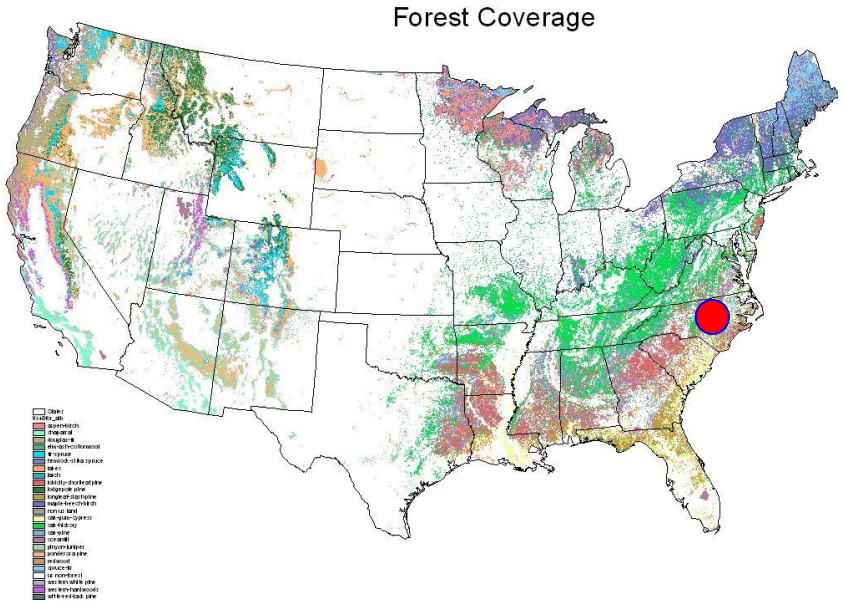
准确理解，定义和量化森林“水源涵养”功能

On accurately defining and quantifying forests hydrologic functions of Shui Yuan Han Yang (SYHY)



Ge Sun
孙阁 (gesun@ncsu.edu)

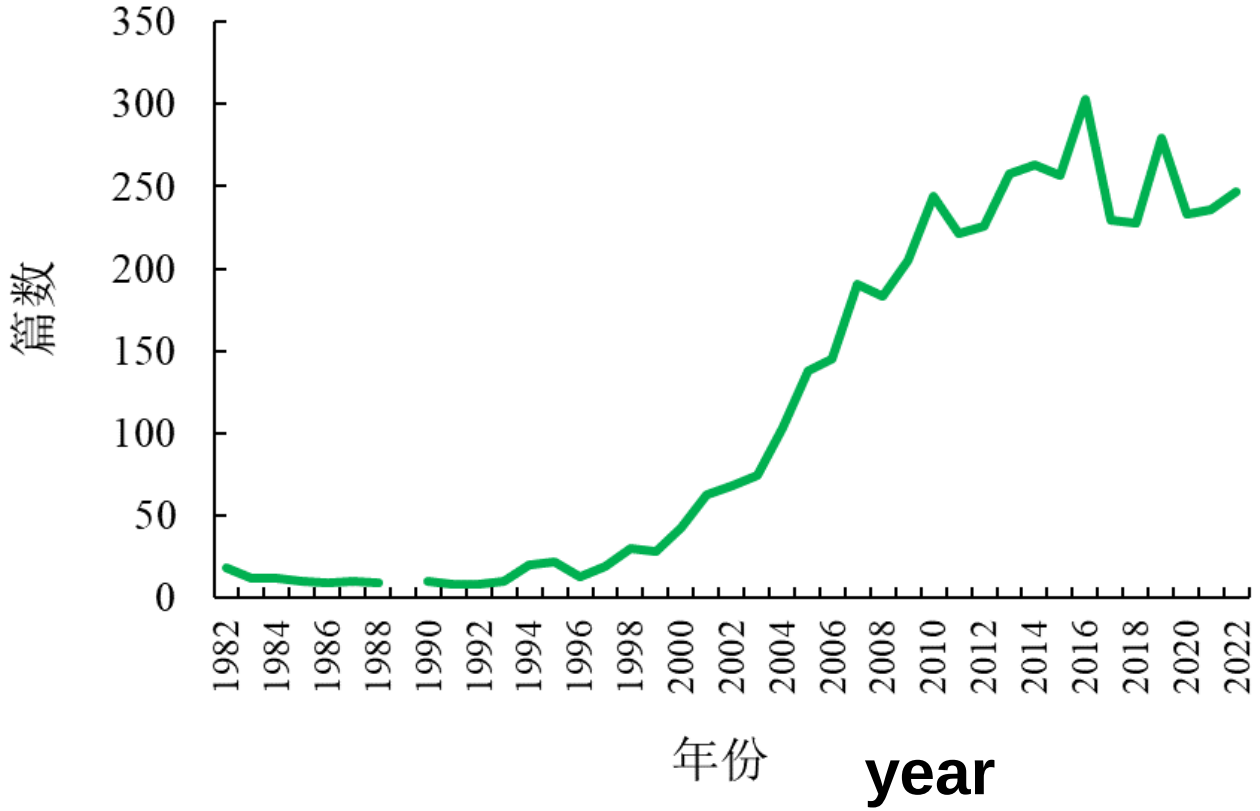
讨论提纲

1. 森林“水源涵养”概念, 起源和范畴 **(What is SYHY?)**
2. 如何理解森林的“水源涵养”作用和森林“水服务”功能？**Functions vs Services**
   - 减洪，增(减)枯机理 （蒸散-入渗权衡理论）**Flood reduction and low flow regulations; ET-Infiltration Tradeoff Hypothesis (Dr. LA Bruijzeel)**
   - “水源涵养”作用与森林水服务功能的区别
3. 如何量化森林“水源涵养”作用实例 **(Quantification)**
   - 对比流域观测 **(Paired watersheds)**
     - *采伐森林 （植被作用）(forest cutting)*
     - *城市化 （植被+土壤+不透水层）(urbanization)*
   - 生态水文模型应用 解释森林水文调节作用 **(modeling)**

of pubs on SYHY

Keywords with forest SYHY

“森林水源涵养”知网检索



第 43 卷第 1 期 生 态 学 报 Vol.43,No.1
2023 年 1 月 ACTA ECOLOGICA SINICA Jan.,2023

DOI: 10.5846/stxb202211013108

孙阁, 张橹, 王彦辉.准确理解和量化森林水源涵养功能.生态学报,2023,43(1):9-25.

Sun G, Zhang L, Wang Y H.On accurately defining and quantifying the water retention services of forests.Acta Ecologica Sinica,2023,43(1):9-25.

准确理解和量化森林水源涵养功能

孙 阁[1,*],张 橹[2,3],王彦辉[4]

1 美国农业部林务局南方研究院, 北卡罗来纳州 27709

2 武汉大学水利水电学院, 武汉 430074

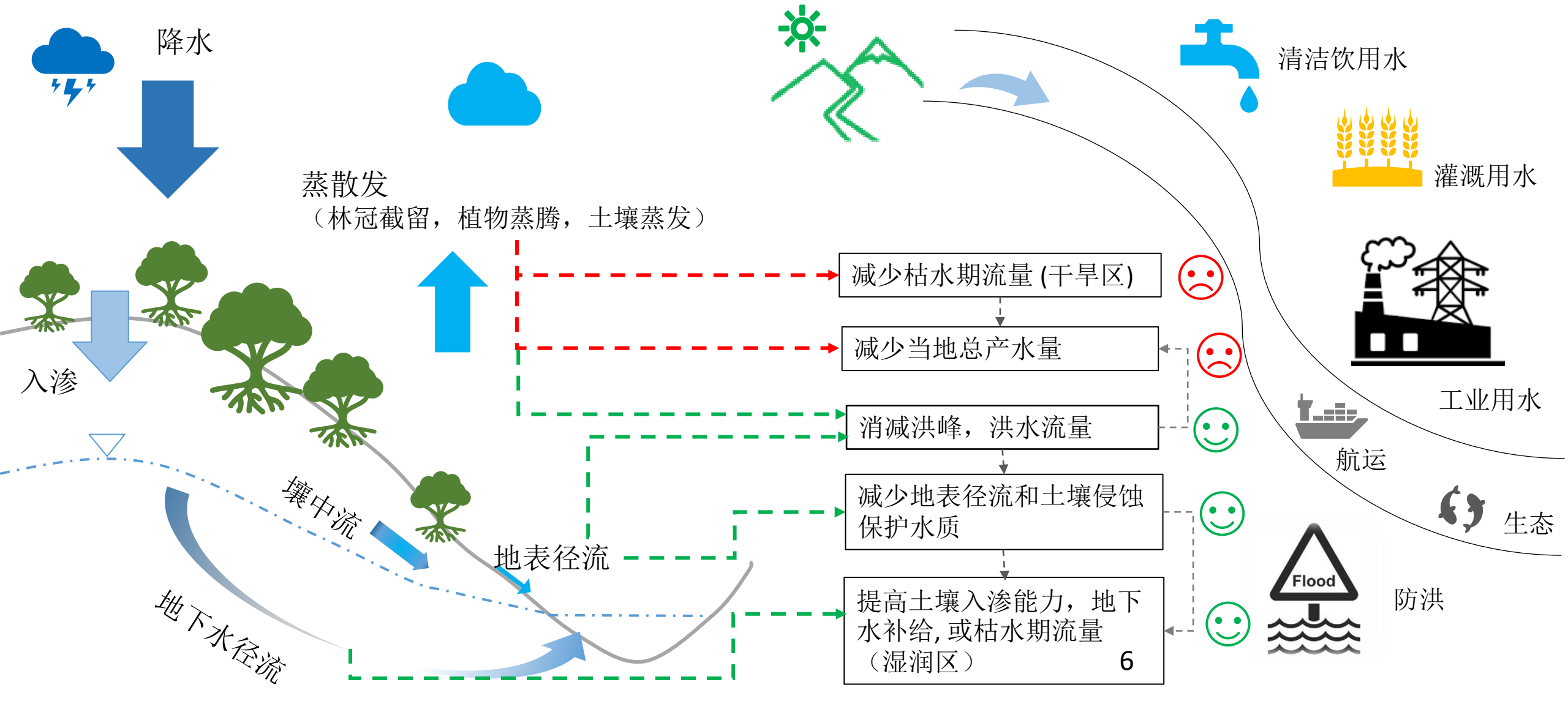
3 澳大利亚联邦科学与工业研究组织水土研究所, 堪培拉 2601

4 中国林业科学研究院森林生态环境与自然保护研究所, 北京 100091

基本认识 What do we know?

1. 森林“水源涵养”概念最早19世纪由日本法律界提出，但科学界对其内涵充满争议 (debate)
2. 森林水源涵养：消洪增枯 ≠ 总水量增加 (SYHY ≠ flow increase)
3. 森林水源涵养 ≠ 基流和旱季流量增加 (not always increase in lowflow or baseflow)
4. 森林蒸散影响径流过程的作用被低估 (ET under estimated?)
5. 森林“水源涵养”水文学作用和“水”服务功能混淆。 充满褒义。(a benign concept)
6. 量化森林“水源涵养”作用和生态系统‘水‘服务功能充满挑战 (challenges in quantifications)
7. “水源涵养”的对应英文含意模糊 (English term: sponges，retention, conservancy, preservation, pumps)

森林调节水文过程　　森林影响“水源涵养”　　生态系统服务功能



森林水源涵养的概念
-《中国水利百科全书》
Encyclopedia of Water Conservancy in China

“..水源涵养林，用于控制河流源头水土流失，调节洪水枯水流量，具有良好的林分结构和林下地被物层的天然林和人工林。水源涵养林通过对降水的吸收调节等作用，变地表径流为壤中流和地下径流起到显著的水源涵养作用 …”。

“ …森林的形成、发展和衰退与水分循环有着密切的关系。森林既是水分的消耗者，又起着林地水分再分配、调节、储蓄和改变水分循环系统的作用 …”

- 滞洪和蓄洪功能
  - 调节坡面径流
  - 调节地下径流
- 枯水期的水源调节功能
  - 对河川水量补给起积极的调节作用。随着森林覆盖率的增加，减少了地表径流，增加了地下径流，使得河川在枯水期也不断有补给水源，增加了干旱季节河流的流量，使河水流量保持相对稳定。
- 水土保持功能
- 改善和净化水质
- 调节气候

森林水源涵养的概念
-ChatGPT学术中文润色

- **水源涵养作用**是指各种自然因素通过多种形式的物理、化学和生物过程，使水在地下或地表逐渐聚集、储存和供给人类和生态系统使用的能力。 涵养水源的过程包括降雨滞留、渗入地下水、河流和湖泊的蓄水以及植物的土壤保持等。

- 森林水源涵养是指森林通过抵抗侵蚀、保持土壤水分和过滤污染物等方式，起到保护和维持水源稳定的作用。
- 首先，森林可以减少水土流失和土壤侵蚀。森林覆盖可以阻止雨水直接落在裸露的土地上，减少水流冲刷地表，减缓土壤流失速度。同时，森林的树根能够牢固固定土壤，减少土壤侵蚀的风险。
- 其次，森林可以存储和释放水分。森林树木通过根系吸收并储存大量的地下水，形成地下水储备。在干旱季节，森林可以通过蒸腾作用将储存的水分释放到大气中，增加降水量和湿度。

森林水源涵养的概念 （日本观点）

第111回東京大学公開講座「水」 2009. 11.

水と森と人
Water, Forests and People

蔵治　光一郎
KURAJI Koichiro

東京大学大学院農学生命科学研究科
附属演習林　愛知演習林　講師
Lecturer, University Forest in Aichi, UT

特に断りのない図、表、写真は講演者がオリジナルで作成・撮影したものです

SYHY Concept: the Japanese Defininition

The “legal” term 水源涵養 was first appeared in 1897 forest law, as one of the categories of “Protection Forest System”.

The Japanese Government adopted the definition of the term 水源涵養 provided by the Science Council of Japan in 2001. The 水源涵養 consists of the following four sub-functions (services).

1. Mitigation of flood
2. Preservation of water resources
3. Control water quantity
4. Water purification

“In academia, even forest hydrologists, the definition of the term 水源涵養 is not yet uniformed.”

Other researchers define 水源涵養 as “Preservation of water resources” and ”Control water quantity” only.

“森林与水” 世纪之争

1981,1998 floods Triggered Debate on Role of Forests in China

长江会变成第二条黄河? (Will Yantze become 2nd Yellow River?)

