Strengthening Water Supply System Adaptive Capacity to Climate Change - Northern and Southern Region

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- Impact Assessment of Climate Change
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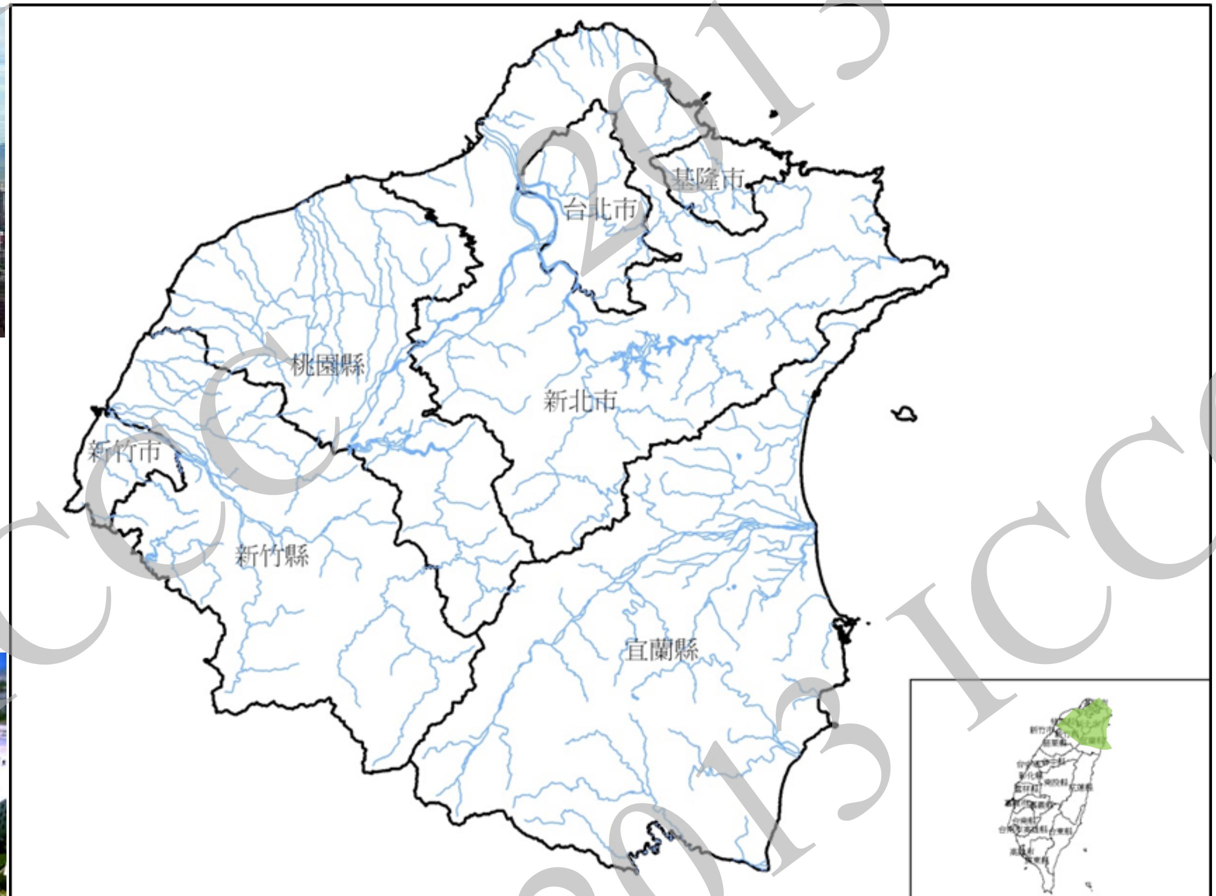
- Final Remarks

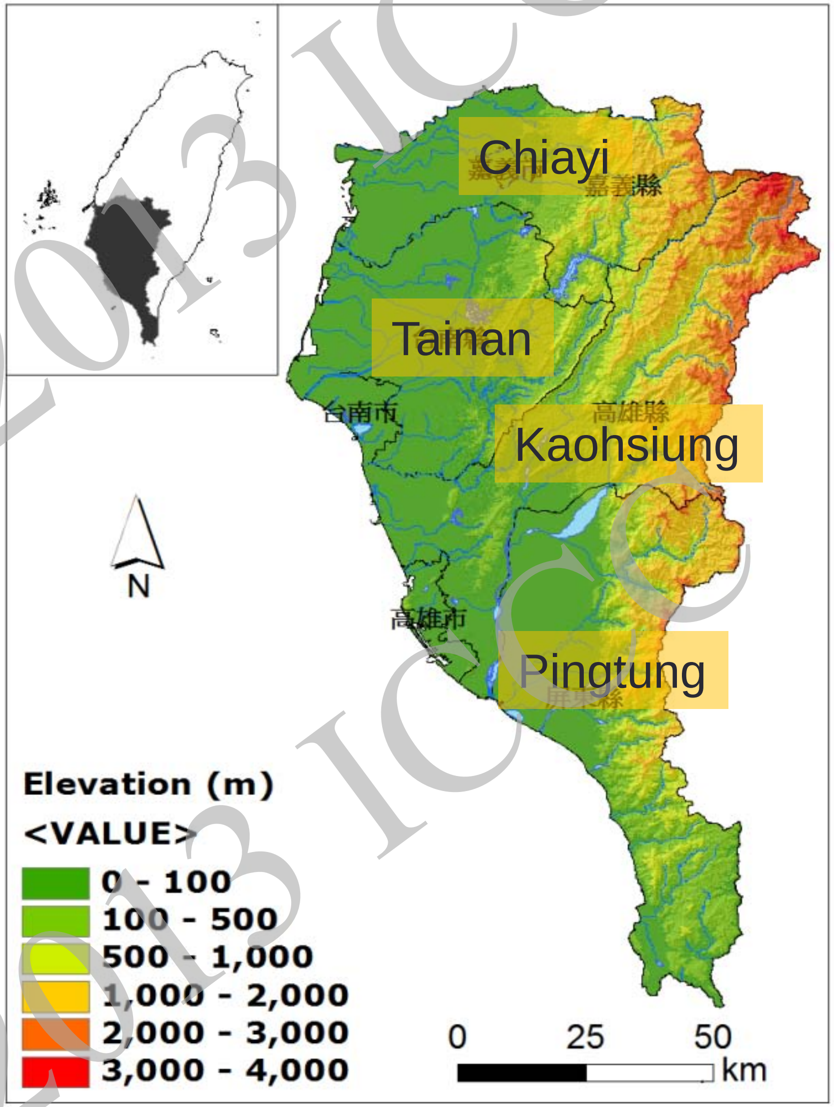
Goals of This Study

- Evaluate the sustainability of water supply systems
- Sketch vulnerability (risk) map and identify hot spot under current and future climatic conditions
- Develop adaptation strategies
- Establish indicator system to evaluate resilience

