Rethinking Urban Drainage Systems and Their Engineering Adaptation in the Time of Climate Change

Y. Jeffrey Yang
US EPA, ORD, WID/SMB, Cincinnati, OH 45268

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To protect human health and the environment
Ancient Metropolitan and Water Environment

Public bath, water supply and wastewater systems in vanished city of Mohenjodaro, India (2600-1700BC)

印度消失的城市（公元前1700-2600）Mohenjodaro已有公共浴室、上下水系统

Dujiangyan irrigation system (256BC)

都江堰水利工程（公元前256年）

Ancient Rome (753BC): The river, Roman aqueduct, and marble-seat bath of philosopher

古罗马城市（公元前753）：河流、水渠、贵族大理石凳浴室

Bian Jing of Song Dynasty depicted in Painting “Along the River in Qingming Festival” (1085-1145 AD)

“清明上河图”中的宋代汴京（公元后1085-1145年）
Modern Urban Growth And Urban Flooding
现代城市发展、内涝与排水

July 20-21, 2021. Zhengzhou

- Happens everywhere
  内涝的广泛性
- Increasing frequency
  内涝的频率增加
- Heavy damage to urban systems, environmental assets, people’s property and the loss of life
  导致城市系统、环境、人民生命财产重大损失
- Why is this happening; why the current drainage design no longer works; and how to rethink and adapt to the change and manage the risk?
  为什么已有城市排水系统出现了问题？我们应该怎样适应性地去改变和管理水系统？

August 2005, New Orleans from Hurricane Katrina

December 2018. Hoboken, NJ

July 6, 2020. Wuhan

Precipitation recurrence since 1901 (U.S. Climate Science Special Report)
Major challenges for urban drainage systems

- Climate change in design precipitation
- LULC change in urban development
- Lock-in infrastructure and adaptation
- Green gentrification and climate justice

EPA’s systems simulation tools for adaptation planning and design
Three Parts in Urban Water Environment
城区水环境的三大板块

Key Factors (关键因素)

- Precipitation - Hydraulic and hydrology
  降雨影响水文和水力条件
  - Temperature – Carrying capacity, land use, water demand, etc.
    温度影响水体负荷总量、土地利用、水需求量，等等
  - Land use – runoff properties
    土地利用影响地表径流特性

Mitigation and control (治理与控制)

- Adaptive land use planning
  整合式适应型规划
- Advanced stormwater & wastewater infrastructure
  先进的中、下水工程系统
- Green infrastructure (sponge city)
  绿色工程/海绵城市
- Sensor-enabled monitoring and management
  传感器监测和管理方式

Water pollution and control (污染与管理)

- Point-source pollution (NPDES/ TMDL)
  点源 (排放标准/负荷总量配额)
- NPS pollution (TMDL)
  面源 (负荷总量配额)
- CSOs (gray and green infrastructure)
  雨污合流 (传统和绿色基础设施)
- Waste disposal (disposal control)
  废物垃圾的二次污染 (废物垃圾治理)
- Air pollution wet deposition (Air pollution control)
  污染湿沉降 (空气污染治理)
Fundamentals in Urban Drainage

Simple principle, but complicated in use

1. Precipitation IDF 24-hr, 1-hr, and other design charts adjusted for local conditions. 24-小时、1-小时等IDF设计数据，对实地水文降雨特征加以调整。

2. Land use and land cover (LULC) projections. 城市土地使用和地表覆盖的预测。

3. Runoff, conveyance and storage modeling against urban flooding in planning and design. 城市集水区的径流、输送、储承的计算模拟增强对内涝的控制。
1. Precipitation IDF 24-hr, 1-hr, and other design charts adjusted for local conditions

24-小时、1-小时等IDF设计数据，对实地水文降雨特征加以调整

- Climate change in precipitation IDF. Existing IDF based on Bayesian or other statistics of past precipitation observations
  气候变化对降雨IDF的影响。现有IDF都基于过去降雨数据的贝叶斯统计或其它统计模拟。

- Climate extreme events promoting intense, often local, heavy precipitation
  极端气候事件带来局部强降雨

- Need to develop all design precipitations to a given location
  同时，需要建立当地的降雨设计数据库
Design intensity from historical precipitation data using statistical methods (GNO, GEV, GLO, PE3, etc.)

Calculation using IDF charts

What if in climate change periodicity?

