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Climate Adaptation and Value Creation of Land and Water for our Life with SWAT

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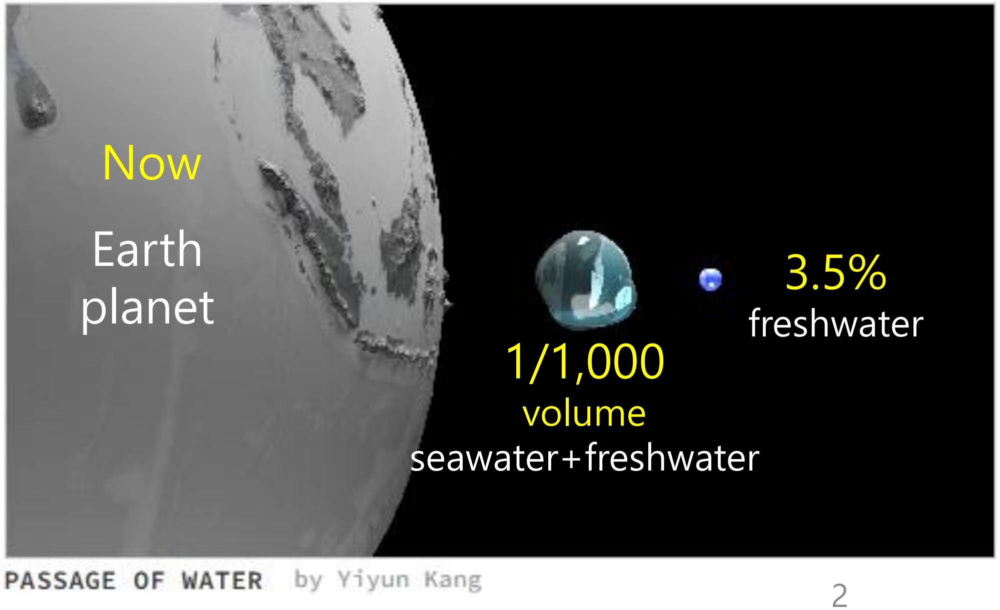
Land and Water to Human

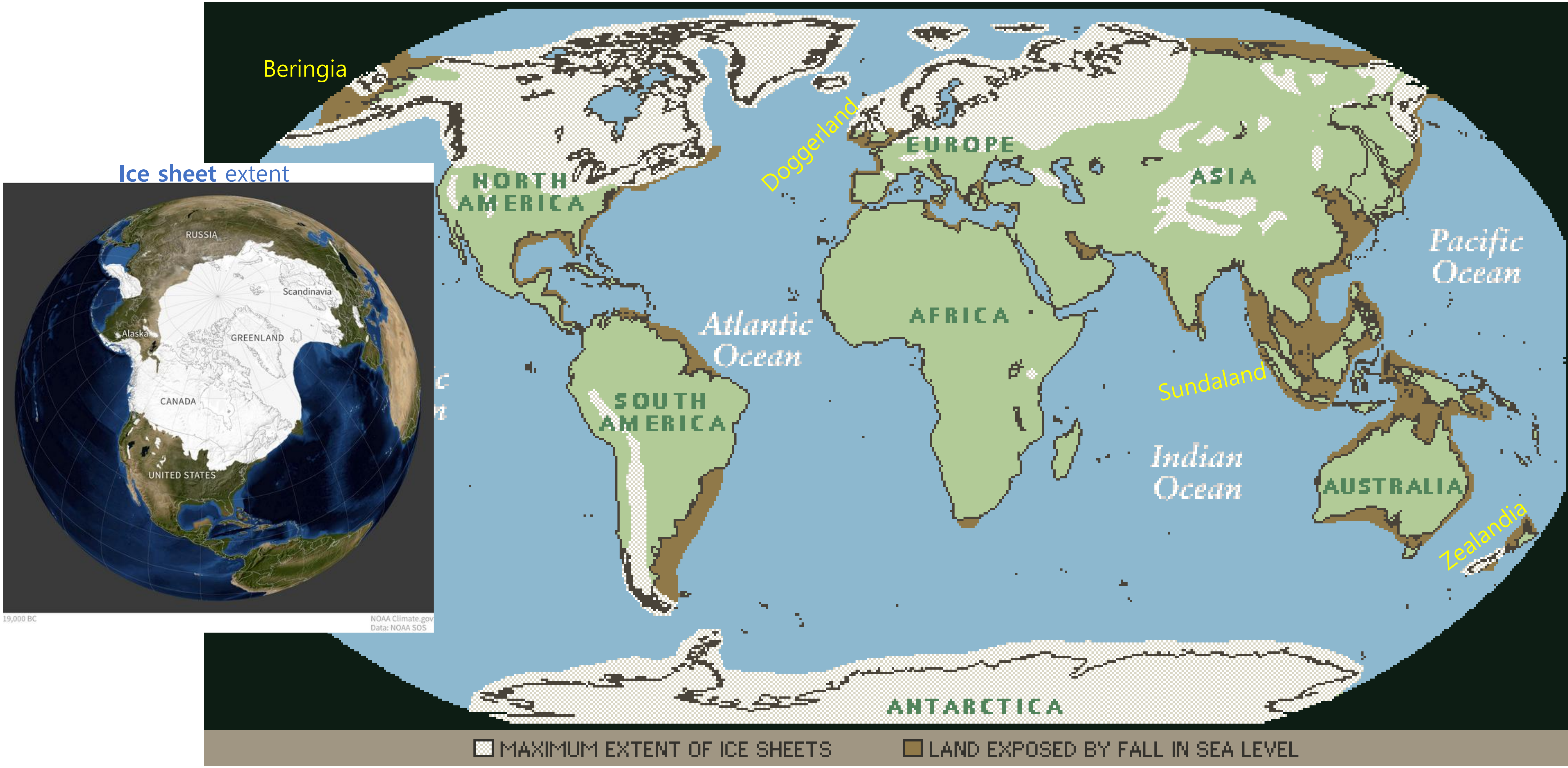
- L&W evolving Earth
  - we **call** our globe of 29% land and 71% water as earth because we live on land
  - we **use** water from precipitation (weather) and glaciers (climate) for land use
  - we **manage** water as surface, subsurface, and ground waters (civilization) for land management
  - we **combine** land and water to produce values (industrialization)
  - we **maintain** land and water for our future (sustainability for next generation)
    - we worry about climate change adaptation (new normal) and weather extremes (flood and drought)
- L&W behaving together and influencing each other
  - they can not be thought separately to human life
  - pioneering to Mars

Earth age: 4.54 Byr

https://artsandculture.google.com/experiment/passage-of-water/dAElpEyEjuE9XQ?hl=en



Land- Last Glacial Maximum - 21,000 yr



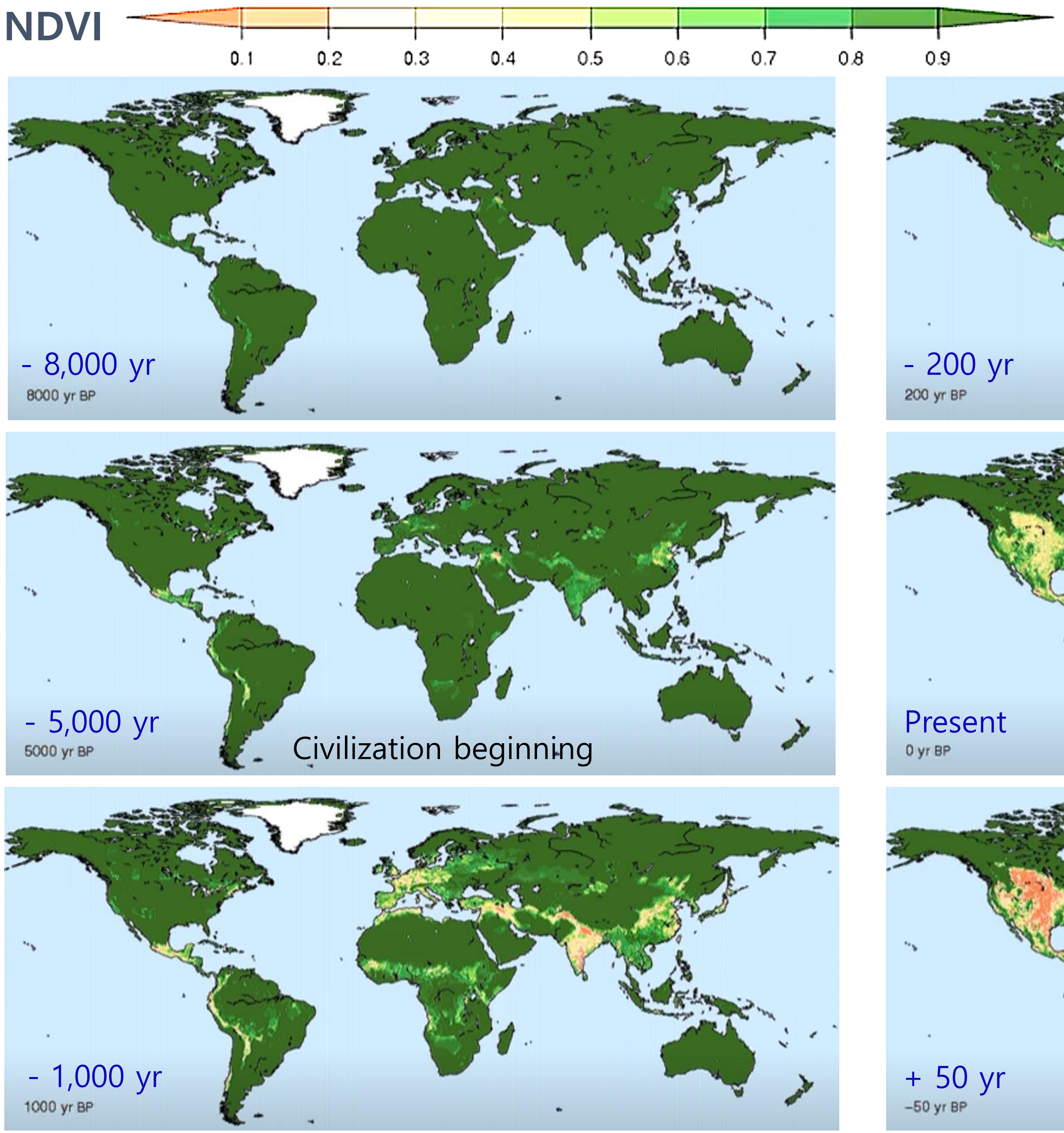
https://www.iro.umontreal.ca/~vaucher/History/Evolution/IceAges.html

- 12,000 yr sea level - 120m

Land present
& land use

Holocene
- 11,700 ~

https://www.youtube.com/watch?v=gBTlIaf12-4
Global land cover change from 8000 BP to -50 BP



Land and Water to Human

Theme	Summary
Past	Land and water were objects of **conquest and ownership**.
Present	Land and water are now sources of **inequality and conflict**.
Future	Land and water will become the ultimate tests of **coexistence and survival**.

Land future outlook

- **Climate Change Impacts**: Desertification and rising sea levels will reduce habitable/agricultural areas.
- **Smart Cities and Density**: Technology will enable efficient urban land use.
- **Space Colonization**: New concepts of "land" (e.g., Moon, Mars) emerge.
- **Tech-Driven Management**: Use of drones, AI, and GIS for sustainable land use

Water future outlook

- **Water Scarcity Crisis**: Climate change and population growth will increase water stress.
- **Desalination Advances**: Greater adoption as cost drops and efficiency rises.
- **The Era of "Blue Gold"**: Water becoming as geopolitically critical as oil
- **More Conflicts Expected**: Without international cooperation, disputes may intensify.

Task Share wisely, cooperate globally, and manage sustainably

smart governance integration

Future Directions in the Water Sector

Category	Key Focus Areas	Examples & Technologies
• **Digital Twin**	Real-time simulation and system modeling	Virtual replicas of water infrastructure, scenario-based planning, predictive analytics
• **Nature-based Solutions (NbS)**	Ecosystem-based water management	Wetlands, green roofs, riparian buffers, floodplains restoration
• **Smart Water Management**	Intelligent monitoring and control	IoT sensors, SCADA systems, AI for demand prediction and leakage detection
• **Climate Resilience**	Adaptation to climate risks	Flood/drought risk assessments, resilient infrastructure design, early warning systems
• **Water Reuse & Circular Economy**	Efficient use and recovery of water resources	Wastewater reuse, rainwater harvesting, resource recovery (nutrients, energy)
• **Integrated Data & Platforms**	Unified water data ecosystems	Hydrology-GIS integration, open data platforms, cloud-based dashboards
• **Participatory Governance**	Inclusive and transparent decision-making	Stakeholder engagement, community water planning, ESG/SDG-aligned governance
• **Remote Sensing & Earth Observation**	Large-scale and real-time environmental monitoring	Satellite imagery, LIDAR, SAR for hydrological tracking and forecasting
• **Sector-specific Water Solutions**	Tailored strategies for different sectors	Precision irrigation (agriculture), green infrastructure (urban), zero-discharge systems (industry)

Future Directions in Water Environment & Aquatic Ecosystem Fields

Category	Key Focus Areas	Examples & Technologies
• **Nature-based Solutions (NbS)**	Ecosystem-based approaches to enhance water and habitat quality	Green infrastructure, urban wetlands, sponge cities
• **Aquatic Ecosystem Health Monitoring**	Assessment of biodiversity and ecological integrity	Index of Biological Integrity (IBI), macroinvertebrate monitoring, eDNA analysis
• **River and Wetland Restoration**	Ecological rehabilitation of degraded water bodies	Re-meandering rivers, reconnecting floodplains, riparian vegetation restoration
• **Water Quality Improvement**	Reducing pollution and enhancing natural purification	Constructed wetlands, ecological wastewater treatment, nutrient load reduction
• **Habitat Connectivity**	Supporting aquatic organism movement and lifecycle	Fish passages, dam removal/modification, ecological corridors
• **Climate Adaptation in Aquatic Systems**	Enhancing resilience of aquatic habitats	Thermal refugia creation, low-flow mitigation, adaptive reservoir operation
• **Integrated Water-Ecology Management**	Linking hydrology, water quality, and ecology	Ecohydrology, environmental flow (e-flow) modeling, multi-criteria planning
• **Citizen Science and Community Participation**	Public involvement in monitoring and stewardship	Local ecological surveys, waterkeeper programs, mobile-based monitoring apps

Future Directions in Socio-hydrology

Category	Key Focus Areas	Examples & Approaches
• **Human–Water Interactions**	Understanding mutual influence between society and hydrology	Water use behavior, infrastructure development, land use change
• **Feedback Loops and Co-evolution**	Analyzing dynamic feedback between human decisions and water systems	Irrigation expansion → water scarcity → policy reform → land change
• **Integrated Modeling**	Coupling social, economic, and hydrological models	Agent-based models, system dynamics, coupled human–natural systems (CHANS)
• **Risk Perception and Decision-making**	Studying how people perceive and respond to water-related risks	Flood memory effects, drought preparedness behavior, risk communication
• **Social Resilience and Adaptation**	Assessing community capacity to adapt to hydrological changes	Adaptive governance, social learning, institutional flexibility
• **Water Justice and Equity**	Exploring access, distribution, and fairness in water systems	Environmental justice, vulnerable communities, participatory water rights
• **Historical and Cultural Dynamics**	Considering long-term social drivers of hydrological change	Legacy effects, traditional water knowledge, societal memory
• **Transdisciplinary and Stakeholder Engagement**	Co-developing knowledge with non-scientific actors	Participatory modeling, community workshops, inclusive scenario planning

Future Directions in Eco-hydrology

Category	Key Focus Areas	Examples & Strategies
• **Integration with Nature-based Solutions (NbS)**	Embedding eco-hydrology within broader NbS strategies	Catchment-scale planning with green infrastructure and ecological corridors
• **Climate-resilient Ecosystem Design**	Enhancing ecosystem adaptability to climate extremes	Designing wetlands for drought/flood buffering, thermal refugia for aquatic life
• **Urban Eco-hydrology**	Applying eco-hydrological principles in cities	Sponge cities, green roofs, bioretention systems, permeable surfaces
• **Coupled Eco-hydrological Modeling**	Integrating hydrological and ecological processes in models	Linking vegetation dynamics with flow regimes and nutrient cycles
• **Water Quality Regulation via Ecosystems**	Using biotic components to improve water quality	Riparian buffers, constructed wetlands, phytoremediation
• **Restoration of Natural Flow Regimes**	Reinstating ecologically beneficial hydrological patterns	Environmental flow (e-flow) implementation, dam reoperation, flow re-naturalization
• **Ecohydrological Engineering**	Hybrid systems combining grey and green infrastructure	Leaky dams, retention basins with wetland edges, vegetated drainage systems
• **Policy and Governance Integration**	Mainstreaming eco-hydrology into planning and policy	Ecohydrological guidelines in water laws, SDG-linked ecosystem management
• **Biodiversity and Ecosystem Services Focus**	Enhancing multifunctionality of water-ecology systems	Managing for habitat diversity, carbon sequestration, recreation, and pollination

Integration Insights with Broader Water Management

- **Digital Twin + Ecohydrology**: simulating hydrological-ecological interactions virtually
- **Nature-Based Solutions + Biodiversity Restoration**: enhancing both ecosystem resilience and water services
- **Smart Monitoring + eDNA/IBI**: AI-enhanced predictions of aquatic ecosystem health

  Index of Biotic Integrity
- **Digital Twin + Nature-Based Solutions**
  - sustainable management of urban infrastructure, water resources, and climate adaptation

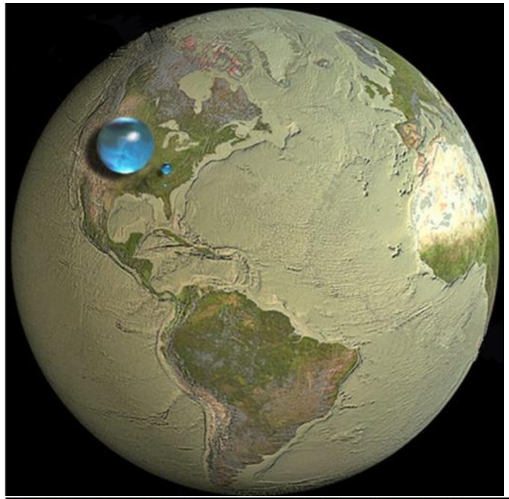
Comparison of attitudes toward new ideas and their absorption capacity

Region	Attitude	Absorption Capacity	Level/Depth
USA	Practical, fast, and proactive	Very fast	Action-oriented, innovative
Europe	Philosophical, cautious, reflective	Slow but thorough	Theoretical, policy-oriented
Asia	Flexible, harmony-focused, integrative	Moderate, very flexible	Adaptive, complex, integrative,

Water – Thales
Air - Anaximenez
Fire - Hercules
Soil – Empedocles

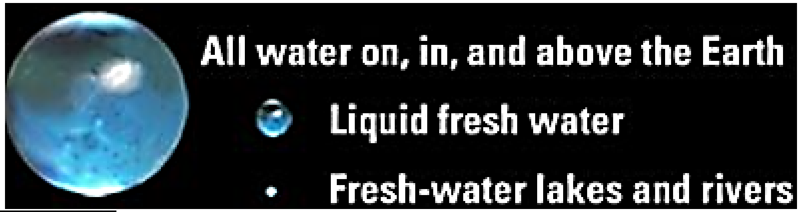
Aristotle gave authority to it.

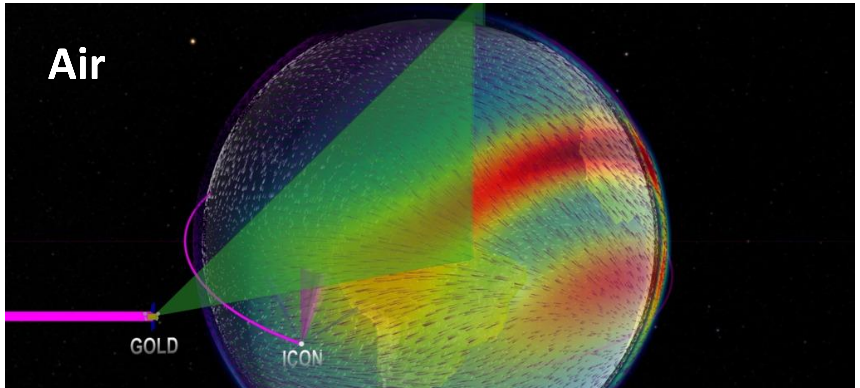
Ancient Greek philosophers thought 'Four Elements' as the sources of all things.



http://ga.water.usgs.gov/edu/earthhowmuch.html

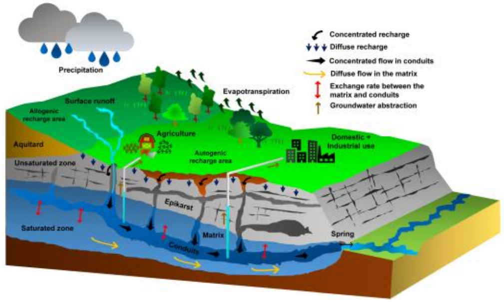
SWOT **S**urface **W**ater and **O**cean **T**opography



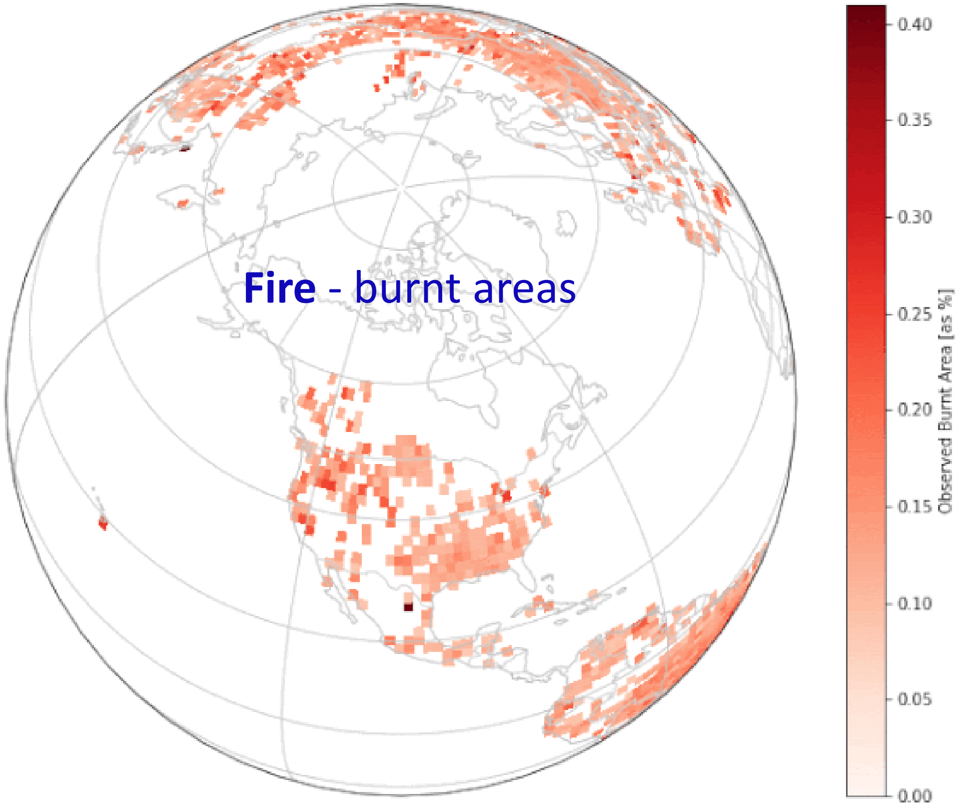


GOLD **G**lobal-scale **O**bservations of the **L**imb and **D**isk
ICON **I**onospheric **C**onnection **E**xplorer

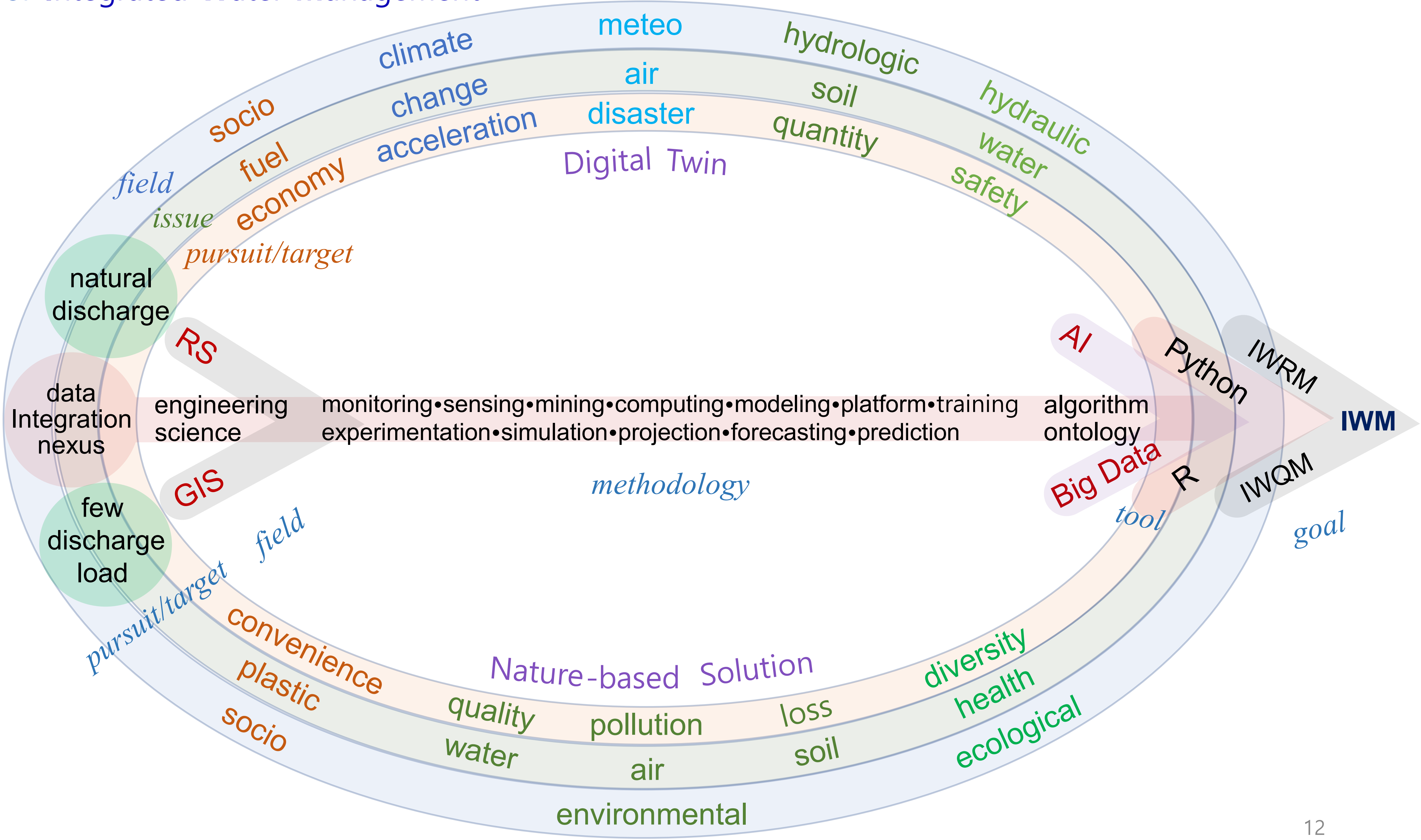
SWAT
Soil & Water Assessment Tool



MODIS Observed : 2015-09



Keywords for **I**ntegrated **W**ater **M**anagement



Digital Twin

First Proposed By **Michael Grieves** (2002, in the context of Product Lifecycle Management)