Northern Taiwan



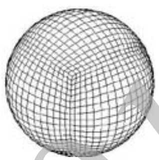
Southern Taiwan



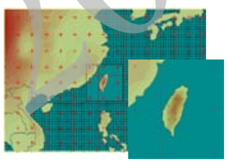
Impact Assessment of Climate Change

- Streamflow
- Carrying Capacity – Water Supply
- Loadings – Water Demand

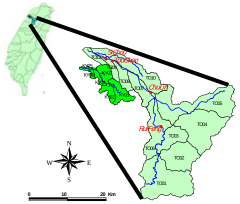
Procedure for Impact Assessment



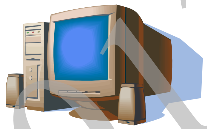
GCM Projections



Downscaling

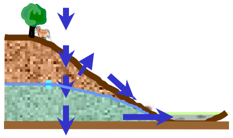


Future
Climate Scenarios

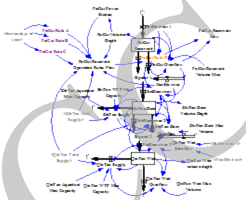


Weather
Generation

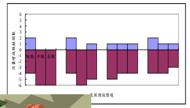
Hydrological Model



Water Supply System
Dynamics Model



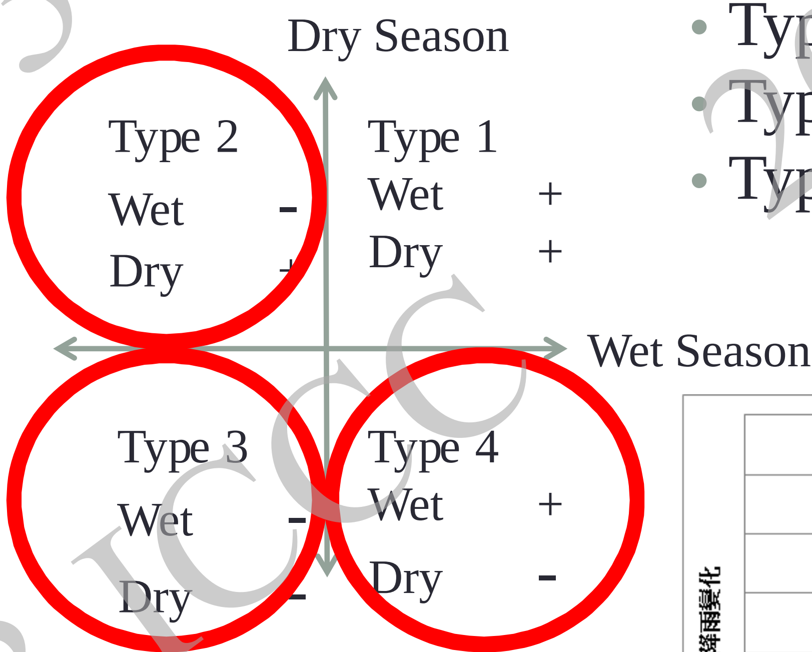
Impact Information for Decision Making



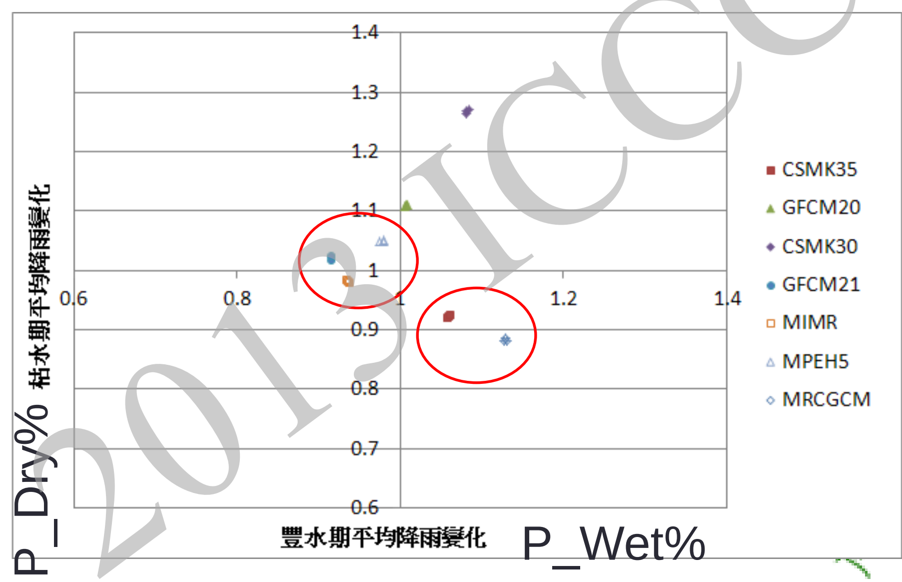
Selection of GCMs

- GCMs: 24
- East Asian monsoon: 9
- Quadrant: 5
- Verification: 5

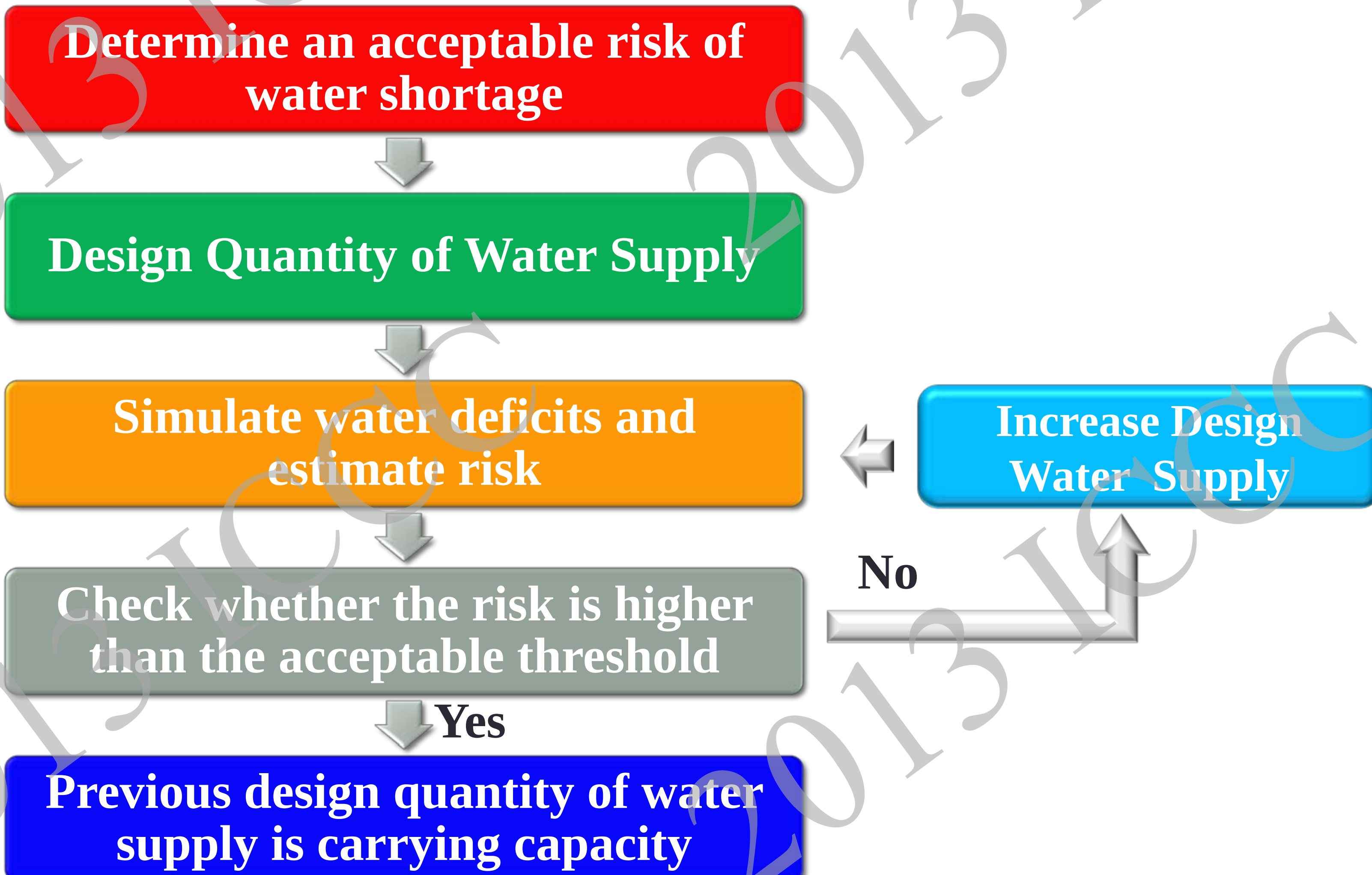