“用洋枪打国内战争” (Civil War with Foreign Guns)

黄秉维 （1913-2000）

汪振儒(1908-2008）

- 1981 年《确切地估计森林的作用》*(地理知识，第一期)*
- 1981《确切的认识森林的作用——与黄秉维先生商榷》
- 1982 年《再谈森林的作用》

“……在多数情况下，来自林区的河流量比较大……概括地说，森林的水文作用是好的’。‘有林就有水’，‘向林要水’等说法已‘风行草偃’，说过了头 …” - 黄秉维 forest functions are beneficial, but exaggerated

“森林与水” 世纪之争

ELSEVIER

Journal of Hydrology

Volume 291, Issues 1–2, 31 May 2004, Pages 1-27

Review

Waters and forests: from historical controversy to scientific debate

Vazken Andréassian

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https://doi.org/10.1016/j.jhydrol.2003.12.015

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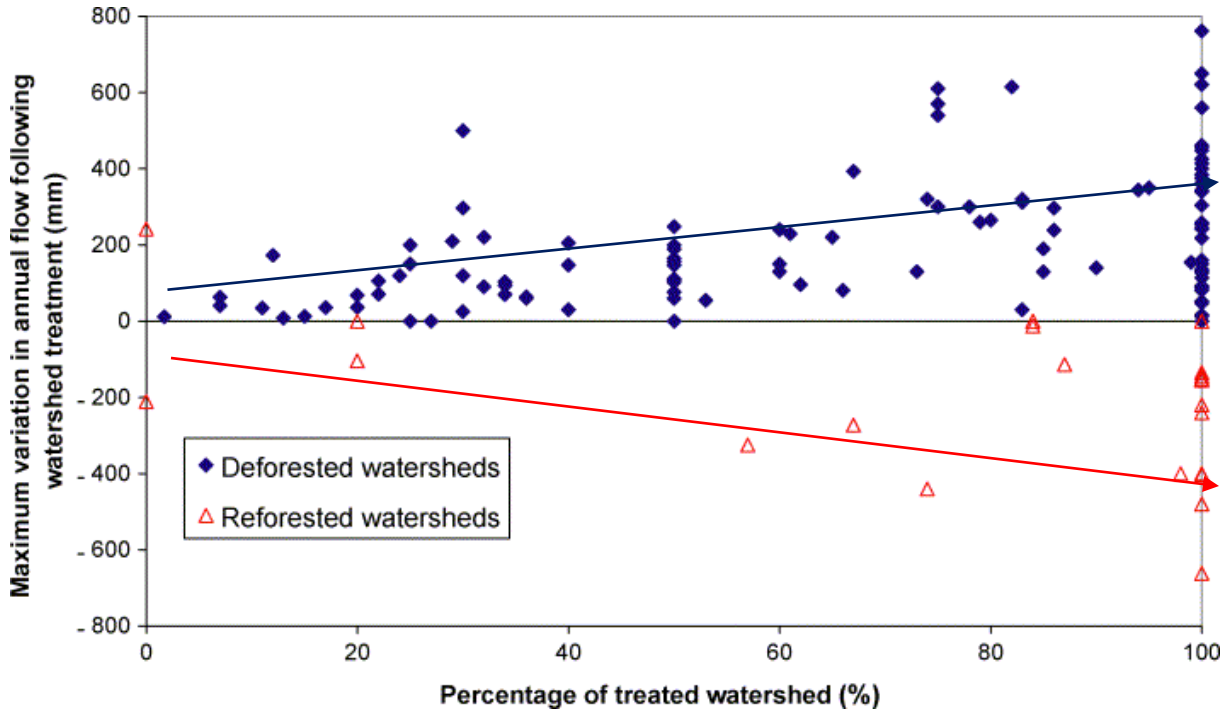


No data points from China!

Controversies Everywhere!

NATURE|Vol 450|13 December 2007

Debate over flood-proofing effects of planting forests

Ian R. Calder*, James Smyle†, Bruce Aylward‡
*Centre for Land Use and Water Resources Research, Newcastle University, Newcastle NE1 7RU, UK
† 149 East Rosewood Avenue, San Antonio, ... Box 2062,

REPORTS

Trading Water for Carbon with Biological Carbon Sequestration

Robert B. Jackson,[1]* Esteban G. Jobbágy,[1,2] Roni Avissar,[3] Somnath Baidya Roy,[3] Damian J. Barrett,[4] Charles W. Cook,[1] Kathleen A. Farley,[1] David C. le Maitre,[5] Bruce A. McCarl,[6] Brian C. Murray[7]

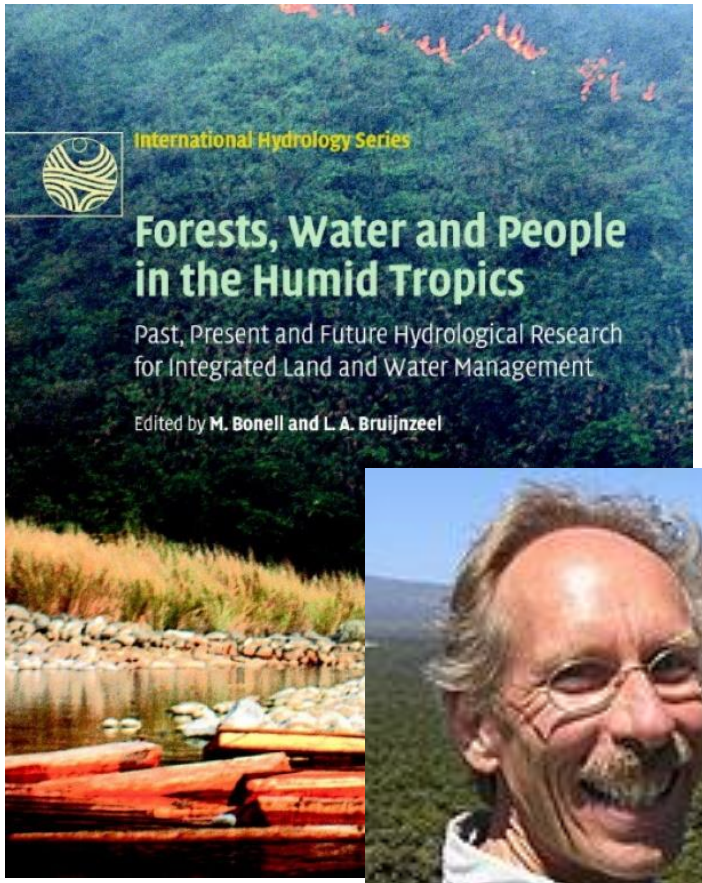
CLIMATE & ENVIRONMENT

We have too many pines and it's not a good thing

Pine trees might have helped repopulate the country's barren mid-hills but they could also have led to springs drying up and reduced

"...the pine forest has triggered an overwhelming reduction in the net recharge rate. So, **it is clear that the most potent and the most devastating agent for the depletion of natural water resources are the pine forests**"

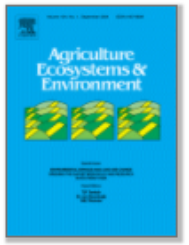
ET is important, but Do Not forget the Soils!



ELSEVIER

Agriculture, Ecosystems & Environment

Volume 104, Issue 1, September 2004, Pages 185-228



Hydrological functions of tropical forests: not seeing the soil for the trees?

L.A. Bruijnzeel

Google Scholar Cited 2010 times by July 28 2023!

Forest and Water on a Changing Planet: Vulnerability, Adaptation and Governance Opportunities

A Global Assessment Report

Editors: Irena F. Creed and Meine van Noordwijk

CPF Collaborative Partnership on Forests

IUFRO Interconnecting Forests, Science and People

(2018)

Cartoon of a pendulum swinging between three public perspectives of the key forest-water relations

Figure 1.7

No forest, no water

Paradise lost
"All problems of too much or too little water are caused by deforestation, tree planting is the universal remedy"

Blue water revolution...

~ 2000

~ 2015

More trees, less water

Blue vs green water tradeoff
"Tree water use competes with streamflow, hydrological functions depend on scale"

Forests and fast-growing trees use more water (up to 20% of PET) than other vegetation

Full hydrological cycle

- Δ (seasonal) Leaf Area Index
- Δ Surface litter, sealing
- Δ Rooting depth
- Δ Macroporosity formation
- Δ Rainfall

The combined effects of trees depend on location; water use means cooling + recycling

It depends (e.g., more trees, more rain elsewhere)

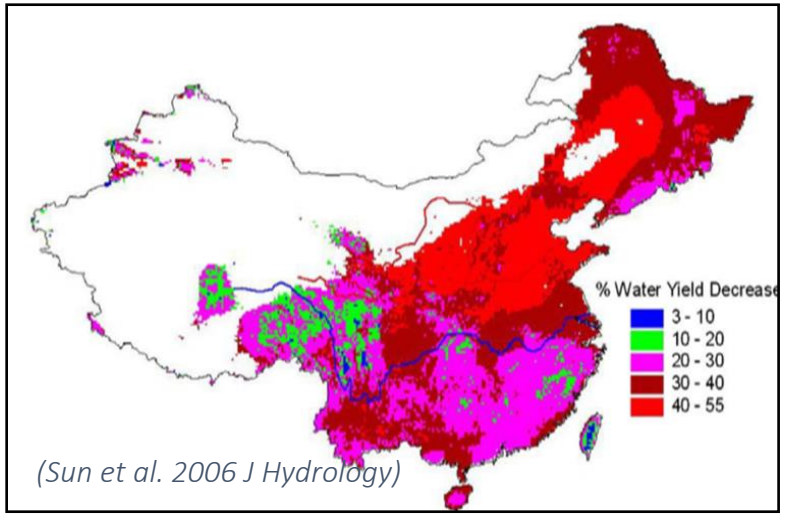
Source: Authors' own elaboration

Green Water **Rainbow Water** **Blue Water**

USDA FOREST SERVICE

森林固碳，耗水，改变气候权衡关系

Greening Reduced River Flow in N China



(Sun et al. 2006 J Hydrology)

中国植树造林将减少径流

10-50%?

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ScienceAdvances

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Time and space catch up with restoration programs that ignore ecosystem service trade-offs

Ruonan Li[1,2], Hua Zheng[1,2,*], Patrick O'Connor[3], Huashan Xu[4], Yunkai Li[5], Fei Lu[1,2,6], Bria...

+ See all authors and affiliations

Science Advances 31 Mar 2021:
Vol. 7, no. 14, eabf8650
DOI: 10.1126/sciadv.abf8650

AMBIO (2011) 40:828–831
DOI 10.1007/s13280-011-0150-8

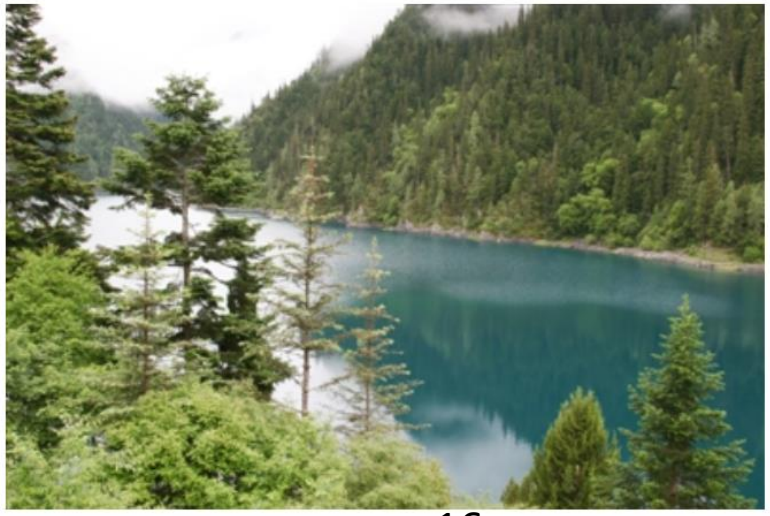
SYNOPSIS

Greening China Naturally

Shixiong Cao, Ge Sun, Zhiqiang Zhang, Liding Chen, Qi Feng, Bojie Fu, Steve McNulty, David Shankman, Jianwu Tang, Yanhui Wang, Xiaohua Wei

为什么要尊重自然、顺应自然、保护自然

来源：科普时报　作者：刘世荣　2020-06-06 10:51



岷江上游森林与水的自然景观。 刘世荣 摄

nature climate change

LETTERS

PUBLISHED ONLINE: 8 AUGUST 2016 | DOI: 10.1038/NCLIMATE3092

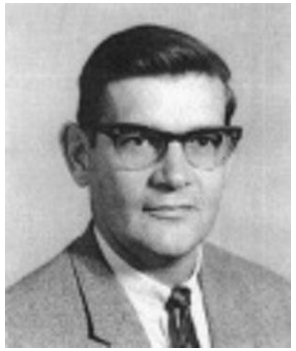
Revegetation in China's Loess Plateau is approaching sustainable water resource limits

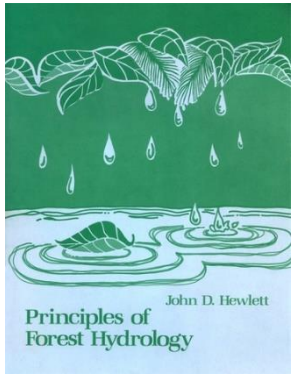
Xiaoming Feng[1,2], Bojie Fu[1,2*], Shilong Piao[3,4], Shuai Wang[1,2], Philippe Ciais[5], Zhenzhong Zeng[3], Yihe Lü[1,2], Yuan Zeng[6], Yue Li[3], Xiaohui Jiang[7] and Bingfang Wu[6]

