

水适应性景观认知与研究框架解析 ——以北京市门头沟地区为例

COGNITION AND RESEARCH FRAMEWORK OF WATER ADAPTIVE LANDSCAPES WITH THE CASE STUDY ON MENTOUGOU DISTRICT, BEIJING

1 前言

“水适应性景观”（water adaptive landscape）从适应性概念发展而来。自2001年开始，联合国政府间气候变化专门委员会先后6次发表评估报告，将“适应性”定义为“对实际或预期的气候及其影响进行调整的过程”以及“在人类系统中，‘适应’旨在通过行动减轻或避免有害的影响或利用有利的机会”^[1]。借鉴这一概念，“水适应性”（water adaptation）可被简单归纳为水系统对实际或预期的气候及其影

张晋*

北京林业大学风景园林学博士，北方工业大学建筑与艺术学院讲师、硕士生导师

*通讯作者

地址：北京市石景山区晋元庄路5号

邮编：100144

Email: zhjblack@126.com

摘要

水适应性景观是人-水相互适应结果下的典型地域景观综合体。对于水适应性景观的研究强调水、适应性、景观三者之间研究视角及研究方法的结合，可看作是全球变化背景下的适应性专项研究。本文首先梳理了“适应性”在各相关学科中的概念，在总结适应性研究主要属性的基础上提出了水适应性景观的概念和研究范畴，认为水适应性景观的研究对象主要包括相关空间形态及行为模式的适应性过程、能力及策略。随后从空间格局及营造经验、评估分析、叙事分析等三方面概括了水适应性景观研究的进展，并以北京市门头沟地区为例，构建水适应性景观研究框架并进行解析；最后从研究框架、量化方法、公众认知、落地性等方面对未来研究提出展望。

关键词

水适应性景观；水；适应性；景观；认知；研究框架；门头沟

ZHANG Jin

PhD of Landscape Architecture at Beijing Forestry University; Lecturer and Graduate Supervisor of School of Architecture and Arts, North China University of Technology

ABSTRACT

Water adaptive landscape is a typical regional complex formed by mutual adaptation between humans and water systems. As a subfield of adaptation research in the context of global changes, research on water adaptive landscapes emphasizes the combination of research perspectives and methods on water, adaptation, and landscape. This paper first reviews the concepts of “adaptation” in related disciplines, summarizes the primary attributes of adaptation, and puts forward a definition and research scope of water adaptive landscape. While pointing out that research on water adaptive landscapes mainly studies the processes, capacities, and strategies of relevant spatial forms and behavioral patterns, it also presents the research progress and achievements in the experience of spatial patterns and construction, evaluation, and narrative analysis, before proposing a research framework of water adaptive landscape by focusing on Mentougou District of Beijing. Finally, it offers prospects for future study from the aspects of research framework, quantitative methods, social cognition, and feasibility.

KEYWORDS

Water Adaptive Landscape; Water; Adaptation; Landscape; Cognition; Research Framework; Mentougou District

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响进行调整的过程；而从人类角度出发，水适应性也被国内相关学者总结为变化环境下所采取的不断学习与调整的系统过程，以改进水资源的规划与管理对策^[2]。区别于生物学、气候科学、地理学、生态学、政治经济学等学科视角，基于景观设计学的水适应性研究进一步强调了这一过程发生的地域空间实体、人水互动模式及景观呈现形式，可被看作是从要素层面对适应性进行的细分研究。

本文的研究意义在于：首先，引入具有学科交叉性质的研究对象，将（景观）生态学、（景观）水文学、乡村地理学等学科相关研究视角与景观设计学科研究视角相结合，探讨与搭建水适应性景观的研究框架，弥补当下水生态环境构建相关理论与实践对中国传统乡村地区水适应性景观研究的不足，并促进当下乡村振兴相应理论与实践对地域性水景观系统的认知与研究。其次，中国乡村区域的水适应性景观是长期“人-地”关系作用下的产物，是乡土地域文化的重要组成部分，对其进行有针对性的系统研究将进一步完善乡土地域文化的构建，为乡村保护与开发及其所在地区的地域文化价值发掘提供新的思路。

2 水适应性景观的概念及研究范畴

适应性的概念产生于生物学领域，最早应用于生物表型特征的研究^[3]，主要指生物个体的生理或行为特征经过长期自然选择在某个环境下能够顺利繁衍并增加数量^[4]，之后被广泛应用于社会学、地理学、（景观）生态学及气候学等领域。社会学认为适应性是在变化的环境中通过文化实践而产生的行为选择结果^[5]，强调人的主观能动性对于目

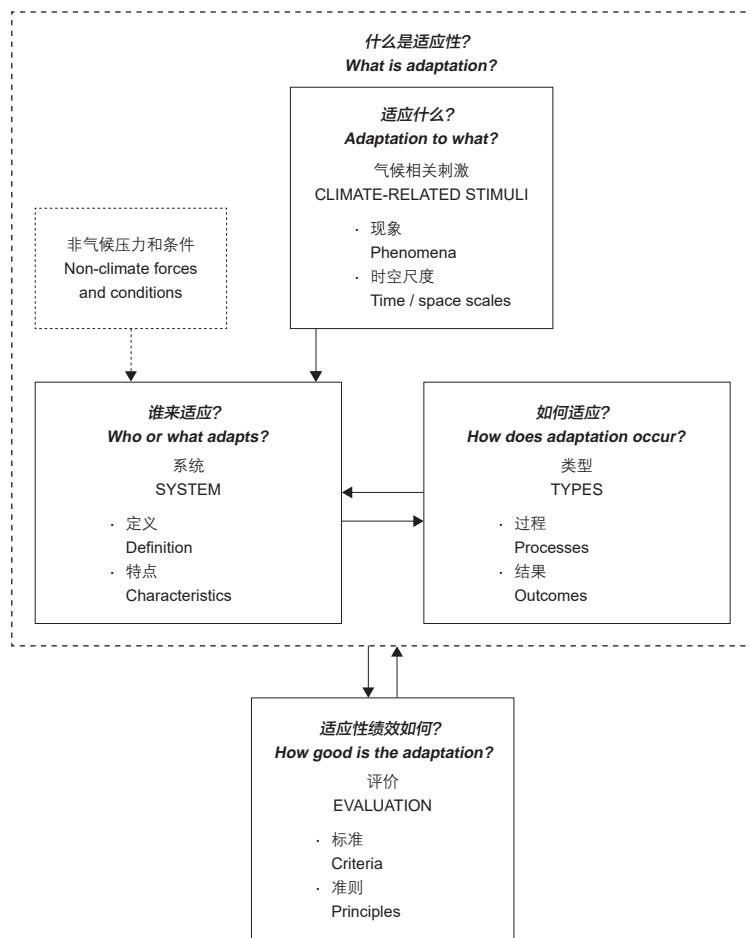
1 Introduction

The term “water adaptive landscape” is derived from the concept of adaptation. Since 2001, the Intergovernmental Panel on Climate Change has published six assessment reports, which hold that adaptation is “the process of adjustment to actual or expected climate and its effects,” and “in human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities.”^[1] Based on such understanding, water adaptation can be briefly referred as the adjustment process of water system to actual or expected climate and its effects. It is also defined by Chinese scholars, from the perspective of human beings, as a systematic process of continuous learning and adjustment to environmental changes for the improvement of planning and management strategies of water resources^[2]. Different from research on water adaptation in the fields of Biology, Climate Science, Geography, Ecology, and Political Economics, research on water adaptation in Landscape Architecture that focuses on the regional territory where the process happens, the interaction pattern between people and water, and the form of landscape appearance represents a subfield of research on adaptation through studies of relevant elements.