- Principles



- Results
  - Type 2: GFCM21 & MPEH5
  - Type 3: MIMR
  - Type 4: CSMK35 & MRCGCM



Procedure to determine carrying capacity - Quantity of Water Supply



Index of Water Shortage

- **SI (Shortage Index)**

$$SI = \frac{100}{N}\sum_{n=1}^{N}\left(\frac{D_i}{S_i}\right)^2$$

N: simulated year, D_i and S_i are annual shortage amount and annual water supply amount, respectively

- **DPD(Deficit Percent Day Index, DPD Index)**

DPD=Σ(daily shortage (%))

Public Water Demand

- Domestic Water Demand

  = Population×Prevalent Rate×$LPCD_{2031}$/(Ratio of Recorded Water Uses) + Other institute water uses

  - LPCD = water use per capita per day (liter/capita/day)
  - $LPCD_{2031}=LPCD_{2007WRA}$+GDPcorr.+Tcorr.

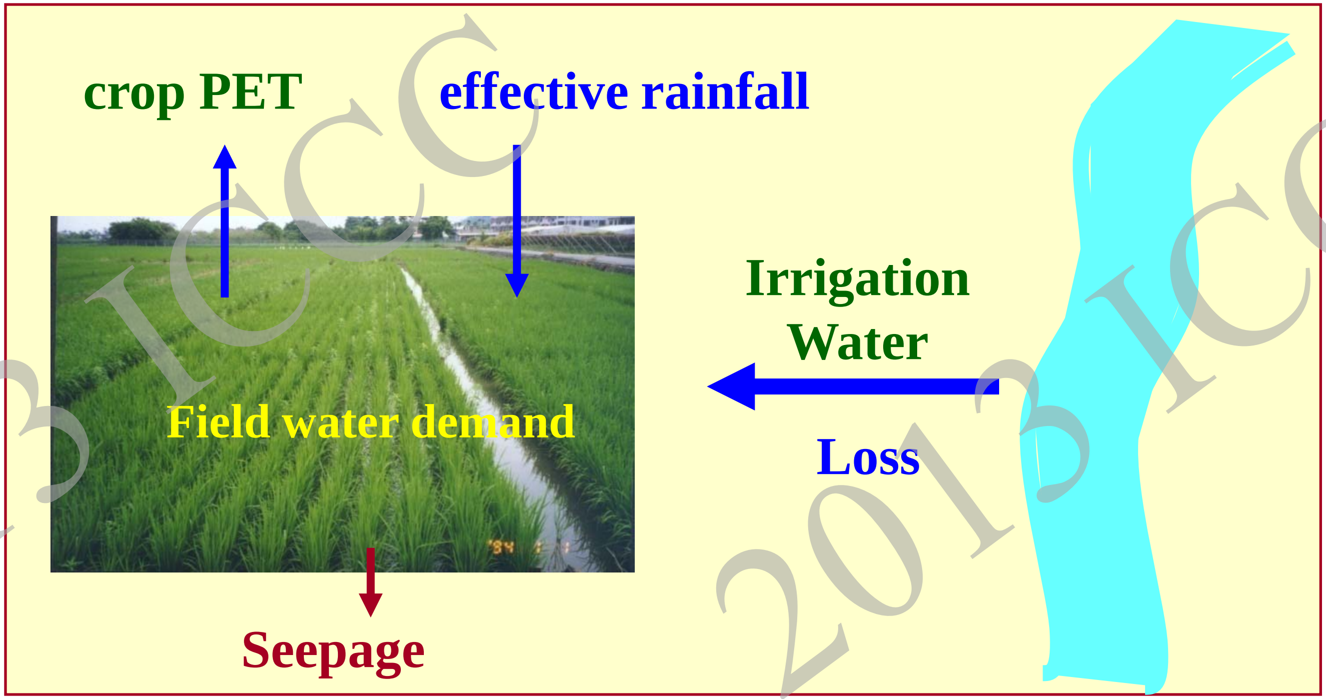
- Industrial Water Demand

  = Σ (Industrial Area×Unit Water Requirement)