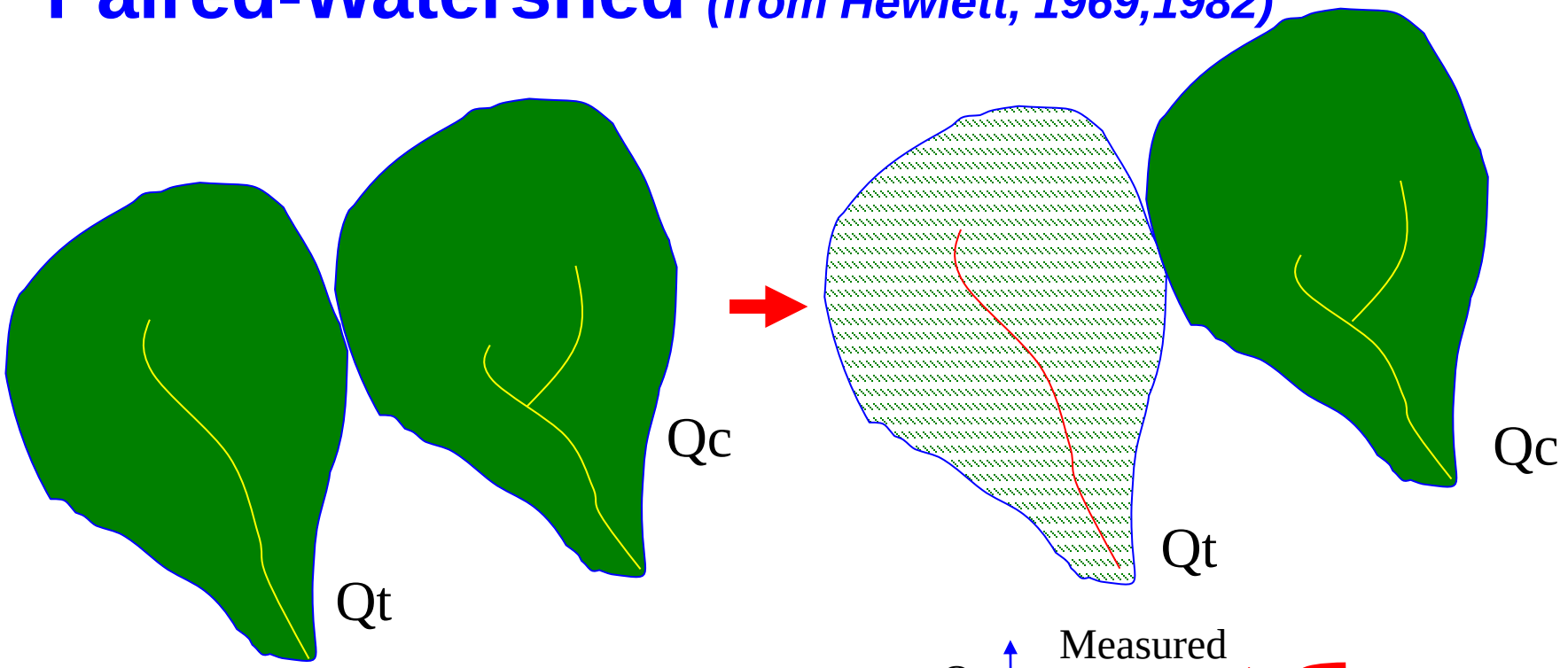
如何科学量化森林水源涵养作用

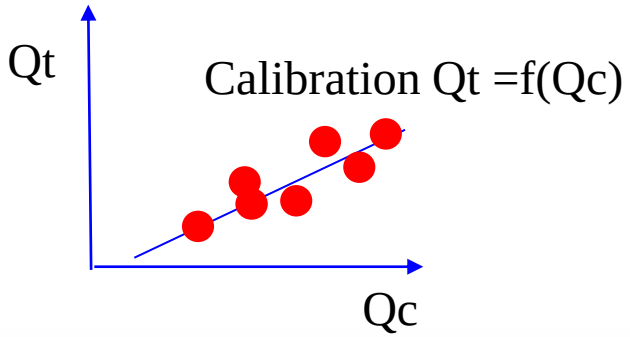
- “配对流域”试验法 （Paired Watershed Experiments) 研究植被变化对径流，蒸散的影响
- “单一流域”统计法 (“Before and After” statistics, Double Mass Curve, Climate elasticity, ARIMA) 量化植被和气候变化对水文的双重影响
- 水文模型模拟法 (Ecohydrological modeling)
  - Budyko framework (‘Zhang Curve’), SWAT, MIKE SHE, WaSSI, DHVSM，InVest

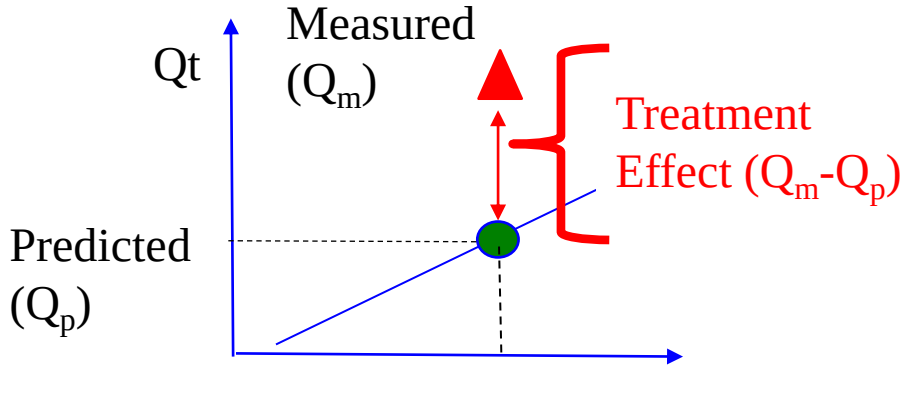
Paired-Watershed *(from Hewlett, 1969,1982)*



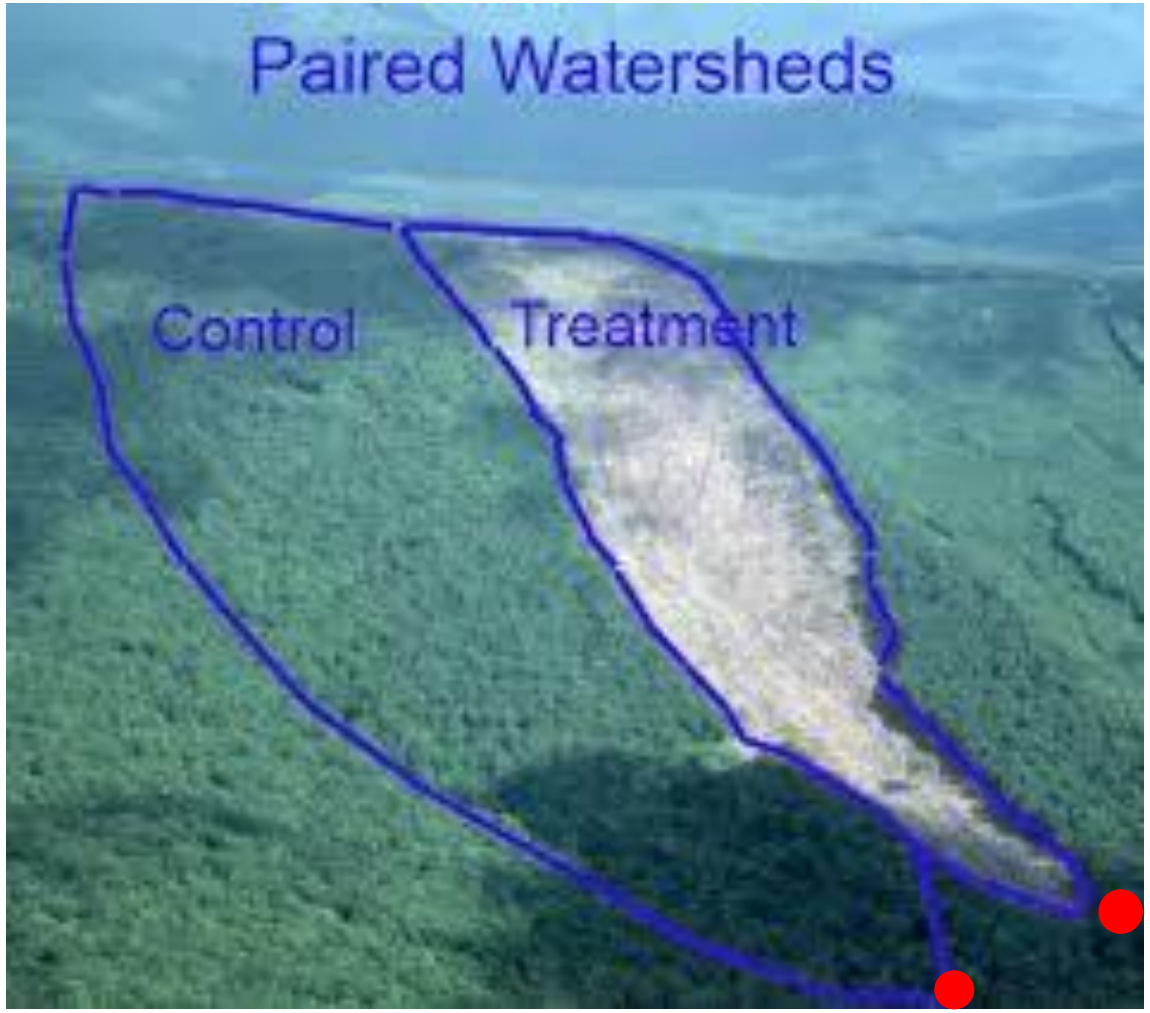






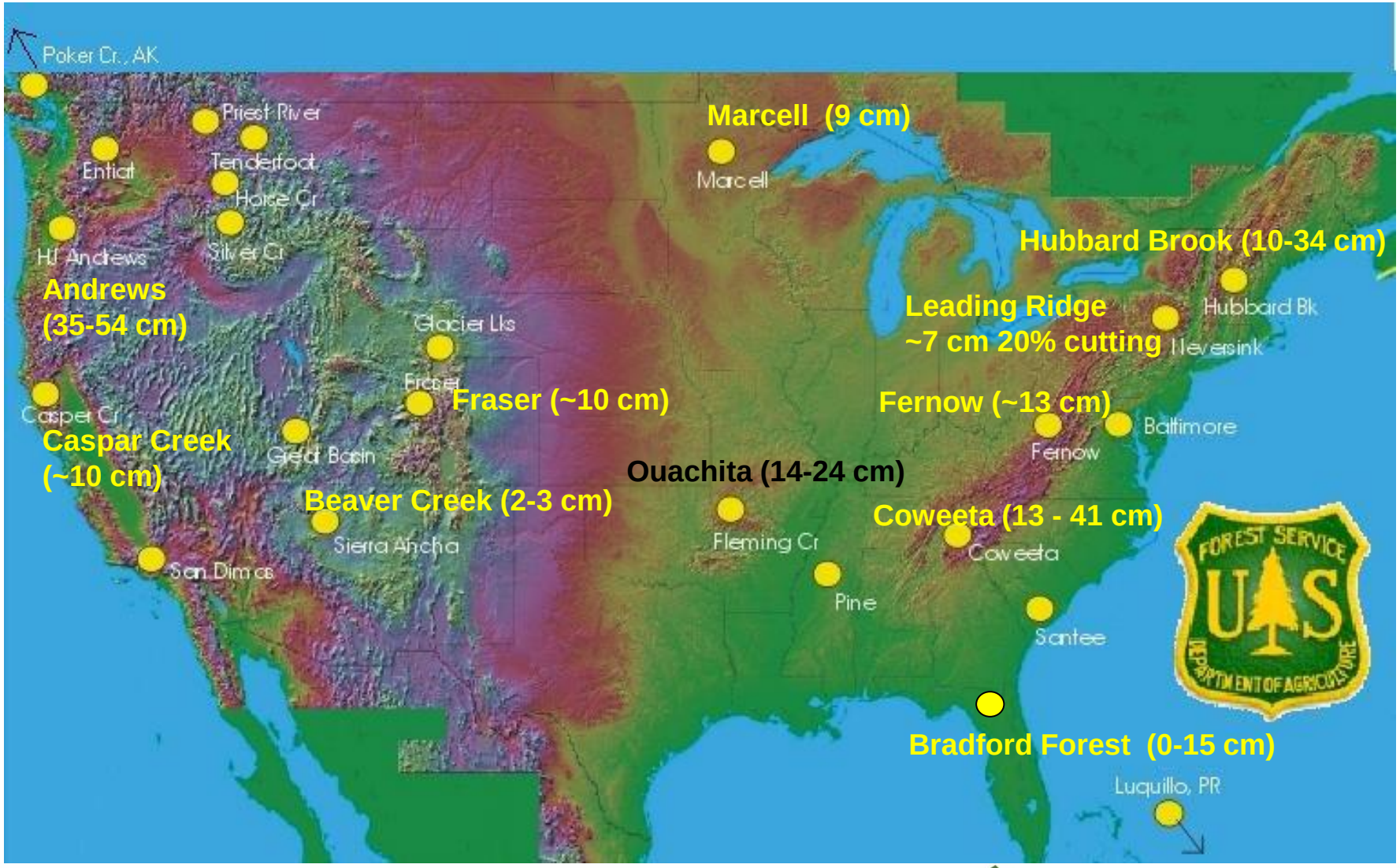


The “Paired Watershed” Experiments to Understand Forest Hydrology

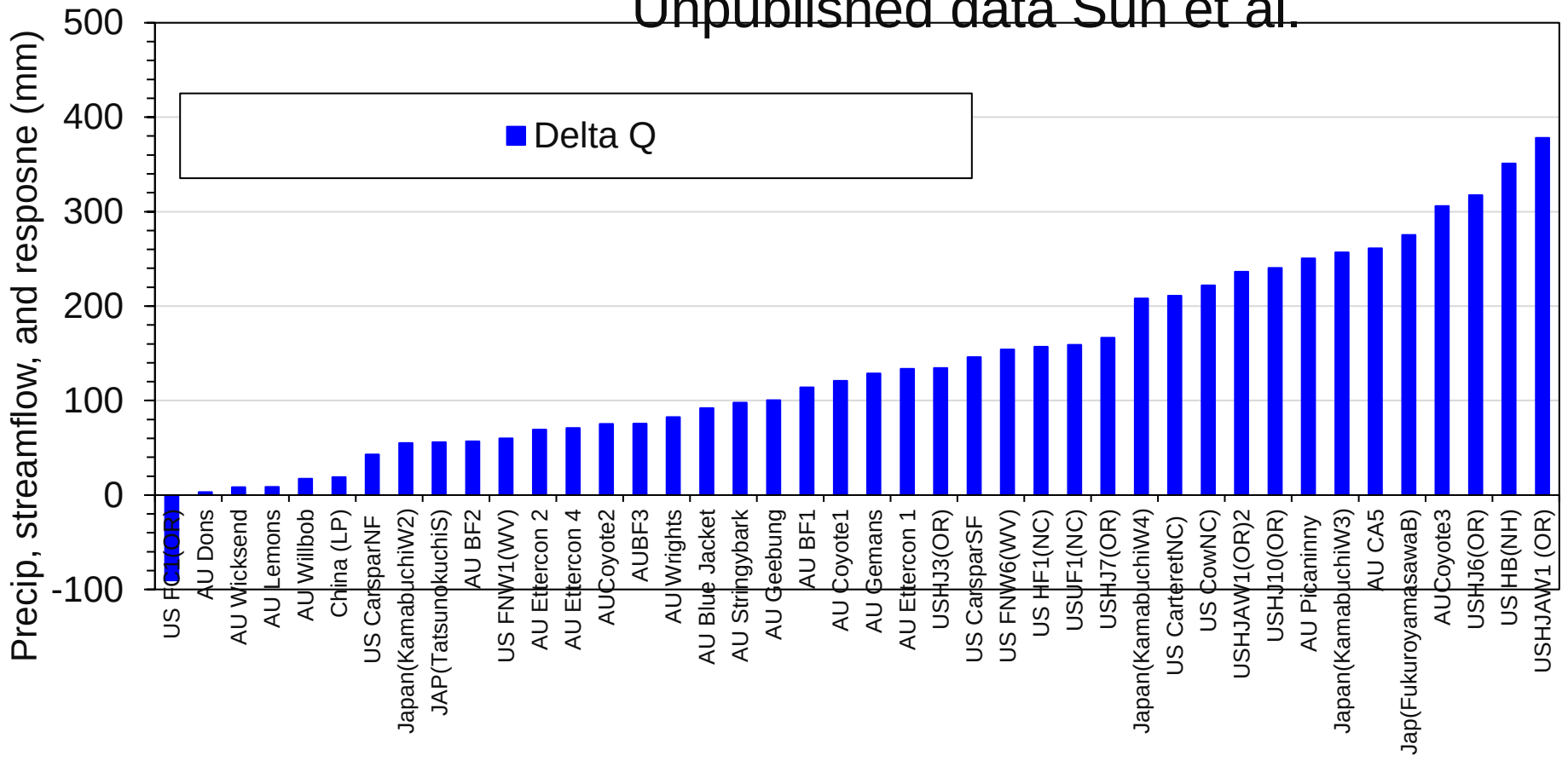


(from C. A. Bolster)