This paper reflects its research significance twofold: First, it studies the objects with interdisciplinary importance from Landscape Architecture perspective by combining with (Landscape) Ecology, (Landscape) Hydrology, Rural Geography, and other related disciplines, to explore and build a research framework for water adaptive landscape. This would not only fill in the gaps in both the theory and the practice of water ecosystem improvement on water adaptive landscapes in traditional rural areas of China, but also promote the understanding and research on regional water landscape systems in the theory and practice of rural vitalization. Second, as an outcome of long-term human-environment interaction, water adaptive landscape in rural China is an important component of Chinese vernacular culture, and a targeted, systematic study will further enhance regional cultural identities in rural China, providing new ideas for its protection and development.

2 The Definition and Research Scope of Water Adaptive Landscapes

The concept of adaptation, referring to the biochemical and behavior characteristics of individual living beings after a long-term evolution that supports species reproduction multiply in a certain environment^[4], was first developed by biologists in research on biological phenotypes of organisms' evolution^[3]



1. 巴里·斯密特提出的适应性研究框架（来源：参考文献[9]）

1. Research framework on adaptation proposed by Barry Smit (source: Ref. [9])

标的选择与调整；地理学的适应性旨在评估全球环境变化对自然生态系统和人类社会的影响，同时也为评估人类适应性对策提供理论基础^[6]；（景观）生态学中的适应性是指景观这一地表镶嵌体在全球变化背景下维持主要功能的特性，涉及不同景观类型、组成单元及层级在不同时空尺度中的不同程度的转变^[7]；气候学领域中的适应性则主要是指自然和人为系统对于实际的或预期的气候刺激因素及其影响所做出的趋利避害的反应^[8]。其中，在气候学领域，巴里·斯密特最早于1999年提出了系统性定义适应性的框架图（图1），明确了适应性研究的三个主要部分^{[9][10]}：1）适应客体，即“适应什么”，指气候变化及非气候的压力和条件，既包括负面响应也包括正面响应，既包括当前响应也包

and later widely applied in the fields of Sociology, Geosciences, (Landscape) Ecology, Climatology, etc. Sociologists hold that adaptation, under human selection and intervention, is the outcome of cultural practice in dynamics^[5]; in Geography, theories of adaption are developed to estimate the impact of global environmental changes on natural ecosystems and human societies, by assessing human measures for adaptation^[6]; in (Landscape) Ecology, adaptation refers to changing characteristics of landscapes, as mosaics on land, in types, components, and hierarchies in different time / space dimensions at varied levels to maintain their major functions against the background of global changes^[7]; adaptation in Climatology refers mainly to the response of natural or human systems to actual or expected climatic stimuli with positive or negative impacts^[8]. In the sphere of Climatology, in 1999 Barry Smit first proposed a framework for systematically defining adaptation and the three major components^{[9][10]} (Fig. 1): 1) objects of adaptation, i.e., “adaptation to what,” can be climate-related stimuli or non-climate forces and conditions, the existing or possible responses to which can be both adverse and active;

括预测响应；2) 适应主体，即“谁或什么来适应”，指自然生态系统和人类社会经济系统两大适应性主体，及其实践、过程与结构；3) 适应过程，即“如何适应”，是指适应主体对客体进行适应的方式以及适应策略的选择，分为自发性适应和计划性适应两类^[11]。

各相关学科对适应性的研究虽各有侧重，但研究视角与内容在以下几个方面体现出交叉性特征：

1) 系统：研究均强调系统性调整，以减少系统的脆弱性，从而提升对环境和气候变化的适应能力；

2) 过程：不管是生物体还是景观系统，与环境变化表现适合都是经过自然与人工长期适应的结果，是在动态适应过程中所表现出的阶段性特征，并被纳入到对于未来的调整管理之中——这一属性意味着适应性研究的重点在于调节的发展过程，而非控制结果；

3) 空间：适应性的发生、评价及预测均涉及适应性主体所处的空间尺度与范围——从区域、地域到国土尺度；

4) 行为：即适应的策略及方式。

上述适应性及水适应性研究视角可简要概括为：适应性研究是基于系统分析与调整的过程性研究，从空间或行为入手，主要包括适应客体、适应主体及适应过程三个方面；水适应性是适应性研究的专项内容，研究视角可概括为将水系统作为适应客体和适应主体两类。水适应性景观研究强调适应性研究与景观研究的结合，并在此基础上探讨如何适应的问题。因此，在总结水适应性景观概念之前，有必要对其中的“景观”一词的主要含义进行阐释。

对于“景观”一词含义的阐释已有较为全面的研究，此处只引用约翰·布林克霍夫·杰克逊在《发现乡土景观》一书中较为简明的定义：“景观是一个由人创造或改造的空间的综合体”^[12]。这一定义将景观的基本范畴概括为空间要素及人类行为，作为一个在此处更偏向人文地理学认知的概念，其强调的是景观作为目之所及的存在性而非单纯的美学性。因此，水适应性景观并非景观美学范畴中的水景营造，这一认知在此处尤为重要。基于这一概念认知便可对景观的特征进行拓展：景观是地理的、历史的、文化的、本土的、变化的、过程的、连续的、系统的……由此可见，景观的非美学属性与适应性的关联性更强。景观概念的加入应该更强调对于适应性空间形态及其发生演变

2) subjects of adaptation, i.e., “who or what adapts,” include natural ecosystems and human societies, as well as associated practices, processes, and structures; 3) the process of adaptation, i.e., “how does the adaptation occur,” including autonomous adaptation and planned adaptation^[11].

Adaptation, though, is interpreted variously from different disciplinary perspectives, common views and interests are seen among such research in aspects as follows:

1) System: such studies all emphasize systematic adjustment to reduce vulnerabilities, so as to improve resilience to environmental and climate changes;

2) Process: for both individual living beings and landscape systems, adapting to environmental changes is the outcome of long-term human-nature interaction, which is characterized with staged evolutions in a dynamic adaptive process and get adjusted according to expected management — this means that such research focuses on the responding process, rather than the results;

3) Space: the occurrence, evaluation, and prediction of adaptation associate with the spatial scale and physical territory where the subject of adaptation exists from district, regional to national;

4) Behavior: the strategies and methods of adaptation.

As above, adaptation research examines adaptation processes through systematic analysis and adjustment, focusing on spatial or behavioral characteristics and covering the subjects and objects of adaptation, as well as the processes of adaptation; water adaptation is a sub-field of adaptation research that basically explores water systems as both the subjects and objects of adaptation. Study of water adaptive landscapes highlights the combination between adaptation research and landscape research, providing a basis for the further development of adaptation strategies and methods. Before defining the concept of water adaptive landscapes, it is necessary to clarify the denotation of “landscape” here.