Term Popularized By **NASA** (around 2010, for spacecraft simulation and remote maintenance)

Field	Use Cases / Applications
Water Sector	**Reservoir and dam simulation** for optimized release control **Groundwater and river system modeling** Optimization of **urban water cycles** and wastewater systems Real-time monitoring of **water flow, pressure, and quality** **Leak detection** and predictive maintenance in pipe networks
Natural Disaster Management	**Flood risk modeling** based on weather, topography, and urban infrastructure City-wide **disaster response systems** using sensors, drones, and CCTV Simulation of **wildfire spread** using wind, vegetation, and terrain data **Landslide risk prediction** in mountainous or vulnerable areas **Earthquake response modeling** for infrastructure impact assessment
Climate & Weather	**Climate modeling and forecasting** using high-resolution simulations Support for **early warning systems** (e.g., typhoons, heatwaves, droughts) through real-time integration with weather satellites and sensors Scenario testing for **climate resilience planning** Creation of **virtual environments** to test policy impacts (e.g., urban heat islands, emission reductions) **Urban climate twin models** for predicting temperature, wind, and pollution in dense cities

Key function of **DT**

Self-evolution Process- the ability to adapt and improve for next success

Anomaly Detection, Error Attribution, Model Update/Calibration, Learning & Reconfiguration, Reinforcement-Like Learning

Archive → **Past** → Understand → **Present** → Predict → **Future** → Decision making
no regret

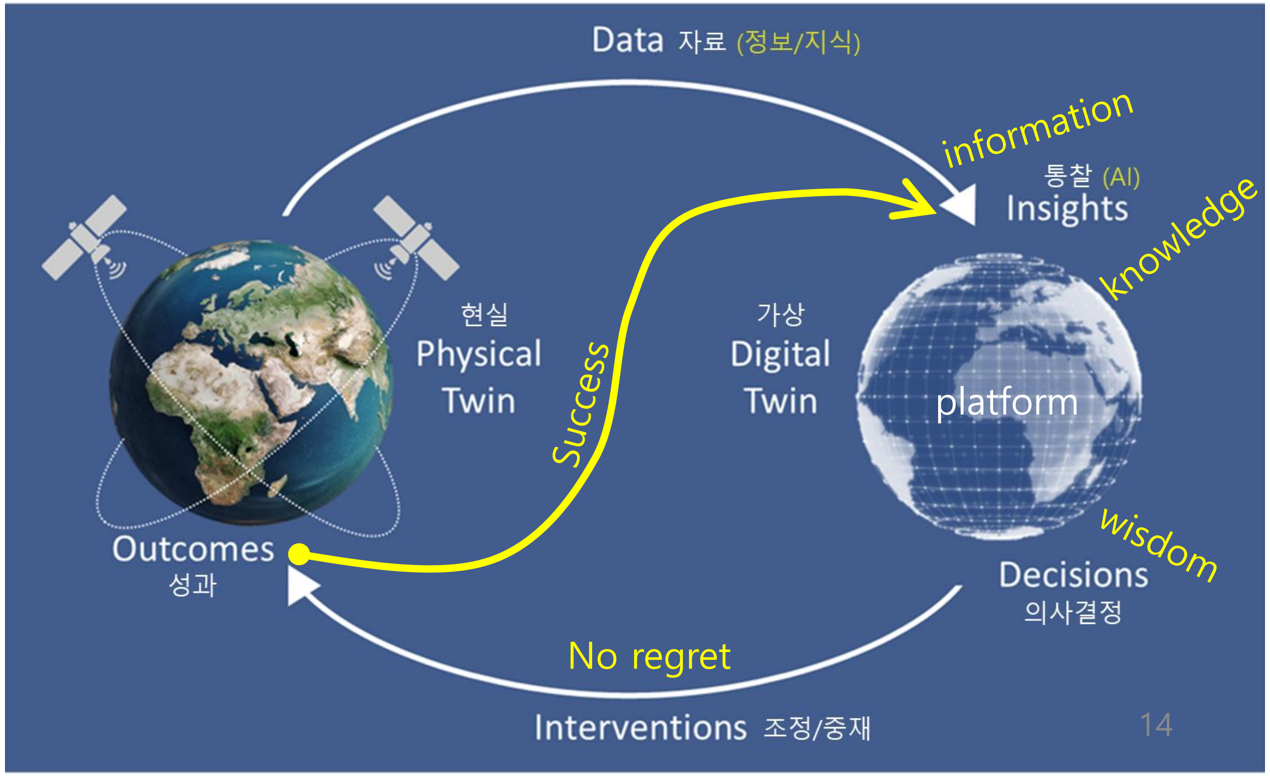
Archive	Past	Understand	Present	Predict	Future
Reports	Models	Monitor	Validate	Operate	Simulate
Studies	Visuals	Educate	Collaborate	Control	Forecast
Playback	Revisions	Analyze	Maintain	Optimize	Manage

✓ hindcast
- auto calibration
- parameter tuning

✓ nowcast
- adaptive calibration
- immediate update

✓ forecast
- trained prediction
- scenario simulation

Dam operation	**Digital Twin** self-evolution process
Failure detection	Downstream flooding despite controlled release
Cause analysis	Underestimated inflow, outdated rule curve, data error
Model correction	Update hydrological model parameters or forecast tools
Simulation update	Rerun scenarios with improved input and logic
Feedback memory	Store success/failure cases for future adaptive learning



Digital Twin for Drought Cycle

US Drought type	Focus & Monitoring Agencies
Meteorological	high focus NOAA, NWS, and NIDIS monitor precipitation, temperature anomalies
Agricultural	**very high focus** USDA uses soil moisture, crop conditions, and Drought Monitor outputs
Hydrological	strong focus USGS and Army Corps monitor streamflows, reservoir levels, groundwater
Socioeconomic	growing focus Integrated into NIDIS with economic loss estimates, especially in the West

EU Drought type	Focus & Monitoring Agencies
Meteorological	**very strong focus** ECMWF, Copernicus Climate Change Service (C3S), EUMETSAT
Agricultural	high focus JRC (Joint Research Centre), Copernicus monitors crop water stress & soil
Hydrological	moderate focus European Drought Observatory (EDO), national hydromet services
Socioeconomic	emerging EU Drought Risk Management frameworks consider economic impact less directly

Drought type	**South Korea**	Role
Meteorological	KMA	real-time precipitation and temperature monitoring climate model-based drought forecasts, SPI/SCPI drought index computation
Agricultural	**KRC**	soil moisture monitoring in farmland rice paddy Irrigation scheduling using sensor networks
Hydrological	K-water	reservoir and streamflow modeling water resource balance forecasting, AI-driven drought response at dam systems
Socioeconomic	Government	water demand planning and emergency response scenario testing for sectoral water allocation public warning and communication systems

자연기반해법 국제자연보전연합 IUCN

- 현재의 사회적 도전문제에 **효율적, 적응적**으로 맞서
- 인류복지와 생물다양성의 혜택을 동시에 제공할 수 있도록
  - 자연 또는 수정 생태계의 보호와 지속가능한 관리 및 회복시키기 위한 일련의 **행동**조치

† **Nature-based Solutions IUCN** International Union for Conservation of Nature (2009, 2016)

- actions 실행
  - to protect, sustainably manage, and restore natural or modified ecosystems
  - that address societal challenges effectively and adaptively 효율적/적응적 도전
  - simultaneously provide human well-being and biodiversity benefits. ① ②

① ② 인간-생태계 **혜택**

자연기반해법 유럽연합집행기관 EC

- **비용 효율적**이고
- 환경•사회•경제적 혜택과 회복력을 증진시키는데 **도움**을 주는
  - 자연으로부터 영감을 받고 지원을 받는 **해법**
- **지역**에 맞춰, 자원 효율적이면서 자연과 인간생태계 전반에 **개입**하여
- 도시, 풍경, 해경에
  - 더욱 다양하고 자연적인 특성과 과정을 제공하는 **해법**

‡ **Nature-based Solutions EC** European Commission (2015, 2017)

- solutions 해법
  - that are inspired and supported by nature
  - which are cost-effective, 비용 효율적
  - simultaneously provide environmental, social and economic benefits and help build resilience. ① ② ③ ④
- solutions
  - bring more, and more diverse, nature and natural features and processes
  - into cities, landscapes and seascapes
  - through locally adapted, resource-efficient and systemic interventions. 지역맞춤형 실행, 자원 효율적, 사회전반 참여유도

① ② ③ ④ 환경-사회-경제 **혜택**->기후변화 **적응**

기후변화 재해위험 물안보 식량안보 건강 사회경제적 발전

In front of

Nature-based Solutions

We need ecosystem-based approaches

Issue-specific ecosystem-related approaches

- 생태계기반 적응
- 생태계기반 완화
- 기후적응서비스
- 생태계기반 재해위험 저감

- Ecosystem-based adaptation
- Ecosystem-based mitigation
- Climate adaptation services
- Ecosystem-based disaster risk reduction

Ecosystem protection approaches

- 보호지역 관리를 포함한 유역기반 보전기법

- Area-based conservation approaches, including protected area management

- 자연 인프라
- 그린 인프라

Infrastructure-related approaches

- Natural infrastructure
- Green infrastructure

- 통합해안관리
- 통합수자원관리

Ecosystem-based management approaches

- Integrated coastal zone management
- Integrated water resources management

Ecosystem restoration approaches

- Ecological restoration
- Ecological Engineering
- Forest landscape restoration

- 생태적 복원
- 생태공학
- 산림경관 복구

사회인프라

명확한 쟁점

관리

보호

복원/복구

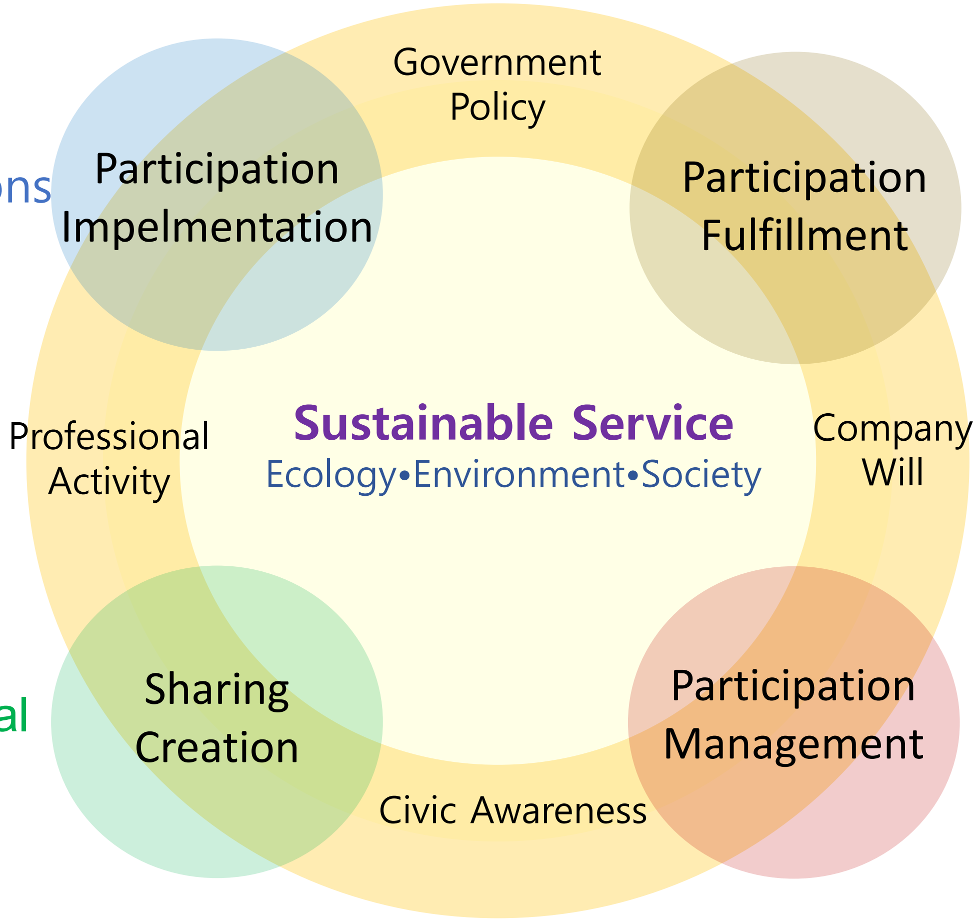
인류복지

생물다양성 혜택

Societal challenges to provide human well-being and biodiversity benefits

탄소중립 Carbon Neutral
- 산업-에너지-물-기후변화 Nexus
- 탄소중립 CO_2 순배출 제로화
- Net-Zero 6대 온실가스 순배출 제로화
  - 이산화탄소, 메탄, 이산화질소, 수소불화탄소, 과불화탄소, 육불화황

Nature-based Solutions
(2009, IUCN)



Carbon Neutral
(1997, Kyoto Protocol)

Green New Deal
(2007, UK)

ESG (2004, UN)
Environment, Social, Governance

그린 뉴딜 (Green New Deal) 기술사업 R&BD
- 사회간접자본 vs. 사회인프라 - 4차산업혁명
- 사회인프라 vs. 그린인프라 - 기후변화
- 그린인프라 - 공유인프라 - 가치인프라 – 치유•창출

그린뉴딜 (지속) 디지털뉴딜 (혁신) 휴먼뉴딜 (창출)

ESG **경영** Administration

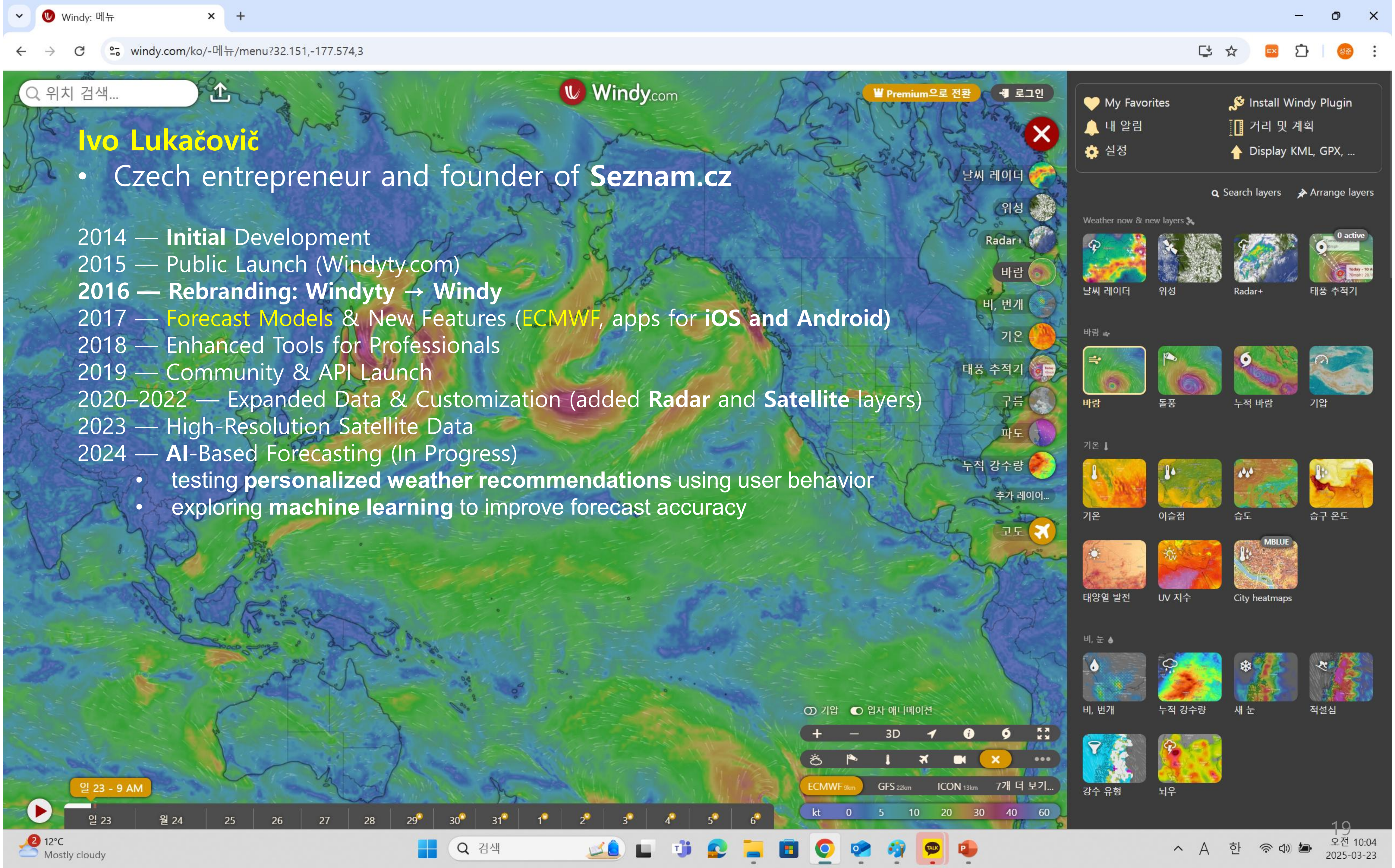
환경(E)이슈	사회(S)이슈	지배구조(G)이슈
- 기후변화 및 탄소배출	- 고객만족	- 이사회 구성
- 대기 및 수질오염	- 데이터 보호 및 프라이버시	- 감사위원회 구조
- 생물의 다양성	- 성별 및 다양성	- 노물 및 부패
- 삼림 벌채	- 직원참여	- 임원보상
- 에너지 효율	- 지역사회 관계	- 로비
- 폐기물 관리	- 인권	- 정치 기부금
- 물 부족	- 노동기준	- 내부 고발자 제도

Ivo Lukačovič

- Czech entrepreneur and founder of **Seznam.cz**

2014 — **Initial** Development
2015 — Public Launch (Windyty.com)
2016 — Rebranding: Windyty → Windy
2017 — Forecast Models & New Features (ECMWF, apps for **iOS and Android)**
2018 — Enhanced Tools for Professionals
2019 — Community & API Launch
2020–2022 — Expanded Data & Customization (added **Radar** and **Satellite** layers)
2023 — High-Resolution Satellite Data
2024 — **AI**-Based Forecasting (In Progress)

- testing **personalized weather recommendations** using user behavior
- exploring **machine learning** to improve forecast accuracy

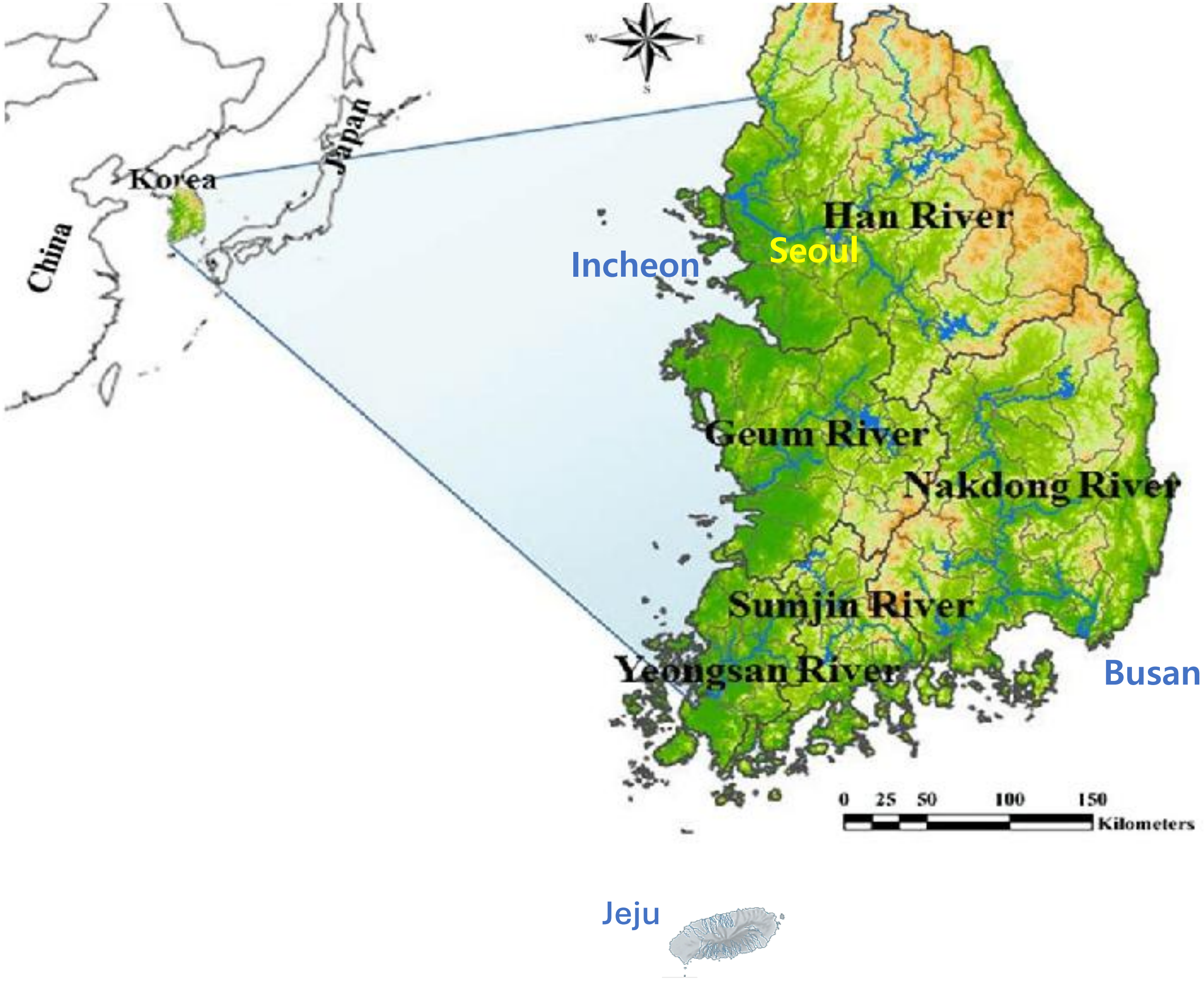


- Windy replicates and visualizes real-world atmospheric systems
  - **Digital Twin** of the Earth's Atmosphere
    - partial or early form of a digital twin
    - **potential with SWAT** for two-way interaction or control of physical environments
      - Flood/Drought Forecasting & Water Resource Management
      - Smart Agriculture / Climate Services for Farming
      - Soil Erosion and Sediment Transport Modeling
      - Climate Change Scenario Simulations
      - Smart Cities & Digital Twin Platforms

- **Nature-Based Solutions applicable in SWAT**
  - Forest Restoration & Vegetation Expansion- modify land use/land cover in HRUs
  - Riparian Buffer Strips- set grassland or forest in HRUs along streams
  - Conservation Agricultural Practices- adjust surface roughness, tillage methods (e.g., no-till), management schedules
  - Wetland Restoration and Construction- define wetland areas in HRUs or insert wetlands as landscape features
  - Vegetative Low Impact Development (LID)- assume land use with infiltration structures
  - Terracing and Slope Stabilization- activate the terrace option or modify slope class in HRUs
  - Cover Crops- add cover crops in management schedules of HRUs
  - Small Dams, Ponds, Sediment Basins- use pond or reservoir features in SWAT

Integration examples with **SWAT**

① Assessment of **watershed health, vulnerability, and resilience** for determining protection and restoration Priorities
② Quantification of long-term watershed environment change impact on **stream drying phenomena**
③ Integration of SWAT, CE-QUAL-2, and PHABSIM to **secure ecological flow**
④ **Advanced detection** of **agricultural drought** using Terra MODIS NDVI