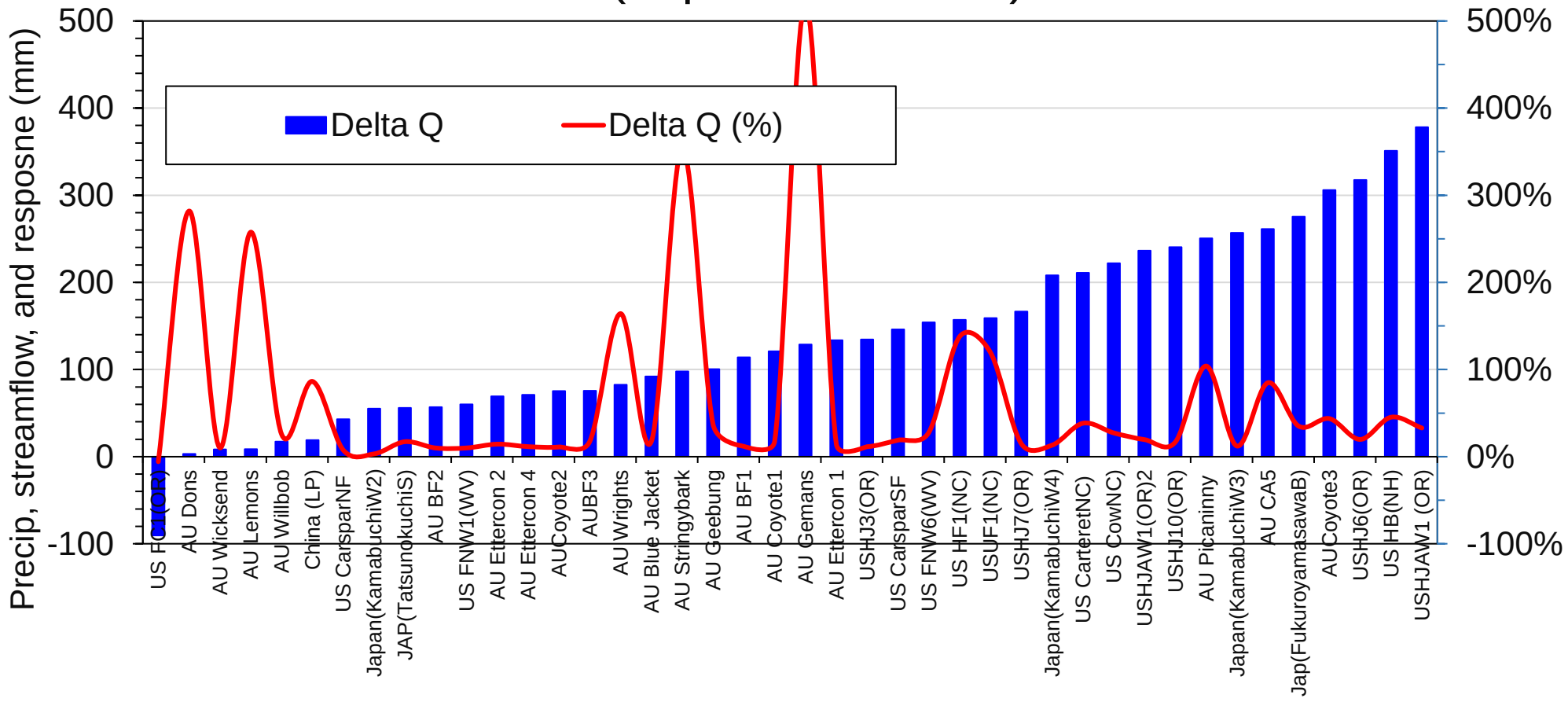
First Year Annual Water Yield (i.e. ET) Responses to Forest Removal



Annual Water Yield Response to Forest Cutting
Unpublished data Sun et al.

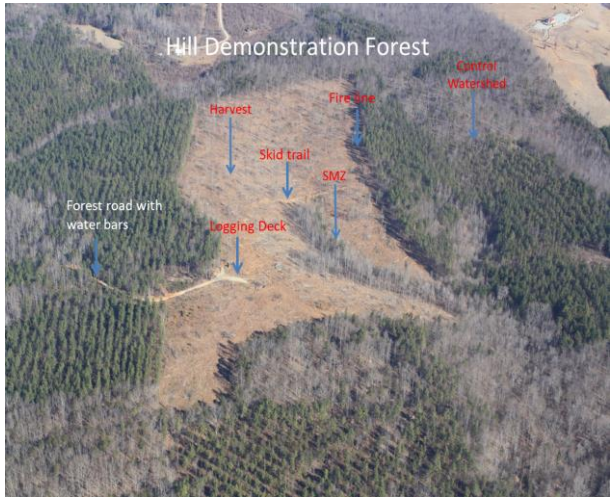


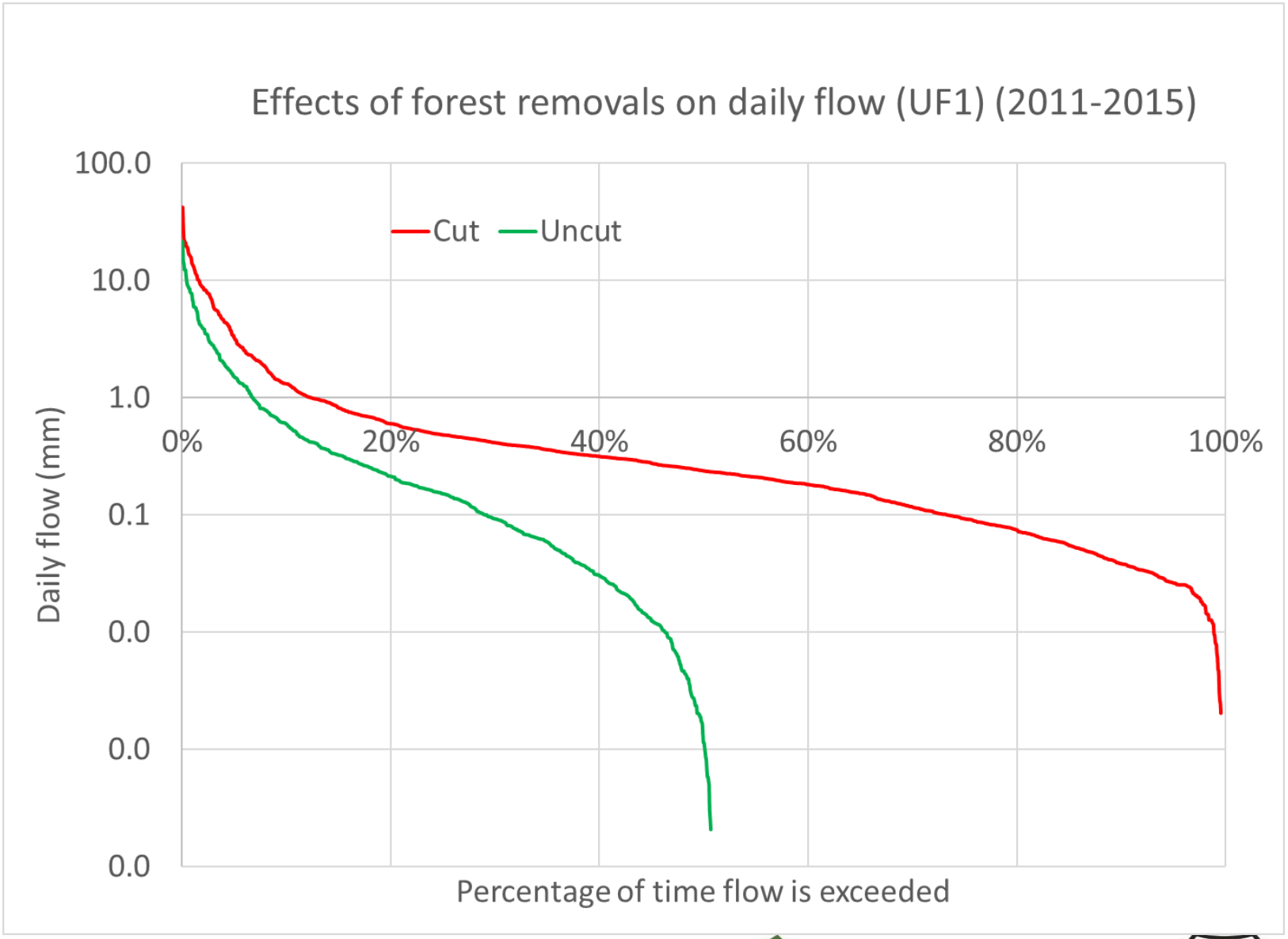
Annual Water Yield Response to Forest Cutting (unpublished data)



Flow distribution (daily flow)