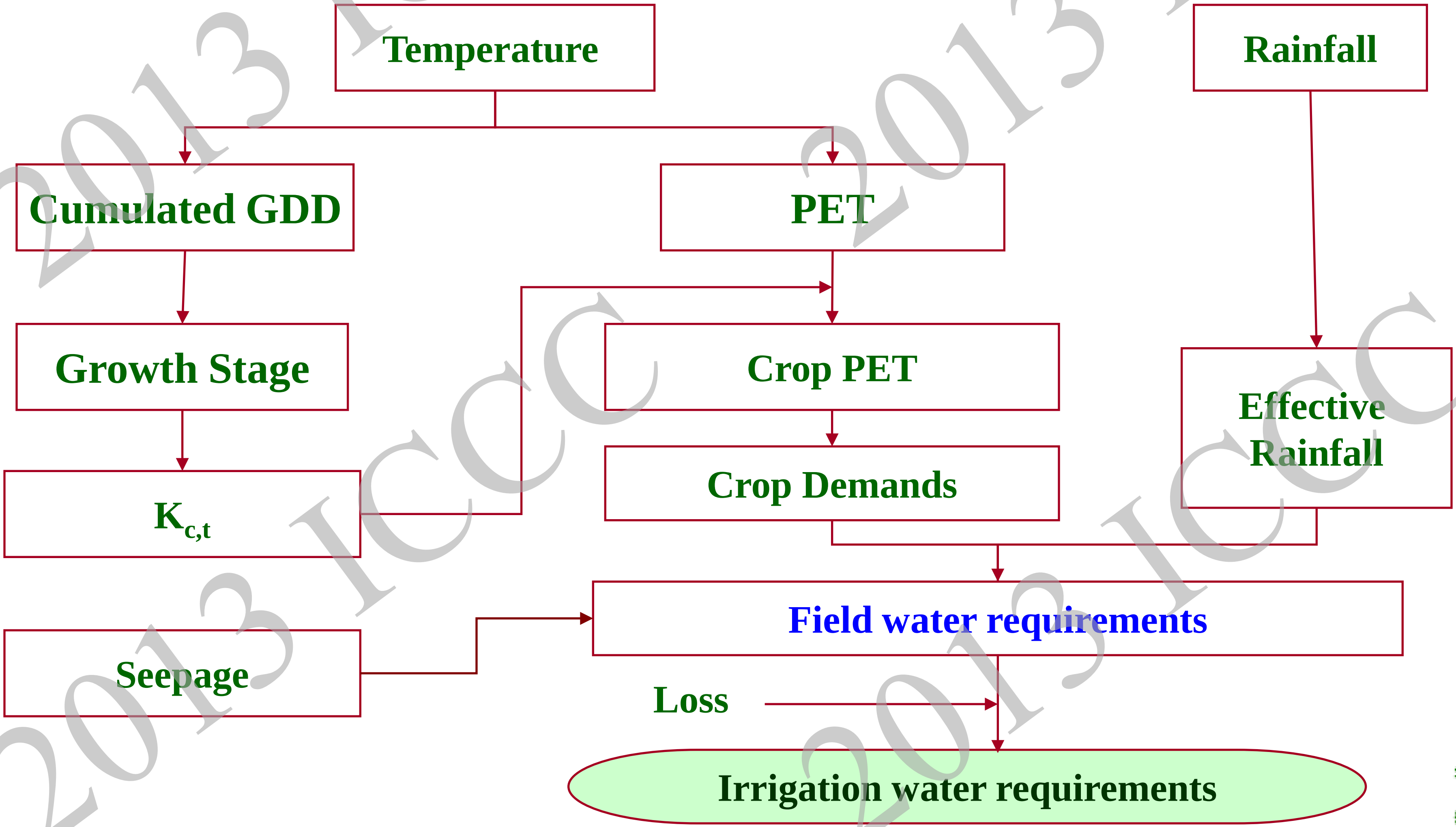
  - Industrial Areas corresponding to SRES scenarios
    - A2 : High Development
    - A1B : Medium Development
    - B1 : Low Development

Agricultural Water Demand - Irrigation Water Analysis

- Irrigation Water =Field Water Requirement + delivery loss
- Field water demand = Crop water demands + Seepage
  - effective rainfall
- Crop water demands = kc PET

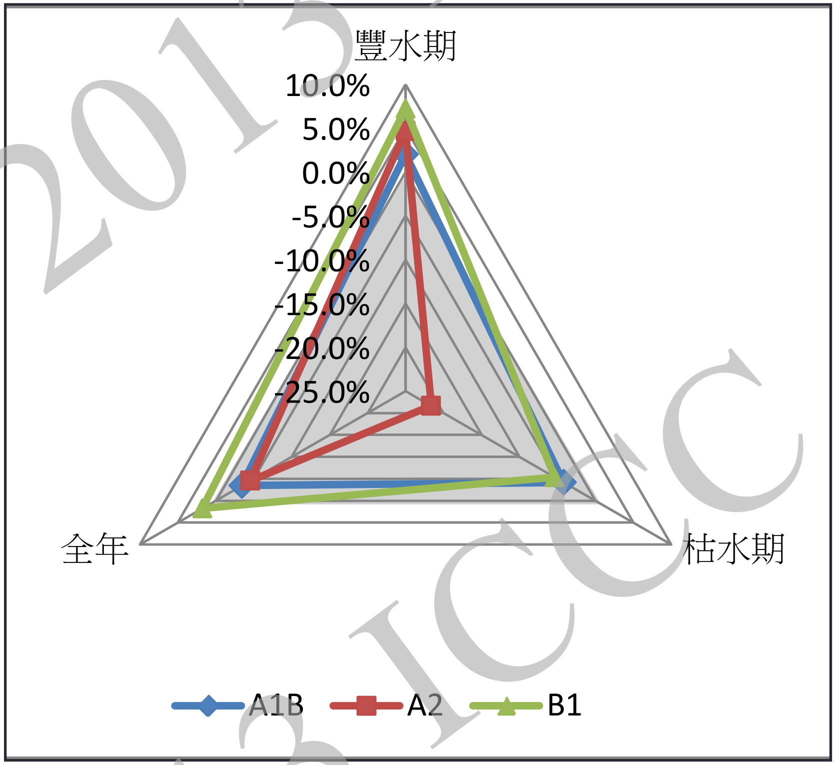


Estimation Procedure of Agricultural Water Demand



Impact of Climate Change on River Flow

- The wet season
  - The river flow increases about 7%.
- The dry season
  - The river flow might decreases most about 22%.