South Korea

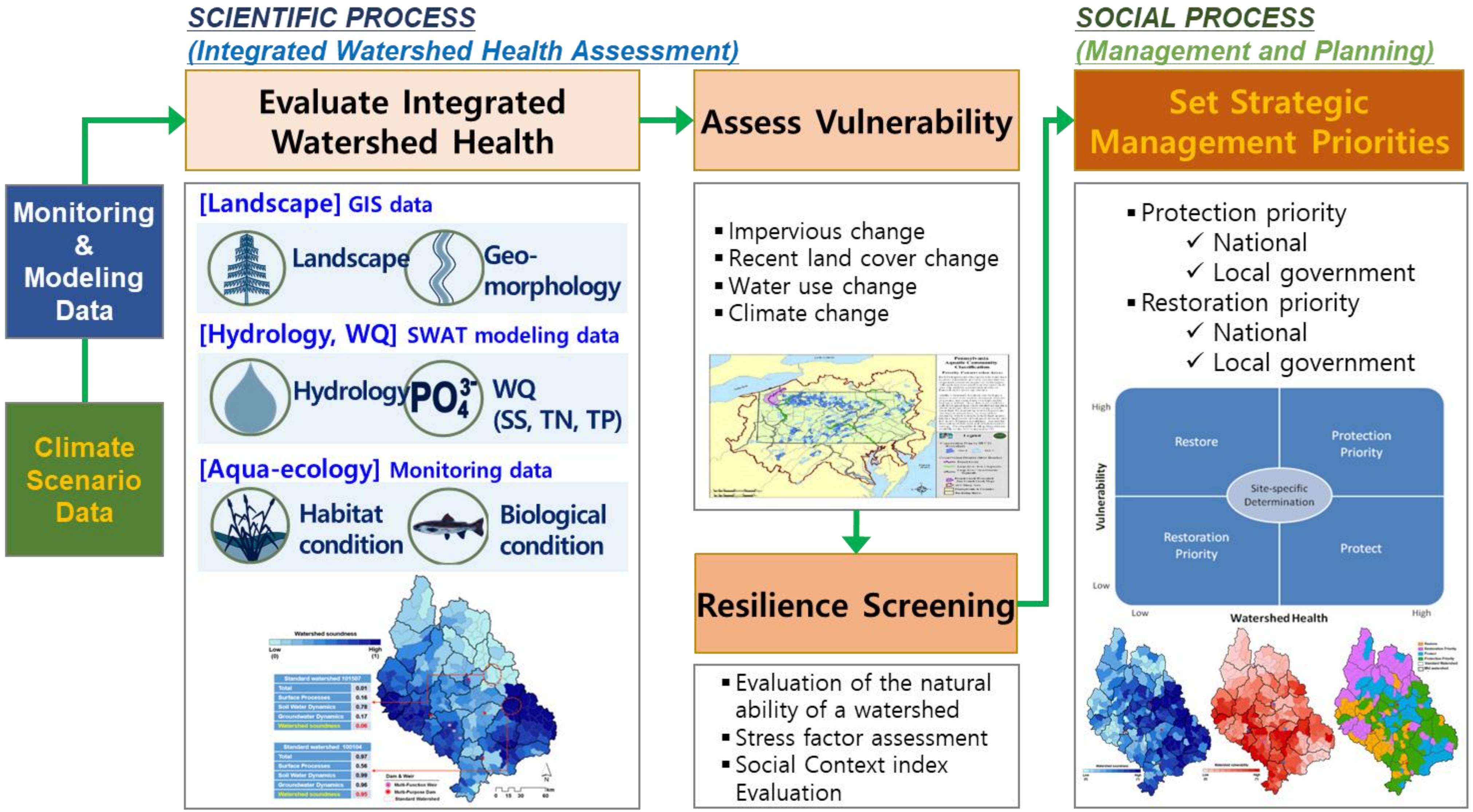
- Area 100,210km²

Name	Area (km²)
Han River	26,018
Nakdong River	23,817
Geum River	9,885
Seomjin River	4,896
Yeongsan River	3,467
Jeju Island	1,849

Land Use Type	Area (km²)
Forest Land	63,000
Agricultural Land	17,000
Residential Area	3,700
Industrial Area	1,200
Commercial Area	500
Public Facilities	3,000
Transportation	2,500
Water Bodies	2,000
Others	2,000

① Assessment of watershed health, vulnerability and resilience for determining protection and restoration Priorities

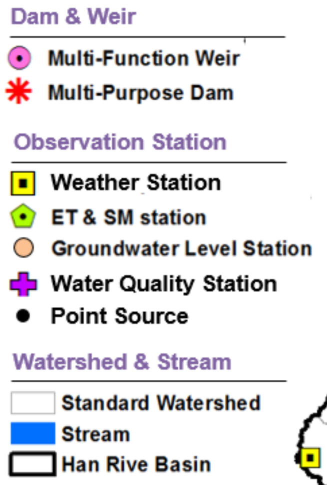
S. Ahn, **S. Kim** *Environmental Modelling & Software*. 122, 103926, 2019.12

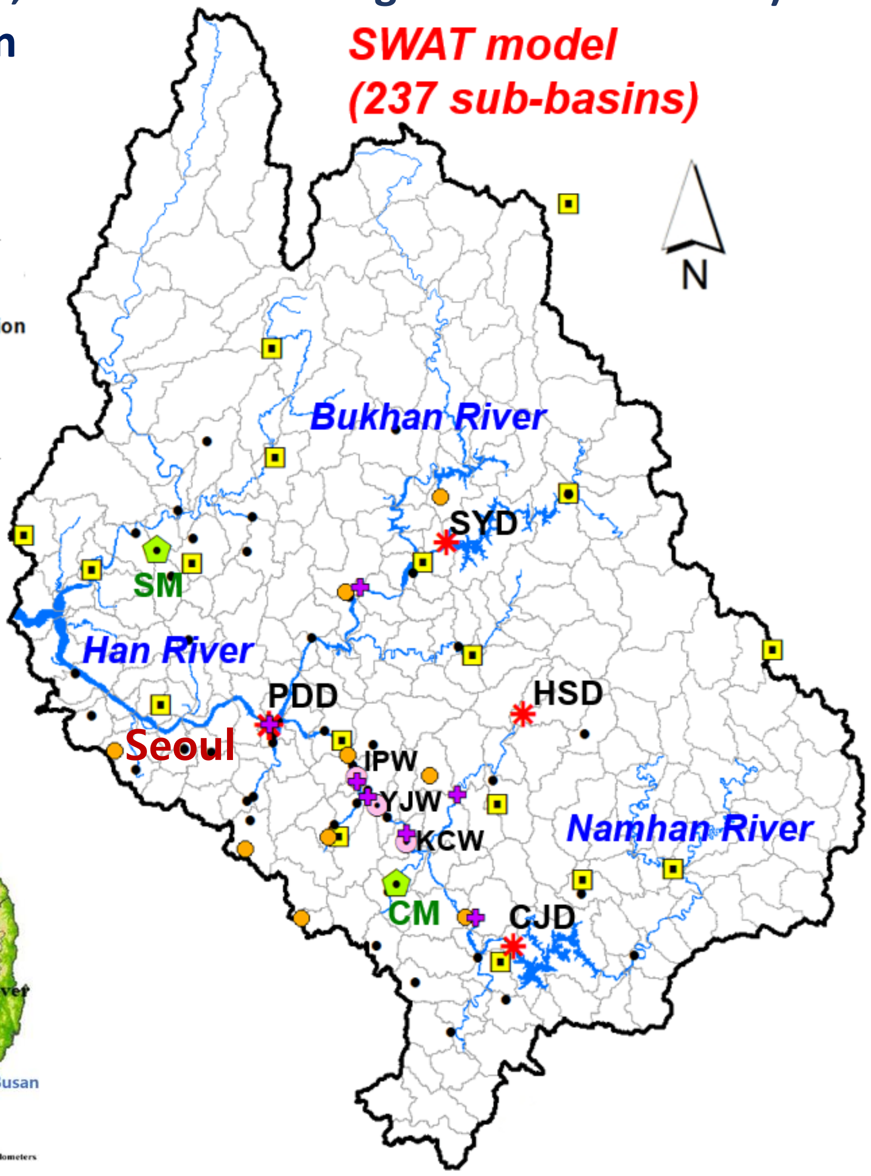


SWAT streamflow & water quality modeling

25,953.6㎢ (35,770.41㎢ including North Korea areas)

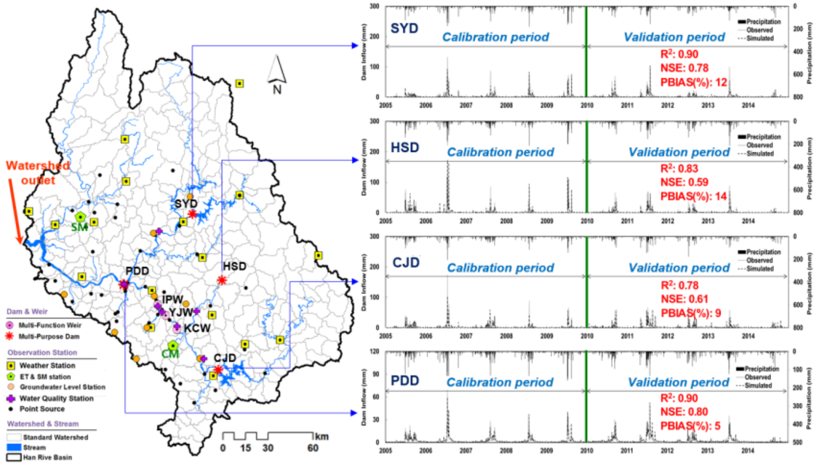
Han river basin



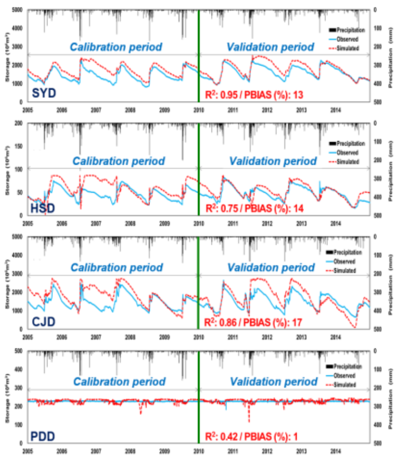


Dam inflows

✓ Calibration : 5 years (2005-2009) / Validation : 5 years (2010-2014)

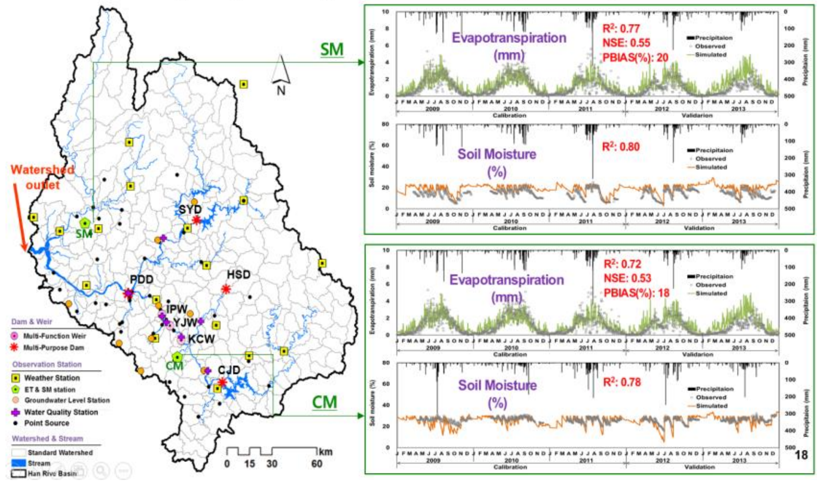


Dam water level

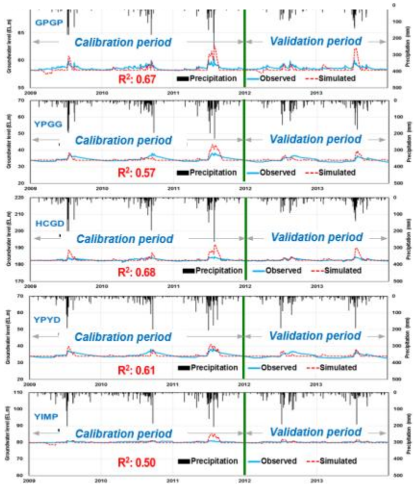


ET & Soil Moisture

✓ Calibration : 3 years (2009-2011) / Validation : 2 years (2012-2013)

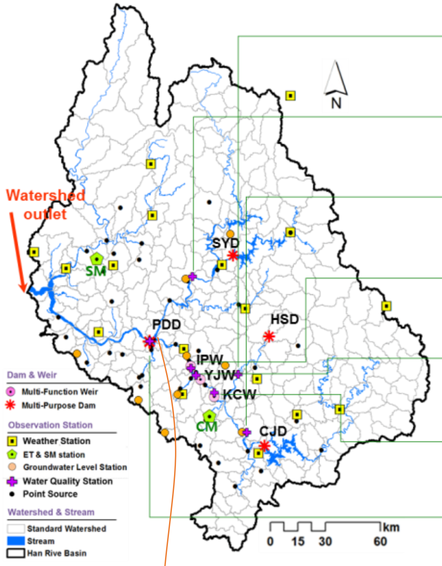


Groundwater level

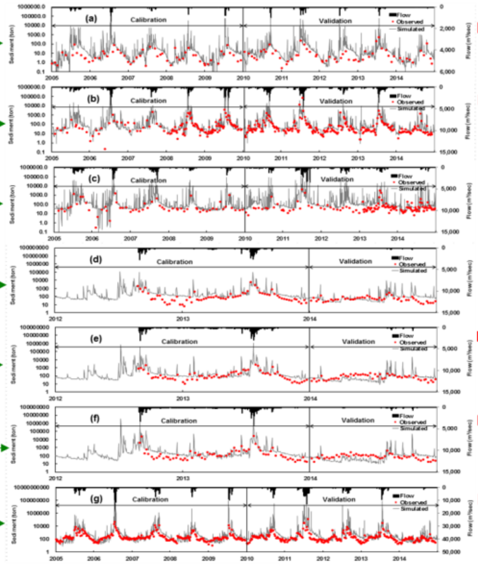


SWAT streamflow & water quality modeling

✓ Calibration : 5 years (2005-2009) / Validation : 5 years (2010-2014)

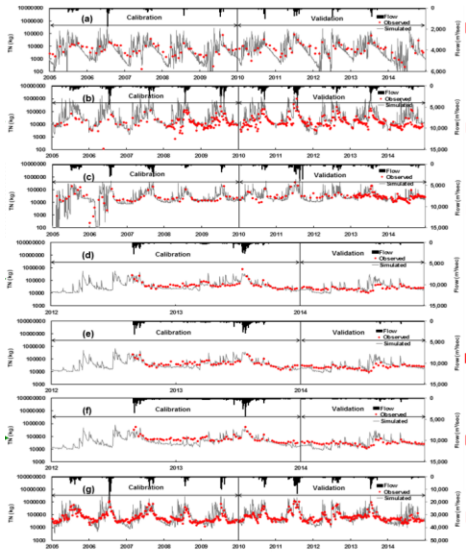


Suspended solid



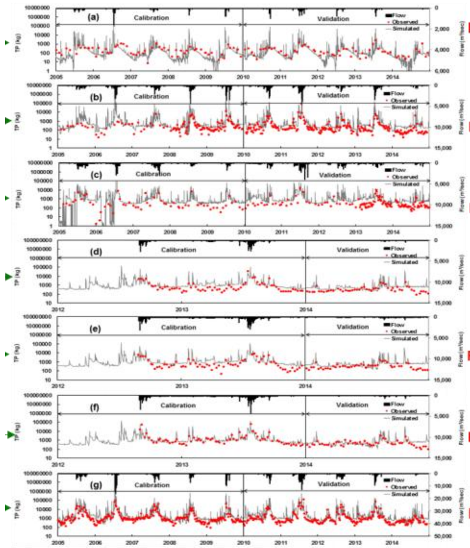
R^2: 0.74
R^2: 0.75
R^2: 0.80
R^2: 0.61
R^2: 0.64
R^2: 0.61
R^2: 0.76

Total Nitrogen



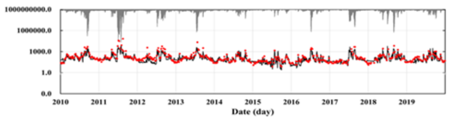
R^2: 0.64
R^2: 0.70
R^2: 0.75
R^2: 0.67
R^2: 0.65
R^2: 0.67
R^2: 0.64

Total Phosphorus

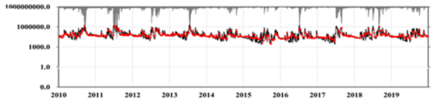


R^2: 0.77
R^2: 0.90
R^2: 0.68
R^2: 0.57
R^2: 0.58
R^2: 0.58
R^2: 0.71

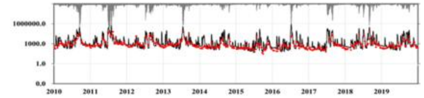
Calibration: 6 years (2010-2015) Validation: 4 years (2016-2019)



R^2 : 0.82

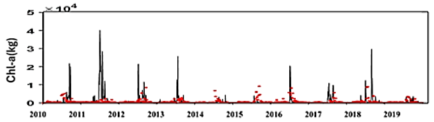


R^2 : 0.80



R^2 : 0.75

Chl-a



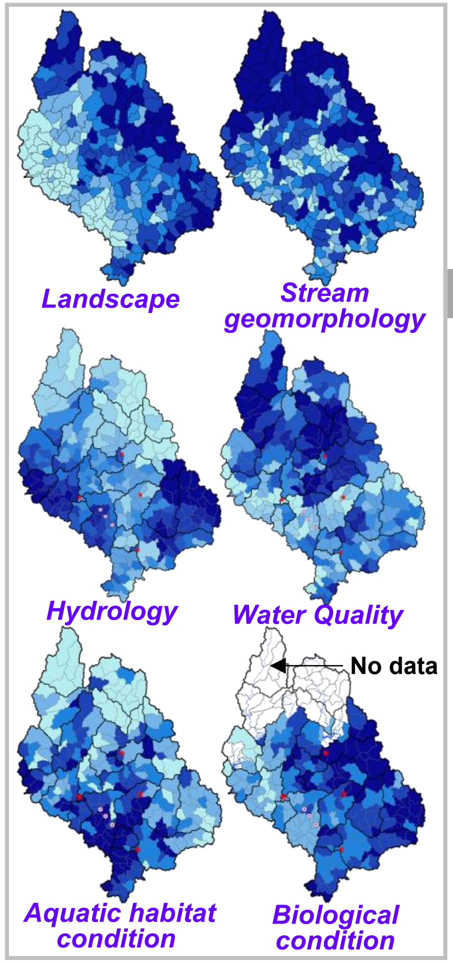
R^2 : 0.50

SCIENTIFIC PROCESS

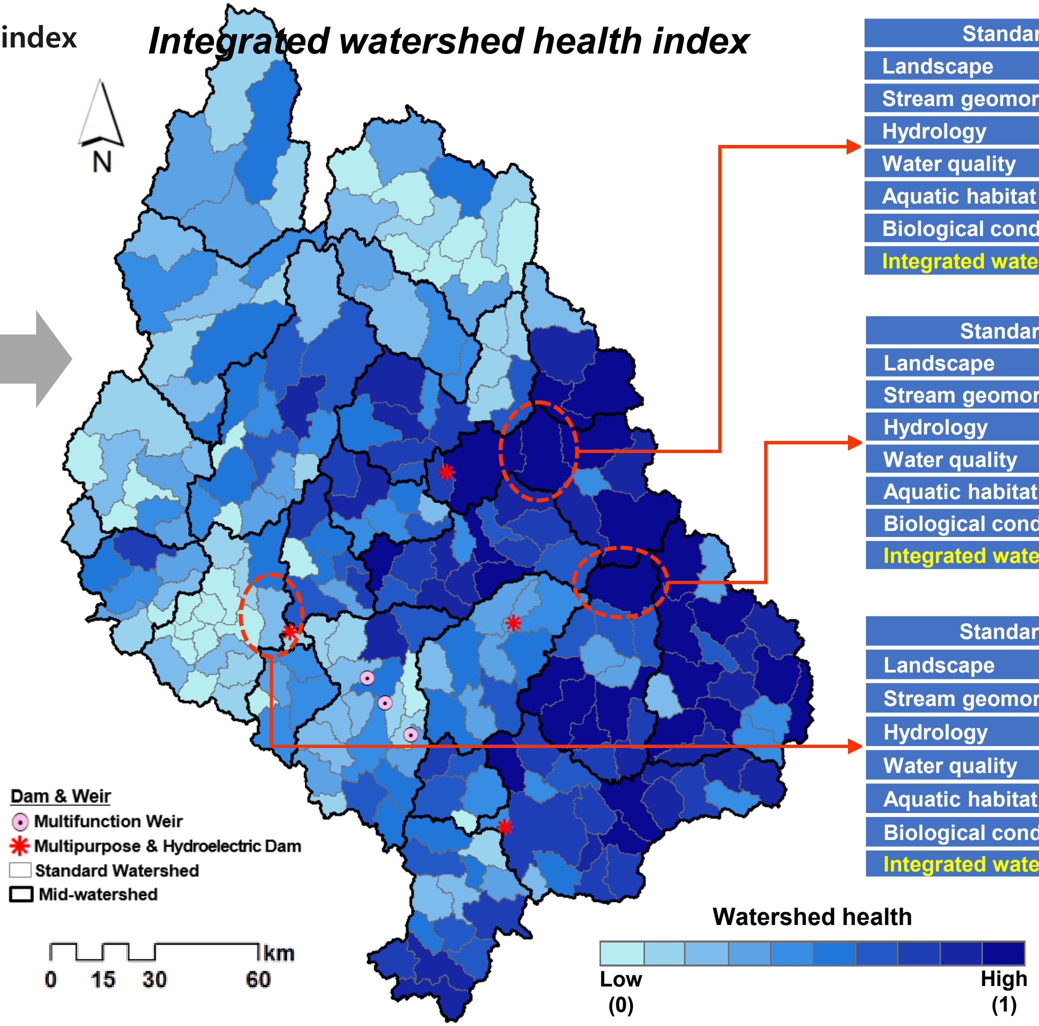
Assessment of watershed health based on natural environment

Assessment of integrated watershed health

- Integrated watershed health index



Integrated watershed health index



Standard watershed 101206	
Landscape	0.89
Stream geomorphology	0.94
Hydrology	0.06
Water quality	0.77
Aquatic habitat condition	0.90
Biological condition	0.91
Integrated watershed health	1.00

Standard watershed 100201	
Landscape	0.66
Stream geomorphology	0.93
Hydrology	0.96
Water quality	0.10
Aquatic habitat condition	0.28
Biological condition	0.83
Integrated watershed health	0.91

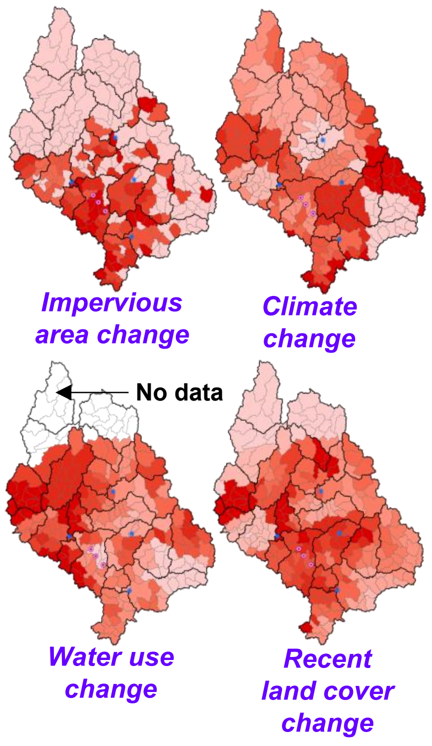
Standard watershed 101801	
Landscape	0.17
Stream geomorphology	0.63
Hydrology	0.85
Water quality	0.03
Aquatic habitat condition	0.68
Biological condition	0.26
Integrated watershed health	0.25

SCIENTIFIC PROCESS

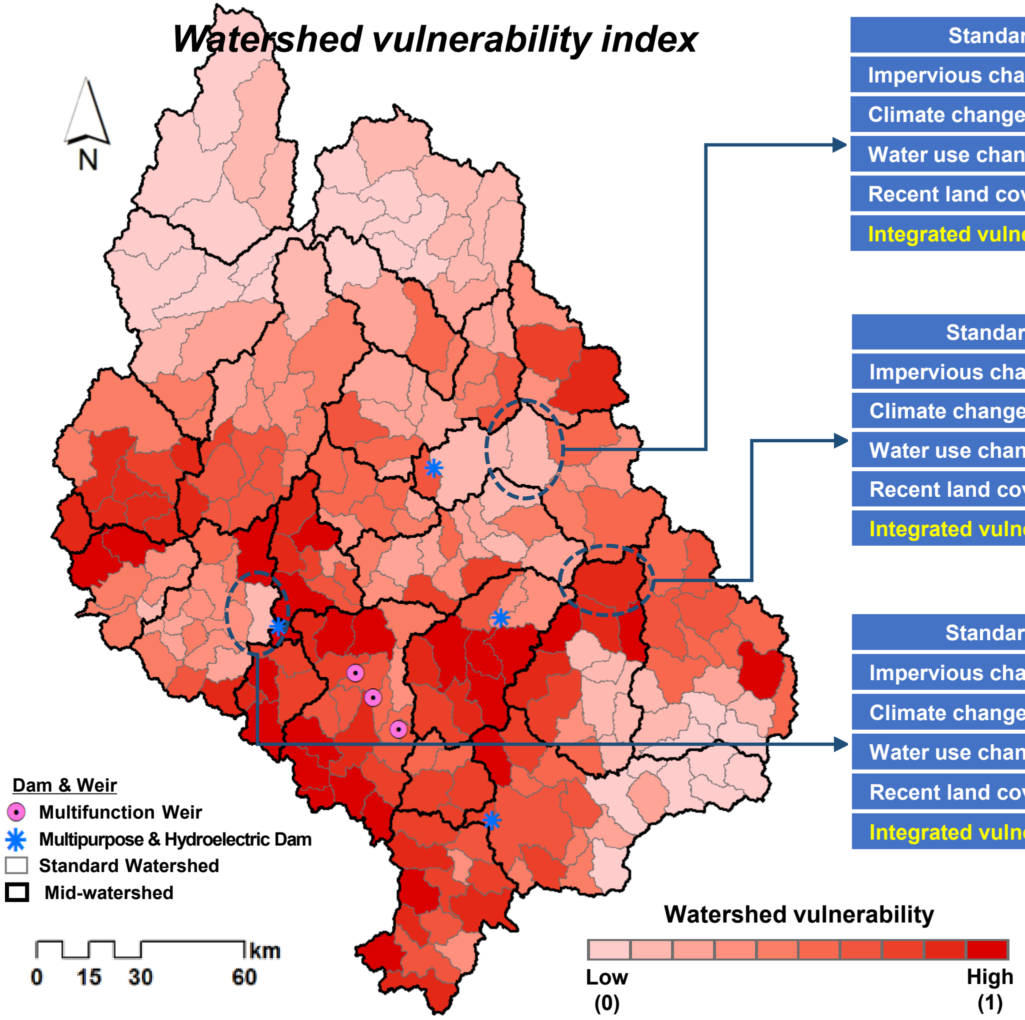
Assessment of watershed vulnerability based on artificiality factor

Assessment of integrated watershed vulnerability

■ Watershed vulnerability index



Watershed vulnerability index



Standard watershed 101206	
Impervious change	0.00
Climate change	0.40
Water use change	0.22
Recent land cover change	0.36
Integrated vulnerability	0.20

