact plant growth the most. By improving the interactive relation of crops and the soil microbiota, an oasis agricultural system where water, soil, and crops are “coordinated” could be formed;

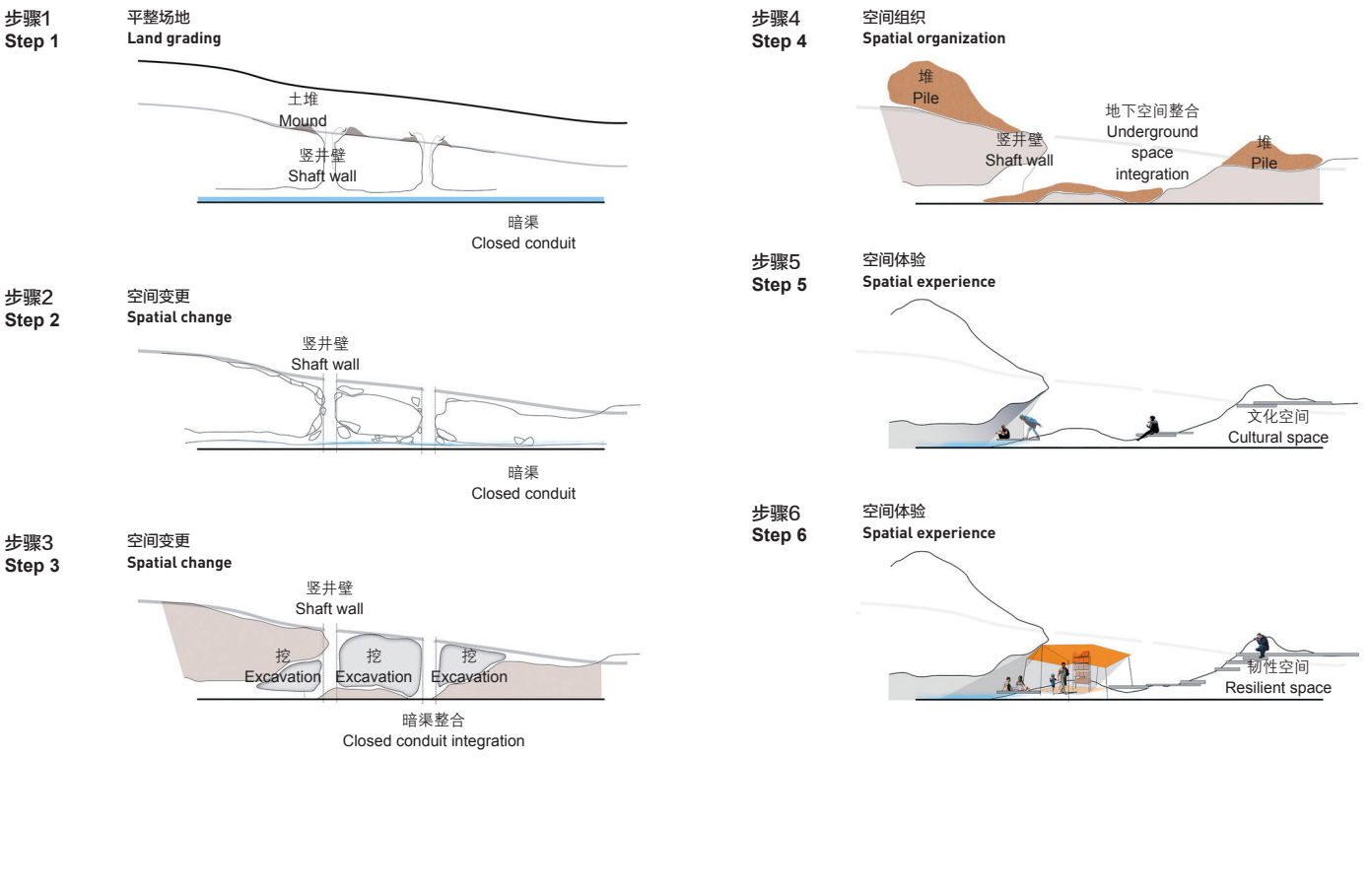
3) Establishing a scientific management system for water saving and control and giving policy priority to related investment, water price regulation, and irrigation. Meanwhile, the system can create a mutually beneficial relationship between government agencies, enterprises, managers of demonstration zones, and farmers in resource utilization and environmental conservation.