The Carrying Capacity and Loadings of Each System

System	Baseline (1980~1999)			2031 W/O climate change			The worst case of A1B		
	Demand (10^4 tons/day)	Carrying Capacity (10^4 tons/day)		Demand (10^4 tons/day)	Carrying Capacity (10^4 tons/day)		Demand (10^4 tons/day)	Carrying Capacity (10^4 tons/day)	
		Based on SI	Based on DPD		Based on SI	Based on DPD		Based on SI	Based on DPD
Yilan	17	26	23	17	26	23	17	26	23
Keelung	51	58	57	51	58	57	51	54	44
Taipei	229	399*	406*	172	401*	406*	148	395*	406*
Banshin	88	92	114	90	91	110	79	89	98
Taoyuan	97	116	112	137	114	113	131	114	112
Hsinchu	52	54	56	64	54	56	64	50	52

*: The carrying capacity of Taipei includes the water demand of Taipei city and the supporting water supply of Banshin and 1st Branch of Taiwan Water Corporation.

Vulnerability (Risk) Map

Definition of Vulnerability (Risk)

- Vulnerability = F(S, E, A)

- Vulnerability = Hazard(Sensitivity) × Exposure

= Water Deficits × Exposure

(Domestic) = Water Deficits × Population Density

(Industrial) = Water Deficits × Values of Production

(Agricultural) =Water Deficits × Agricultural Area

Rank of Hazard and Exposure

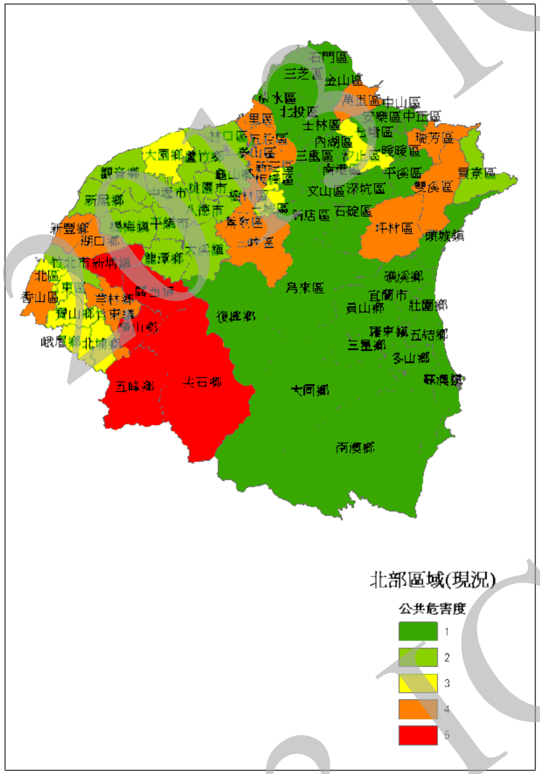
Water Use	Hazard	1	2	3	4	5
Public	DPD	<100	100~600	600~1500	1500~3500	>3500
Agriculture	Water shortage (%)	<15	15~20	20~30	30~40	>40

Water Use	Exposure	1	2	3	4	5
Domestic	Population density (person/km^2)	<174	174~468	468~967	967~2771	>2771
Industrial	Output value (billion dollars)	<0.6	0.6~2.4	2.4~8.9	8.9~25.5	>25.5
Agricultural	irrigation area (ha)	<97	97~607	607~1387	1387~2221	>2221

The Vulnerability (Risk) Ranking Matrix

		Vulnerability				
Hazard		1	2	3	4	5
	1	1	1	1	1	2
	2	1	1	2	2	3
	3	1	2	2	3	4
	4	1	2	3	4	5
	5	2	3	4	5	5

Hazard Maps of Public Water Uses – Northern Region



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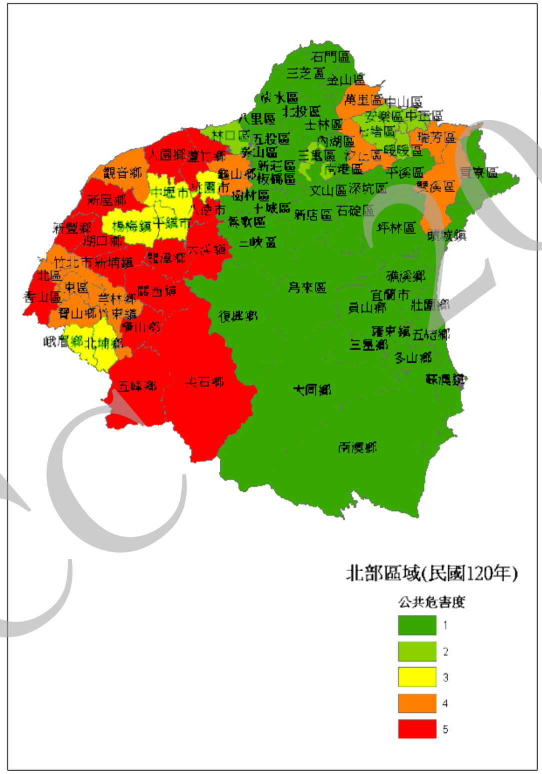
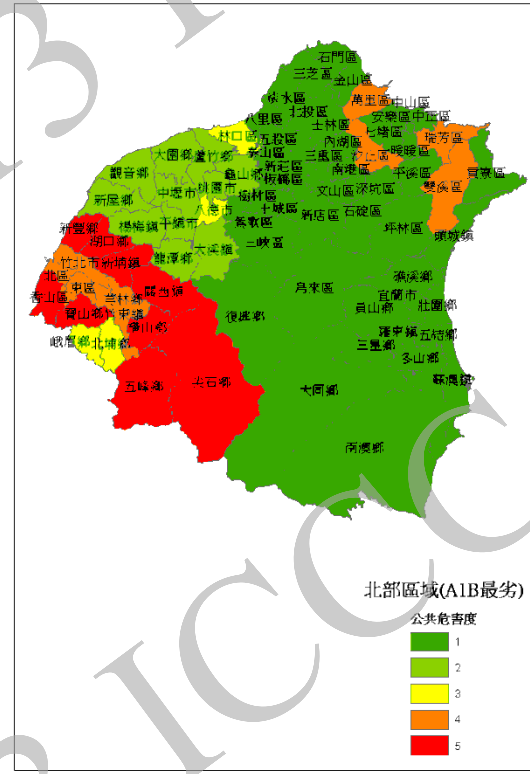
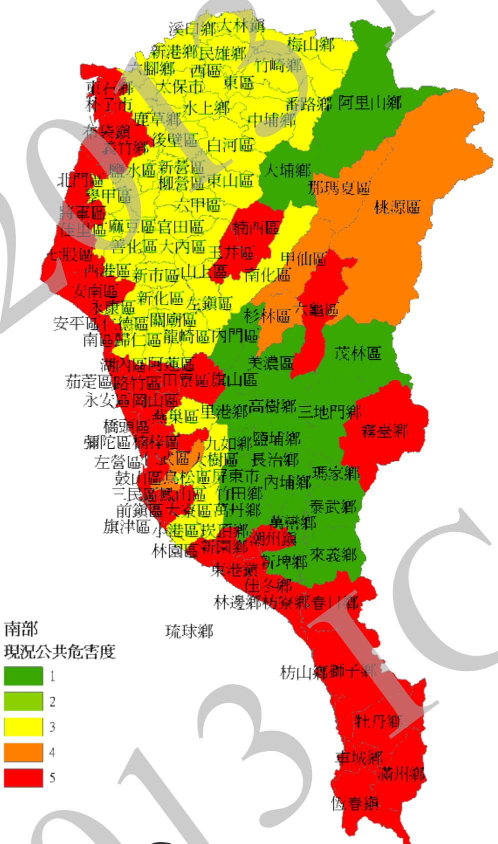