The term “landscape” has been comprehensively studied and interpreted. Here, a concise definition from John Brinckerhoff Jackson’s *Discovering the Vernacular Landscape* is adopted that a landscape is “a composition of man-made or man-modified spaces to serve as infrastructure or background for our collective existence.”^[12] Jackson’s idea basically decomposes landscapes as a combination of spatial elements and human activities through an anthropogeographical lens, while emphasizing the physical attributes of landscapes instead of purely aesthetic features. This means that water adaptive landscapes are not simply about waterscapes with aesthetic values — It is extremely important to comprehend. Based on this, landscapes can be considered

规律的研究,从而体现适应性景观视角相结合的特色与价值。

综上,本文将水适应性景观定义为:人-水相互适应所产生的典型地域景观综合体;水适应性景观的研究对象则主要包括相关空间形态及行为模式的适应性过程、能力及策略。

3 水适应性景观研究进展

基于上述水适应性景观的概念与研究范畴,本文将国内外水适应性景观相关研究归纳为水适应性景观空间格局及营造经验分析、水适应性景观评估、水适应性景观叙事分析三类。

3.1 水适应性景观空间格局及营造经验分析

此类研究主要运用景观空间格局相关研究视角及方法来探索水系统的演变规律与作用机制,包括流域尺度下的景观格局及其演变研究,以及城市尺度下的水系空间格局研究。两者均强调水系统是由其包含的各个自然及人文要素构成的不可分割的整体。

研究与建立生态可持续流域景观格局是流域综合治理的发展方向^[13],在流域尺度上多以不同时期的遥感影像和景观类型图为基础,通过景观指数、生态系统服务价值计算等方法进行景观格局变化特征的定量分析^{[13][14]},进而研判景观格局变化与径流等因素的关系^[15]、流域生态经济价值^[16]、动植物生境空间分布与水文动态过程的关系^[17]、流域水文补给过程^[18]等。

城市尺度的水系空间格局研究主要针对具体城市及乡村区域水系单元,且多对不同时期水系格局与城乡格局关系特征^{[19][20]}、不同尺度的

geographical, historical, cultural, vernacular, changing, progressive, continuous, and systematic... which reveals that adaptation more accompanies less-aesthetic-associated attributes of landscapes. Therefore, bridging with landscape research requires an emphasis on the adaptive spatial forms and evolving laws, so as to stress the interests and values of this combination.

In this paper, water adaptive landscape is defined as a typical regional complex formed by mutual adaptation between humans and water systems; research on water adaptive landscapes mainly studies the processes, capacities, and strategies of relevant spatial forms and behavioral patterns.

3 The Progress and Major Achievements of Research on Water Adaptive Landscapes

Existing studies on water adaptive landscapes in China and abroad can be summarized into empirical analysis of spatial patterns and construction of water adaptive landscapes, evaluation of water adaptive landscapes, and narrative analysis of water adaptive landscapes.

3.1 Empirical Analysis of Spatial Patterns and Construction of Water Adaptive Landscapes

Basically, such research applies the perspectives and methods of landscape spatial pattern studies into the exploration of evolving laws and mechanisms of water systems. It includes research on landscape patterns and their evolution at watershed scale and the one on spatial patterns of water systems at city scale, both of which emphasize the integration of all kinds of natural and cultural elements in the systems as a whole.

Studying and building ecologically sustainable landscape patterns of watersheds is one of the current and future research interests on watershed integrated management^[13]. Quantitative analyses of variation characteristics of landscape patterns are often used, based on watershed-scaled remote sensing images and landscape typological maps in different time periods, through calculation of landscape indexes and evaluation of ecosystem services^{[13][14]}. This helps further identify the correlations between variations in landscape patterns and impact factors such as runoff^[15], economic values of watershed ecology^[16], correlations between spatial distributions of fauna and flora habitats with hydrographic processes^[17], watershed hydrographic circulation processes^[18], etc.

Research on spatial patterns of water systems at city scale mainly focuses on specific water systems in urban / rural areas and usually adopts qualitative analyses on the characteristics of relations between water system patterns and urban / rural

水适应性景观构成要素, 以及不同气候类型下典型水适应性景观运行机制进行定性分析总结^{[21]-[23]}。

3.2 水适应性景观评估

对水系统及相关要素的适应性能力和趋势做出评估及预测是适应性及水适应性研究中最重要研究内容之一, 主要包括情景驱动及决策矩阵两种模型的应用。

情景驱动模型是适应性研究中最常见的研究方法, 研究过程包括: 1) 定义问题(明确研究区域、研究内容及相关部门和机构); 2) 选择适合大多数问题的评价方法; 3) 选择测试方法, 进行敏感性分析; 4) 选择并应用气候变化情景; 5) 评价对生物、自然生态系统和社会-经济系统的影响; 6) 评价既有的、自发的调整措施; 7) 评价适应性对策^[5]。

决策矩阵模型主要基于Excel或Lotus的适应性决策矩阵, 根据评价对象及目的设置评价内容进行基于主观判断的重要性经验赋值, 并运用相关方法展开分析。例如, 保罗·麦考德等人在针对肯尼亚半干旱灌溉农业生态系统的分析中, 确定区域灌溉系统影响气候适应性策略应用的影响因子, 并通过构建逻辑回归模型对适应性策略的影响进行评估^[24]; 乌切·T·奥克派亚等人使用定性文档分析方法和主观集成评分标准, 对非洲乍得湖流域与气候适应、水治理和冲突管理相关的跨界政策和干预文件进行分析, 探讨整合性治理方法^[25]。

在上述两种模型的应用过程中, 相关水文建模工具也为适应性的评估和决策提供支持。例如, 联合国环境规划署的环境评估与管理工具这一决策支持系统以多准则、多标准决策技术为基础, 并以图示、人-机对话等手段使评估过程简明清晰, 适用于对受气候变化影响的水资源、沿海地区和农业活动及相关适应性策略进行评估研究^[26]。又如联合国全球水伙伴组织开发的综合水资源管理系统, 通过对城

construction patterns in different time periods^{[19][20]}, components of water adaptive landscapes at varied scales, and operation mechanisms of typical water adaptive landscapes in different types of climate^{[21]-[23]}。