Standard watershed 100201	
Impervious change	0.68
Climate change	0.95
Water use change	0.28
Recent land cover change	0.79
Integrated vulnerability	0.86

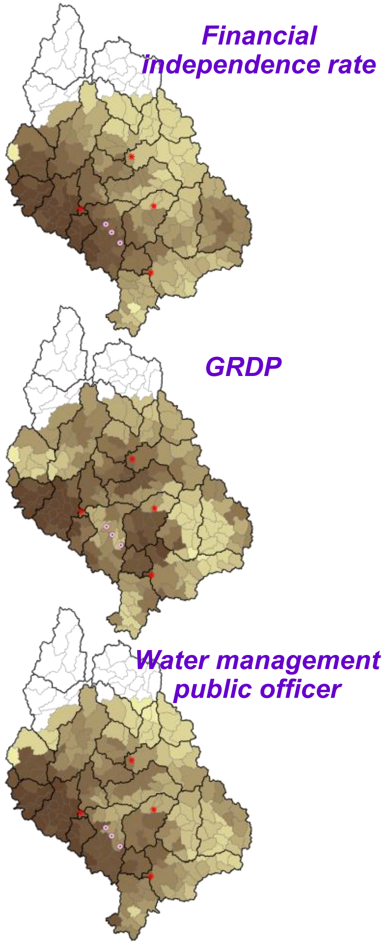
Standard watershed 101801	
Impervious change	0.00
Climate change	0.15
Water use change	0.70
Recent land cover change	0.15
Integrated vulnerability	0.20

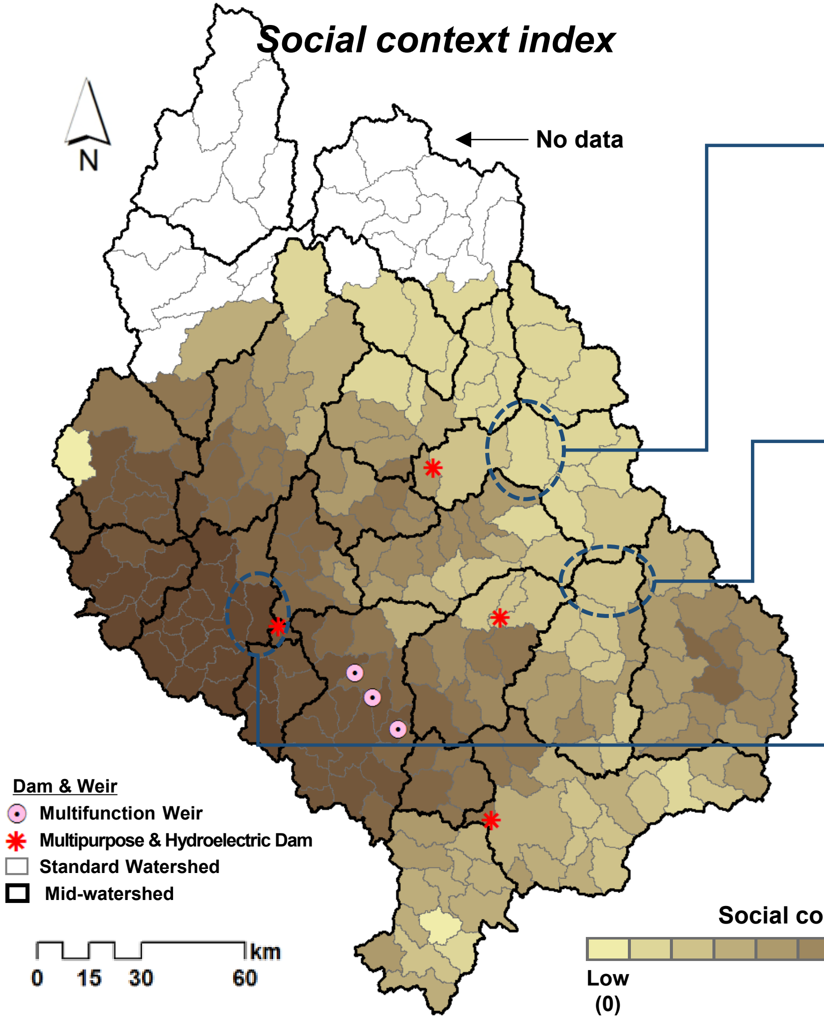
SCIENTIFIC PROCESS

Assessment of watershed social context

Assessment of social context metrics

- Social context index





Standard watershed 101206	
Financial independence rate	0.18
GRDP	0.47
WM public officer	0.29
Social context	0.18

Standard watershed 100201	
Financial independence rate	0.22
GRDP	0.27
WM public officer	0.33
Social context	0.23

Standard watershed 101801	
Financial independence rate	0.94
GRDP	0.95
WM public officer	0.96
Social context	0.96

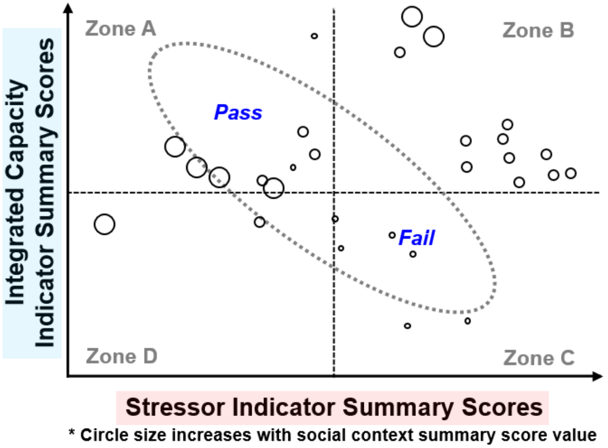
GRDP Gross Regional Domestic Product

SOCIAL PROCESS

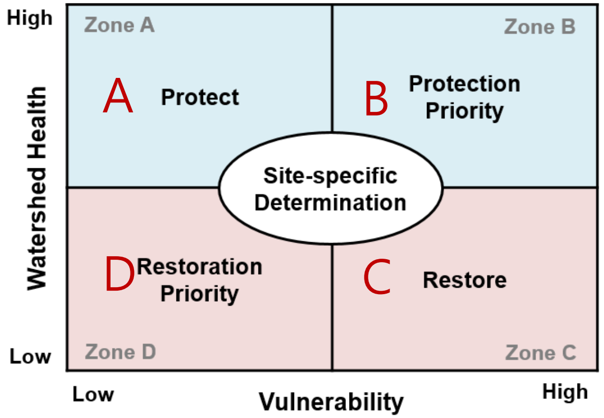
Assessment of watershed resilience and restoration priority

Assessment of watershed resilience and restoration priority considering watershed health, vulnerability, and social context

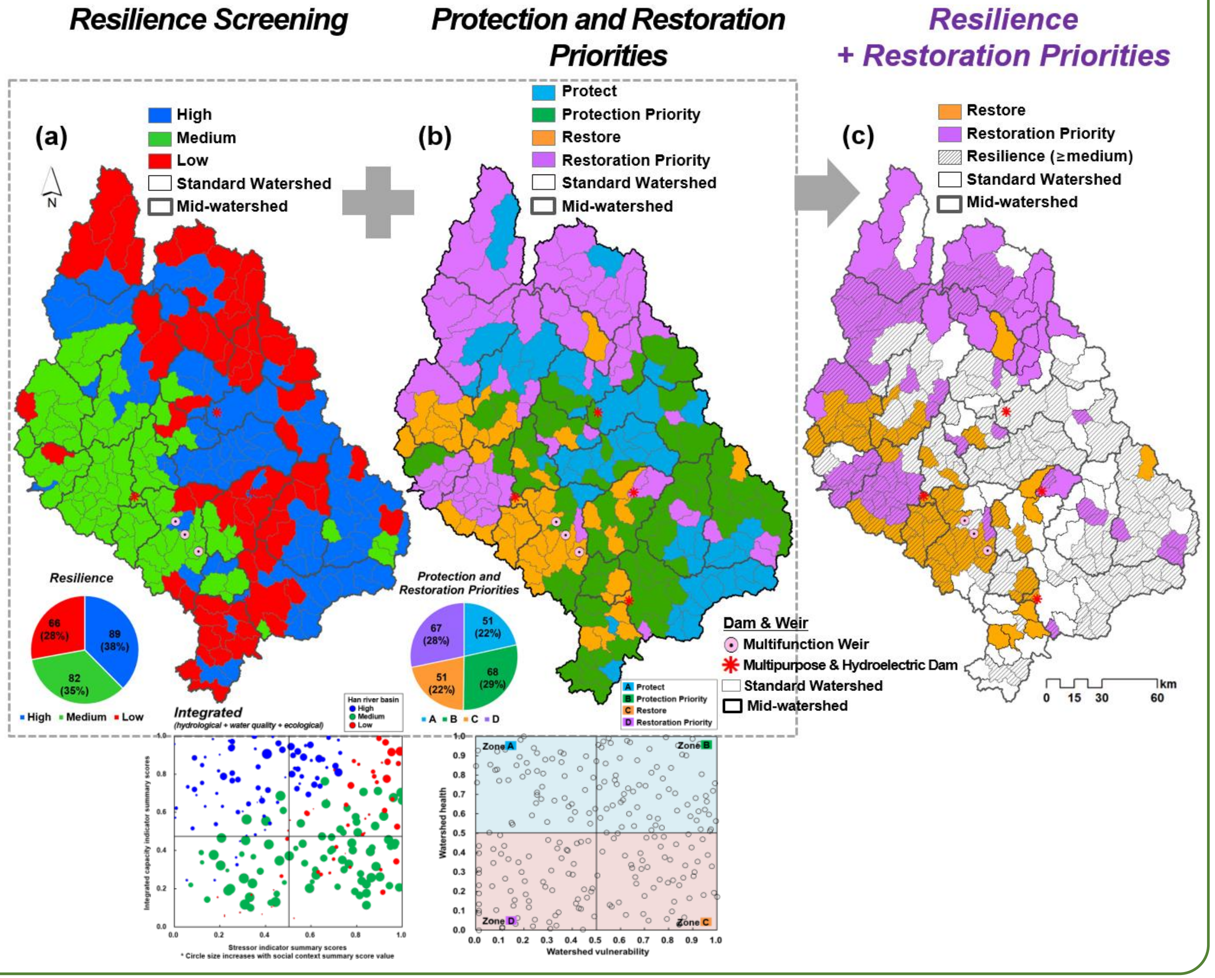
Resilience screening



Priority



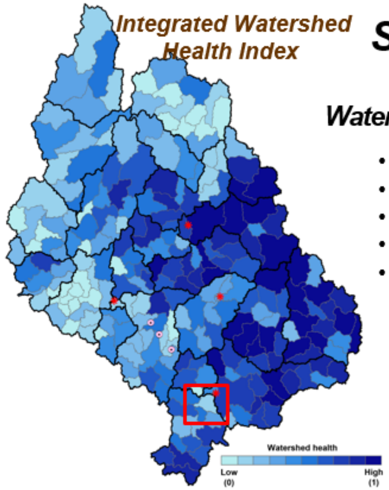
Assessment of Resilience and Restoration priorities



SOCIAL PROCESS

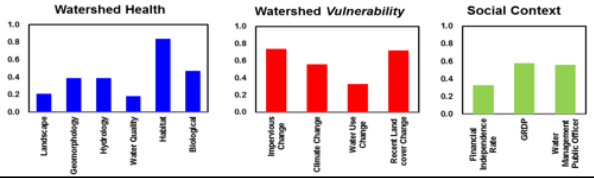
Assessment of watershed resilience and restoration priority

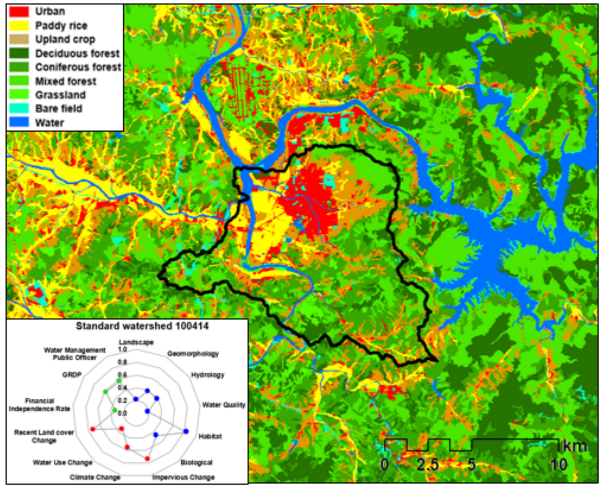
Application Strategy for restoration priorities to the watershed management



Standard watershed 100414
(Dal-cheon downstream)
Watershed Health, Vulnerability, Resilience and Priority

- *Watershed Health Score* 0.18
- *Watershed Vulnerability Score* 0.70
- *Social Context Score* 0.34
- *Resilience (Recovery Potential)* Low
- *Protection and Restoration Priority* Zone C (Restore)





Component Scores → Result

Watershed Health

Landscape 0.21	Hydrology 0.39	Habitat 0.84
Component Scores • Green Area 0.19 • Active River Area 0.25	**Component Scores** • Total 0.15 • Surface Processes 0.76 • Soil Water Dynamics 0.18 • Groundwater Dynamics 0.12	**Component Scores** • Aquatic Habitat Connectivity 0.82 • Wetland 0.89
Geomorphology 0.39	**Water Quality 0.18**	**Biological 0.47**
Component Scores • Stream Geomorphology 0.39	**Component Scores** • Sediment 0.27 • T-N 0.58 • T-P 0.19	**Component Scores** • TDI 0.53 • BMI 0.61 • FAI 0.38

Watershed Vulnerability

Impervious Change 0.74	Water Use Change 0.33
Component Scores • Impervious Change 0.74	**Component Scores** • Domestic Water 0.51 • Industrial Water 0.36 • Agricultural Water 0.23
Climate Change 0.56	**Recent Land cover Change 0.72**
Component Scores • Precipitation 0.81 • Max. Temperature 0.06 • Min. Temperature 0.22	**Component Scores** • Recent Land cover Change 0.72

Social Context

Social Context 0.34
Component Scores • Financial Independence Rate 0.33 • GRDP 0.58 • Water Management Public Officer 0.56

Result

Zone C (Restore)

↓

Action

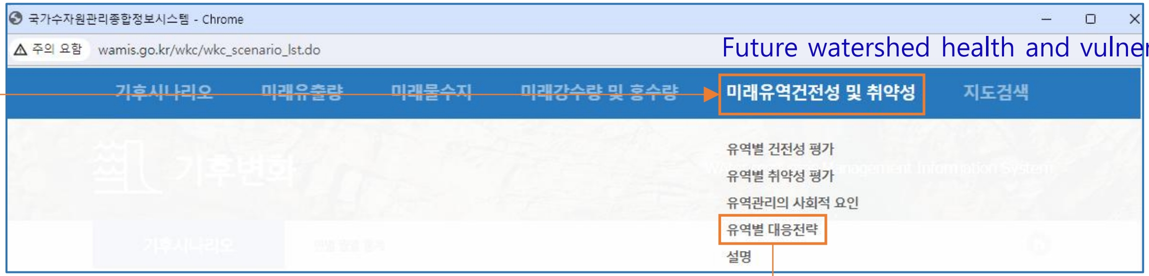
National
- Grassland reserve
- TMDL program
- NPS management
- Groundwater management

Local
- Reforestation
- Conjunctive surface-groundwater management

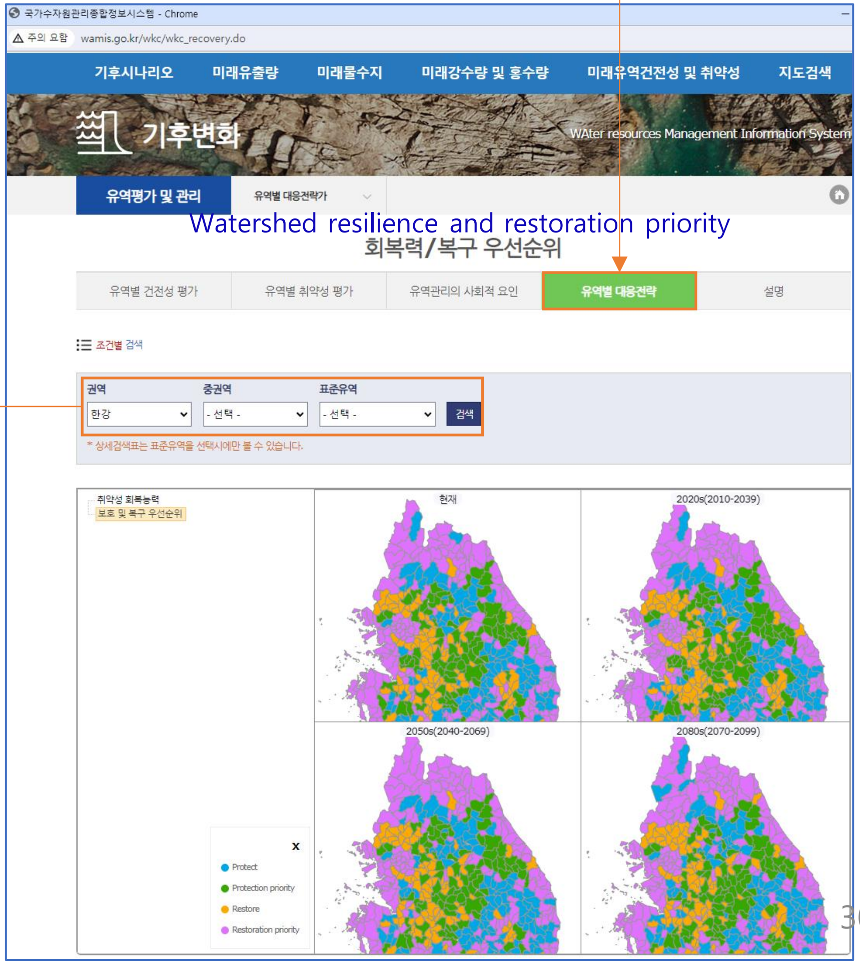
http://www.wamis.go.kr/ for each standard watershed (120 km^2, 850)

Water Resources Management Information System

Climate change

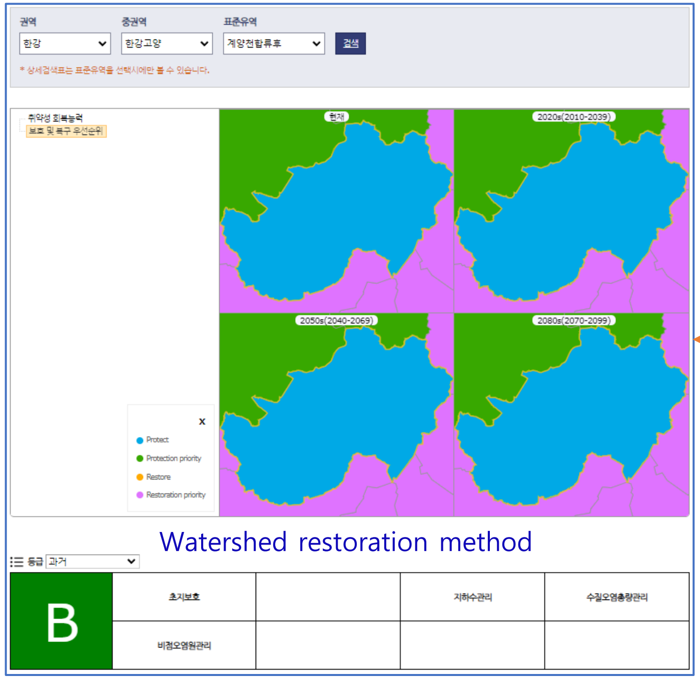


Future watershed health and vulnerability



Watershed resilience and restoration priority

회복력/복구 우선순위

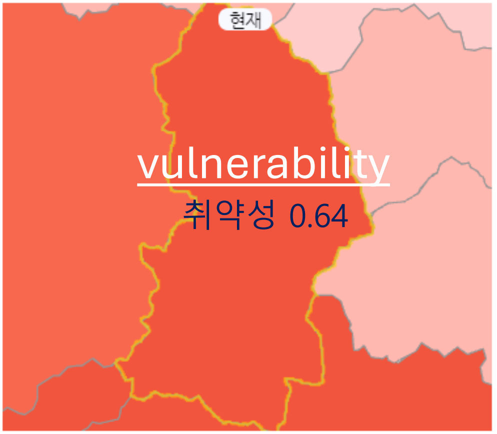


Watershed restoration method

- 0.9 < 건전성 <= 1
- 0.8 < 건전성 <= 0.9
- 0.7 < 건전성 <= 0.8
- 0.6 < 건전성 <= 0.7
- 0.5 < 건전성 <= 0.6
- 0.4 < 건전성 <= 0.5
- 0.3 < 건전성 <= 0.4
- 0.2 < 건전성 <= 0.3
- 0.1 < 건전성 <= 0.2
- 0.0 < 건전성 <= 0.1

유역 건전성 watershed health

유역 건전성 통합지수 (0.36)		과거			
Landscape 토지피복지수 0.41		***Hydrology*** 수량 건전성 0.98		***Biological condition*** 생태서식지 건전성 0.33	
자연식생	0.26	총유출	0.95	호소	0
수변구역	0.61	지표유출	0.92	습지	0.57
		중간유출	0.94		
		기저유출	0.76		
Stream geomorphology 하천 0.6		***Water Quality*** 수질 건전성 0.09		***Aquatic habitat condition*** 수생태 건전성 0.35	
하천형상	0.39	Sediment	0.17	TDI	0.21
		T-N	0.16	BMI	0.72
		T-P	0.45	FAI	0.18



- 0.9 < 취약성 <= 1
- 0.8 < 취약성 <= 0.9
- 0.7 < 취약성 <= 0.8
- 0.6 < 취약성 <= 0.7
- 0.5 < 취약성 <= 0.6
- 0.4 < 취약성 <= 0.5
- 0.3 < 취약성 <= 0.4
- 0.2 < 취약성 <= 0.3
- 0.1 < 취약성 <= 0.2
- 0.0 < 취약성 <= 0.1

유역 취약성 watershed vulnerability

유역 취약성 통합지수(0.64)		과거					
Impervious area change 불투수층변화(도시개발) 0		***Water use change*** 물수요변화 0.84		***Climate change*** 기후변화 0.99		***Recent land cover change*** 최근토지피복변화 0.42	
불투수면적 변화(도시개발)	0	상수도	0.65	강수량	0.97	최근토지이용변화	0.42
		공업용수	0.71	최고기온	0.97		
		농업용수	0.84	최저기온	0.76		

- 0.9 < 사회적요인 <= 1
- 0.8 < 사회적요인 <= 0.9
- 0.7 < 사회적요인 <= 0.8
- 0.6 < 사회적요인 <= 0.7
- 0.5 < 사회적요인 <= 0.6
- 0.4 < 사회적요인 <= 0.5
- 0.3 < 사회적요인 <= 0.4
- 0.2 < 사회적요인 <= 0.3
- 0.1 < 사회적요인 <= 0.2
- 0.0 < 사회적요인 <= 0.1

- Low
- Medium
- High

- Protect 보호
- Protection priority 보호우선
- Restore 복구
- Restoration priority 복구우선

사회적 요인 watershed social context

사회적요인 통합지수(0.38)		과거			
재정자립도 ***Financial independence rate***	0.38	지역내 총생산 ***GRDP***	0.54	물관리 공무원 수 ***Water management public officer***	0.54

등급 과거 ~현재 2080S(2070-2099) watershed protection and restoration priorities

A	protection of grassland	management of surface water	management of groundwater	management of TMDL
	management of NPS pollution	management of industrial water	reforestation	

1970s




2000s ~



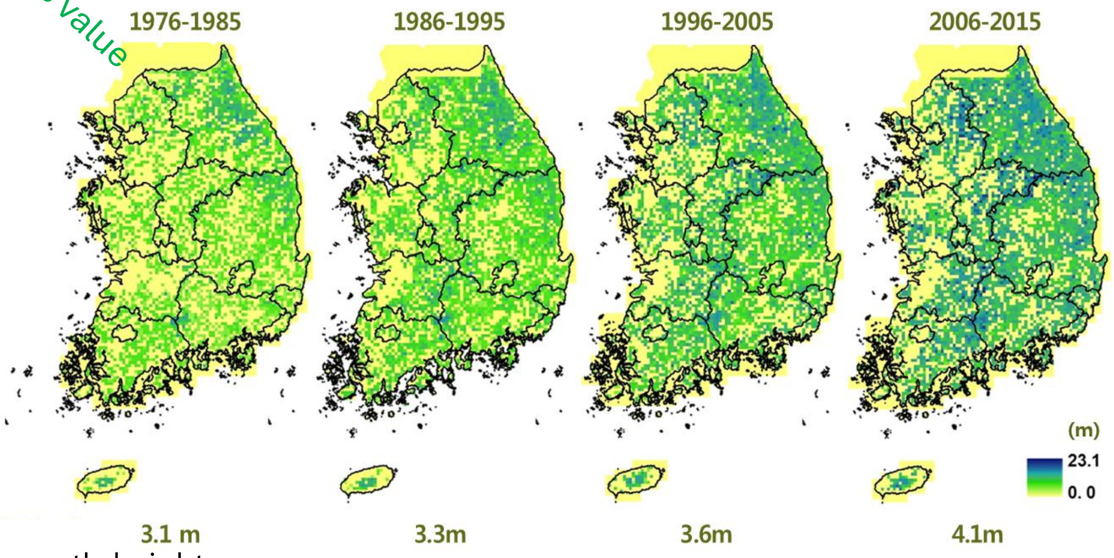



② Quantification of long-term watershed environment change impact on **stream drying phenomena**