Year 2031 without Climate Change



Worst Case
Year 2031 under Climate Change A1B

Hazard Maps of Public Water Uses – Southern Region



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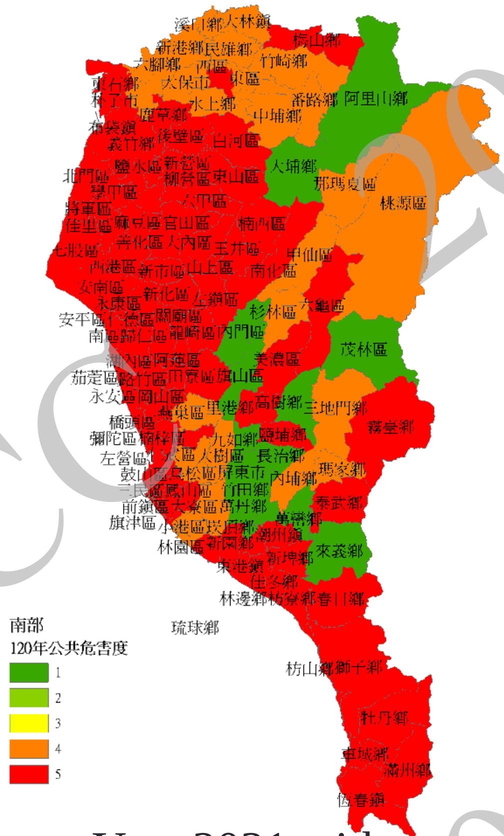

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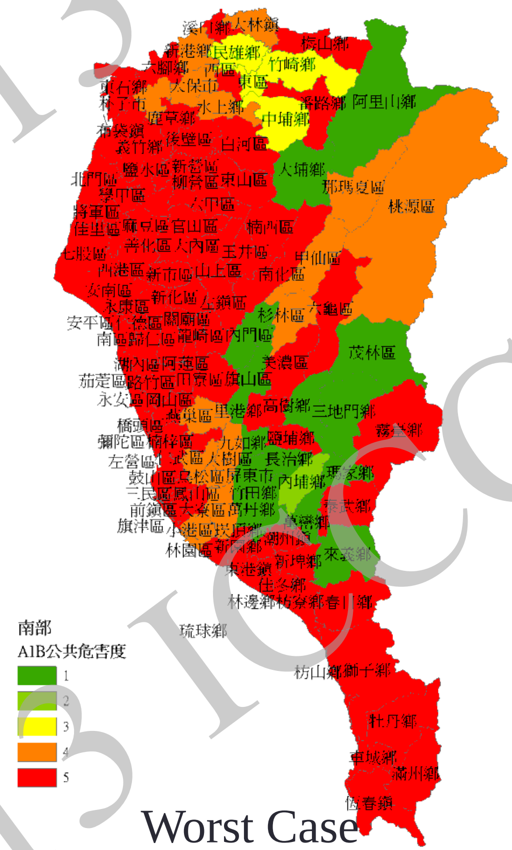
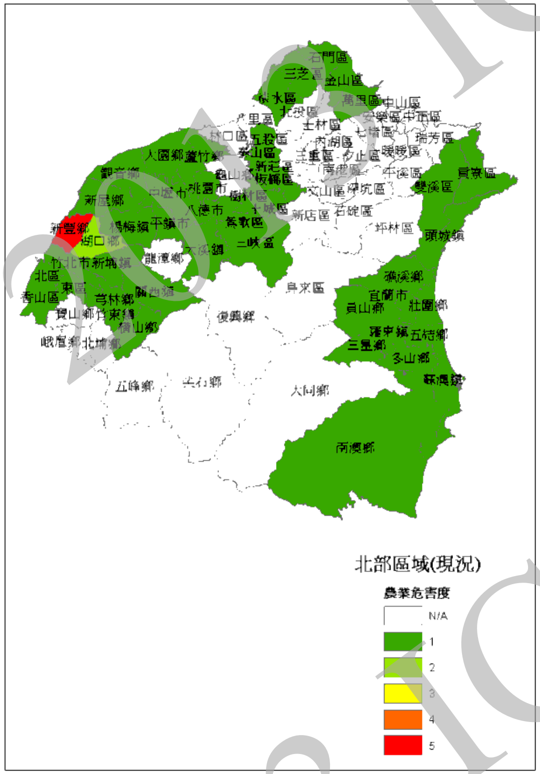