Piedmont watershed in North Carolina

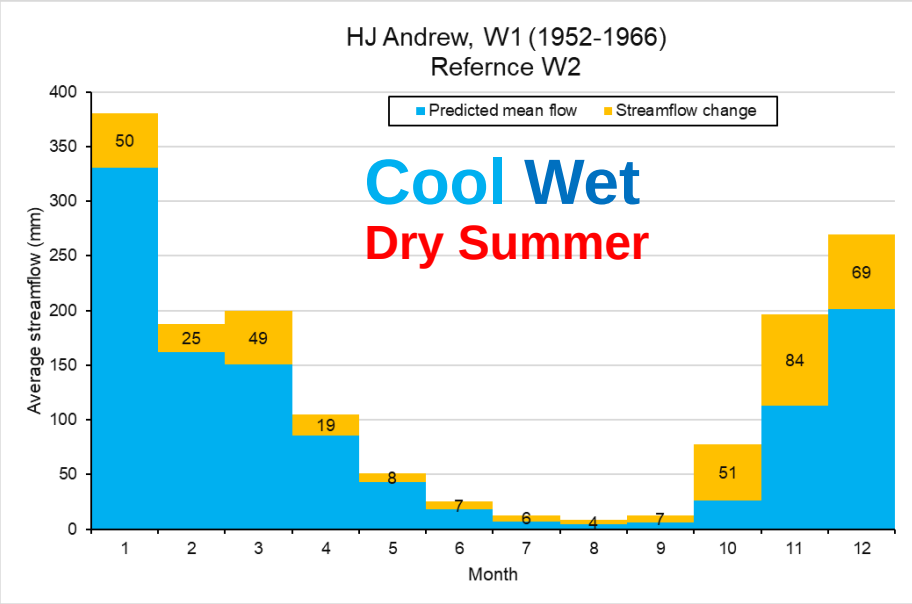


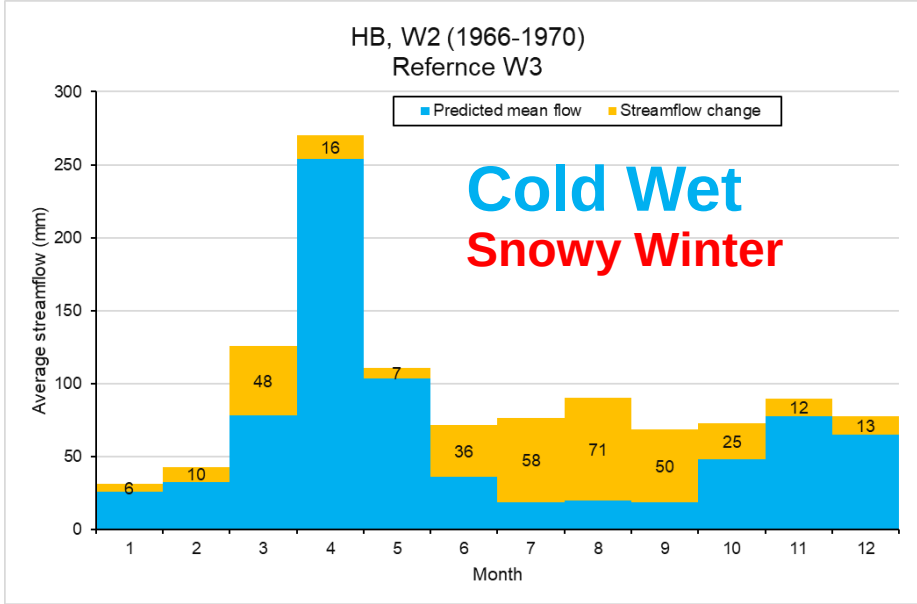


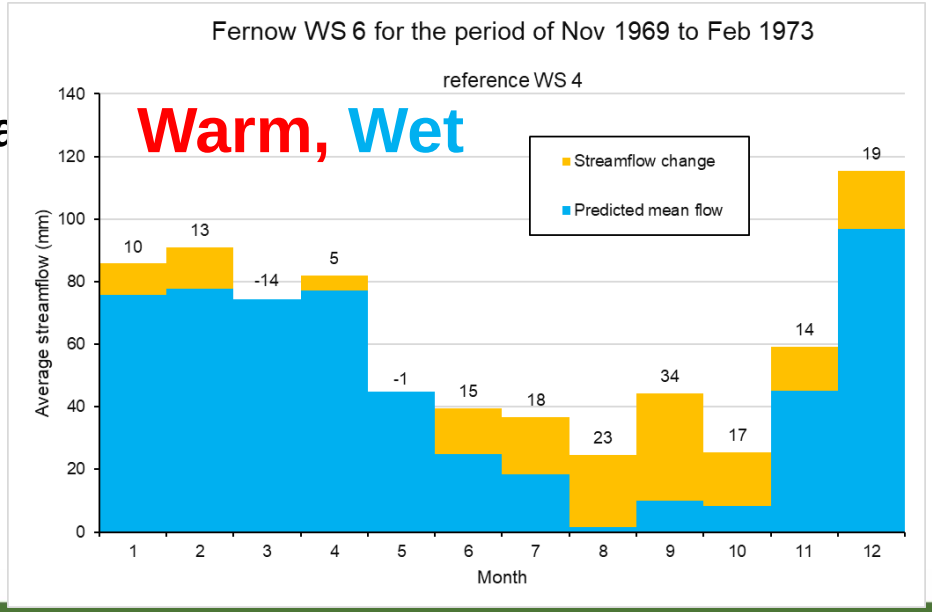
Seasonal response to deforestation

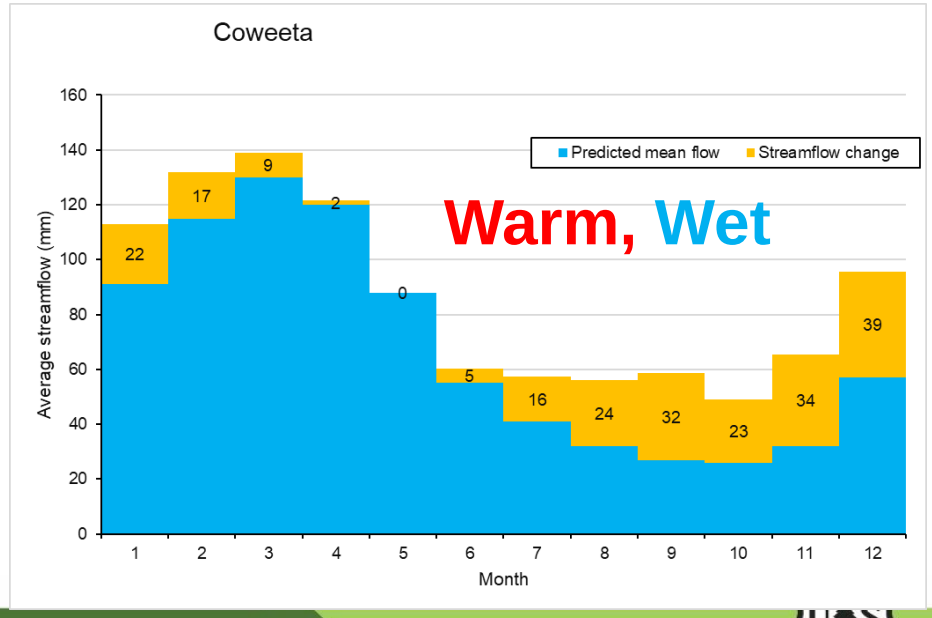
Data from paired watersheds

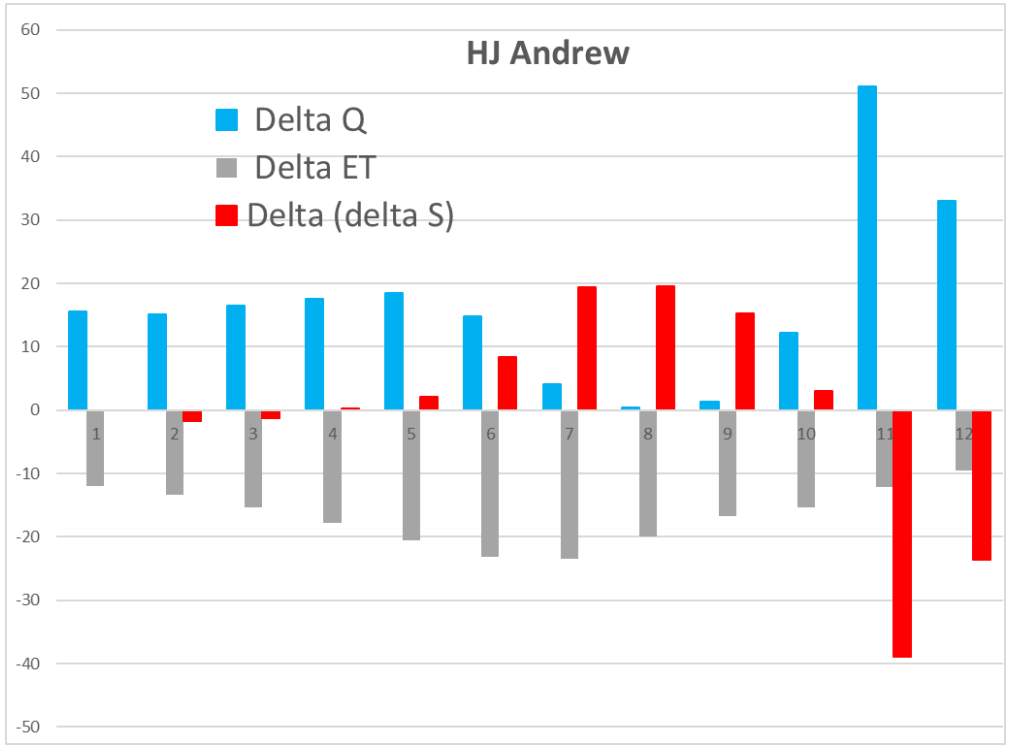
Unpublished data Sun et al.

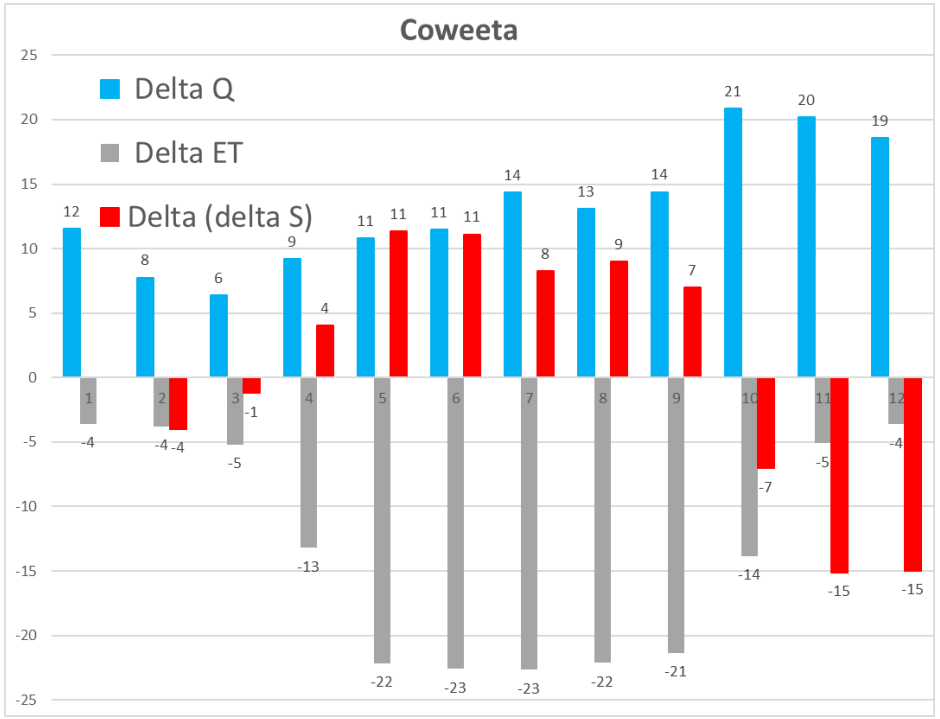












ΔQ_t

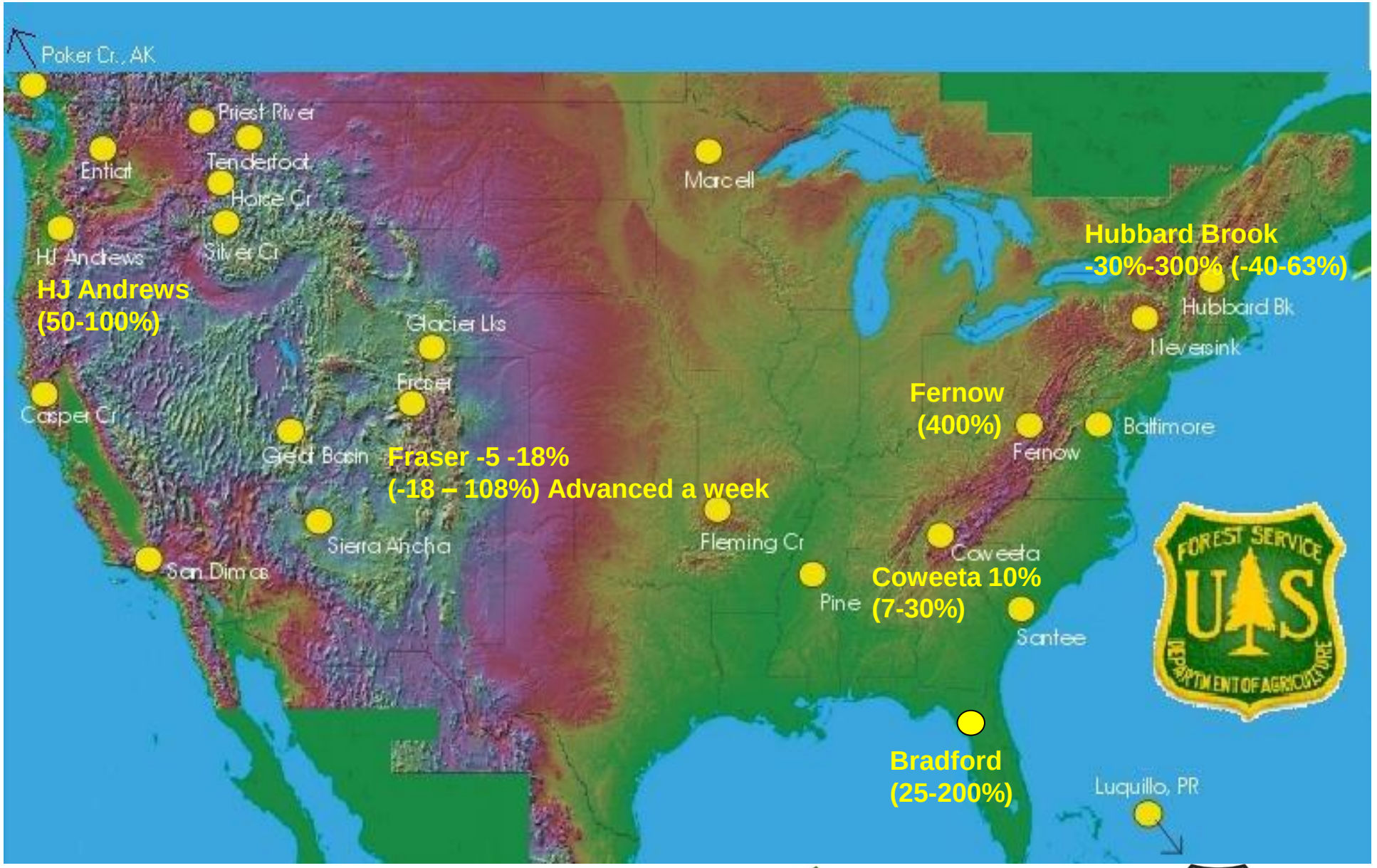
$= -\Delta ET_t – (\Delta S_{d,t} - \Delta S_{f,t})$

$= -\Delta ET_t – \Delta(\Delta S_t)$

WaSSI model simulation

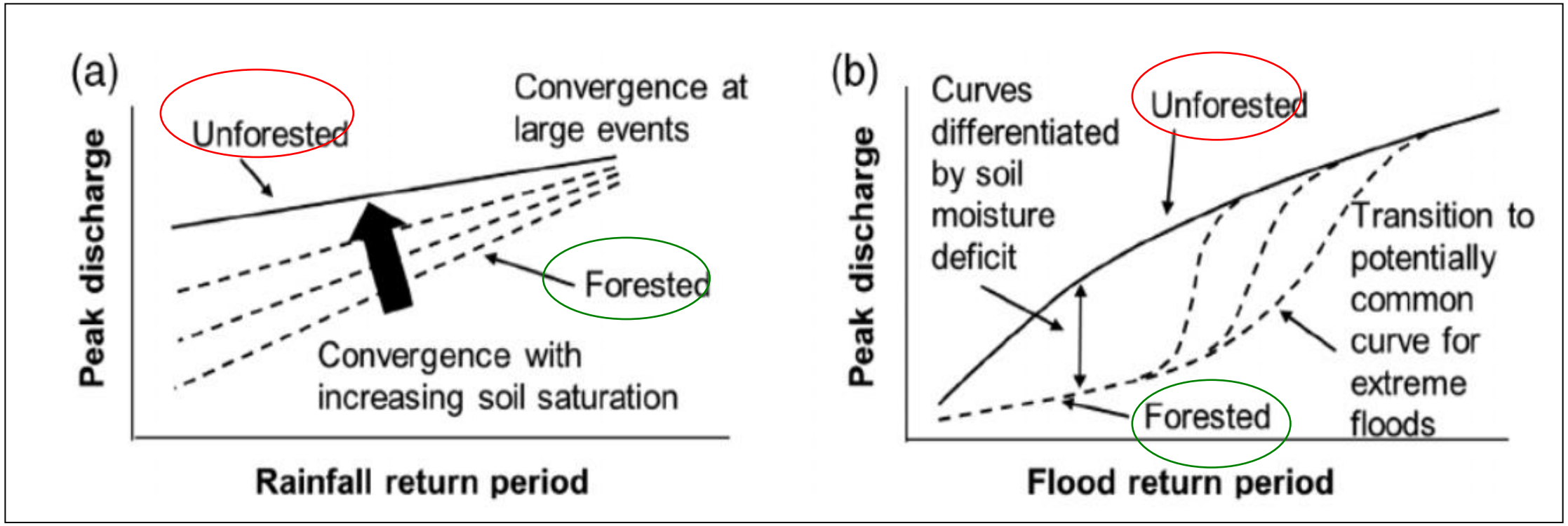
Unpublished data (Sun et al.)

Storm Volume (Peakflow) Responses % to Forest Removal



Forests or floods?