Streamflow reducing factors

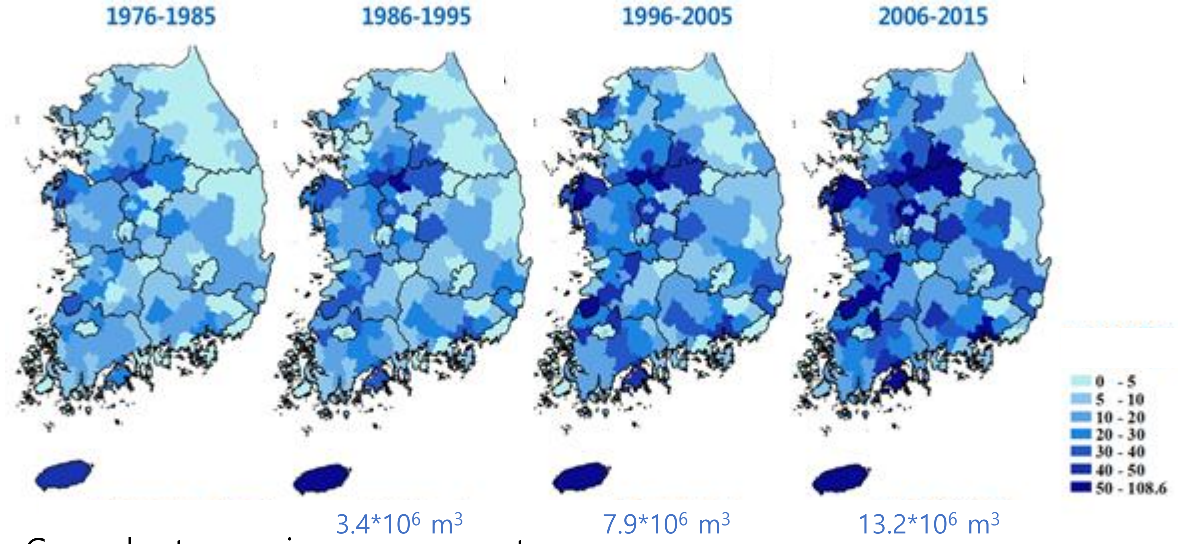
reference value

Forest grown up



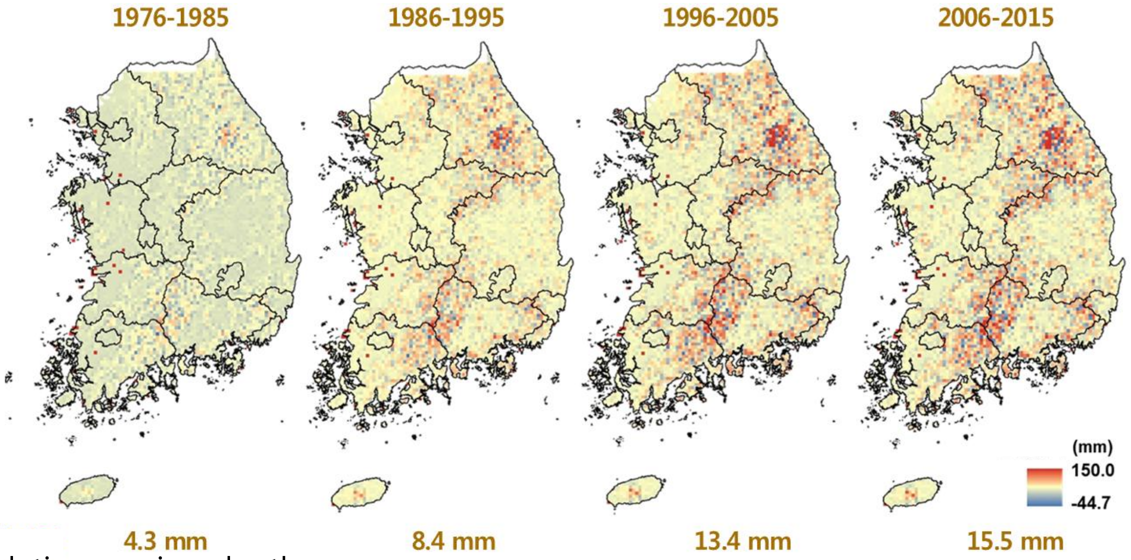
Tree growth height

Groundwater use increased



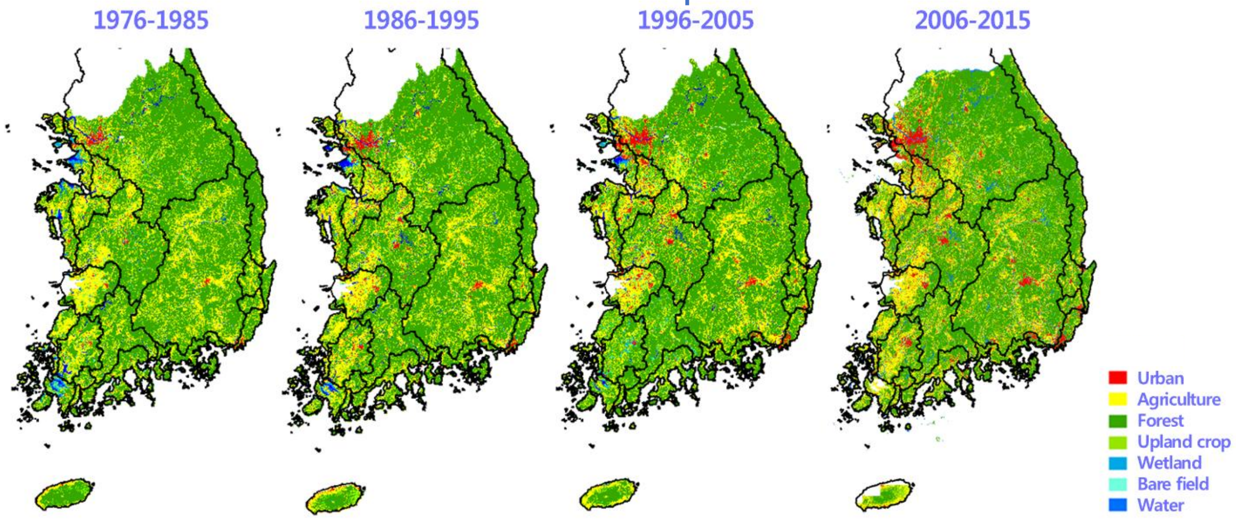
Groundwater use increase amount

Soil eroded



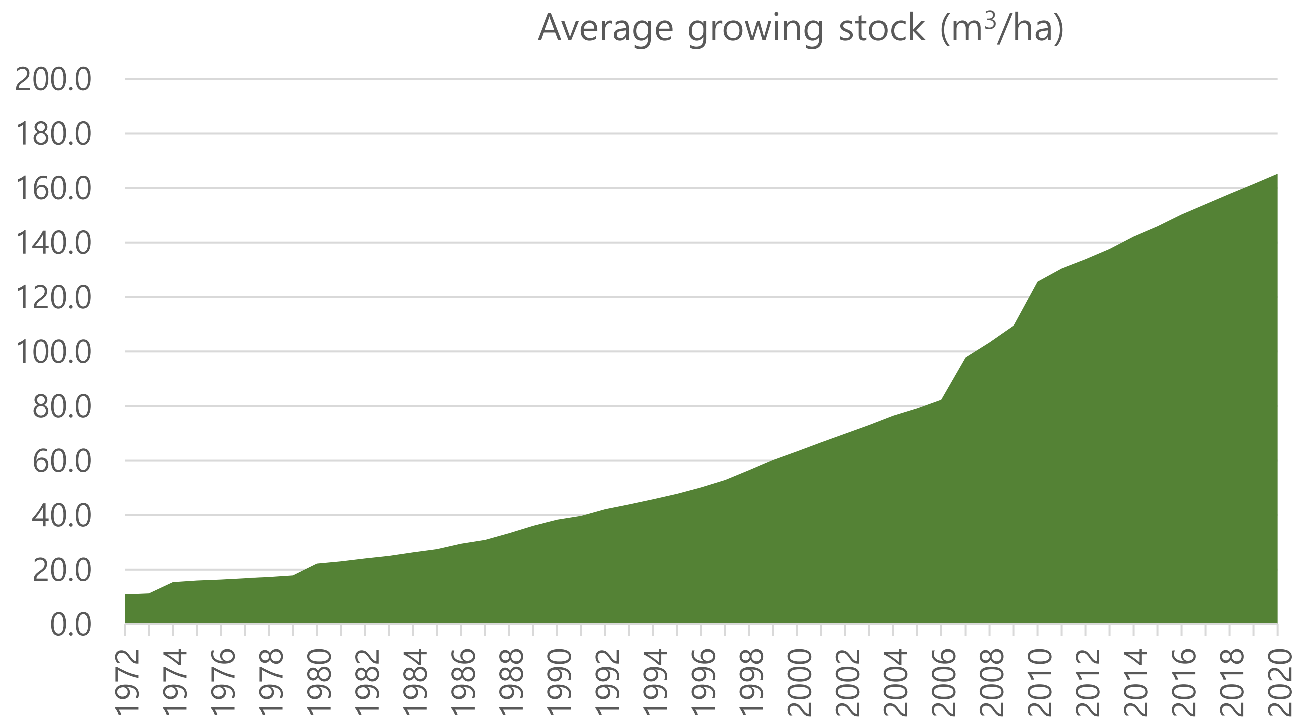
Cumulative erosion depth

Land developed



South Korea

- Area 100,210km²
  - Forest 63%
    - Average growing stock **165.2** m³/ha (2020)
      - New Zealand 391, Germany 320, Japan 170
      - Norway 95.5, Spain 65.8, Greece 47.6



Arbor Day in Korea (Sikmogil)

- April 5th: national holiday
  - 1949~2006
- National Forest Plan
  - 1973~

Afforestation

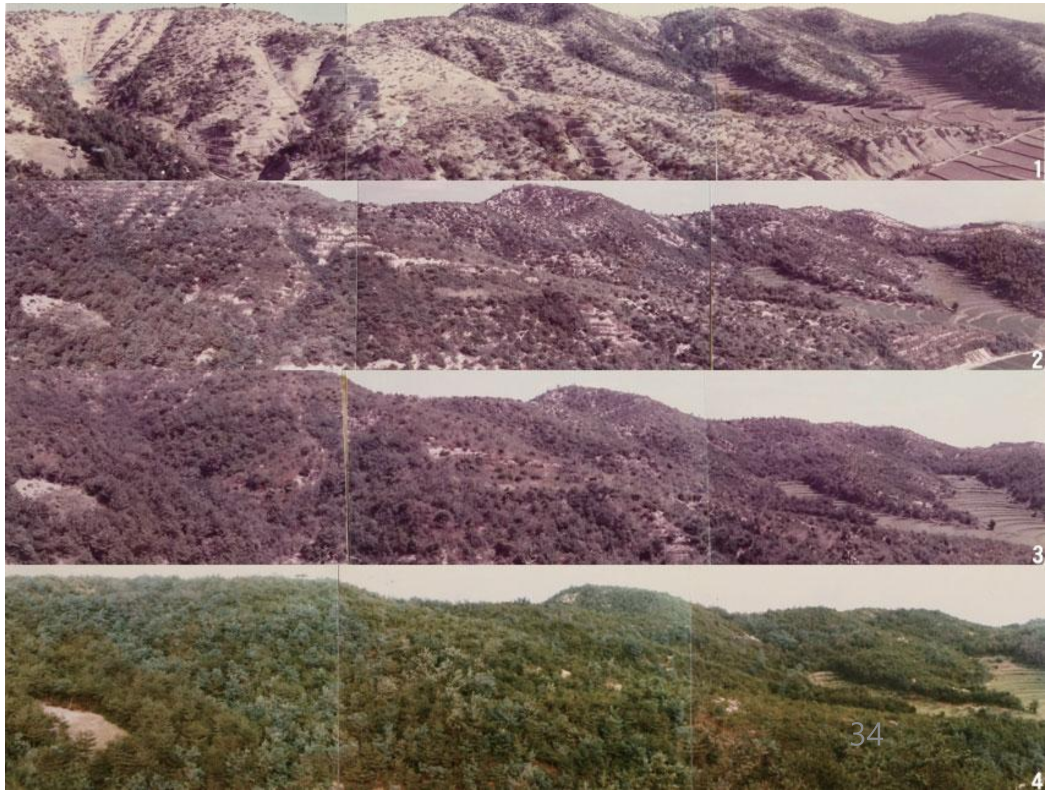
경북 영일 학전동 뒷산

1973

1974

1976

1981



Forest functions

Category	Major Functions
Ecological	Provide habitat for wildlife and support biodiversity
	Protect soil and prevent erosion
	Regulate water cycles and improve water quality
	Regulate climate through carbon sequestration and oxygen production
Economic	Supply timber and non-timber forest products (e.g., fuelwood, medicinal plants)
	Generate employment and income for forest-dependent communities
	Contribute to local and national economies
Social & Cultural	Offer recreation and tourism opportunities
	Hold cultural and spiritual significance for indigenous and local peoples
	Provide resources for education and scientific research
Protective	Serve as buffers against natural disasters like floods, landslides, and storms
	Act as windbreaks and help stabilize microclimates

National Forest Plan of South Korea

Period	Main Characteristics
1973–1987	Quantitative afforestation and reforestation focused on recovering degraded forests.
1988–1997	Shift to qualitative forest management, focusing on maintaining and utilizing existing forests.
1998–2007	Emphasis on the economic value of forests; promotion of forest-related industries.
2008–2017	Forests as a solution to climate change; emphasis on carbon sinks and ecosystem services.
2018–2037	Comprehensive plan focusing on forest welfare, biodiversity conservation, and smart forest management.

Economic Valuation of Forest Functions in South Korea (Estimated Annual Value)

Function	Estimated Economic Value (KRW)	Estimated Economic Value (USD)	Description
Carbon Sequestration	₩1.5 trillion	~$1.1 billion	Value of CO_2 absorption and carbon credits
Water Resource Regulation	₩1.3 trillion	~$950 million	Improvement in water quality, groundwater recharge, and flood mitigation
Soil Erosion Prevention	₩800 billion	~$600 million	Protection against landslides and soil loss, especially in mountainous areas
Air Purification	₩1.1 trillion	~$820 million	Absorption of pollutants such as PM10, NOx, and ozone
Timber and Forest Products	₩500 billion	~$370 million	Commercial forestry including timber, mushrooms, herbs
Recreation and Tourism	₩6.0 trillion	~$4.5 billion	Forest-based tourism, healing forests, and national park visitation
Biodiversity & Habitat	Difficult to quantify	-	Ecological insurance value; sometimes estimated via willingness-to-pay surveys

Korean Red Pine (*Pinus densiflora*) Growth

Age (Years)	Avg. Tree Height (m)	Stand Density (trees/ha)	Stand Volume (m^3/ha)
5	2.0 – 2.5	4,000 – 5,000	–
10	4.0 – 5.0	3,000 – 4,000	10 – 30
20	8.0 – 10.0	1,500 – 2,500	50 – 80
30	12.0 – 15.0	1,000 – 2,000	120 – 150
40	15.0 – 18.0	500 – 1,000	180 – 220
50	18.0 – 20.0	300 – 800	250 – 300

Relationship between Stand Volume and Evapotranspiration (ET)

Forest Stage	Stand Volume (m^3/ha)	Annual ET (mm/year)	Remarks
Young Forest	Low (< 50)	300 – 400	Small trees, low leaf area, low transpiration
Maturing Forest	Moderate (100 – 200)	500 – 700	Rapid canopy expansion, increasing transpiration
Mature Forest	High (200 – 300+)	700 – 900+	Large biomass, high LAI, maximum water use
Overstocked Forest	Very high density, stagnating growth	May decline slightly	Water stress or competition may reduce efficiency

Rainfall **Interception** by Korean Red Pine (*Pinus densiflora*) by Stand Age

Age Class	Mean Tree Height (m)	Stand Density (trees/ha)	Stand Volume (m^3/ha)	Estimated LAI	Litter Depth (cm)	Rainfall Interception (% of annual rainfall)	Remarks
5 years	~2.5	3,500 – 5,000	<20	0.5 – 1.0	~0.5	5 – 8%	sparse canopy, low leaf area, minimal litter
10 years	~4.5	~3,000	~40	1.2 – 1.8	~1.0	8 – 12%	canopy expanding, slight litter layer
20 years	~8.5	~2,500	~100	2.0 – 3.0	~2.0	13 – 17%	moderate canopy, growing litter cover
30 years	~12.0	~1,800 – 2,200	~160	3.0 – 4.0	~3.0	17 – 22%	developed canopy and litter layer
40 years	~15.0	~1,200 – 1,800	~220	4.0 – 4.5	~4.0	20 – 25%	peak canopy cover, thick litter layer
50+ years	~18.0	~800 – 1,200	250 – 300+	4.5 – 5.0	5.0+	22 – 28%	fully mature, maximum interception potential

Integration of Stand Volume and Evapotranspiration in Hydrological Models

Model	Key Features	Representation of Stand Volume	Evapotranspiration (ET) Calculation
SWAT (Soil & Water Assessment Tool)	Watershed-scale rainfall-runoff modeling	Vegetation type and LAI assigned via GIS input layers; stand volume indirectly reflected by LAI	Empirical methods like Penman-Monteith, Priestley-Taylor
RHESSys (Regional Hydro-Ecologic Simulation System)	Eco-hydrological model integrating vegetation and water dynamics	Dynamic vegetation module translating biomass to LAI; stand volume dynamically updated	Physically-based canopy transpiration models
Tethys & Chloris (T&C)	High-resolution process-based model	Detailed growth model incorporating biomass, DBH, and LAI explicitly	Physiological ET models based on photosynthesis (e.g., Farquhar model)

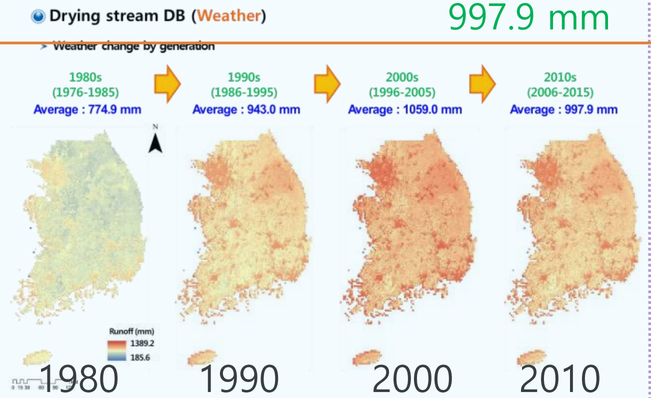
Examples of Model Application

Analysis Objective	Approach
Change in ET Before and After Thinning	Set thinning scenarios to reduce LAI and analyze resulting ET changes
Forest Survival Prediction under Climate Change	Combine climate scenarios with changes in stand volume to assess forest resilience
Comparison of Water Budgets by Forest Type	Compare ET and water use between deciduous and coniferous forests
Evaluation of Reforestation Effects	Analyze watershed hydrological response before and after afforestation based on changes in stand volume

Watershed environment change impact on Streamflow

Base condition

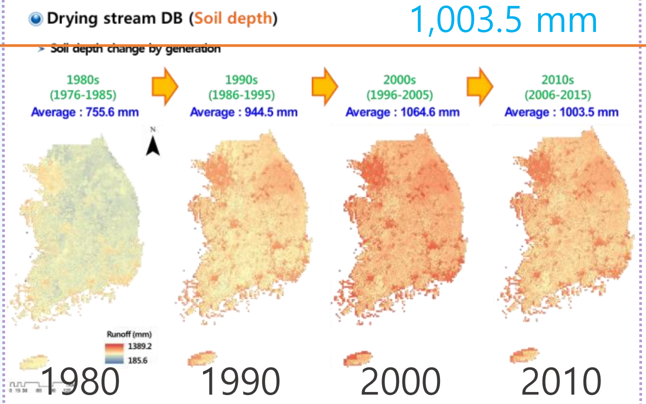
Streamflow 997.9 mm



Soil erosion

Surface Runoff increase

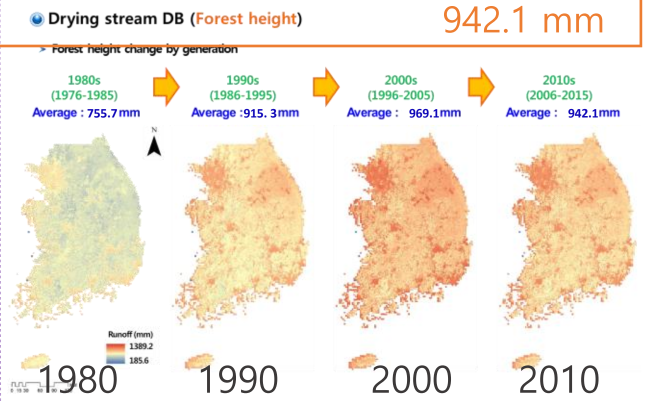
1,003.5 mm



Forest growth

ET increase

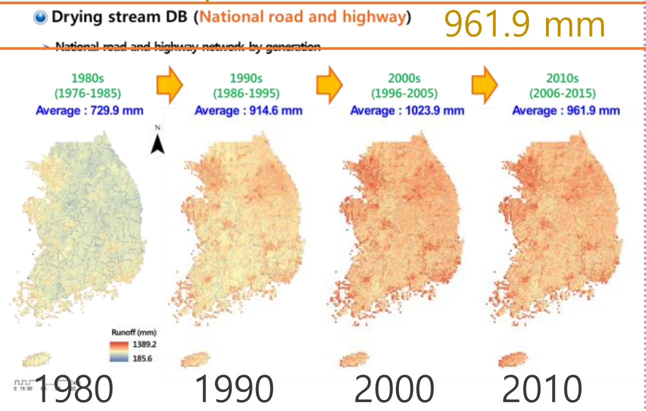
942.1 mm



Road construction

Evaporation increase

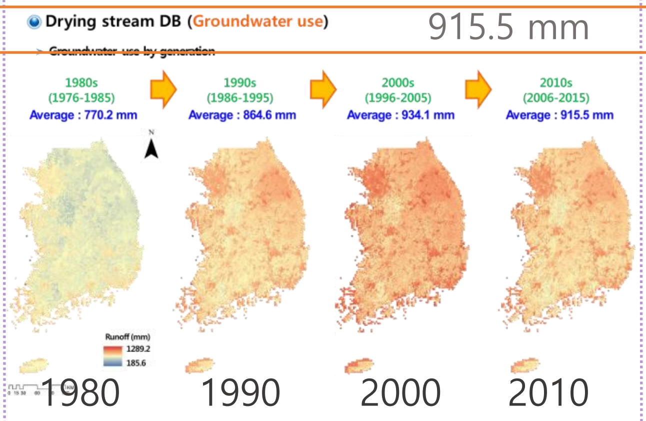
Streamflow 961.9 mm



Groundwater use

Baseflow decrease

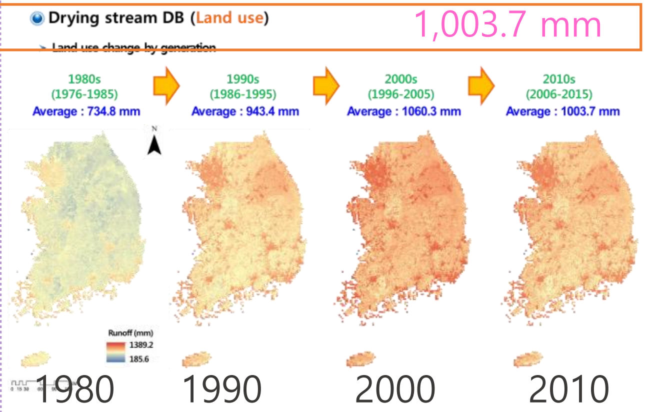
915.5 mm



Land use

Surface Runoff increase

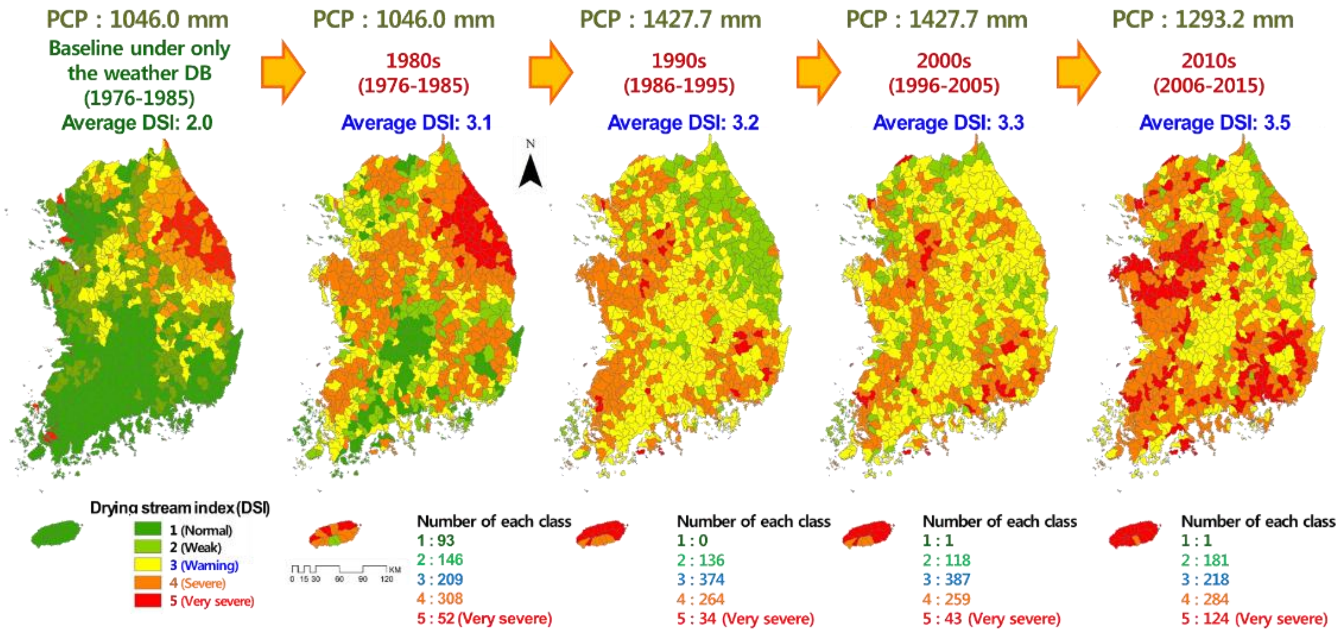
1,003.7 mm



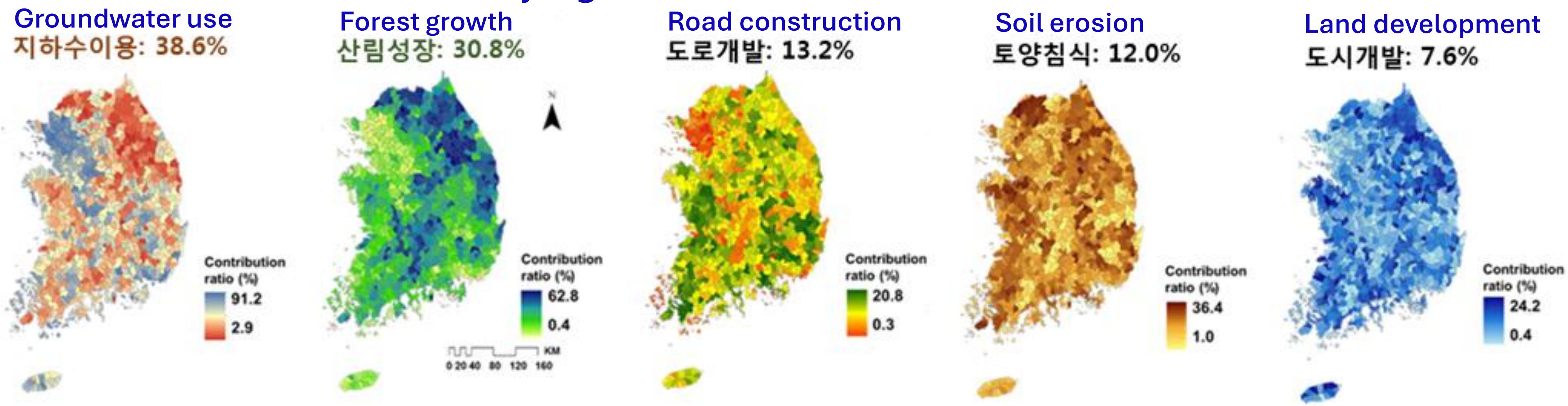
Assessment of Long-term Groundwater Use Increase and Forest Growth Impact on Watershed Hydrology