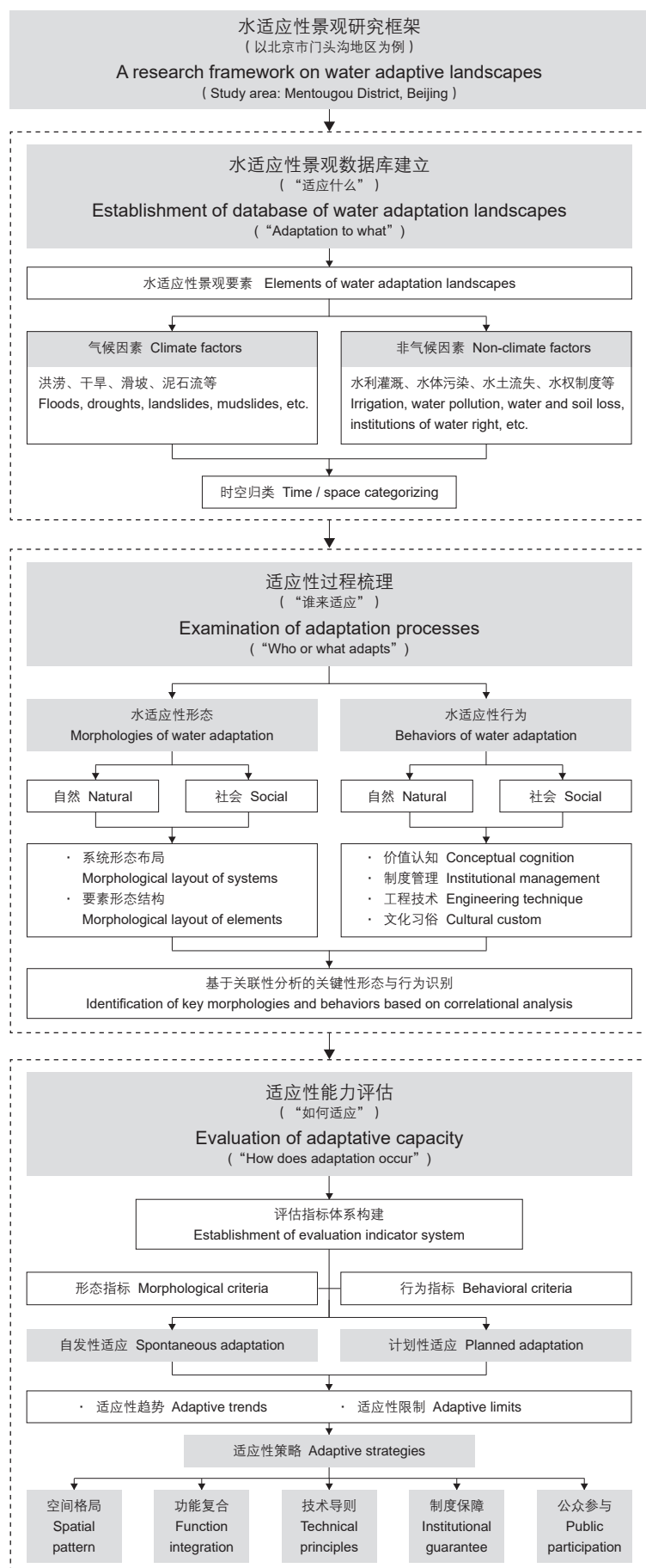
3.2 Evaluation of Water Adaptive Landscapes

The evaluation and prediction of adaptive capacity and tendency of the whole systems and different sorts of components is one of the most important aspects in research on adaptation and water adaptation. There are two major models in application: context-driven and decision matrix.

The context-driven model is the mostly-applied method in research on adaptation, which follows a series of steps: 1) problems finding (identifying study area and contents, as well as relevant agencies); 2) selection of evaluation method suitable for most issues; 3) test method selection and sensitivity analysis; 4) selection and application of climate change scenarios; 5) evaluation of the impacts on organisms, natural ecosystems, and socio-economic systems; 6) evaluation on existing spontaneous adjustment measures; and 7) evaluation on adaptive strategies^[5]。

Decision matrix model often relies on the application of adaptation decision matrixes with Excel or Lotus to develop evaluation criteria according to the objects and goals, which are weighted based on researcher's empirical knowledge in further analyses. For instance, targeting the semi-arid irrigation farming ecosystems in Kenya, Paul McCord et al. analyzed and worked out the factors to the regional irrigation systems that would impact the application of climate adaptive strategies, which were further assessed with a logistic regression model^[24]。Through qualitative document analysis and with manual integrated scoring standards, Uche T. Okpara et al. analyzed the Lake Chad basin in Africa and reviewed relevant cross-boundary policies and intervention documents in order to map out governance methods that integrate goals in climate adaptation, water remediation, and conflict management^[25]。

The application of these two models is supported with relevant hydrologic modeling tools in evaluation and decision-making of adaptation. For example, the Tools for Environmental Assessment and Management launched by the Environmental Protection Agency of the United Nation is a simple decision support system applicable to assessing climate change impacts on water resources, coastal areas, and agricultural activities, as well as associated adaptive measures, through approaches of diagrams and man-machine interaction, with aid of multi-criteria and multi-standard decision-making techniques^[26]。Besides, Integrated Urban Water Management,



2. 本文提出的水适应性景观研究框架
2. The research framework on water adaptive landscapes in this paper

developed by Global Water Partnership, is an integrated management system in urban water supply, rainwater and waste water treatment, and public health, so as to maximize the sustainability in economy, society, and environment^[27]. Scholars have applied it into water vulnerability analyses in land use changes, water quality and hydrology, rivers and floods, urban drainage systems, wetlands, ecosystems, social vulnerability, etc.^[28]

3.3 Narrative Analysis of Water Adaptive Landscapes

Narrative analysis of landscapes is a representative method in studies of adaptation in Anthropological Sociology^[29]. Landscape narrative, originated from the theoretical study and design practice of spatial narratives in the 1980s, considers movements of events a driving force of the generation and evolution of landscapes, where narrative is a basic method to gain experience and form understanding of landscapes^[29]. In relevant research on water adaptive landscapes, it has been mostly applied by combining literature review and interviews about regional knowledge and experience. For example, Vera Köpsel and Cormac Walsh analyzed how professionals from different fields and stakeholders perceive and understand the same coastal landscapes, based on theories on social constructivism landscapes and through in-depth qualitative landscape narratives and interviews about their perceptions,

市供水、雨水和废水处理、公共卫生的整体性管理来实现可持续的经济、社会和环境目标^[27]。相关学者将其应用于水脆弱性分析,包括土地使用变化、水质水文分析、河流洪水、城市排水、湿地、生态系统、社会脆弱性等方面^[28]。

3.3 水适应性景观叙事分析

景观叙事分析是人类社会学领域研究适应性的代表性方法之一^[29]。景观叙事源于20世纪80年代空间叙事的理论研究与设计实践,将事件的运动视为景观生成与演变的动力,并将叙事作为人们形成经验和理解景观的一种基本方法^[29]。应用于水适应性景观的相关研究多采用文献分析与访谈相结合的方式,针对地域认知及经验展开。例如,薇拉·科赛尔和科马克·沃尔什基于社会建构主义的景观理论及通过深入个性化的景观叙事及感知访谈,分析不同专业从业者和利益相关者对同一沿海景观的感知与理解,从而为气候适应性背景下的景观管理提供借鉴^[30];密尔·拉比乌尔·伊斯拉姆等人通过文献研究与深入访谈,从洪水治理、社交网络和收入多样化三个层面对孟加拉国相关地区在洪水方面的地方认知与传统经验进行总结^[31]。

3.4 小结

1) 总体来看,当下以“水适应性景观”为主题的相关研究较少,对适应性的概念、原有学科领域中的研究视角与方法、应用于景观学科体系下的研究范畴等基本议题缺乏系统性认知,尚不足以体现“水”“适应性”“景观”三者结合的研究意义。

2) 从研究内容上来看,水适应性的研究视角与方法同适应性研究关联度较高,但目前仅在较大尺度上开展了特定案例研究。国内相关研究主要侧重于景观空间格局与要素分析以及经验总结;相较而言,国外研究侧重于将适应性研究方法应用于相关评估和预测分析。

3) 从研究方法上来看,适应性的过程属性使得适应性研究具有不确定性的特点,因此适应性研究强调定量研究与定性研究相结合、数据分析与生态性思维相结合——这意味着相关研究的最终落脚点不是对研究对象得出静态的量化结果,而应关注研究对象功能正常与否,以及是否能向着持续、高效、稳定的方向发展^[32]。

4 水适应性景观的研究框架

基于上述分析,本文试图构建水适应性景观的研究框架(图2):研究以北京市门头沟地区为对象,由水适应性景观数据库建立、适应性过程梳理、适应性能力评估三部分构成,具体包括水适应性景观分析要素提取与归类研究、水适应性形态与水适应性行为研究、水适应性趋势及限制因素研究,以及水适应性策略研究等内容。

to provide references for landscape management in climate adaptation^[30]. Mir Rabiul Islam et al. summarized the locals' perceptions and traditional experience of floods in Bangladesh and its environs in terms of flood control, social network, and varied income, by means of literature review and in-depth interviews^[31].