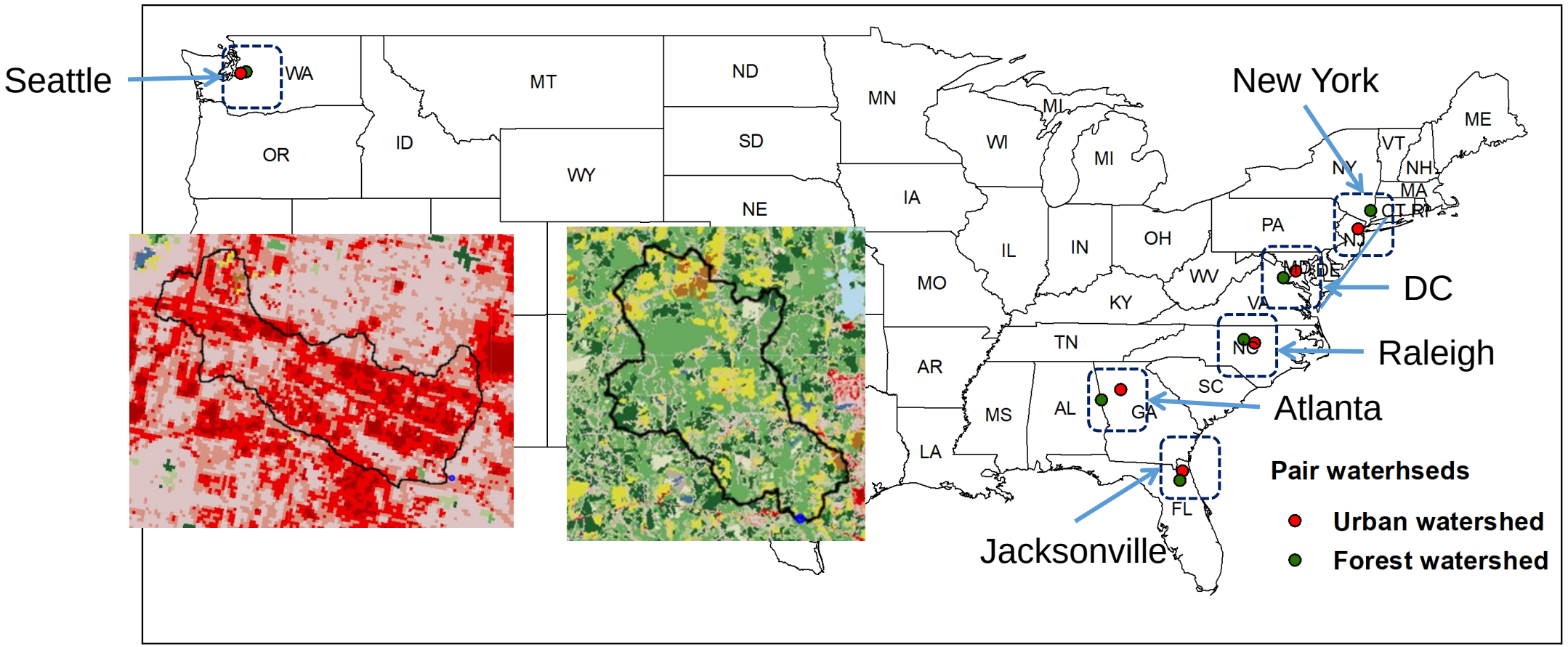
Bathurst et al., 2020. Hydrological Processes

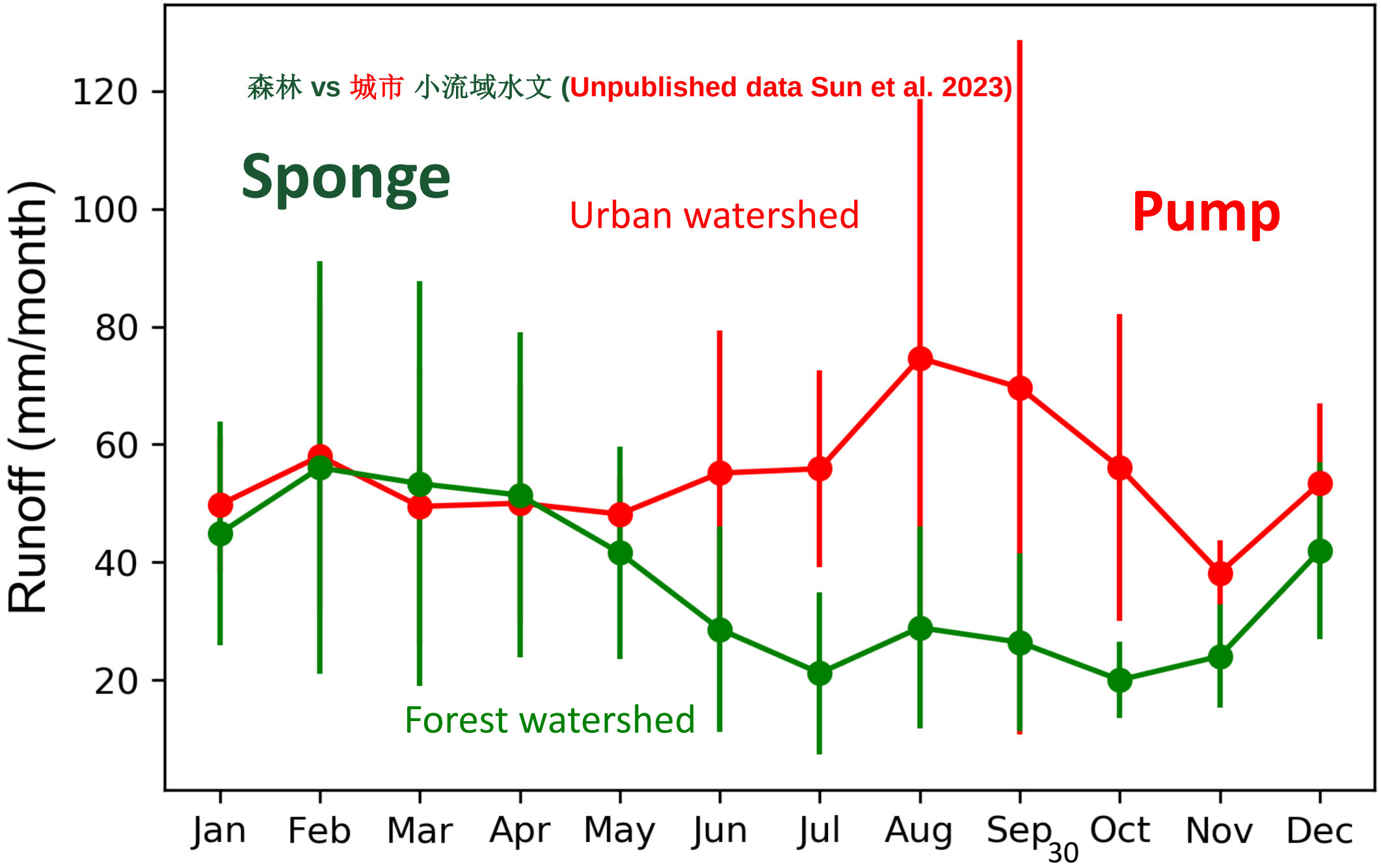


森林 vs 城市 小流域水文

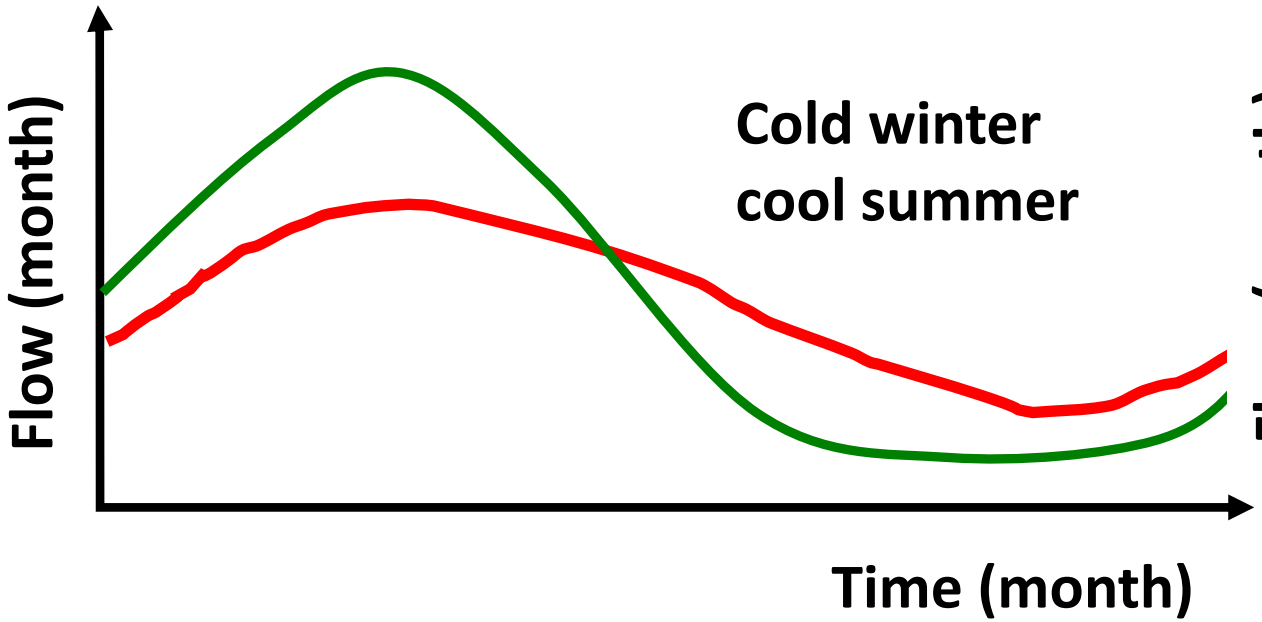
Extreme Disturbances
Unpublished data

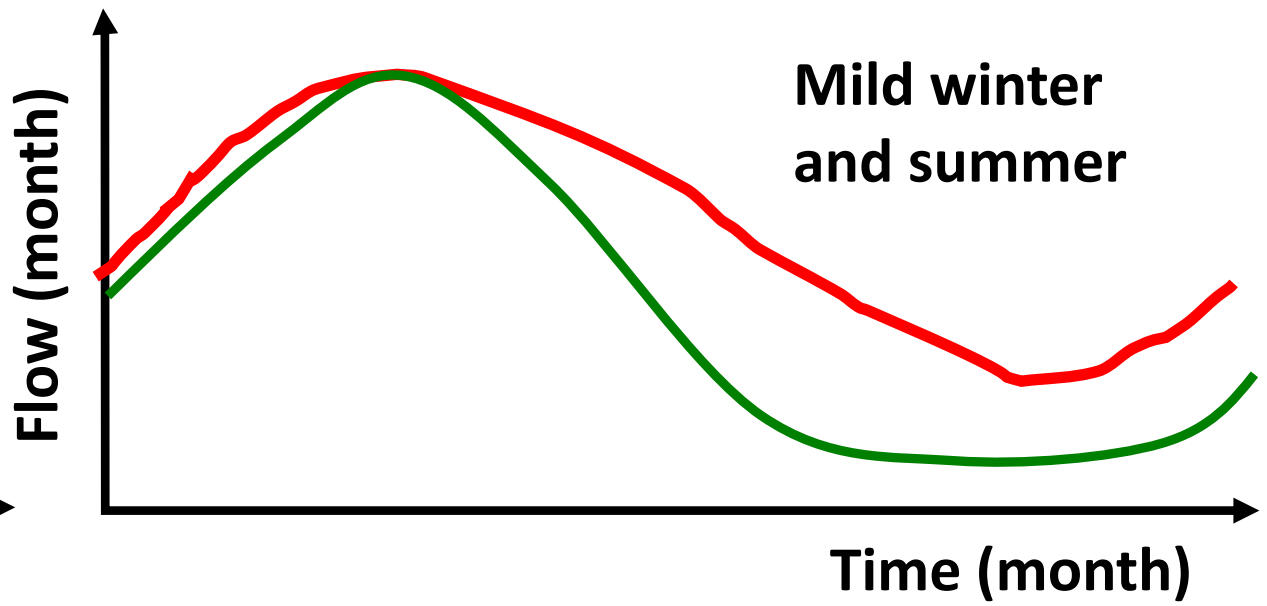
10 Urban-Forest Quasi-Paired Watershed

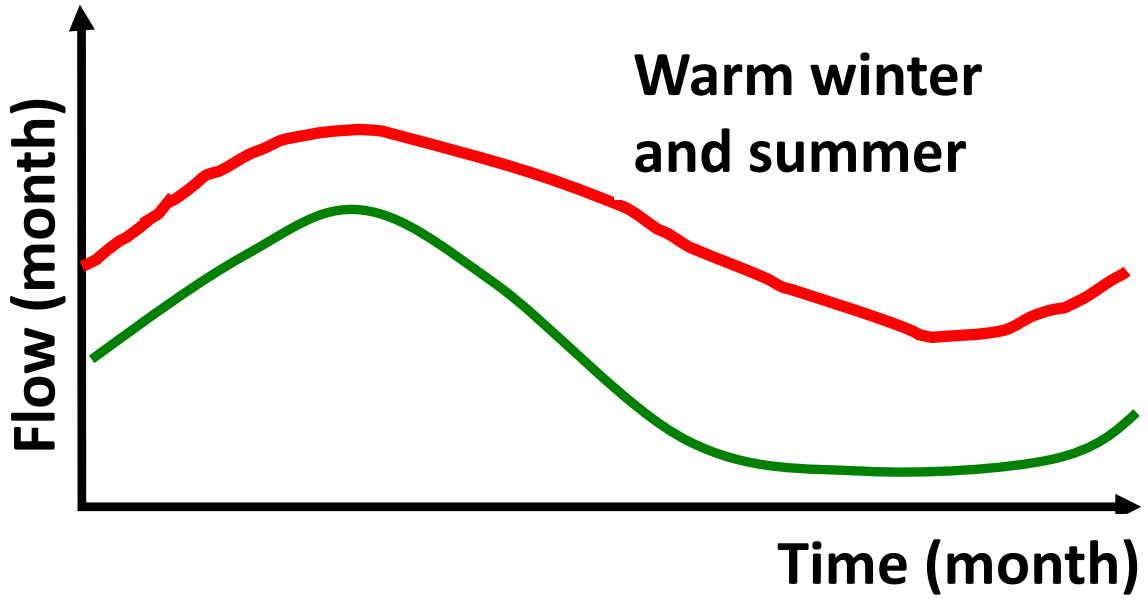



森林 vs 城市 小流域水文 (Unpublished data Sun et al. 2023)
Sponge
Urban watershed
Pump
Forest watershed
Runoff (mm/month)
120
100
80
60
40
20
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

Seasonal Flow Patterns (Forests vs Urban)