W. Kim, **S. Kim***, Ji. Kim, Ji. Lee, S. Woo, S. Kim *Water Resources Management*. 36, 5801-5821, 2022.08

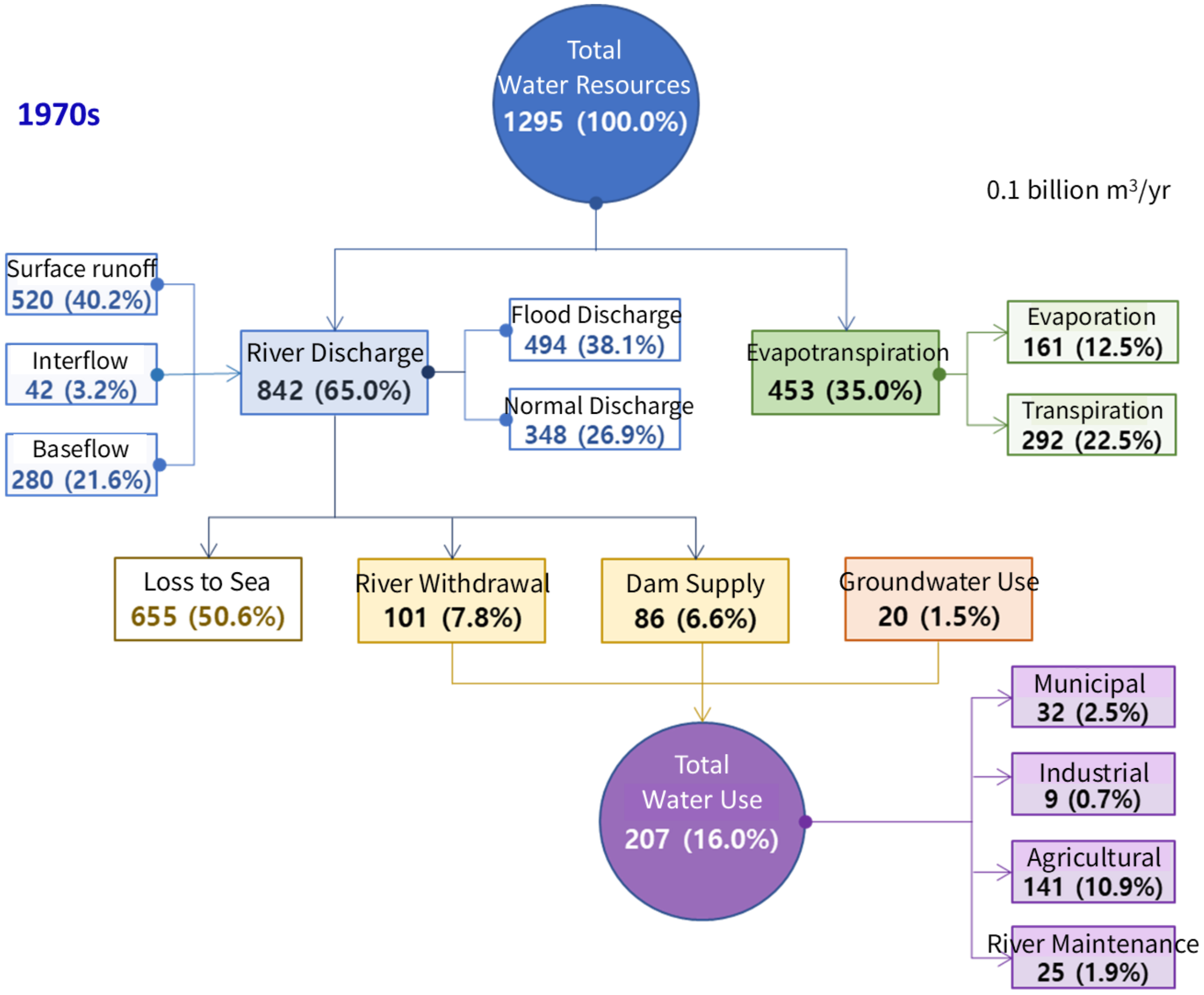
Stream Drying Intensification (1976~2015)

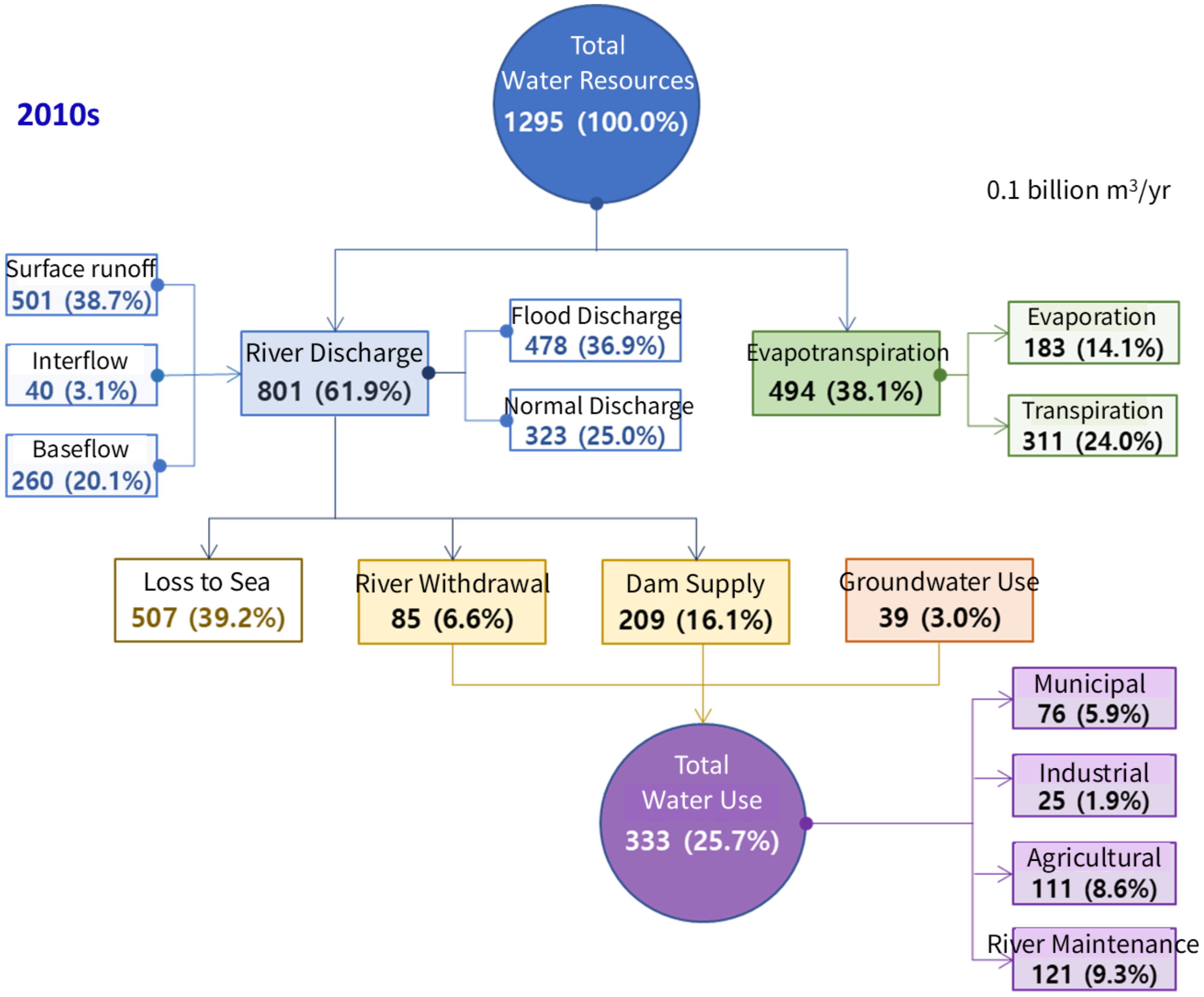


Drying stream contribution ratio



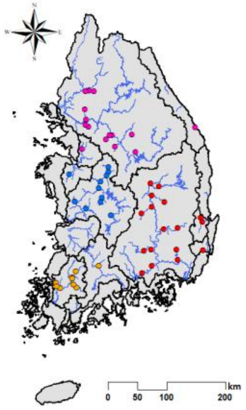
Comparison of South Korea water resources changes by long-term streamflow reducing watershed environment factors using **SWAT**





③ Integration of SWAT, CE-QUAL-2, and PHABSIM to secure ecological flow

52 points



Monitoring data

- 기상청 Korea Meteorological Administration — Meteorological data
- 물환경정보시스템 Water Environment Information System — Water quality data
- WAMIS 국가수자원관리종합정보시스템 — Hydrological data

SWAT Input
- Meteorological data
- GIS: DEM, land cover, soil type, water resources unit map
- RS: NDVI, LAI
- Streamflow, dam & weir releases, groundwater level data
- Water Quality (SS, T-N, T-P, Chl-a) data

Water Quality Research Group — CE-QUAL-W2 Hydrodynamic and Water Quality Model

CE-QUAL-W2 Input
- Meteorological data
- Intake water data
- TMS data

USGS science for a changing world — Physical Habitat Simulation Software (PHABSIM)

PHABSIM
Water velocity, depth
Cross-section
Roughness coefficient
Channel depth, width
HIS (field investigation)

HEC-RAS

SWAT
Flow Duration Curve • High flow (Q10) • Wet condition (Q95) • Mid-range flows (Q185) • Dry conditions (Q275) • Low flows (Q355)

Output

SWAT
Streamflow (CMS)
DO (kg/day)
PO4 (kg/day)
NO3 (kg/day)
NH4 (kg/day)
Water temperature (℃)
Chl-a (ppm)
TOC (measured)

Input

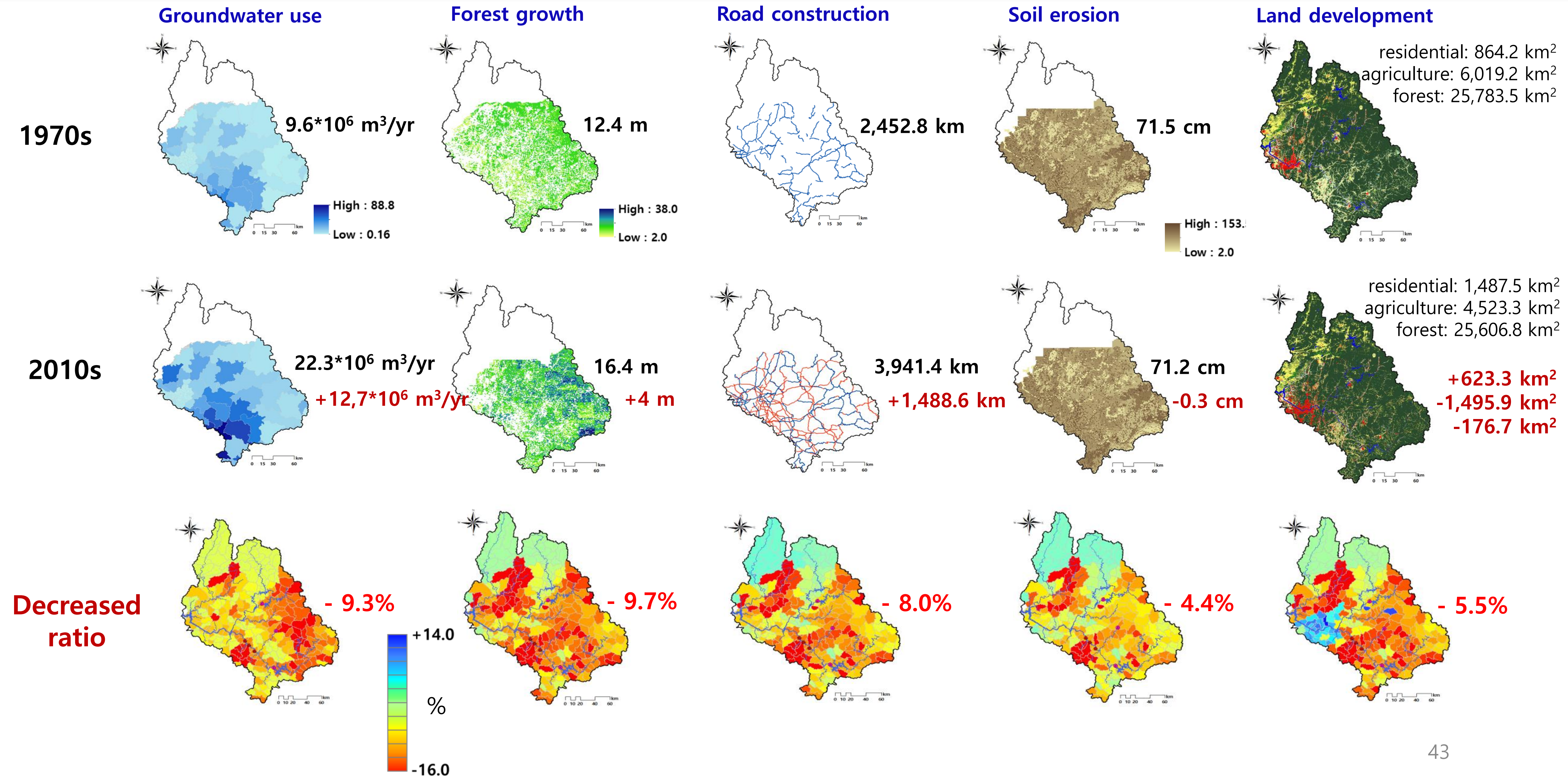
CE-QUAL-W2
Streamflow (CMS)
DO (mg/L)
PO4 (mg/L)
NO3 (mg/L)
NH4 (mg/L)
Water temperature (℃)
Chl-a (mg/m³)
OM group (mg/L)

Output

Required ecological flow (WUA, $m^2/1000m$)

Determine necessary ecological flow and days based on 1976 → Apply BMPs to improve stream water quality under the secured ecological flow condition and present watershed environment → Compare water velocity distribution, water depth and perimeter increases before and after securing ecological flow

SWAT modeling results by applying 1970s & 2010s watershed environments



PHABSIM ecological flow

Estimation of an Optimum Ecological Stream Flow in the Banbyeon Stream Using PHABSIM - Focused on Zacco platypus and Squalidus chankaensis tsuchigae –
Park, Jinseok · Jang, Seongju · Song, Inhong
Journal of the Korean Society of Agricultural Engineers, 62(6), 2020. 11

Study area

Hydraulic input data preparation (HEC-RAS)

Hydraulic simulation (PHABSIM)

Application of habitat suitability index (HSI)

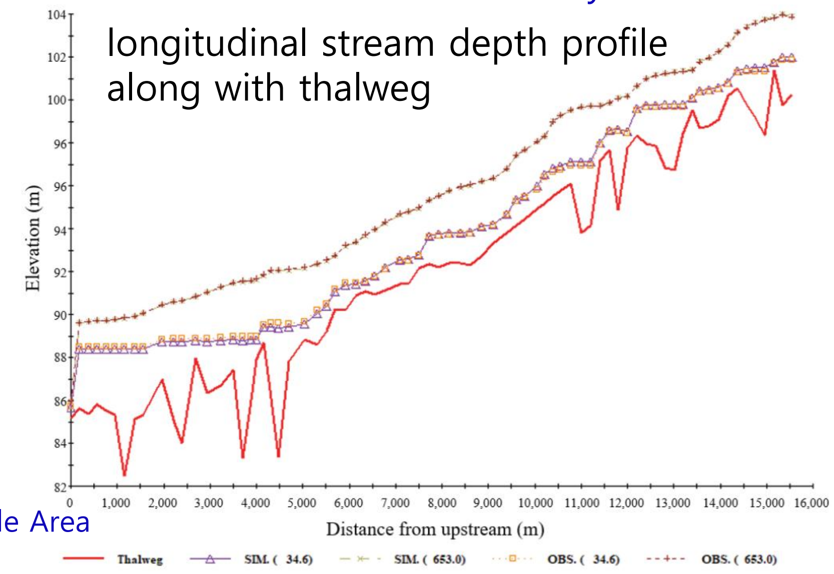
Habitat simulation (PHABSIM)

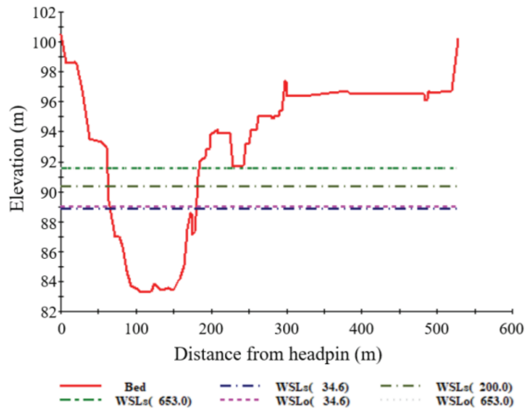
Correlation between flow rate and WUA

Weighted Usable Area

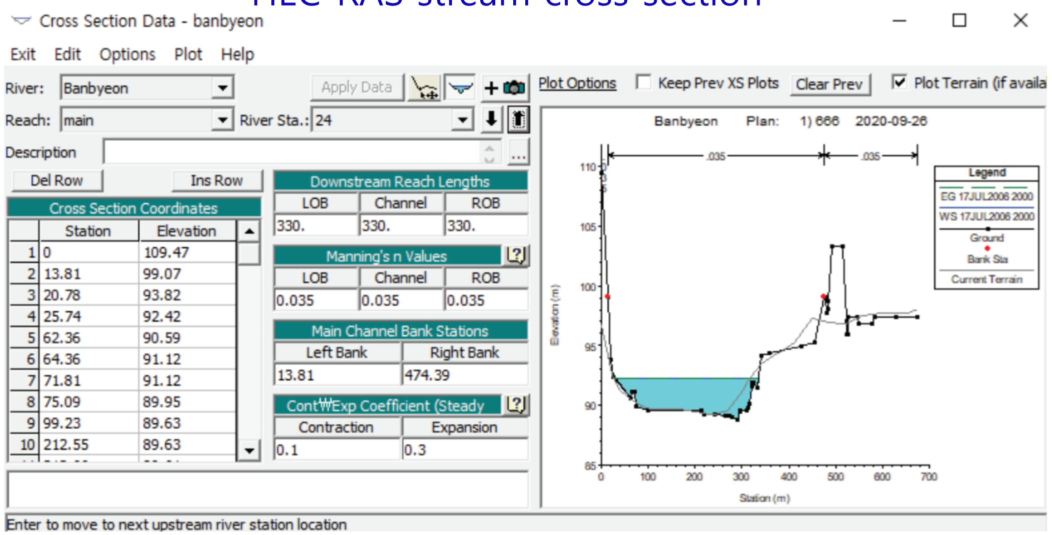
Determination of an optimal ecological flow rate

PHABSIM hydraulic simulated result





HEC-RAS stream cross section



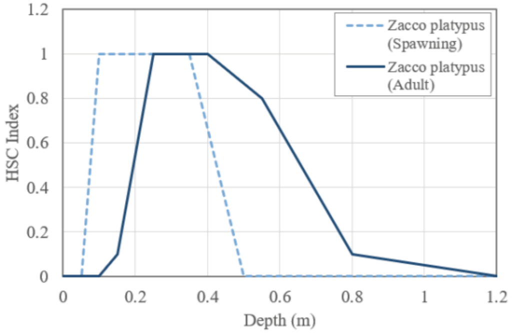
Habitat Suitability Curve (HSC) index estimated for the representative fish species

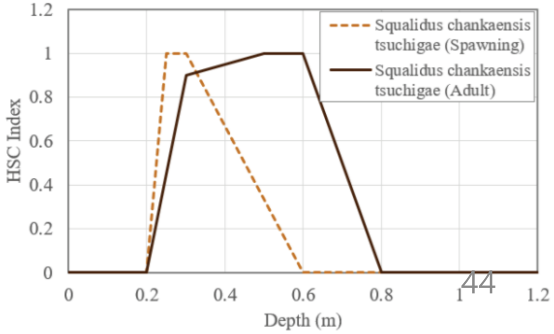
minnow, pale chub

Zacco platypus

Korean gudgeon
small carp

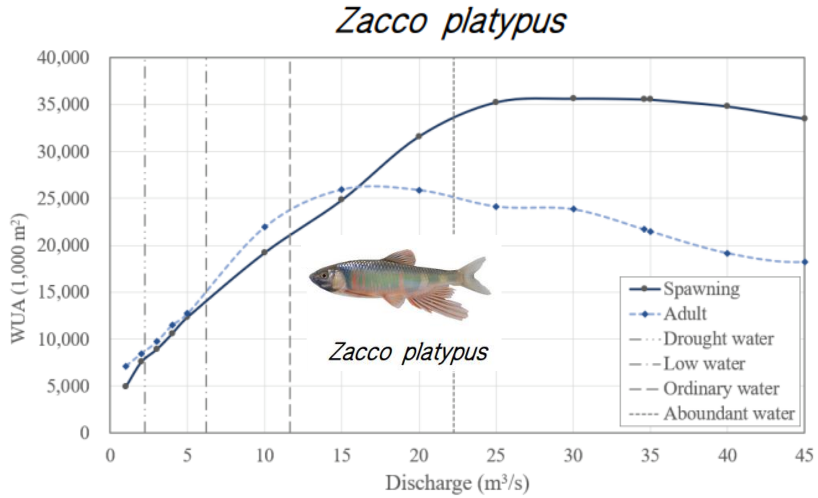
Squalidus chankaensis tsuchigae

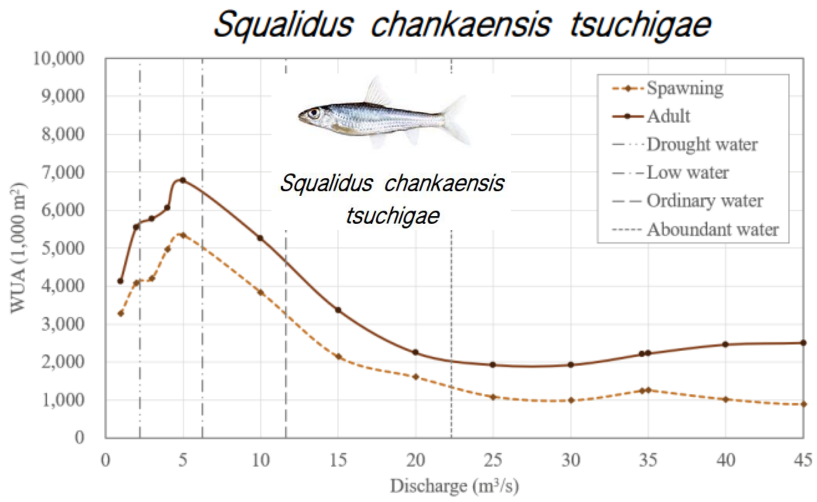




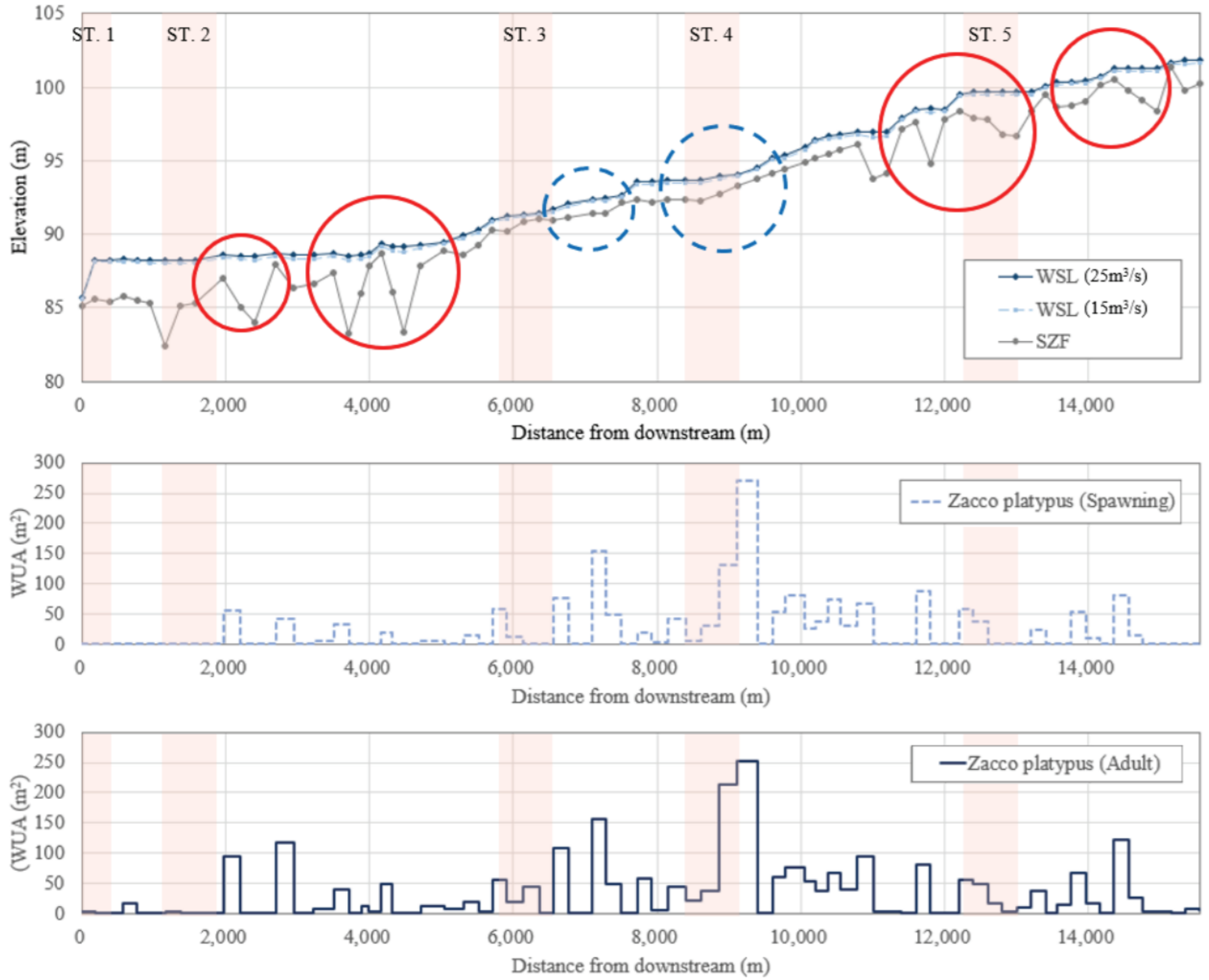
PHABSIM ecological flow

Weighted Usable Area (WUA) estimated for the representative fishes





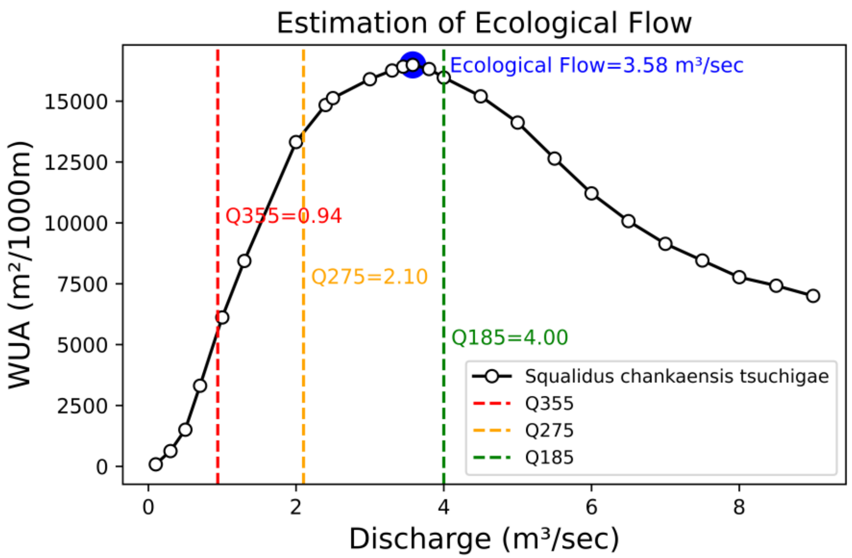
Longitudinal profile of water surface level and WUA at the optimal ecological flow rate for Zacco platypus