3.4 Summary

1) Overall, current studies on water adaptive landscapes are inadequate, which lack systematic, holistic understanding on basic topics such as the definitions of adaptation concepts, research perspectives and methods in the original disciplinary fields, and research categories applied in existing discipline system of Landscape Architecture, and cannot embody the significance of the research combination of “water,” “adaptation,” and “landscapes.”

2) In terms of research contents, research perspectives and methods of water adaptation highly correlate with research on adaptation, and the existing research is dominated by individual case studies at larger scales. Current studies in China mainly lay emphasis on the analysis of landscape patterns and elements and relevant empirical studies, while studies among international academia focus more on evaluation and prediction analyses by employing research methods from adaptation studies.

3) As for research methods, since adaptation research is characterized by uncertainty during the adaptive processes, it necessitates the combination between quantitative study and qualitative study, and between data interpretation and ecological thinking. This means the focus and aim of research should not be generating static quantitative results, but examining the functional performance of the studied objects and their capability to a more efficient, more steady, and long-lasting development.^[32]

4 A Research Framework on Water Adaptive Landscapes

Here, an attempt is made to build a research framework on water adaptive landscapes (Fig. 2): by focusing on Mentougou District in the western area of Beijing, this study establishes a database of water adaptive landscapes, examines the adaptive processes, and evaluates the adaptive capacity. Specifically, it extracts, categorizes, and analyzes elements of water adaptive landscapes; studies the water adaptive morphologies and behaviors; identifies water adaptive trends and constraints; and develops water adaptive strategies.

4.1 水适应性景观数据库建立

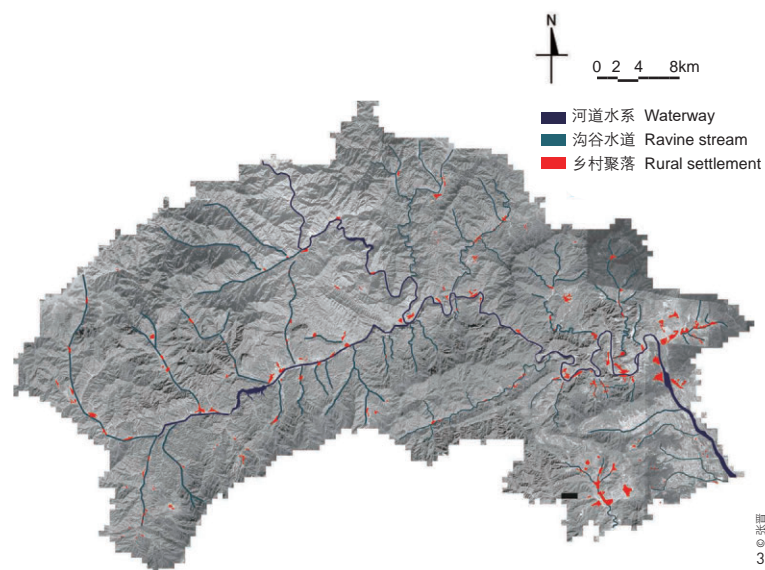
水适应性景观数据库的建立主要通过对典型地域环境的适应性对象进行提取与分类（即确定“适应什么”），适应性对象总体上可分为气候因素和非气候因素两类：前者主要包括气候变化导致的洪涝、干旱、滑坡、泥石流等相关时空资料，后者主要包括人为条件影响下的水利灌溉、水体污染、水土流失、水权制度等相关时空资料。收集数据资料时应体现适应性的过程属性，除了极端条件变化情况，也应当包括非极端环境情况。资料的初步获取途径包括文献研究、田野调查及地形影像资料收集等，在此基础上进行数据标准化处理并按时空结构进行分类，以为后续适应性分析与应用提供基础。

4.2 适应性过程梳理

如前文所述，适应性表现是动态变化过程中的阶段性产物。基于这一认知，适应性过程的梳理强调的是包含历史与当下的整体性脉络研究（即“谁或什么来适应”的问题），具体研究内容包括水适应性景观形态与水适应性景观行为两类。

4.2.1 水适应性景观形态

水适应性景观形态的研究包含系统维度和要素维度，前者的研究对象是总体系统及其各个分系统的形态布局，后者则对单一典型要素的形态结构进行研究。以北京市门头沟地区为例，在系统维度上，门头沟地区整体上属于典型的中国北方山地沟谷农业景观，其中包含河谷、滩地、盆地、农业灌溉系统、塘坝水库等水适应性景观子系统，各系统中的相关景观要素形成不同的网络化体系。研究重点应放在跨时间尺度的形态布局演变特征及规律。要素维度是对于系统中各典型构成要素——如自然河道和溪流、山体沟道、坑塘、村落、关城、农田、梯田、淤地、水渠、水库、水井等——的景观形态、类型划分、结构特征及演变等进行细分研究（表1，图3）。



4.1 Establishment of Database of Water Adaptive Landscapes

Basically, the building of a database of water adaptive landscapes is to extract and categorize adaptive objects within a typical regional environment (i.e., to determine “adaptation to what”). The objects can be categorized into climatic and non-climatic factors: the former includes time / space data of floods, droughts, landslides, and mudslides caused by climate changes and the effects, and the latter involves time / space data of irrigation, water pollution, water and soil loss, institutions of water right, etc. impacted by human activities. The process attribute of adaptation makes data collection cover both the changes in extreme and ordinary climate conditions. Preliminary data can be acquired through literature review, field study, and collection and analysis of topographic graphic data, which is then processed in accordance with specific scientific criteria and sorted out by time / space structure, to support subsequent analysis and application of adaptation.

4.2 Examination of Adaptive Processes








As mentioned above, the forms and actions of adaptation are results on a certain stage in a dynamic changing process. At this point, the analysis of adaptive processes should highlight holistic contextual research, both historical and present (i.e., to identify “who or what adapts”). This section examines the morphologies and behaviors of water adaptive landscapes.

4.2.1 Morphologies of Water Adaptive Landscapes

Morphologies of water adaptive landscapes can be studied by system and element, corresponding to the research on the morphological layout of the whole system and its subsystems, and research on the morphological structure of a single typical element. Overall, the study area sees a morphology of a mountainous valley agricultural landscape system that is commonly found in north China, and its subsystems of water adaptive landscapes range from valleys, floodplains, basins to farmland irrigation systems, ponds, dams, and reservoirs, each forming a network of its landscape elements. This research should focus on the evolutionary characteristics and patterns of the morphological layouts across time scales. At the same time, each typical component of the landscape systems — including natural rivers and streams, mountain ravines, ponds, villages, farmlands, terraced fields, silt land, ditches, reservoirs, and wells — can be studied by morphology, category, structural features, and evolution patterns (Table 1, Fig. 3).