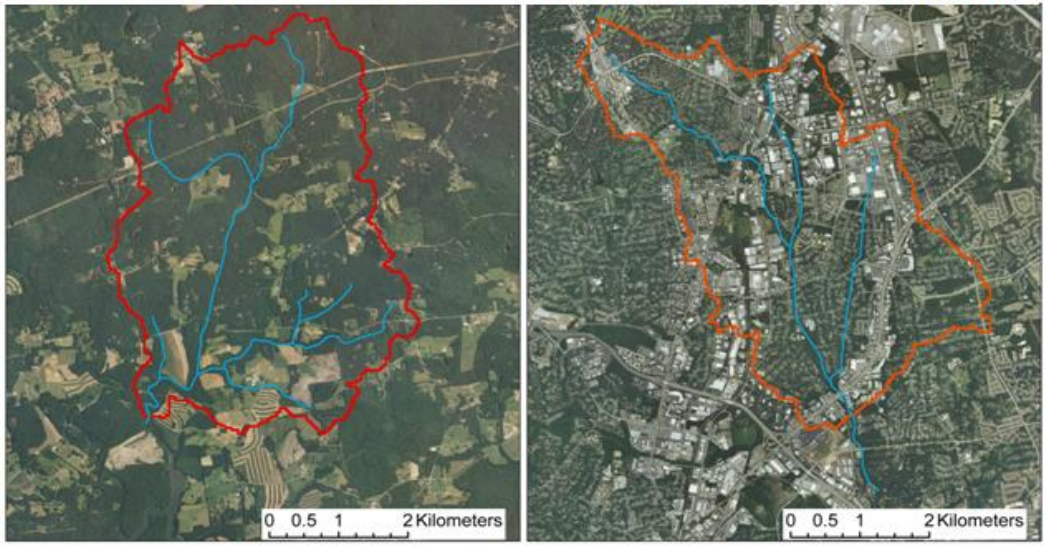




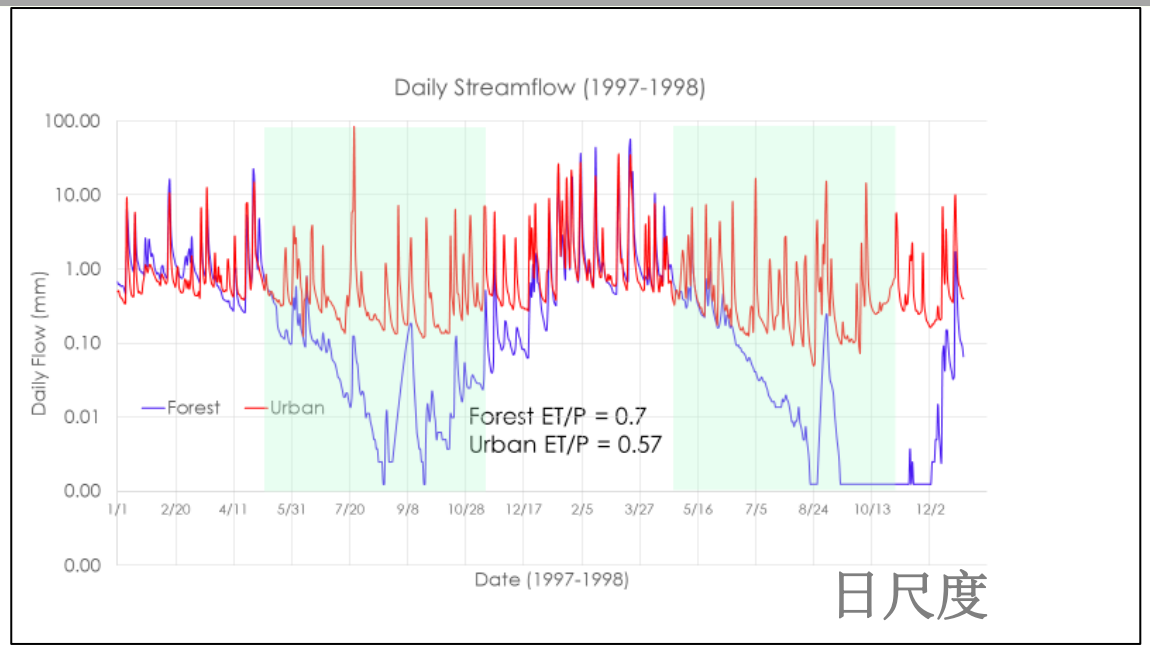
森林流域与城市流域水文对比

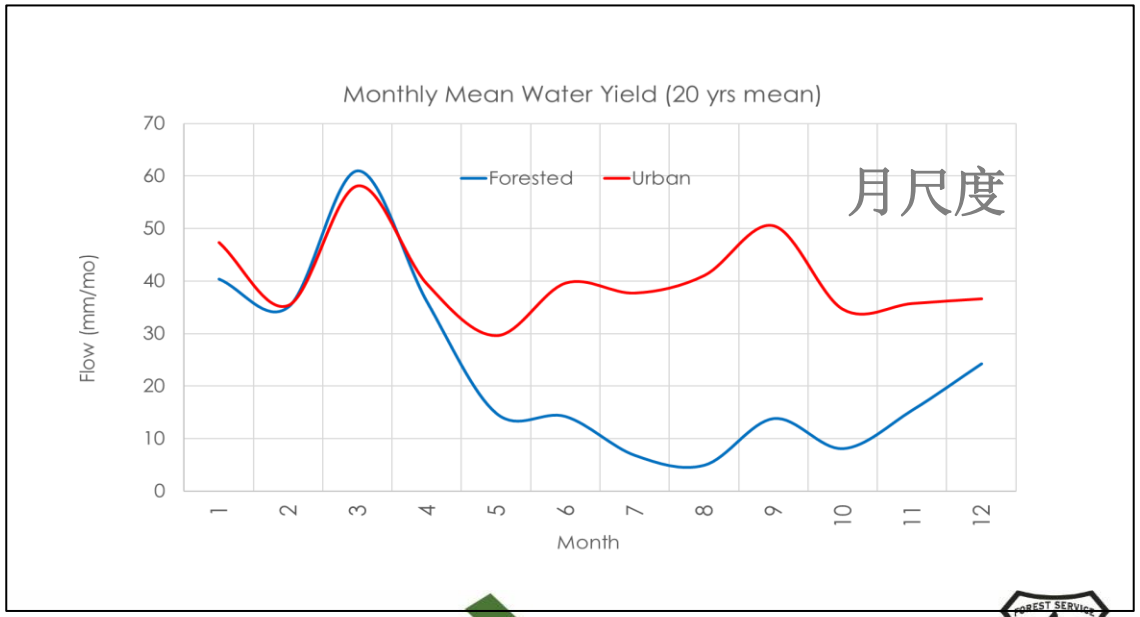
Reference Watershed
19.6 km², 73% forest, 0.3% Impervious
Mean Annual PPT 1197 mm, TEMP 14.5°C
Mean Annual Water Yield 275 mm

Urban Watershed
17.8 km², 4% forest, 29.6% Impervious
Mean Annual PPT 1182 mm, TEMP 15.3°C
Mean Annual Water Yield 486 mm (+77%)