Securing days and amount of **ecological flow** to recover 2010s Q to 1970s Q

Watershed area (492.3 km²) Unit: m³/sec

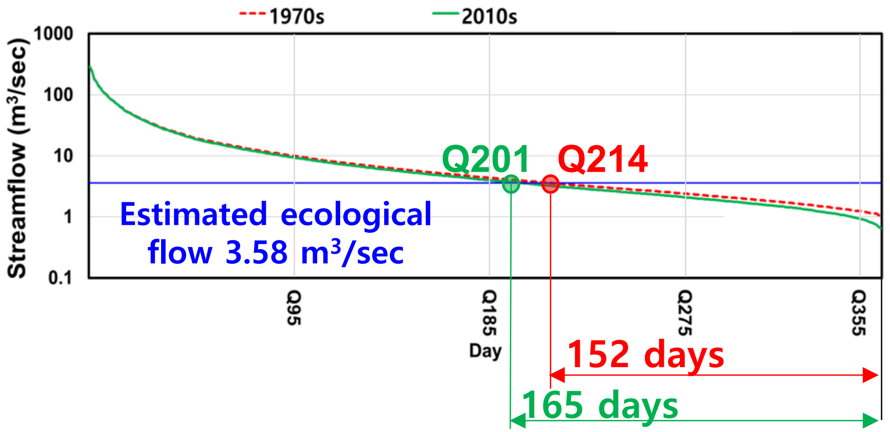
Flow duration	1970s (1)	2010s (2)	(2)-(1)
Q95	9.94	9.37	-0.57
Q185	4.37	4.00	-0.37
Q201	3.91	**3.56**	-0.35
Q214	**3.58**	3.21	-0.37
Q275	2.41	2.10	-0.31
Q355	1.26	0.94	-0.32



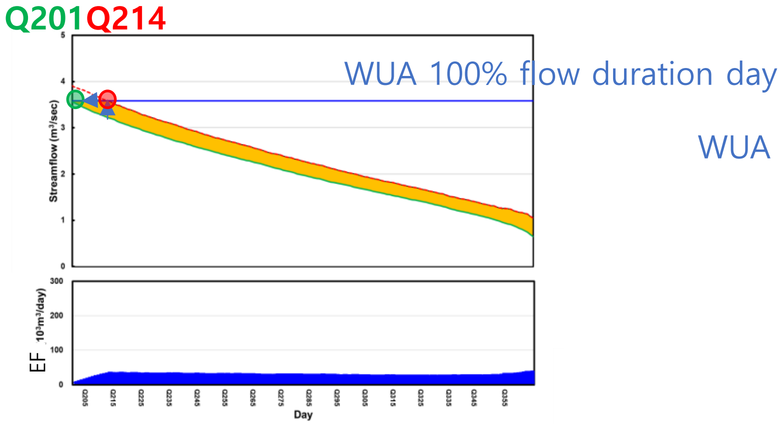
▪ **WUA ecological flow (m³/s)**

WUA	100%	90%	80%	70%	60%	50%	25%
EF	3.58	2.40	1.98	1.69	1.46	1.26	0.80

Weighted Usable Area

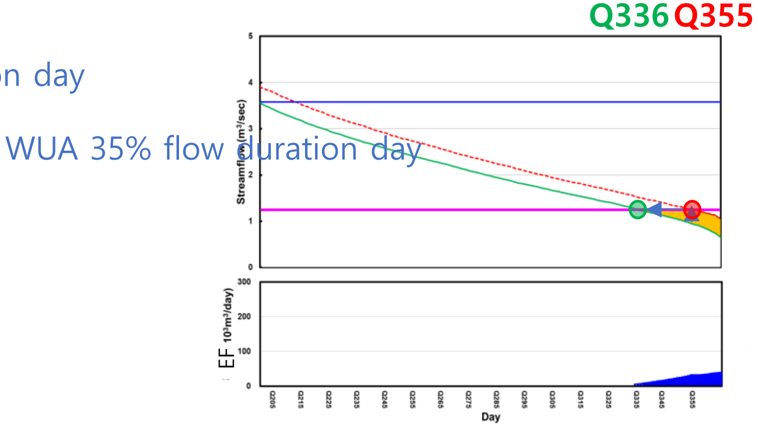


WUA 100% flow duration day recovery of 2010s Q to 1970s Q



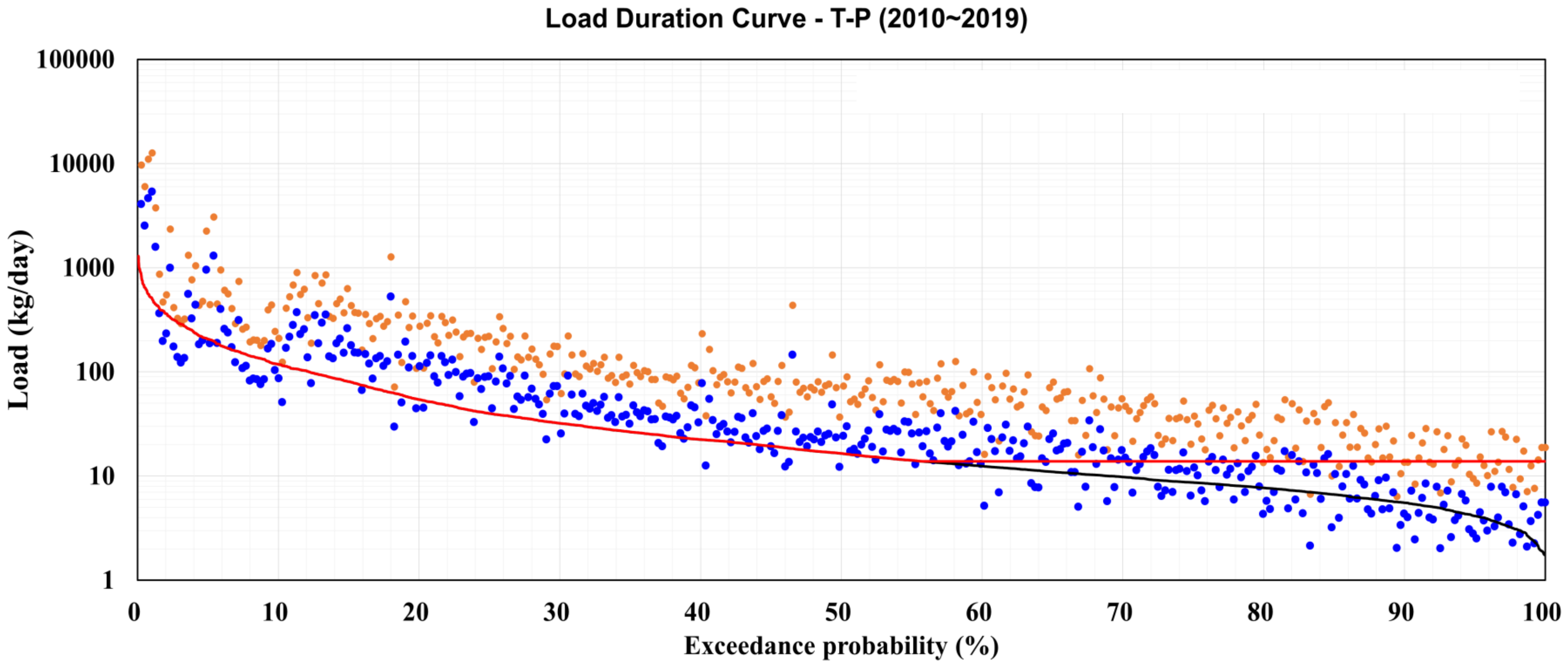
Securing days: 165 days
Average amount: 0.30 m³/s
(25,920 m³/day)

Streamflow recovery of 2010s Q355 to 1970s Q355



Securing days: 31 days
Average amount: 0.22 m³/s
(19,008 m³/day)

BMPs application to improve stream water quality after securing ecological flow



Flow duration	Ave (mg/L)		Excess rate (%)	
	Obs.	BMPs (30%)	Obs.	BMPs (30%)
Q95 (10%~40%)	0.075	0.031	100.0	94.9
Q185 (40%~60%)	0.056	0.019	100.0	87.2
Q275 (60%~90%)	**0.044**	**0.014**	**98.3**	**62.4**
Q355 (90%~100%)	**0.037**	**0.011**	**100.0**	**46.2**

for **Integrated Water Management**,

Watershed management <u>for stable water resources</u>

- Land development- Low Impact Development
- Soil conservation practice- keep on soil water storage & groundwater recharge
- Forest management- Periodic thinning to reduce ET loss
- Groundwater use- keep safe yield of groundwater

Land management <u>for healthy stream water quality</u>

- Nonpoint source pollution- BMPs
- Point source pollution- sewage treatment and reprocessing
- Water pollution accident- rapid trace & strict punishment
- Gas station oil leak- steady surveillance & prompt action

Disaster management <u>for safe water & healthy stream ecology</u>

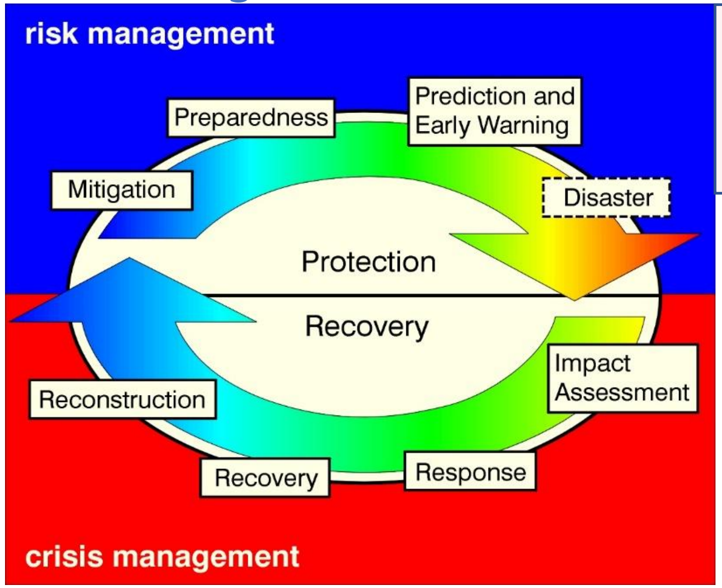
- Risk management- promised solution
- Building resilience- climate change adaptation

with **SWAT**

④ **Advanced detection** of **agricultural drought** using Terra MODIS NDVI

Drought Management

Risk Management



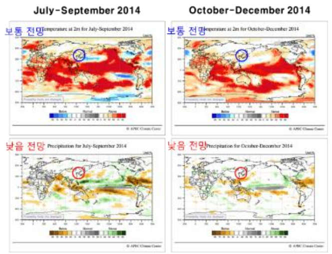
Drought Mitigation

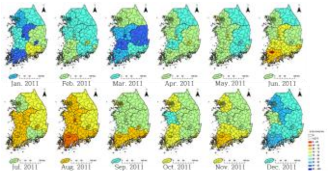
Preparedness

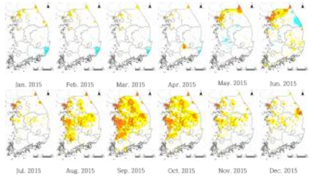
Prediction and early warning

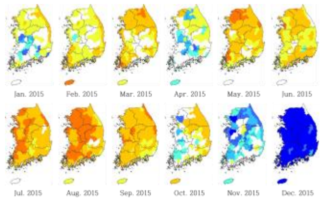
Mitigation

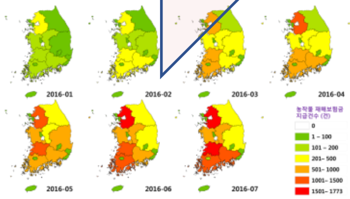
Weather forecasting	**Meteorological drought**	**Agricultural drought**	**Hydrological drought**	**Drought assessment**
APCC 3,6 month KMA GS5 1,3 month	Rainfall deficit SPI 1,3,6,9,12,24,48	Reservoir storage deficit RDI	Water supply restriction WADI	Drought insurance Recovery support





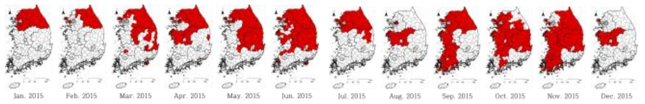






Socio-economic drought

Crop damage,
Food price **Big data**

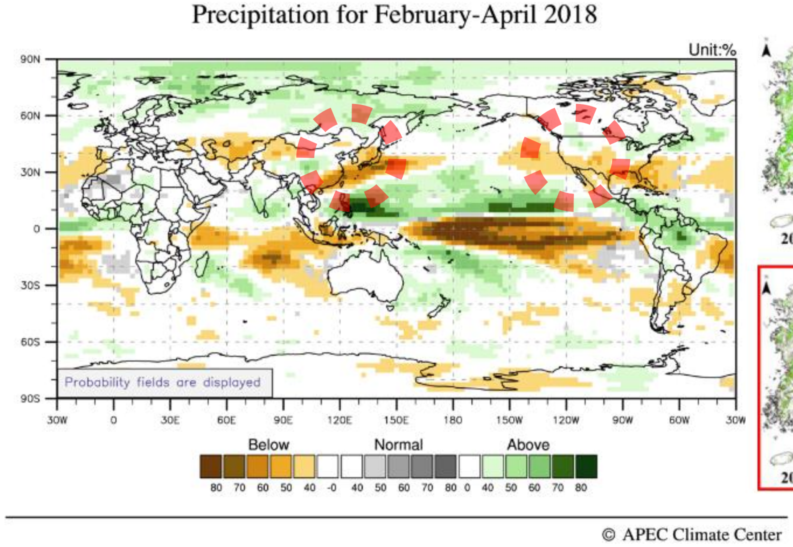


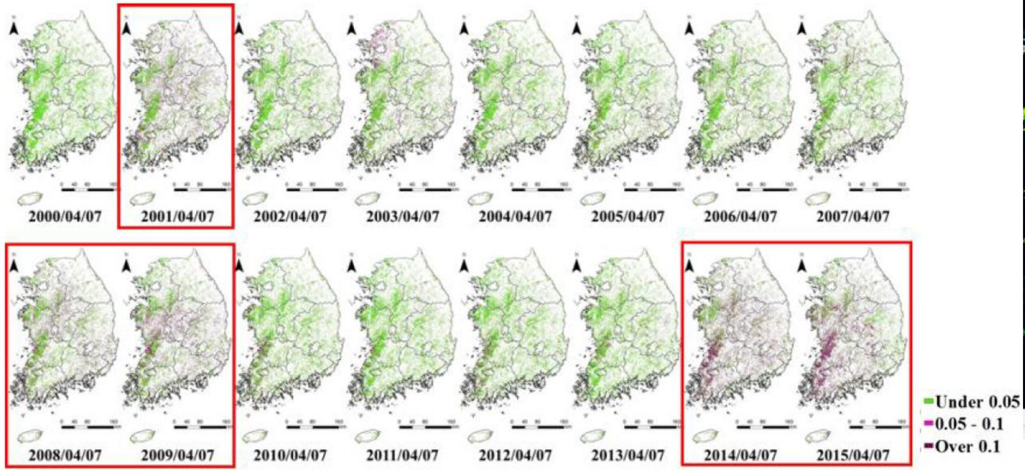
Drought Advanced Detection and Prediction

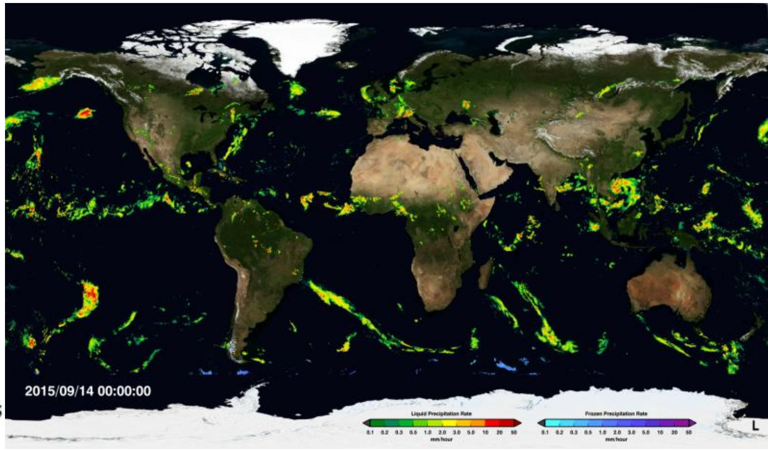
before 6~3 months

before 2~1 months

Present to Future





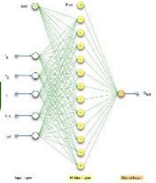


GCM scenarios ensemble

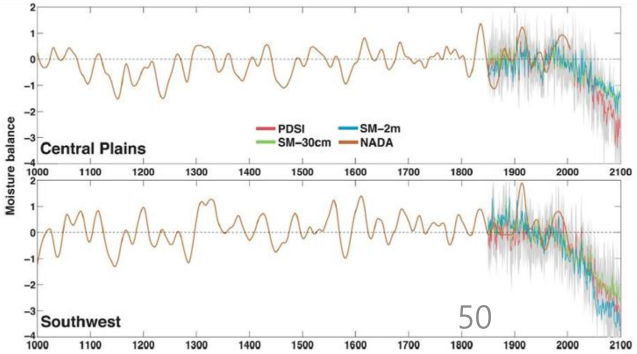
Satellites

SWAT

AI, Machine Learning



Mega Drought Study



https://www.apcc21.org/main.do?lang=en

APCC
APEC CLIMATE CENTER

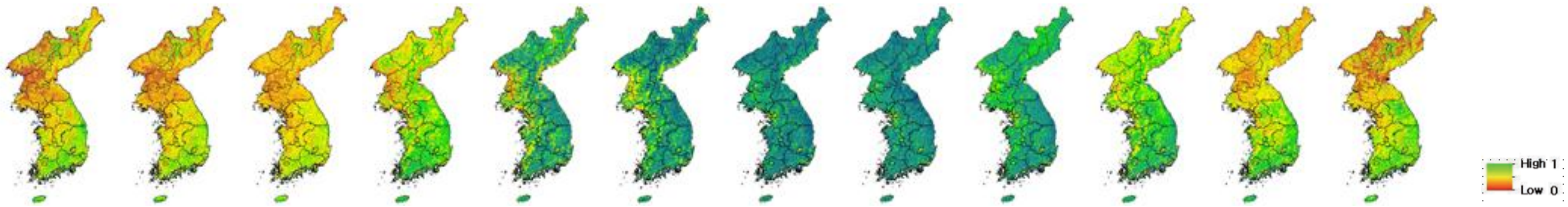
- **MOD13** 16-days composite product
  - NDVI, Normalized Difference Vegetation Index

$$NDVI = \frac{Band2 - Band1}{Band2 + Band1}$$

- to identify the health status of plants
- to depict phenological changes
- to estimate green biomass and crop yield