2.3 Introducing an Agriculture-Husbandry-Fishery Circular Development Mode

The Karez system nurtures the oasis civilization in Turpan. It has been the physical foundation of the local ecology, society, economy, and culture, providing a skeleton for polycentric governance. While benefiting from the Karez for generations, local residents are also the builders and maintainers of this system. With innovations in the Karez construction and repair craftsmanship, improved approaches to operating and managing the system, and regular monitoring of the water level and quality changes with modern techniques, a standardized governance mode could be gradually formulated. This article envisions an agriculture-husbandry-fishery circular development mode, a new agricultural production and operation mechanism that makes full use of the existing cold water resources and builds water reserve and diversion systems. Specific strategies include:

1) The ecological performance of the water storage space of the dam systems can be improved by integrating the abandoned ones with the collapsed Karez after raising the groundwater level;

2) Since the temperature of the groundwater in the Karez remains low in summer, ecological fishery of cold water fishes, such as *Oncorhynchus mykiss* and *Salmo aguabonita*, and filter-feeding commercial fishes, such as



Hypophthalmichthys molitrix and *Aristichthys nobilis*, can be cultivated. In particular, filter-feeding fishes can inhabit even in aquatic environments of lower water quality, which allows for a reutilization of the water and residual nutrients from cold-water fishery zones (Fig. 7). Regular fish fry releasing is also necessary. In addition, installations like "foam floating islands" can be introduced into the ponds to purify the water and the activated carbon in the installations can be recycled as fertilizer for crops, to realize a circular agriculture economy and make the best cascade utilization of the residual materials and energy in water;

3) Using the surplus water to develop desert eco-prataculture could promote household paddocks and reduce bare-ground lands. A healthy cycle of natural ecology can be formed by implementing comprehensive ecological grazing and breeding programs, collecting livestock excrement as organic fertilizers for crops, and encouraging fresh water aquaculture.

2.4 Revitalizing Abandoned Space

The Karez plays a unique role in local biodiversity: the mounds above the canals provide habitats for cave animals; the inner walls of the wells offer shelters for birds; the dams home fish and amphibians. The spatial function and ecological performance of such spaces can be improved by integrating and transforming abandoned electromechanical wells and the collapsed Karez (Fig. 8). Specific strategies include:

1) Integrating and reconstructing the irreparable Karez and abandoned reservoirs to form recreational public space for local residents and tourists to gather, communicate, and take a rest;

2) Local residents, merchants, and farmers with full understandings of local space are encouraged to participate in the reconstruction of abandoned public spaces. The impact of new structures on local ecological environment should be minimized;

3) Building an online database of public spaces to comprehensively learn about people's satisfaction degree and expectation in space use and inform spatial integration.

Although the above strategies have different priorities and applicable scales, they are interrelated and inter-conditioned. Only by synchronizing all these strategies can we deconstruct the existing top-down unidirectional management model and establish a positive circulation of polycentric governance mechanism.

8. 整合、改造废弃的机电井与坍塌的坎儿井，赋予其更多的空间价值和生态价值。
9. 策略总平面图

8. The strategy of integrating and transforming abandoned electromechanical wells and the collapsed Karez to improve the spatial function and ecological performance of such spaces.
9. Site plan with general strategies

3 Strengthening Landscape Resilience under a Polycentric Governance Model

In the current context of resource utilization and social system, landscape is increasingly endowed with an expectation of proactively adapting to contemporary development (Fig. 9). This article explores how to adopt a polycentric governance model for renewing Turpan's Karez system, an agency of the regional information transfer and material exchange. Through resource, functional, and structural integrations of the Karez into larger-scale ecosystems, the landscape can be ecologically revitalized with cultural, technological, economic, and policy considerations, becoming a resilient system that delivers lasting and multiple benefits and be capable to respond to uncertainties.

Nowadays, technological innovation is pushing ahead the development of society and generating high profits, while aggravating the unsustainability of resource exploitation. Traditional governance methods and strategies are facing challenges in balancing and dealing with uncertain factors in the future. This article is to facilitate the engagement of all stakeholders, and coordinate public interest based on common consensus. Under the polycentric governance model, landscape performance and benefits can be ensured. According to the First Law of Ecology defined by Barry Commoner, "everything is connected to everything else,"[5] and "we can never do merely one thing,"[6] as what Garrett Hardin believed. **LAF**

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