What if different future climate system or extreme events?
Chesapeake Bay area

- The Chesapeake Bay example in spatial and temporal changes
- Atlas-14 and other regional models underestimate along the Bay's shores, and overestimate in other areas, due to orographic effects
- Atlas-14 values good for the entire region or at HEC-1 rivershed scale.ダウンscaled climate model values have greater errors.

Implications: Stormwater management at local watersheds should use location-specific or location-adjusted precipitation & hydrogeologic design values.

意义：雨水管理和内涝治理要基于当地的或修改后的降雨和水利设计标准
Details on the Chesapeake Bay case
切萨皮克湾案例细节

- Significant changes, especially after 1990s, in both base and intense precipitations
  90年代后，常规和强降雨都发生了变化

- Spatially varied in local watershed scales (e.g., HEC-4), responding to hurricanes and extreme events
  空间上，局部流域或集水区(HEC-4)的设计值受飓风和极端气候的影响，变化很大

- The spatial and temporal variability is not captured in regional design guide or modeling outputs
  这些局部的时空变化没有在区域性的设计标准和大气模型中得到体现

- Some underestimated and some overestimated with difference up to 100%
  高估和低估可能超过100%

*Implication: 15-yr and 30-yr storms important to water infrastructure, and high frequency storms such as 5-yr storm for green infrastructure all need careful re-evaluation*

意义：水工程的15年、30年一遇设计标准，和绿色工程中的5年一遇设计标准都需要重新评估
2. Land use and land cover (LULC) projections

- LULC projection can be simulated for a given growth objective. Central planning in China yields more certainty in future LULC.

- Projected LULC enables calculation of surface runoff coefficients in GIS for computing peak flows in streams and sensitive locations.

- Projected LULC and land use master planning can include green infrastructure, climate justice, and other policy measures.
Land Use Change As a Wild Card

城区土地利用：适应变化的魔牌

Rapid urban sprawl - Beijing

城镇市区快速扩伸 - 北京
Las Vegas, USA
美国拉斯维加斯

Housing, by Year Built

New homes
Existing homes

Population, Pima County

Courtesy of Kenneth Seasholes
Arizona Department of Water Resources
With precipitation/climate and LULC projections, integrated hydrological models used in flow, water quality, and other hydrological outputs for design and planning. The accuracy is improved with monitoring data.

Yr 2050 LULC

Tong et al. (2010, 2012); Sun et al. (2014)
3. Runoff, conveyance and storage modeling against urban flooding in planning and design

对城市集水区的径流、输送、储承的计算模拟增

对内涝的控制

- Systems model simulation and analysis on urban systems and socioeconomic implications
  对城市进行系统性的模拟分析，包括气候适应性工程的社会经济影响

- Stormwater and flooding control starting from urban planning
  城市雨水管理和内涝控制得从整体城市规划入手

- EPA tools and models are available for integrated analysis
  美国环保总署已开发和发表了综合分析的工具和模型

Key factors in urban adaptation

这是城市对大气变化适应性变化的关键
Resilient Drainage in Urban Adaptation

Watershed management programs (e.g., TMDL)

Development policy & governance

Urban land use modeling

Urban land use and employment/residents

Hydrological parameters: flow, flooding, sea level rise, storm surge, water quality

Watershed hydrological modeling (BASINS – HSPF)

Watershed land use modeling (iCLUS, CA-Markov)

Hydrolimate Modeling

Satellite Monitoring

NPDES/TMDL limits

source water quality

water demand and generation

Trip demand and Traffic modeling

Storm water systems model

Wastewater systems model

Drinking water systems model

Development scenario evaluation against management matrix

Optimized water supply systems

Water treatment plant (WPT) model

Data-driven model-based distribution

New scenarios

efficiency and resilience economics, and compliance

SmartWater

USEPA (2020)

Simple principle, complicated in use

原理简单，应用复杂
Lock-in infrastructure and adaptation

已有机基础设施对适应性变化的限制

目前的规划框架

**Current Planning Framework**

- **Growth factors**
  - Economic expansion/contraction
  - Population change
  - Life style change

- **Socio-physical constraints**
  - Climate, carbon allocation
  - Water and land availability
  - Economics and policy preference

- **Planning**
  - Buildings - Residential
  - Buildings - Commercial
  - Buildings - Industrial
  - Parks, recreations
  - Green space & eco. reservation

- **Urban forms**
  - Monocentric
    - Transformation districts
    - Polycentric
      - Low density
      - High density
      - Mixing
      - Green development