Band1 (Red) 0.620~0.670 μm
Band2 (NIR) 0.841~0.876 μm

Korean Peninsula

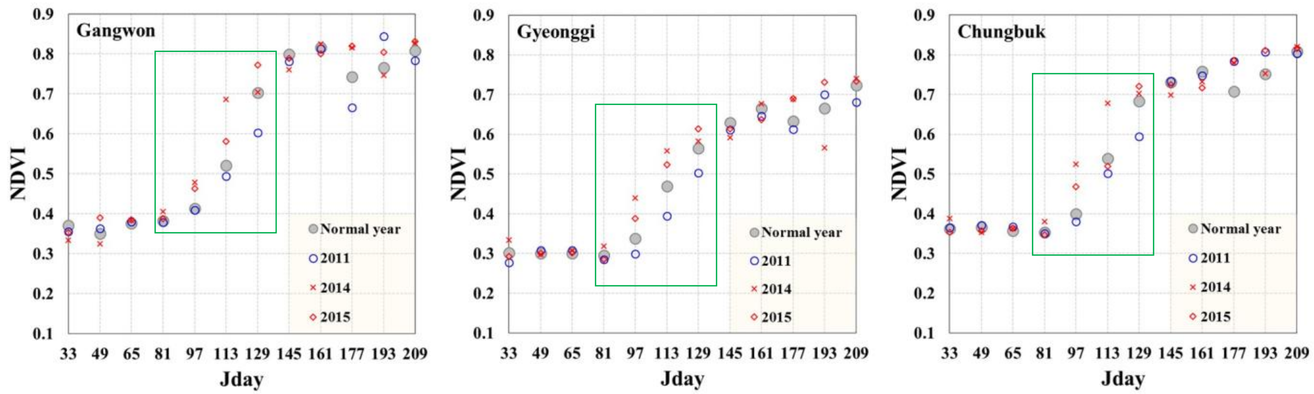


- **MOD15** 8-days composite product
  - LAI

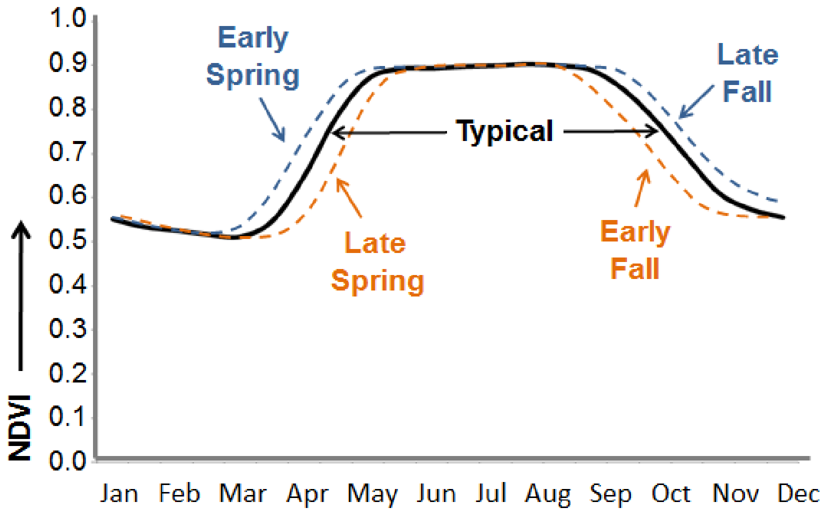
South Korea

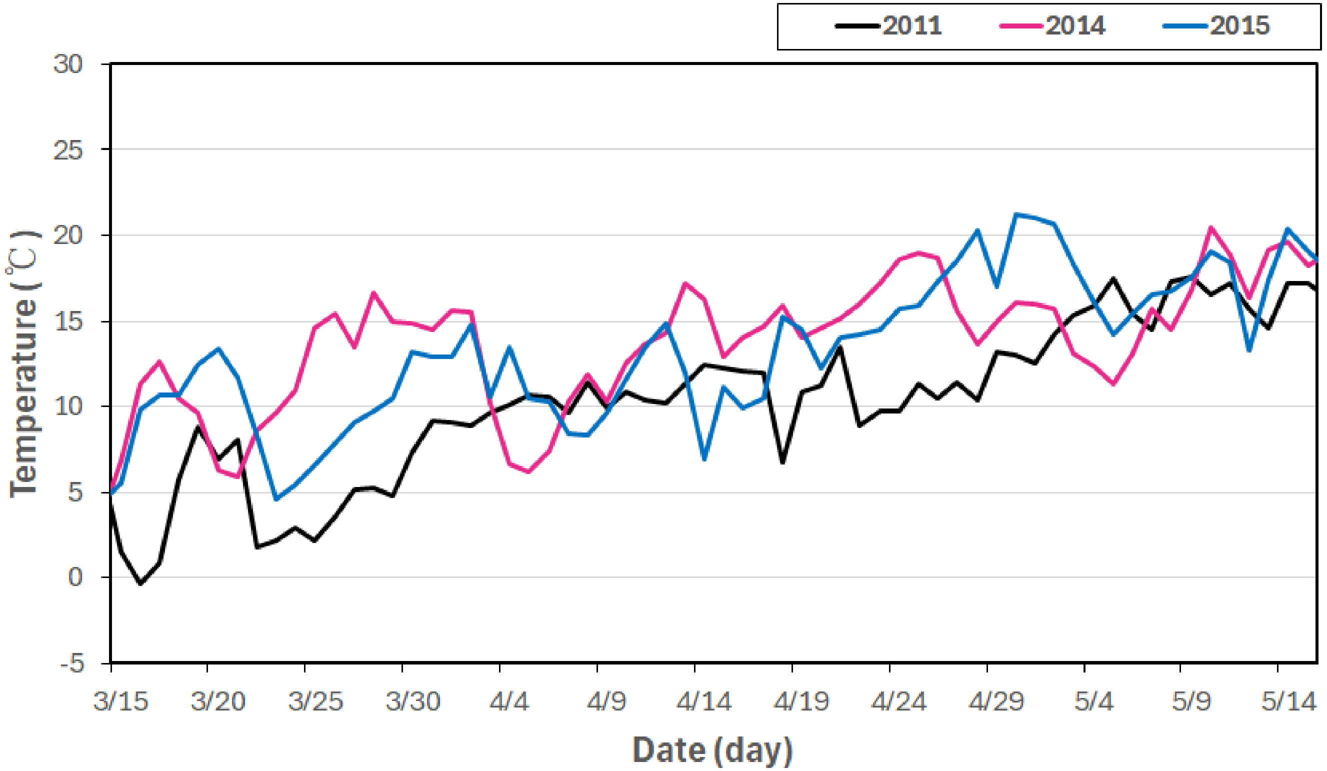
Forest

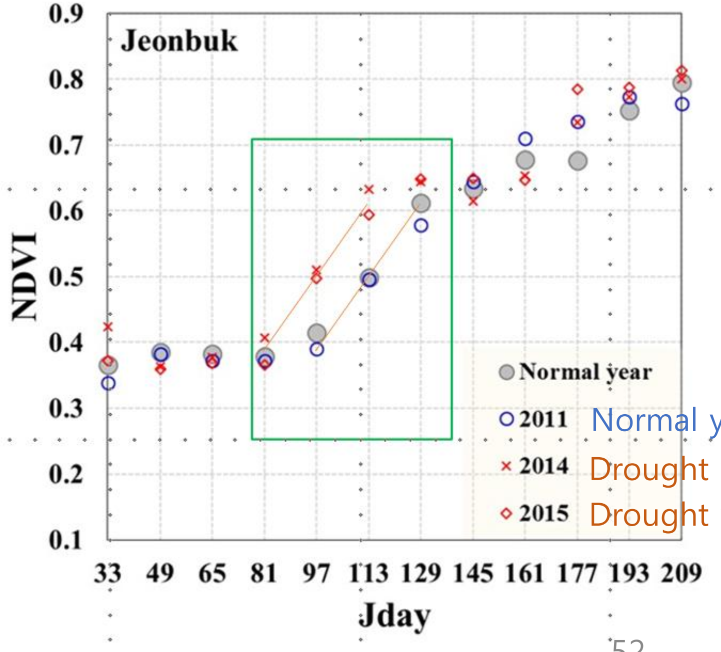
- NDVI



advance temperature rise from March of 2014 & 2015 compared to normal years

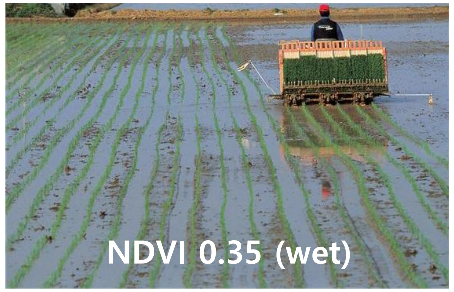


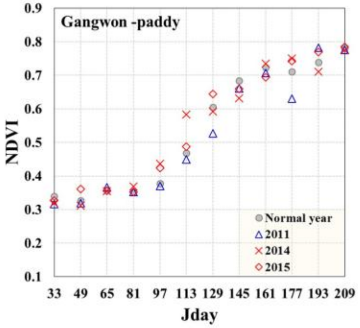


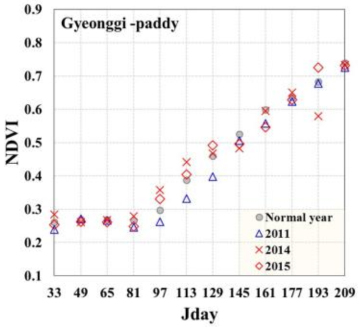


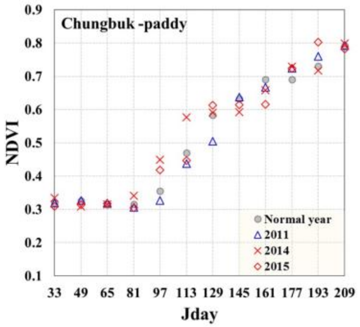
Normal year
Drought year
Drought year

Rice paddy

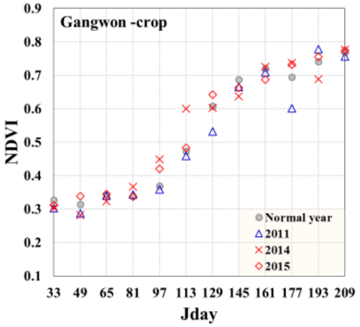


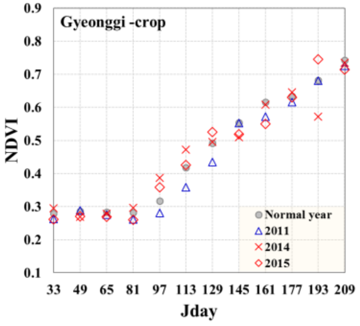


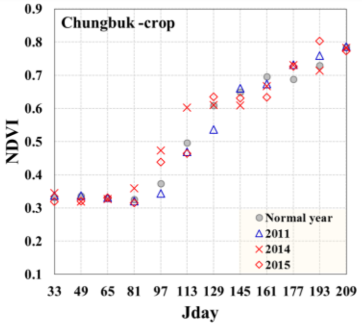




Upland field





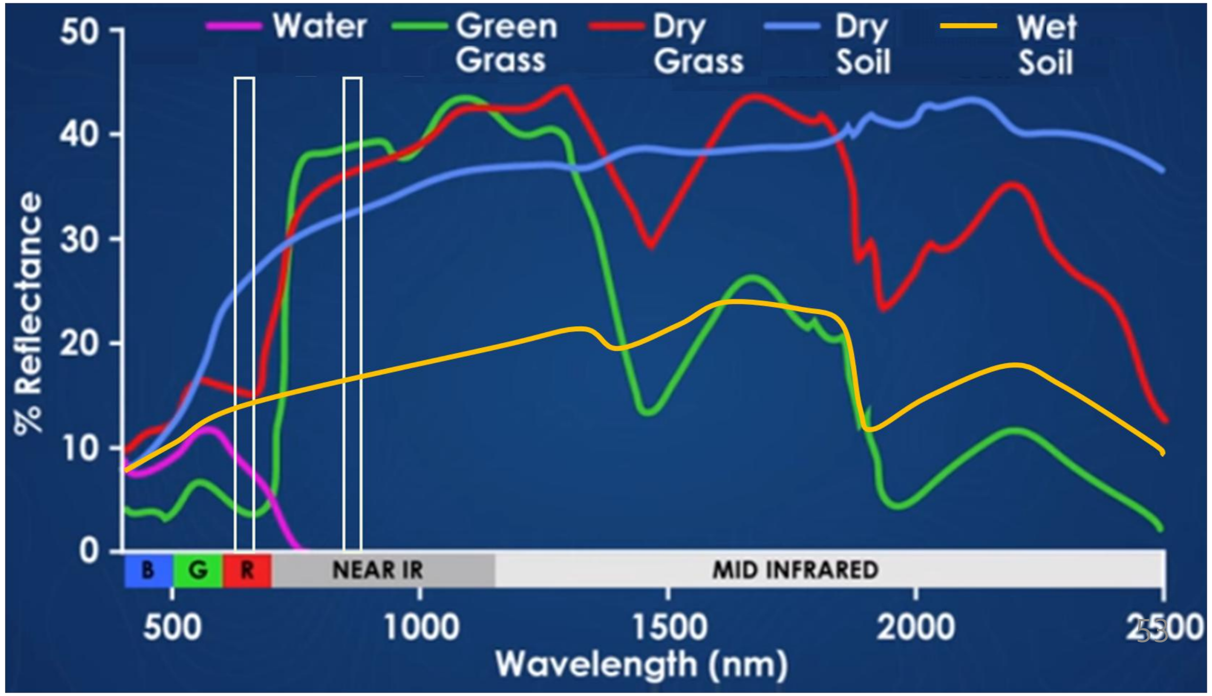


$$\mathrm{NDVI} = \frac{\mathrm{Band2} - \mathrm{Band1}}{\mathrm{Band2} + \mathrm{Band1}}$$

Terra MODIS

Band1 (Red) 0.620~0.670 μm

Band2 (NIR) 0.841~0.876 μm



Water Supply for Rice Paddy

Region	Seedbed Water Supply Starts	Transplanting Period (Approx.)
Southern Korea	Late March ~ Early April	Early May ~ Mid-May
Central Korea	Mid ~ Late April	Mid-May ~ Late May
Northern/Highland	Early May	Late May ~ Early June

March Sowing Crops

Crop Type	Crops
Grains & Legumes	Barley (spring), Oats, Peas, Mung beans (southern areas)
Root Vegetables	Carrots, Radishes, Beets, Burdock
Leafy Greens	Lettuce, Spinach, Garland chrysanthemum, Swiss chard, Bok choy
Others	Potatoes (southern & central regions), Garlic, Onions (non-winter)

April Sowing Crops

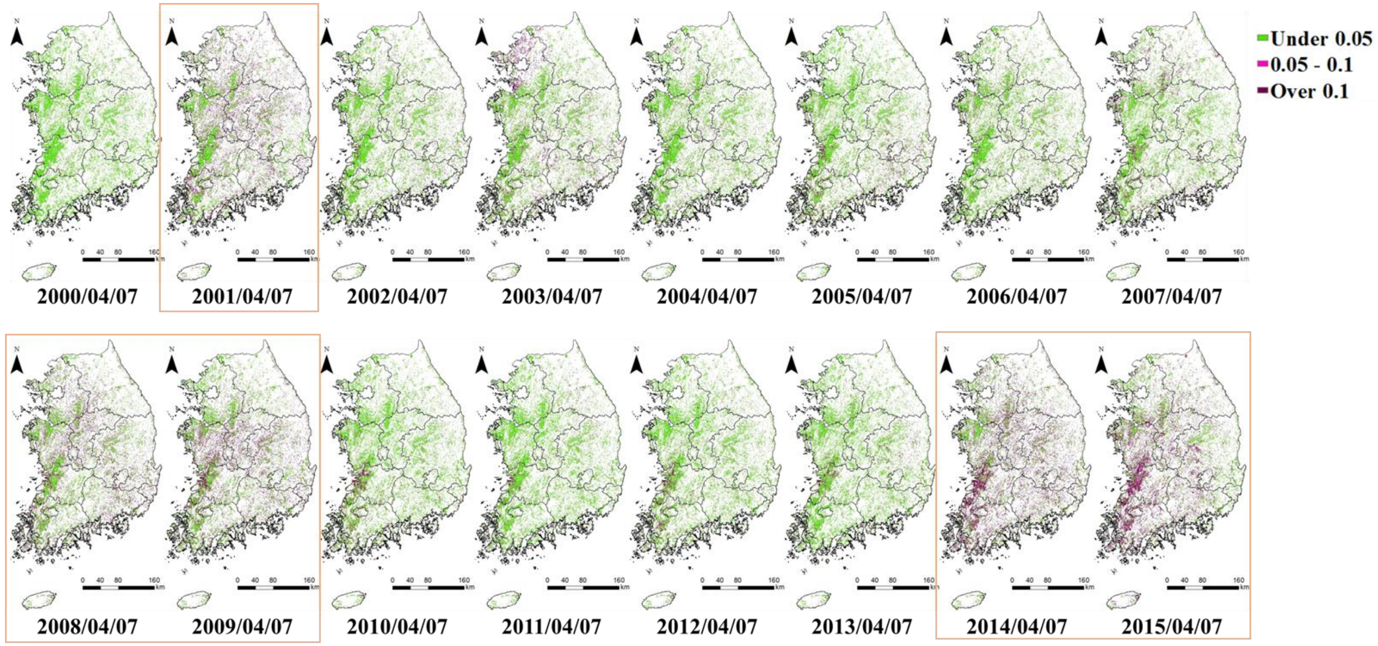
Crop Type	Crops
Grains & Legumes	Corn (sweet/silage), Kidney beans, Mung beans *(central/south)*, Peanuts
Root Vegetables	Sweet potatoes *(sprout raising)*, Carrots, Radishes, Potatoes *(north)*
Leafy Greens	Chinese cabbage (spring), Cabbage, Lettuce, Spinach
Fruiting Vegetables	Cucumbers, Watermelons, Melons, Pumpkins, Tomatoes, Eggplants, Chili peppers *(transplant mid-late April)*

Terra MODIS

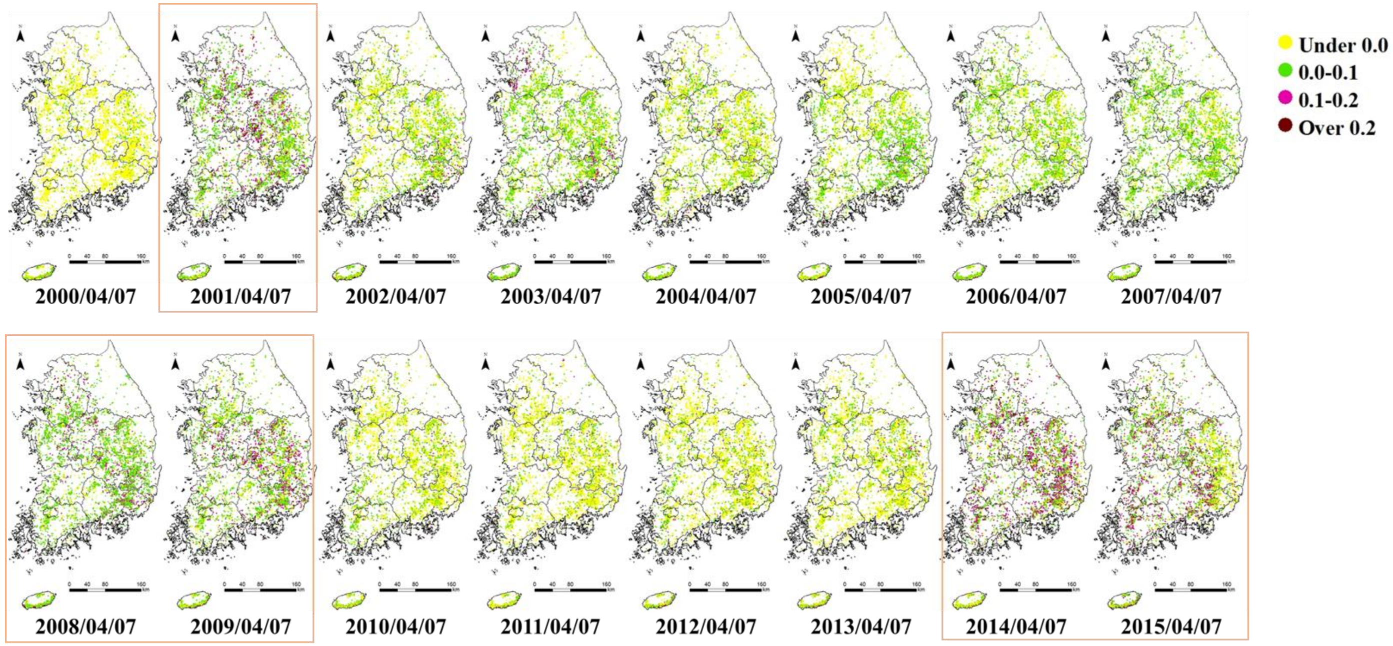
7 April (2000~2015)

$NDVI_i - NDVI_{mean}$

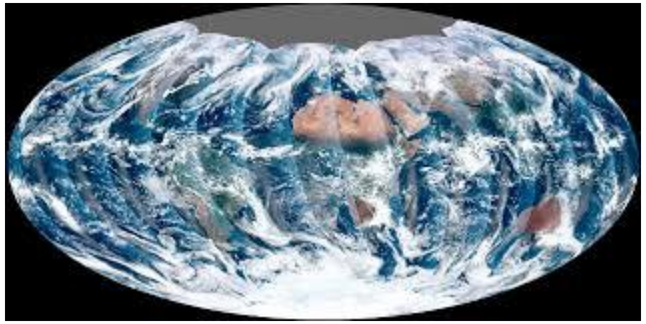
Rice paddy
775,000 ha, 7.8%



Upland field
752,000 ha, 7.5%



Satellites, GCM etc.



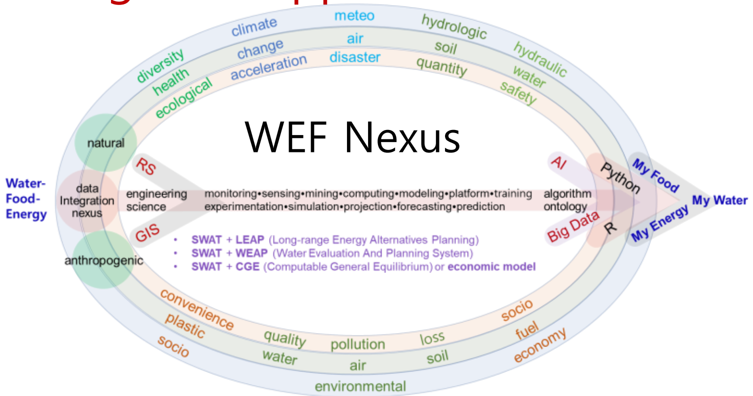
SWAT modeling

Global soil, landuse, evapotranspiration, historical and future weather databases for SWAT applications

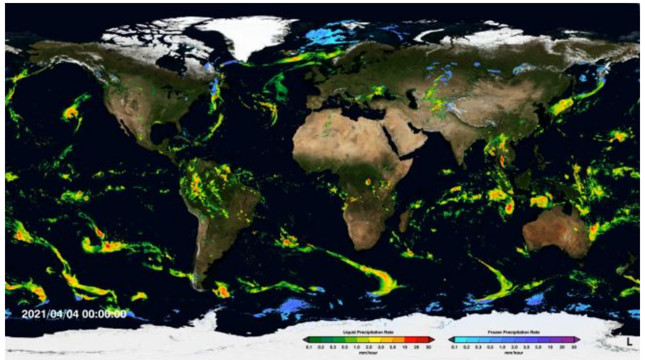
K. C. abbaspour1, S. ashraf Vaghefi 1, H. Yang1* & R. Srinivasan

Scientific Data, 2019
https://doi.org/10.1038/s41597-019-0282-4

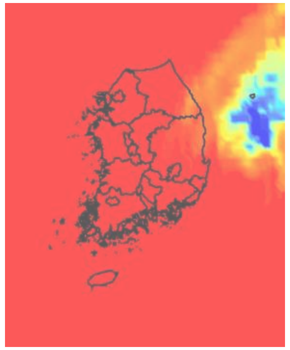
Integrated application



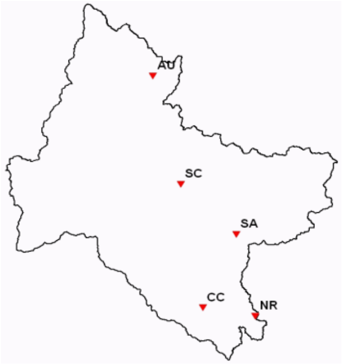
GPMclick



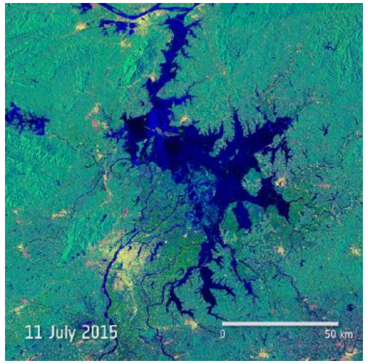
Ground Radar



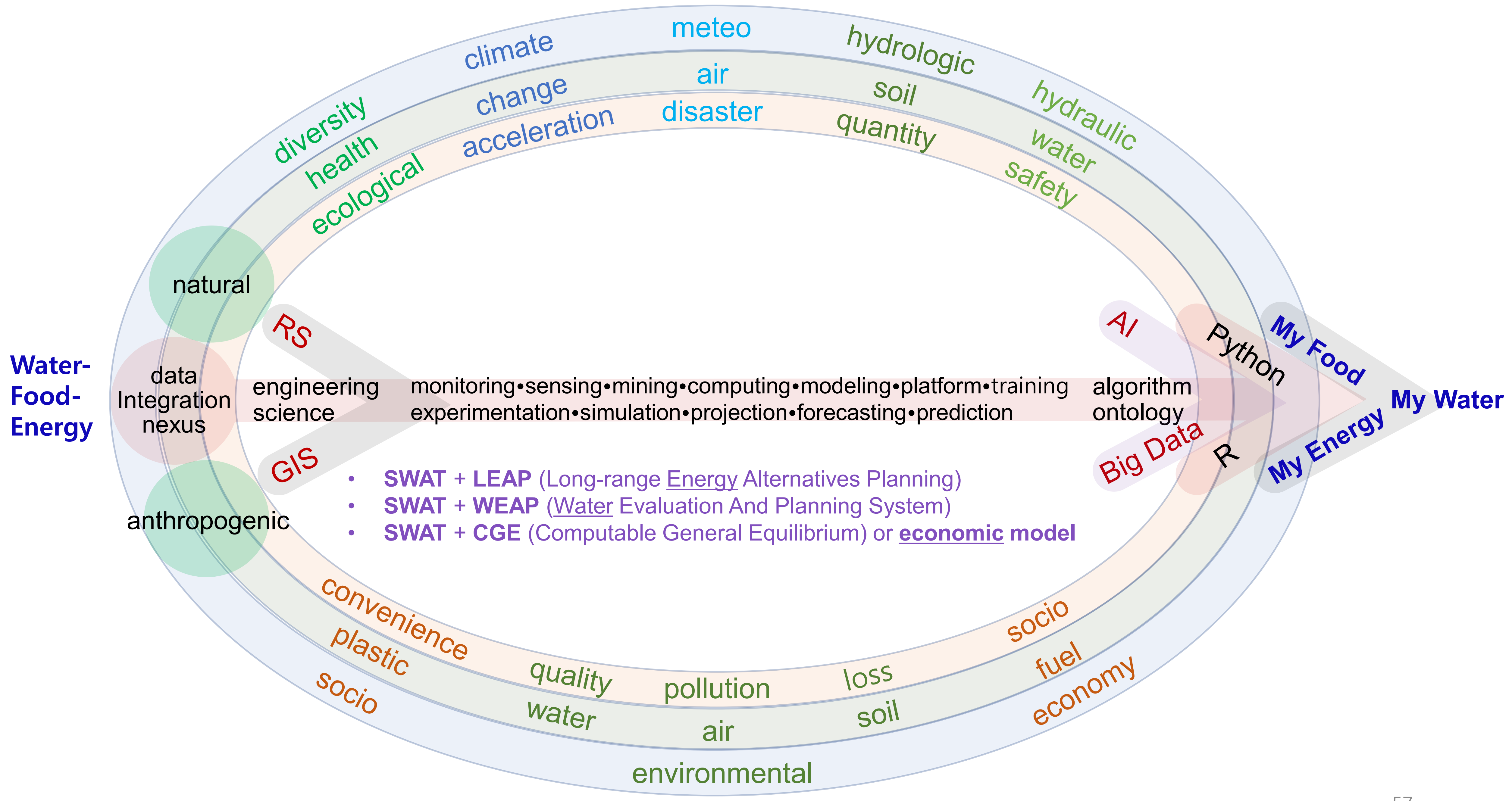
Flood modeling



AI, Machine Learning



Sentinel-1 Inundation area



meteo
climate
hydrologic
air
change
soil
hydraulic
diversity
disaster
acceleration
quantity
water
health
safety
ecological
natural
Water-Food-Energy
data Integration nexus
RS
engineering
science
monitoring•sensing•mining•computing•modeling•platform•training
experimentation•simulation•projection•forecasting•prediction
algorithm
ontology
AI
Python
Big Data
R
My Food
My Water
My Energy
GIS
anthropogenic
• SWAT + LEAP (Long-range Energy Alternatives Planning)
• SWAT + WEAP (Water Evaluation And Planning System)
• SWAT + CGE (Computable General Equilibrium) or economic model
convenience
plastic
socio
quality
water
pollution
air
loss
soil
socio
fuel
economy
environmental

	KCI	SCI
2001	0	1
2003	1	0
2004	0	3
2005	2	0
2006	9	2
2007	5	2
2008	5	4
2009	5	3
2010	1	13
2011	1	14
2012	1	7
2013	20	9
2014	17	20
2015	6	8
2016	5	22
2017	1	24
2018	12	23
2019	9	19
2020	3	11
2021	4	18
2022	1	11
2023	1	4
2024	0	3
2025	0	1
	109	222

SWAT study in South Korea

~2010

- Watershed hydrology simulation & nonpoint source pollution assessment

~2015

- Projection of watershed hydrology and water quality using climate change scenarios

2016~2020

- Agricultural water supply capacity assessment
- Integration of watershed SWAT and lake/river hydraulic models such as WASP, CE-QUAL-W2

2021~

- SWAT-K
- SWAT+