3. 研究区域内村落与主要水系分布图
3. The distribution of villages and water systems in the study area

表1: 研究区域内典型水适应性景观系统要素类型
Table 1: Typical elements of water adaptative landscape systems in the study area

典型水系系统类型 Typical categories of water systems	典型水系系统要素 Typical elements of water systems	代表性村落 Representative villages	典型现状 Typical appearances
自然资源类 Natural resource	河道 River	东/西胡林村、付家台村、青白口村、丁家滩村、沿河城村 East- / West-Hulin Village, Fujiatai Village, Qingbaikou Village, Dingjiatan Village, and Yanhecheng Village	
	溪流 Stream	西达摩村、青龙涧村、韭园村、新村、冯村、沟涧村、苇子水村 West-Damo Village, Qinglongjian Village, Jiuyuan Village, Xincun Village, Fengcun Village, Goujian Village, and Weizishui Village	
	山体沟道 Mountain ravine	上/下苇甸村、柏峪村、淤白村、樱桃沟村 Upper- / Lower-Weidian Village, Baiyu Village, Yubai Village, and Yingtaogou Village	
生产生活类 Human living and production	农田/梯田 Farmland / terraced fields	上苇甸村、黄台村、黄岭西村、黄土贵村、天桥浮村、王坡村 Upper-Weidian Village, Huangtai Village, Huangling-West Village, Huantugui Village, Tianqiaofu Village, and Wangpo Village	
	坑塘 Pond	李家庄村、上苇甸村、灵水村、天桥浮村、赵家洼村 Lijiazhuang Village, Upper-Weidian Village, Lingshui Village, Tianqiaofu Village, and Zhaojiawa Village	
	水渠 Ditch	三家店村、傅家台村、东石古岩村、桑峪村 Sanjiadian Village, Fujiatai Village, East-Shiguyan Village, and Sangyu Village	
	水井 Well	碣石村、灵水村、马栏村 Jieshi Village, Lingshui Village, and Malan Village	
蓄洪防灾类 Flood retention and disaster prevention	水库 Reservoir	珠窝村、高铺村、鲁家滩村、淤白村、高台村、苇子水村 Zhuwo Village, Gaopu Village, Lujiatan Village, Yubai Village, Gaotai Village, and Weizishui Village	

4.2.2 水适应性景观行为

水适应性景观行为是指人类对待水、利用水、管理水、治理水的行为模式，是适应性空间形态表现的内部驱动因素，同时也是水系统及水要素得以正常运转并发挥适应性能力的关键保障。水适应性景观行为包括价值认知、制度管理、工程技术、文化习俗4个层面。在价值认知层面的适应是指人们对于环境变化、已有水适应性行为及影响景观系统未来适应性发挥的行为的认识与理解；制度管理层面的适应是指通过经济和财政手段、立法和组织变革来提高用水效率的相关行为^[33]；工程技术层面的适应是指通过工程技术措施和流程保障水适应性景观要素正常运转的行为；文化习俗层面的适应是指通过文化实践增进人-水和谐共生的行为^[34]。水适应性景观行为的过程梳理应着重体现人类活动在各个层面和阶段对于景观表达及其适应性的作用与影响。

具体就本研究区域而言，首先，门头沟的聚落历史起源于约一万年前的清水河谷的东胡林人聚落^[35]，人类的生活、生产、防卫等行为不仅缓慢而持续地影响了水环境，也促生了局部水适应性行为的出现，这一早期水适应性行为应作为研究内容之一；其次，永定河在历史上呈周期性泛滥，对下游危害极大，而北京西部地区的开阔平原用水需求量较大，曾多次引流永定河水以缓解灌溉与运输问题^[36]，因此研究应包含以永定河为主体的治河与水利灌溉工程；第三，门头沟整体山体沟谷切割较为剧烈，易发生山洪，同时山区大部分区域缺乏可用地表水资源，尤其是西部深山区^[36]，因此研究也应包含山地水土保持、防洪、储水等相关适应性行为。

4.3 适应性能力评估

适应性能力评估是针对上述研究对象在当下及预测情景下的适应性功能及作用进行的定性与定量研究，研究结果用以解决“如何适

4.2.2 Behaviors of Water Adaptive Landscapes

Behaviors of water adaptive landscapes refers to humans' behavioral patterns in the treatment, use, management, and governance of water, which are the inner driving factors defining the spatial forms of adaptation and significantly guarantees the functional running and adaptive performance of water systems and related elements. Such behaviors can be studied from perspectives of conceptual cognition, institutional management, engineering technique, and cultural custom. Adaptation in the conceptual cognition dimension includes people's understanding of environmental changes, existing water adaptive behaviors, and the behaviors that will impact the adaptive performance of future landscape systems. At the level of institutional management, adaptation is to improve the efficiency of water-use with economic and financial approaches, or legal and organizational reforms^[33]. Adaptation on engineering technique refers to the behaviors guaranteeing the functional operation of the elements of water adaptive landscapes with engineering technical measures and processes. Adaptation on cultural custom covers all kinds of culture practices that improve the harmony between human and water^[34]. The examination of behavioral processes of water adaptive landscapes should be a full-level and -stage study that highlights the effects and impacts of human activities on the forms of landscapes and associated adaptive actions.

In terms of the study area, first, the history of human settlements in Mentougou traced back to about 10,000 years ago when the East-Hulin people started to occupy the Qingshui River Valley^[35]. Human activities of living, production, and defense had gradually and continuously shaped the water environment; meanwhile, early local water adaptive behaviors were found in this area, which should be included in the research. Secondly, the Yongding River flooded periodically in history, causing severe damage to its lower reaches; while, the open plains in the west of Beijing have a great demand of water and historically the Yongding River has acted as a water source for irrigation and transportation^[36], meaning that the management and irrigation projects of the river should be reflected in the research. Thirdly, the dramatically-shaped ravines and valleys of the mountains in Mentougou are vulnerable to flash floods and lack surface water resources in most parts, especially the remote mountainous area in the west^[36]. Hence, the research is expected to include the adaptive behaviors of conservation of soil and water, flood control, and water storage in mountainous regions.