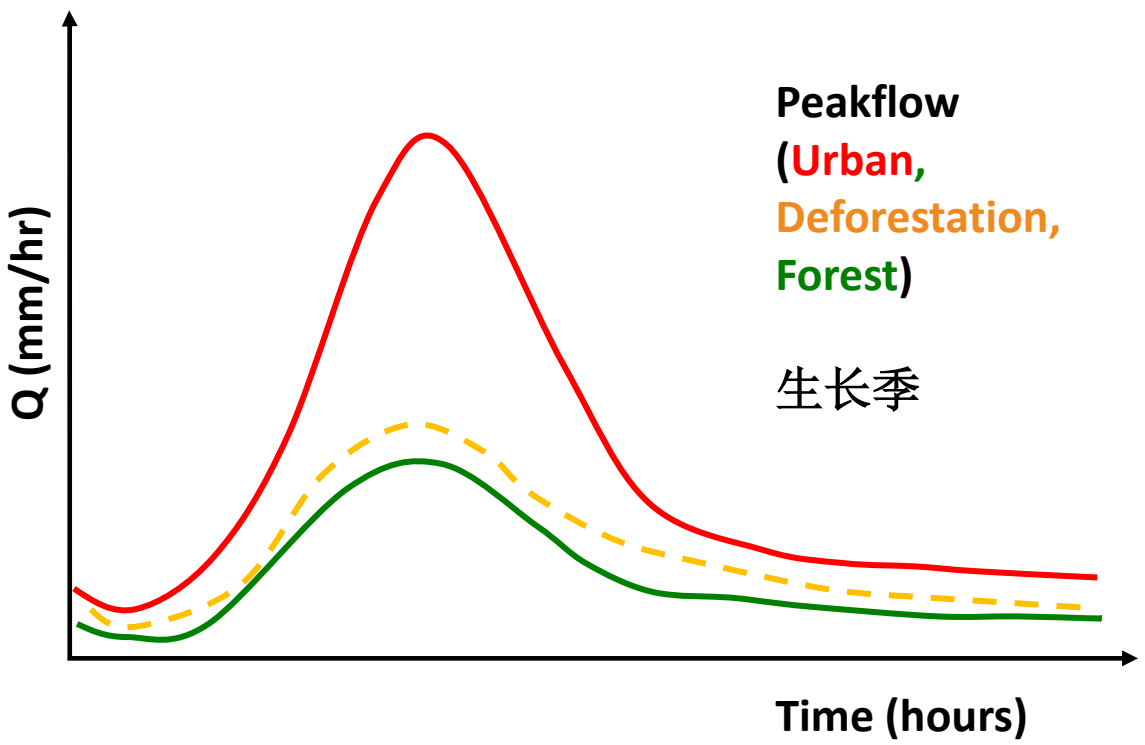


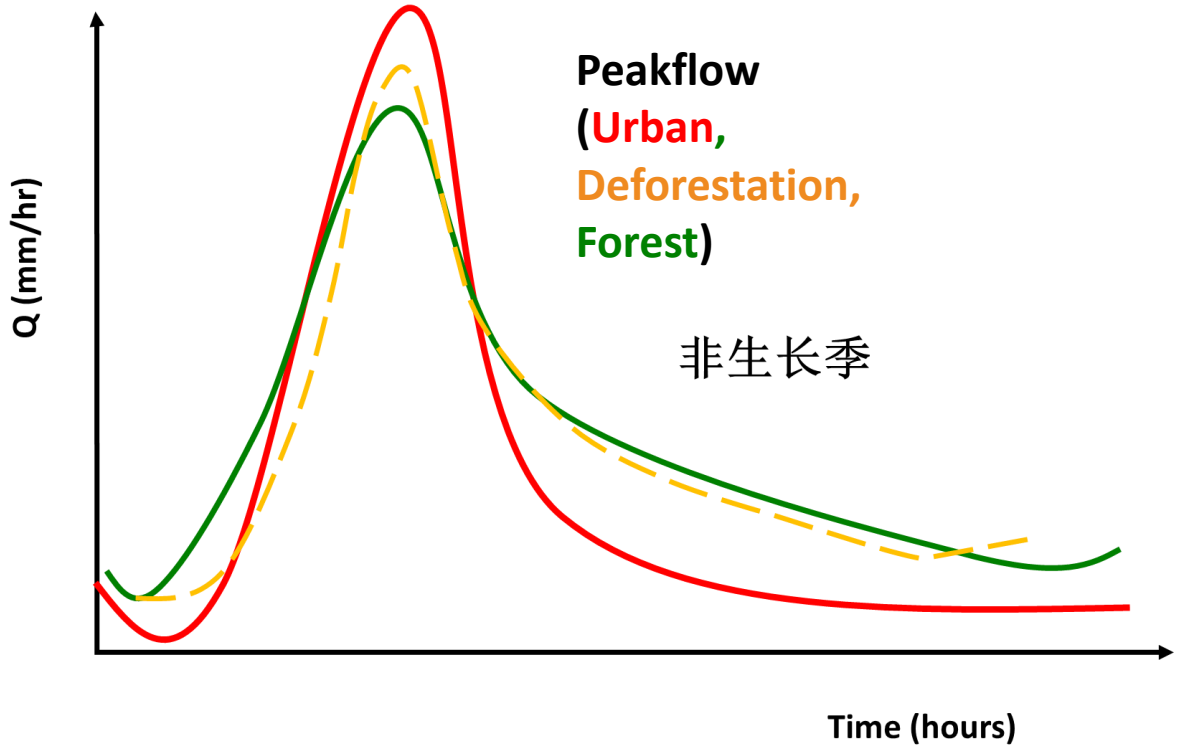
Sun et al. Unpublished data





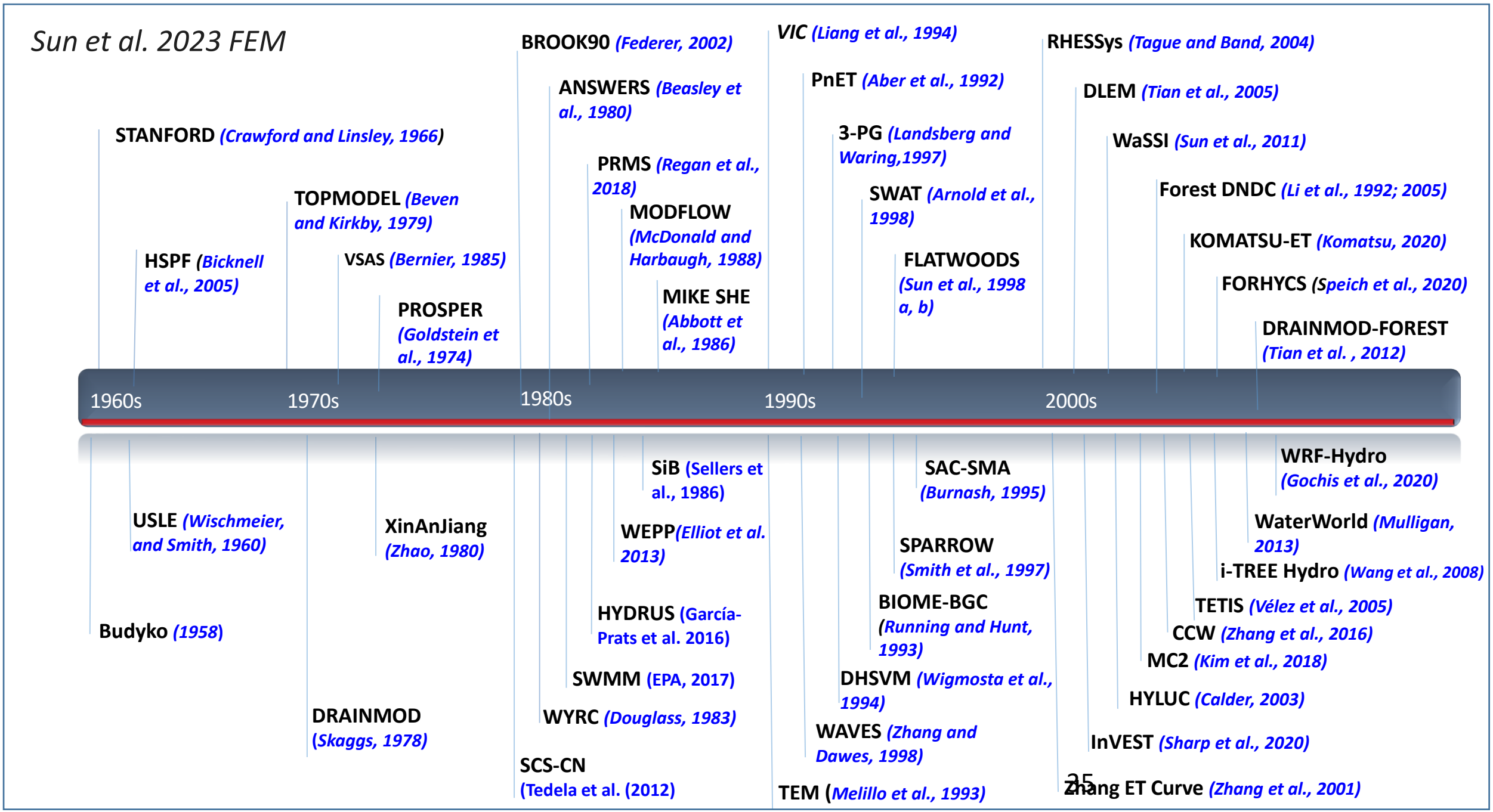
森林消减洪峰的季节性差异

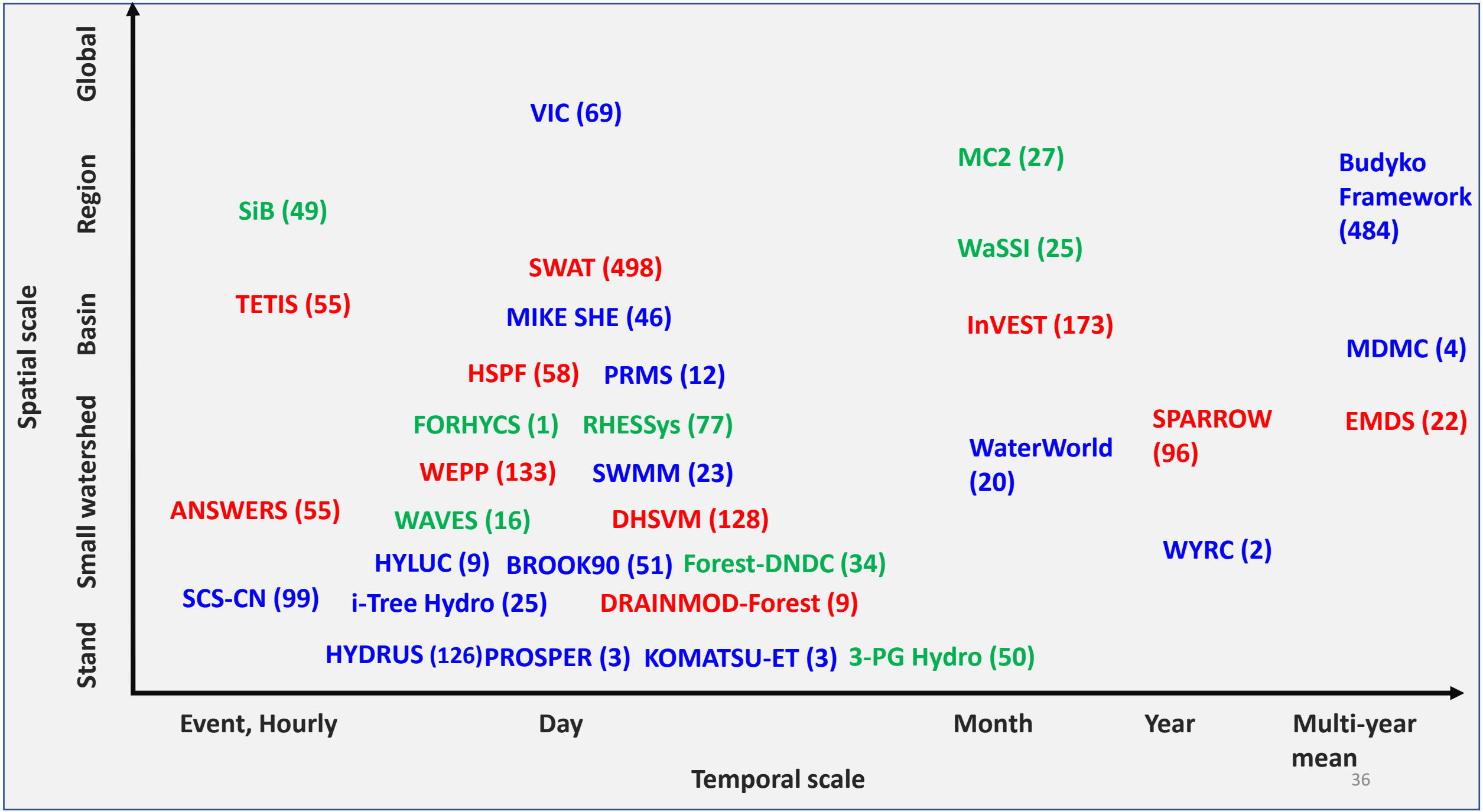




量化‘水源涵养’数学模型

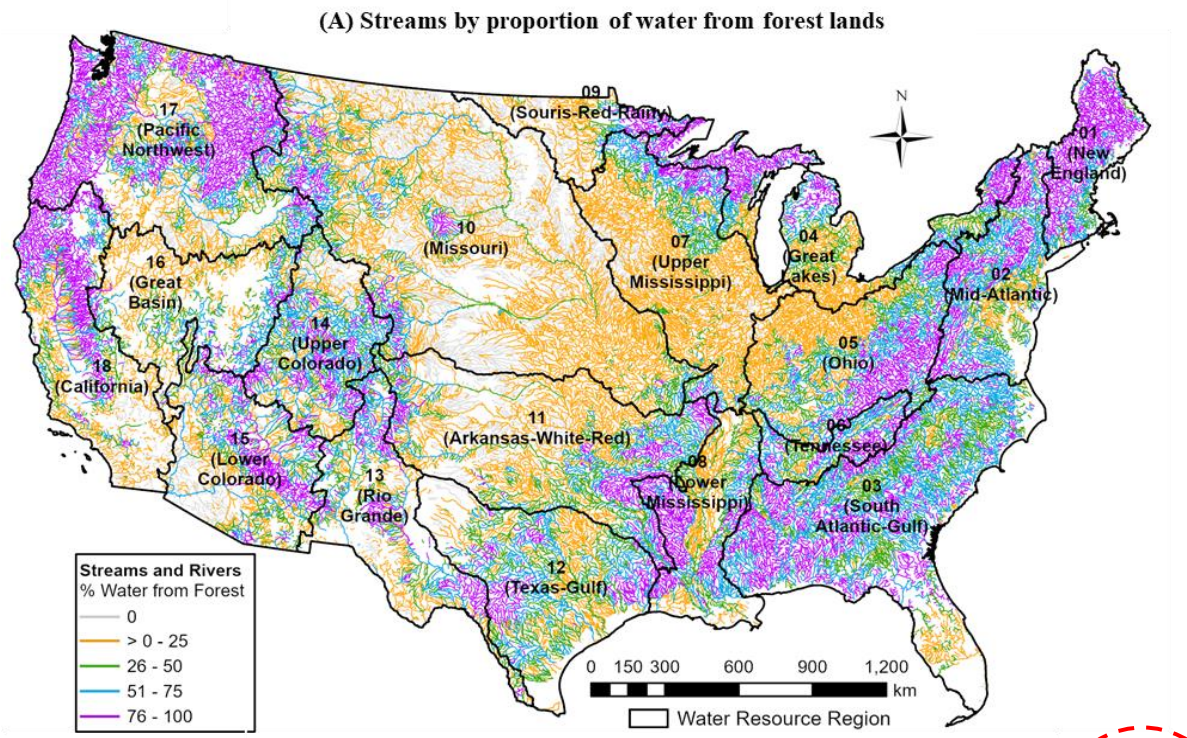
Modeling


Sun et al. 2023 FEM
STANFORD (Crawford and Linsley, 1966)
HSPF (Bicknell et al., 2005)
TOPMODEL (Beven and Kirkby, 1979)
VSAS (Bernier, 1985)
PROSPER (Goldstein et al., 1974)
BROOK90 (Federer, 2002)
ANSWERS (Beasley et al., 1980)
PRMS (Regan et al., 2018)
MODFLOW (McDonald and Harbaugh, 1988)
MIKE SHE (Abbott et al., 1986)
VIC (Liang et al., 1994)
PnET (Aber et al., 1992)
3-PG (Landsberg and Waring,1997)
SWAT (Arnold et al., 1998)
FLATWOODS (Sun et al., 1998 a, b)
RHESSys (Tague and Band, 2004)
DLEM (Tian et al., 2005)
WaSSI (Sun et al., 2011)
Forest DNDC (Li et al., 1992; 2005)
KOMATSU-ET (Komatsu, 2020)
FORHYCS (Speich et al., 2020)
DRAINMOD-FOREST (Tian et al. , 2012)
1960s
1970s
1980s
1990s
2000s
Budyko (1958)
USLE (Wischmeier, and Smith, 1960)
DRAINMOD (Skaggs, 1978)
XinAnJiang (Zhao, 1980)
SCS-CN (Tedela et al. (2012)
WYRC (Douglass, 1983)
SWMM (EPA, 2017)
HYDRUS (García-Prats et al. 2016)
WEPP(Elliot et al. 2013)
SiB (Sellers et al., 1986)
TEM (Melillo et al., 1993)
WAVES (Zhang and Dawes, 1998)
DHSVM (Wigmosta et al., 1994)
BIOME-BGC (Running and Hunt, 1993)
SPARROW (Smith et al., 1997)
SAC-SMA (Burnash, 1995)
Zhang ET Curve (Zhang et al., 2001)
InVEST (Sharp et al., 2020)
HYLUC (Calder, 2003)
MC2 (Kim et al., 2018)
CCW (Zhang et al., 2016)
TETIS (Vélez et al., 2005)
i-TREE Hydro (Wang et al., 2008)
WaterWorld (Mulligan, 2013)
WRF-Hydro (Gochis et al., 2020)


Spatial scale
Global
Region
Basin
Small watershed
Stand
VIC (69)
MC2 (27)
Budyko Framework (484)
SiB (49)
WaSSI (25)
SWAT (498)
TETIS (55)
MIKE SHE (46)
InVEST (173)
MDMC (4)
HSPF (58)
PRMS (12)
FORHYCS (1)
RHESSys (77)
SPARROW (96)
EMDS (22)
WaterWorld (20)
WEPP (133)
SWMM (23)
ANSWERS (55)
WAVES (16)
DHSVM (128)
WYRC (2)
HYLUC (9)
BROOK90 (51)
Forest-DNDC (34)
SCS-CN (99)
i-Tree Hydro (25)
DRAINMOD-Forest (9)
HYDRUS (126)
PROSPER (3)
KOMATSU-ET (3)
3-PG Hydro (50)
Event, Hourly
Day
Month
Year
Multi-year mean
Temporal scale

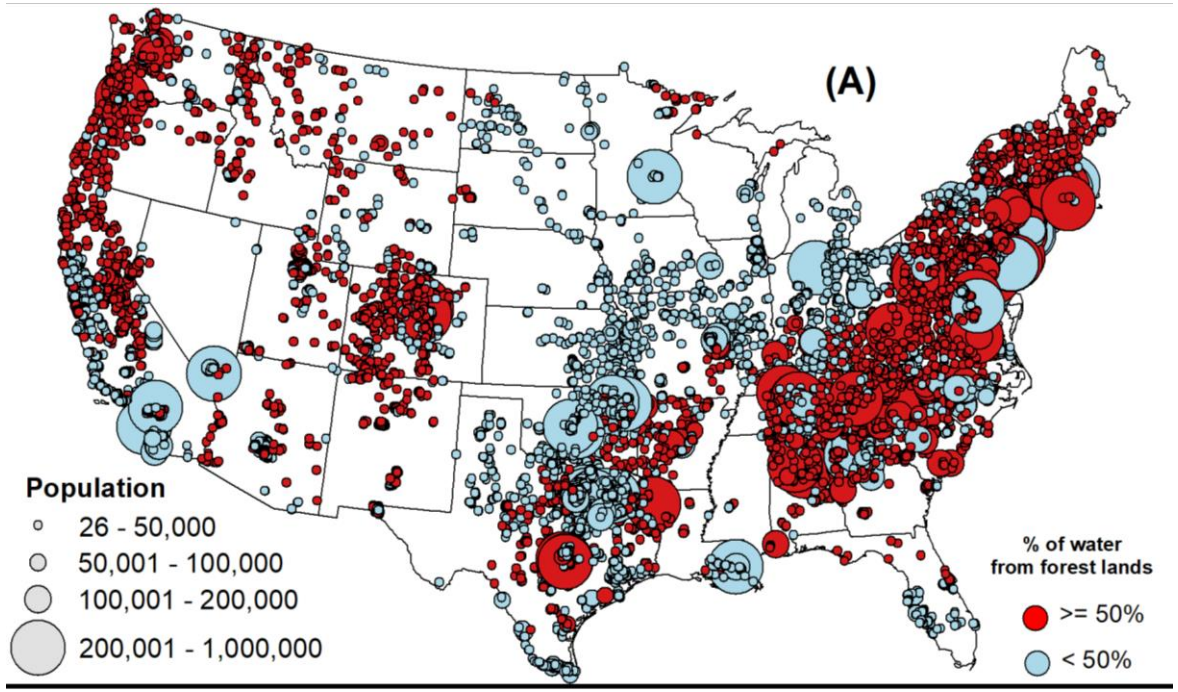
from Forests to Faucets （从木头 到 水龙头？）

Modeled with the WaSSI model



(B) Forest ownership type

	Federal	State	Local	Family	Corporate	Other private	Tribal	Total
Area (%)	11.0%	3.3%	0.6%	13.2%	5.9%	0.6%	1.1%	**35.7%**
Water supply (%)	14.4%	4.8%	0.9%	18.5%	10.0%	0.9%	0.6%	**50.0%**



Liu N. et al. ERL, WRR, 2022

森林“涵养水源” Future Research

1. 统一森林“水源涵养”定义：调节径流的作用。Flow regulations?
2. 森林植被影响***降水入渗 - 蒸散权衡***； 气候，土壤，植被临界确定 (Thresholds of ET-Infiltration trade-offs in space and time)
3. 量化森林水源涵养时间，尺度效应：如洪峰， 对下风方向降水的影响 (Scale effects; downwind water supply, dry season flows
4. 森林水量平衡对气候变化直接（气候）或间接（CO2， 树种变化, 火，间伐管理）影响； 观测不同植被ET及其组成 (Management effects on ET)
5. 加强**长期**野外观测，模型验证 (Nee more field data to test hypothesis and models)

Heathy Forests are Sponge + Pumps

健康的森林 既是海绵体也是抽水机！

+

Reforestation
(Moderate ET, Ks)

ET

Healthy Forests
(high ET, Ks)

Urban
(Very Low ET, low Ks)

Infiltration
Ks

Deforestation
(Low ET, moderate Ks)

Peakflow

High peak flow and lowflow, and water yield, but low/high baseflow

Baseflow/Lowflow

Moderate peak flow, baseflow, lowflow, water yield

Low peak flow, baseflow, lowflow, and water yield

Moderate peak flow, baseflow, lowflow， water yield