Worst Case
Year 2031 under Climate Change A1B

Hazard Maps of Agricultural Water Uses – Northern Region



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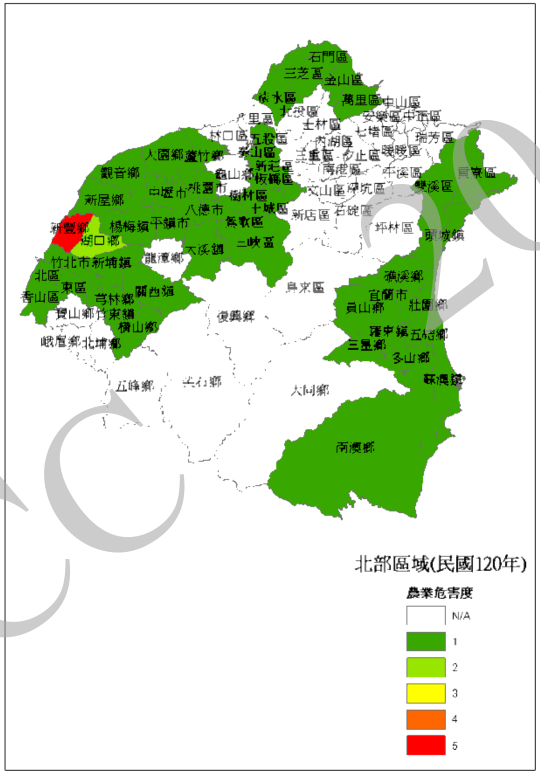

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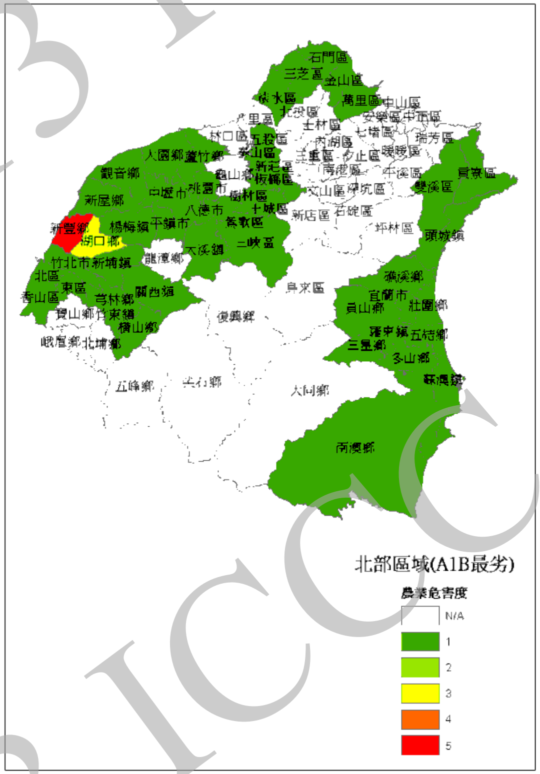
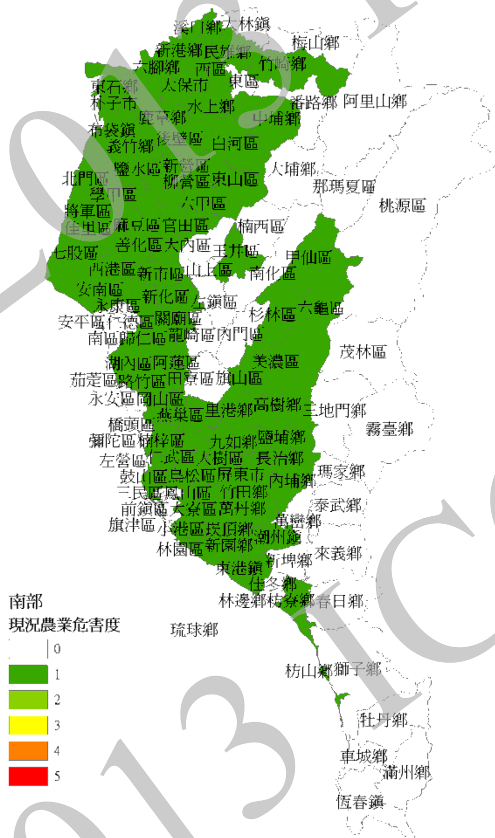