4.3 Evaluation on Adaptive Capacity

An evaluation of adaptive capacity should be a qualitative and quantitative study on the adaptive functions and performance of

应”的问题。此部分研究包括指标选取、自发性和计划性适应能力评估,以及适应性策略制定三个步骤。

4.3.1 指标选取

与平原区域所面临的水环境问题不同,山地乡村环境所面临的最主要问题是对瞬时大规模地表径流的管控与水资源的时空不均匀分布。在以往相关研究中,评价指标的选取多从生态及景观美学的理论层面入手^{[37][38]},但由于缺乏针对性及可落地性的地域环境指标设置,后期的规划设计途径往往实施不力、效果不佳。因此,本研究结合适应性过程梳理的分类,提出评价指标的选取应包括形态指标与行为指标两类。

其中,形态指标必须具备空间特征属性,包括:

1) 沟谷行洪面积:研究区域内山地沟谷地形特征明显,沟谷行洪面积越大,对瞬时大规模地表径流的适应性就越强;

2) 水体岸线形态:主要包括研究区域内永定河和清水河水系大小河道,及沿线主要沟渠和水道;其中上游岸线形态越蜿蜒曲折,阻水性能越强,而下游岸线形态的曲折程度越小,径流调节速率越高;

3) 水道基底及驳岸渗透性:在保障行洪结构安全的前提下,自然或人工池底和驳岸的渗透性越高,防洪抗旱的能力越佳;

4) 滨水区植被缓冲带宽度:大量研究表明,宽度不小于30m的植被缓冲带可以有效防止滨水区水土流失,并有助于过滤污染物和增加下游水流的稳定性^[39];

5) 坡面阻水性:坡面是山地环境地表径流的主要承载面,坡面阻水性越高,越容易减弱径流量,促进径流下渗,从而降低水土流失、滑坡和泥石流的风险;

6) 水系连通度:包括结构连通性和水力连通性^[40],连通度越高,水系安全性越高;

the above interests in current and predicted scenarios, and the research findings should offer answers to the question of “how does adaptation occur.” An evaluation includes selection of indicator criteria, evaluation on the capacity of spontaneous and planned adaptation, and development of adaptive strategies.

4.3.1 Selection of Indicator Criteria

Different from the water environmental problems encountered in plains, the major problems in mountainous rural areas are the control of massive torrential runoff and the uneven spatiotemporal distribution of water resources. The evaluation indicator criteria of most existing studies are selected under theories of Ecology and landscape aesthetics^{[37][38]}, which, however, usually could not work well through planning and design approaches because of the lack of targeted and feasible indicator criteria to mountainous environment. Therefore, based on the categories in the examination of adaptive processes, the indicators selected in this paper include morphological and behavioral criteria.

Morphological indicators should be selected with spatial considerations, including:

1) Flood discharge surface volume of ravines: the study area is characterized by its terrain of mountainous ravines, where a larger flood discharge surface volume means a stronger adaptation to massive torrential instantaneous runoff;

2) Morphology of waterfronts: it covers all kinds of waterways within the water systems of the Yongding River and the Qingshui River in the study area. In upper reaches the more winding and zigzagging the morphology of a waterfront is, the higher water resistance it has, while that in lower ones the more straight, the higher efficiency of runoff regulation it has;

3) Permeability of waterway bottoms and banks: the higher the (natural / constructed) permeability is, the better the effect of flood control and drought relief will be, without impact on the safety of flood discharge structure;

4) Width of vegetation buffer in waterfronts: a great number of research findings prove that vegetation buffers of no less than 30 meters in width can effectively prevent water and soil loss while helping filter pollutants and improving the downstream stability^[39];

5) Water resistance of slopes: slope is the main surface of runoff in mountainous areas; a higher water resistance would help reduce runoff, facilitate infiltration of runoff, and mitigate water and soil loss and risks of landslides and mudslides;

6) Connectivity of water systems: it includes structural and hydraulic connectivity^[40], the higher the connectivity is, the safer a water system will be;

7) 水库与水塘数量: 在径流线路的适当位置增加水库及水塘的数量可提高径流调节的效能^[41], 并增加日常及早期用水的补给量。

行为指标则应从如下方面对不同地域特征的居民/机构进行评估:

- 1) 对水适应性的认知情况、认知渠道和认知表现;
- 2) 在水资源开发管理过程中采用的适应性政策与行动;
- 3) 水利设施建设与定期维护情况;
- 4) 生产及生活过程中的雨水收集及利用情况;
- 5) 生产及生活过程中的污染物排放和控制情况。

4.3.2 自发性和计划性适应能力评估

此步骤是在指标选取的基础上, 结合ArcGIS空间分析、情景及经验决策、逻辑回归模型、景观叙事等方法, 对不同情景模式下的适应性形态及行为进行评估的过程。自发性适应是系统为应对气候变化的影响而形成的自发性调节; 计划性适应是指人类基于对已发生、正在发生和可能发生的状况及应对措施可能产生的后果的认识, 所进行的有计划的行动。计划性适应不仅需要能够预测全球变化的状况并对可能的影响进行有效评估, 而且需要具备合理的适应性策略并采取有效的经济技术保障手段^[11]。

各学科在适应性能力评估方面的研究均强调研究对象结构与功能层面的复杂性与不确定性; 而在生物学领域, 对于适应性的探讨还有两个重要维度——可逆性和有限性, 前者指适应性的某些形态及生理变化是可逆的, 后者强调适应性所涉及的形态及行为具有适应极限。由于适应的过程及变化趋势相对难以被量化, 且多体现出非线性特征^{[33][42]}, 因此适应性研究的关键在于识别适应过程中影响适应性绩效的适应性约束^[43]/限制^[44]。

7) The number of reservoirs and ponds: by suitably increasing the number of reservoirs and ponds along runoff paths, the efficiency of runoff regulation can be improved^[41], and the supply volume of water for daily and dry-season can be increased.

Behavioral indicators should be selected to evaluate the people / agencies in geomorphologically different regions as follows:

- 1) The status quo, assess, and reaction of residents of cognition of water adaptation;
- 2) Policies and actions of adaptation adopted in the management and development of water resources;
- 3) Construction and regular maintenance of water conservancy facilities;
- 4) Collection and utilization of rainwater in daily life and production;
- 5) The discharge and control of pollutants in daily life and production.

4.3.2 Evaluation on the Capacity of Spontaneous and Planned Adaptation

Based on the selection of indicator criteria and combined with research methods such as ArcGIS spatial analysis, scenario and experiential decision-making, logistic regression model, and landscape narratives, this step evaluates the morphologies and behaviors of adaptation in different scenarios. Spontaneous adaptation refers to systems' natural adjustments to the impact of climate changes; planned adaptation refers to humans' programed actions according to their cognition of past, present, and potential situations, as well as possible outcomes of associated actions. Planned adaptation not only needs to effectively predict global changes and possible impacts, but also develop sound adaptive strategies and employ efficient economic and technical guarantee measures^[11].

Studies of evaluation of adaptive capacity among different disciplines all emphasize the complexity and uncertainty of research objects in structure and function; in the field of Biology, reversibility and finiteness are the two mostly important dimensions in adaptation studies, the former stressing that some morphological and biological changes are reversible while the later emphasizing that limits exist in morphology and behavior of adaptation. As the process and changing trend of adaptation are difficult to quantify and often show non-linear characteristics^{[33][42]}, it is important to identify adaptation constraints^[43] / limits^[44] in processes of adaptation, which have an influence on adaptive performance.