- **Evaluation/assessment**
  - Carbon footprint (global & local)
  - Water footprint
  - Efficiency
  - Economics
  - Satisfaction

- **Urban Sprawl**
  - New Developments

- **Energy source; Source water**
  - Construction Phase
  - Operation Phase

- **Material flow**
  - Building Structure
    - Energy consumption
    - Water consumption
    - Waste generation

- **Transportation Infrastructure**
  - Subway, mass transit
  - Urban roads
    - Mass transit
    - Individual transit
  - Other roads (biking, pedestrian, etc.)
  - Tele-commuting

- **Water Infrastructure**
  - Centralized
    - Water supply
    - Storm water
    - Waste water
    - Waste and solid waste

USEPA (2020)
Adaptive Planning Framework

Planning

- Buildings - Residential
- Buildings - Commercial
- Buildings - Industrial
- Parks, recreations
- Green space & eco. reservation

Urban forms

- Monocentric
  - Transformation districts
    - Polycentric
      - Low density
      - High density
      - Mixing
      - Green development

Climate justice

Urban Adaptation

Minimize New Developments

Evaluation / assessment

- Carbon footprint (global & local)
- Water footprint
- Efficiency
- Economics
- Satisfaction

Growth factors

- Economic expansion / contraction
- Population change
- Life style change

Socio-physical constraints

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Energy source: Source water
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Material flow

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USEPA (2020)
Adaptive Urban Planning Tools

- Objective-based planning and optimization on a GIS platform
  基于发展目标的GIS规划和优化系统
- Simulation modules integrated for optimizing transportation, water infrastructures, catchment hydrology, and land use (soil, etc.)
  城市交通、水设施、流域水文、和土地利用（土壤，等）模拟单元的系统优化
- Systems evaluation of urban development scenarios, from urban forms, to physical attribute optimization, to planning and management adjustment.
  系统分析评价从城市发展场景开始，实行城市和自然环节的优化、到规划管理微调。基于系统优化原理
- Precipitation changes as input
  模型输入包括将来降雨的变化

- Existing or projected LULC as input
  模型输入还包括城市发展的土地利用变化

- GIS-based for calculating stormwater time-concentration in catchment, conveyance capacity and storage needs
  利用地理信息系统，可对系统分析评价从城市发展场景开始，实行城市和自然环节的优化、到规划管理微调。基于系统优化原理

- Design and evaluation of green and gray infrastructure performance in stormwater management locally and in entire city
  利用地理信息系统，可模拟集水区径流的时间-流量曲线，对绿色和常规排水工程进行规划、设计和评估，改善局部和海绵城市的功效
Example research topics:

- Water partition in urban area: evapotranspiration, infiltration, surface runoff, water diversion for human use
  - Agent-based modeling
  - Soil Conservation Service method

- Landscape alteration and mitigation
  - Land use → local climate → urban hydrology
  - Role of green infrastructure
Green Infrastructure Approaches

Open swale, Portland, OR
开放式洼地，俄勒冈州波特兰市

Terraced open swale, Washington, DC
梯田开放式洼地，华盛顿特区

Permeable pavement, Seattle
透水路面，西雅图

Porous pavers, Philadelphia
多孔式摊铺机，费城

Large cistern, Chicago
储陈大水箱，芝加哥
Conclusions

小结

- Precipitation and LULC changes in new climate and urban development cause urban flooding, drainage and water quality problems. 随着气候变化和城市发展，降雨和土地利用的改变能引起内涝、排水和水质问题
- An effective urban adaptation needs systems modeling and analysis starting from urban planning. 有效的适应性发展需要城市系统模拟和分析，并从城市规划开始
- Current hydrological design guide and standards need to update with climate change effects. The timing and magnitudes of climate and LULC changes are important to: 现有水利设计规范应该考虑气候变化的影响。这些变化的时间耦合和相对幅度能影响城市排水系统的诸多方面，例如：
  - Size and manage drainage systems of gray infrastructure 传统排水系统的大小、设计与管理
  - Design and maintain green infrastructure 设计维护绿色工程系统
  - Integrate green and gray stormwater infrastructure systems in sponge cities 传统排水系统和绿色工程系统在海绵城市的结合应用
Thank You!

Yang.jeff@epa.gov

https://cfpub.epa.gov/si/si_public_record_Report.cfm?dirEntryId=349841&Lab=NRMRL