4.3.3 适应性策略制定

此步骤是适应性能力评估的最终落脚点，即通过定量及定性研究识别适应性约束/限制，并针对相应因素制定解决及改善策略，从而达到提高研究对象适应性能力的目的。针对门头沟地区涉及以下方面：

1) 水适应性景观空间格局优化：针对山地沟谷水道特征，选取重点径流线路建立汇水廊道、截水廊道、滞水湿地等多层级水适应性空间结构，从宏观层面保障水环境安全；

2) 功能复合：针对地域传统村落保护与开发现状，将水适应性景观与遗产保护、休憩、生产性旅游等功能相结合，使得适应性过程与结果能够满足社会-经济发展、环境改善、生活品质提升等需求；

3) 技术导则：针对不同的径流调节、雨洪管理、水质改善情景，制定具体设计策略与工程措施；

4) 制度保障：对现有政策及管理模式提出改进方案，从制度层面保障适应性的发挥；

5) 公众参与：建立政府、村民、科研机构、企业多方联动的社区化平台，推动水适应性景观的公众认知与实践。

5 结论与展望

1) 水适应性景观研究需要构建更为完整、细分的跨学科研究框架。水适应性景观研究涵盖不同时期、不同地域条件下的适应性及景观的认知、空间格局、景观要素与行为、水文化与历史、适应性管理等方面，来自各学科的不同视角可以使水适应性景观具备成为新兴研究领域的潜力，而研究的进一步开展在很大程度上取决于研究框架的

4.3.3 Development of Adaptive Strategies

This is the final step and the objective of evaluation of adaptive capacity, which is to identify adaptation constraints / limits through quantitative and qualitative research, and develop targeted solutions and improvement strategies, so as to strengthen the adaptive capacity of studied objects. In terms of the study area in this paper, it involves the following aspects:

1) Optimization of spatial patterns of water adaptive landscapes: considering the ravines and waterways in the mountainous setting, multileveled water adaptive spatial structures (catchment corridors, water retention corridors and wetlands, etc.) should be introduced along key runoff paths to ensure the safety of the water environment at a macro scale;

2) Function integration: according to the status quo of the protection and development of local traditional villages, water adaptive landscapes should be integrated with opportunities in heritage preservation, recreation, and productive tourism, to make the adaptive process and result meet the needs of socio-economic development, environmental improvement, and living standards upgrading;

3) Technical principles: specific design strategies and engineering measures should be devised according to different scenarios in runoff regulation, rainwater and flood control, and water quality improvement;

4) Institutional guarantee: plans on improving current policies and management modes can be presented, to ensure the implementation and performance of adaptation through top-down approaches;

5) Public participation: community platforms should be built through which the government, villagers, research institutions, and enterprises can coordinate in a more efficient way to promote public cognition and practice of water adaptive landscapes.

5 Conclusions and Prospects

1) Research on water adaptive landscapes needs more efforts in the construction of a more systematic and subdivided interdisciplinary research framework. Since the research covers cognition, spatial patterns, landscape elements and behaviors, water culture and history, and adaptive management of adaptation and landscapes in different time periods and geomorphological regions, multiple disciplinary perspectives would offer it great potential to become an emerging research field, yet the development of research depends on the wholeness and guidance of the research framework. Currently, studies in different fields show an increasingly obvious interdisciplinarity,

完整性与指导性。当下，各研究领域的学科交叉特征越来越明显，这就要求研究框架的制定在形成整体性共同认知的基础上体现各学科的研究特色，而且研究框架涵盖的内容需要明确、细分，应避免过于宽泛的界定导致研究内容模糊。

2) 水适应性景观研究需要进一步加强科学量化方法的开发与应用。定量研究是适应性研究的关键方法之一，尤其在适应性评估及预测阶段，具体涉及到指标体系的选择、相关因子的确定、静态评价与动态评价的时空尺度转换及评价模型结果的精度验证等^[6]。现阶段的分析方法尚未对水适应性的复杂性与不确定性进行有效量化。例如前文提到的决策矩阵模型，相关研究在评价打分环节主要依赖研究者的主观判断，缺乏科学性支撑，使得量化分析结果的可信度受到影响。因此，开发针对不同研究目标的更加科学的量化研究方法将是未来水适应性研究需要解决的重要问题。

3) 水适应性景观研究需要加强专业及公众认知。水适应性景观研究强调适应性与景观的结合，虽然两者在各自传统研究学科内部已形成较为普遍的认知，但从学科交叉层面来看，水适应性景观及其研究范畴尚未形成明确界定，尤其是在国际学界几乎很少看到以“water adaptive landscapes”或类似英文表达为题的代表性研究。这一认知局限也直接导致了现阶段社会公众对水适应性景观及其研究的认知局限，相应研究成果的应用和公众参与程度较低。因此，未来有待加强学科构建及面向相关政府机构、科研机构、社会组织及公众的教育宣传，从而使水适应性景观研究发挥更广泛的社会影响。

4) 水适应性景观研究需要加强探索研究成果的可落地性。适应性研究的最终落脚点是适应性策略的制定，以增强研究对象的适应性能力。现阶段的适应性及水适应性研究大多以经验总结、适应性评估、影响因子确定、适应性趋势预测等作为研究结果，在适应性策略的探

which requires the development of research framework to establish common, holistic cognition and combine various research outlooks. At the same time, the research framework needs to avoid overbroad and ambiguity contents.

2) Research on water adaptive landscapes needs more efforts in the development and application of scientific quantitative methods. Quantitative research is key in studying adaptation, especially in the evaluation and prediction of adaptation, involving the selection of indicator criteria, identification of impact factors, spatiotemporal data interpretation and precision verification of results through evaluation models in static and dynamic evaluation, etc.^[6] Existing methods of quantitative analysis of adaptation fail to support the scientific study of the complexity and uncertainty of water adaptation. For example, the scoring in the decision matrix model largely depends on researchers' individual knowledge, compromising the reliability of results. In the future, it is important to strengthen the development of scientific and targeted quantitative research methods.

3) Research on water adaptive landscapes needs more efforts in cognition promotion among professionalism and the public. The research is built on the combination of adaptation and landscapes. Though both of them have been widely studied in respective disciplines and general conceptual understanding has been shaped, water adaptive landscapes and the research scope have not been clearly defined with interdisciplinary concerns. Representative studies with “water adaptive landscapes” or similar topics are seldom seen in international academia. Such limitations of cognition also lead to today's poor cognition on water adaptive landscapes and relevant research among the public, as well as the less application of research results and a low level of public participation. It is necessary to enhance cognition through disciplinary construction and specific methods to educate government agencies, research institutions, social organizations, and the public, so as to broaden the social influence of research on water adaptive landscapes.

4) Research on water adaptive landscapes needs more efforts in enhancing the feasibility and guidance of research findings in practice. The final objective of research on adaptation is to develop adaptive strategies, so as to help improve the adaptive capacity of studied objects. Existing studies on adaptation and water adaptation mostly draw conclusions about empirical summary, adaptation evaluation, identification of impact factors, and prediction of adaptation trends, but provide no further discussion on development of adaptive strategies in spatial planning, institutional establishment, guidance on behavioral patterns, and guidelines on adaptive practice. Water

讨与制定方面（如空间规划、制度建设、行为模式引导、适应性建设导则制定等）相对欠缺。而水作为与人类生活、生产及自然生态系统密切相关的景观物质及文化载体，水适应性能力的发挥需要切实可行的适应性策略的指导。因此，在水适应性景观研究中要注重适应性策略的可落地性，从而指导区域保护及开发的规划和营建等相关实践，而这也必将大力促进水适应性景观研究的发展。LAF

is a landscape resource and a cultural medium closely related to human life, production and natural ecosystems, it is more necessary to conceive practicable adaptive strategies to better increase water adaptive capacity. Therefore, research on water adaptive landscapes should also aim at developing feasible adaptive strategies, so as to provide sound guidance for the planning and construction of regional protection and development, which will in turn vigorously promote the development of research on water adaptive landscapes. LAF

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