Worst Case Year 2031 under Climate Change A1B

Hazard Maps of Agricultural Water Uses – Southern Region

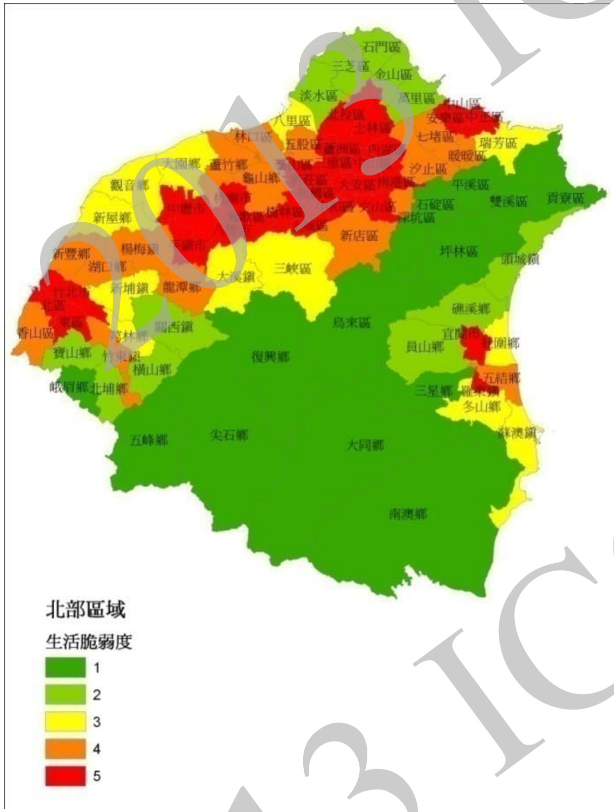


Current

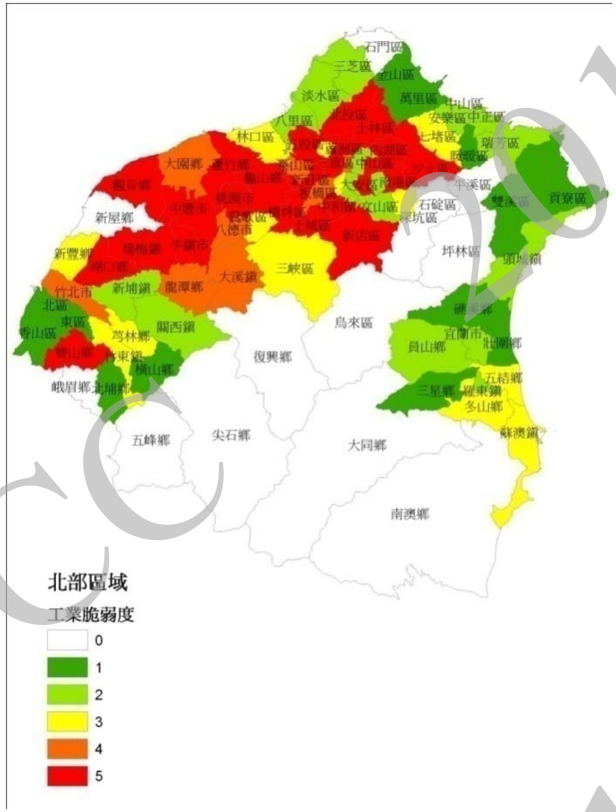
Year 2031 without Climate Change

Worst Case
Year 2031 under Climate Change A1B

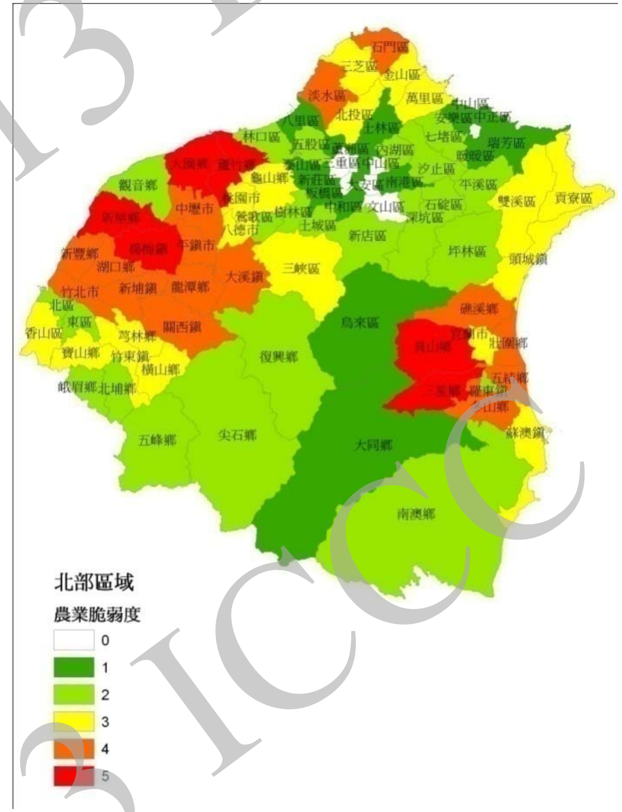
Exposure Maps – Northern Region



Domestic

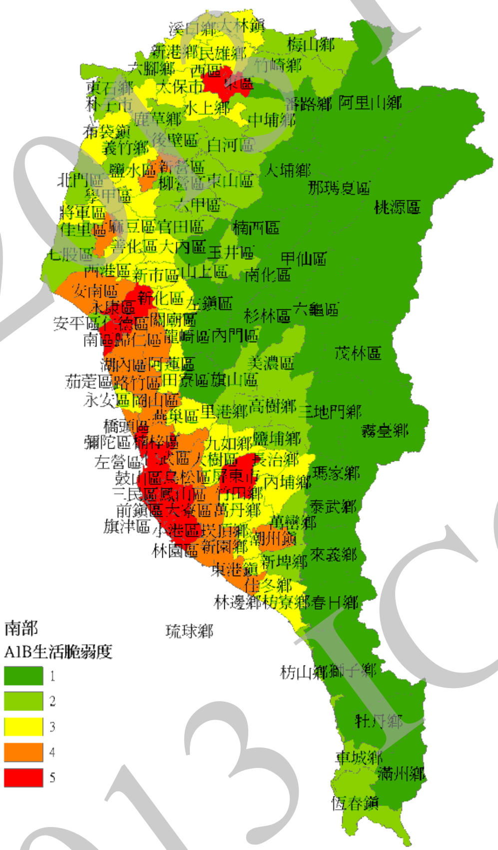


Industrial

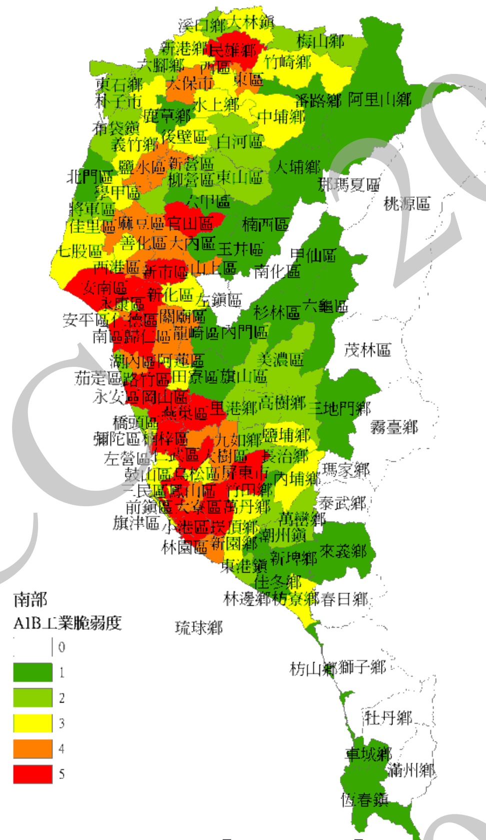


Agricultural

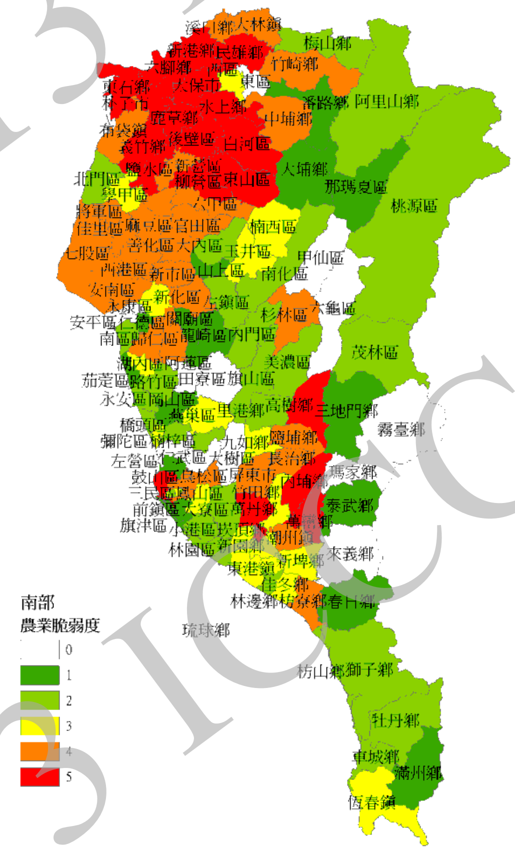
Exposure Maps – Southern Region



Domestic

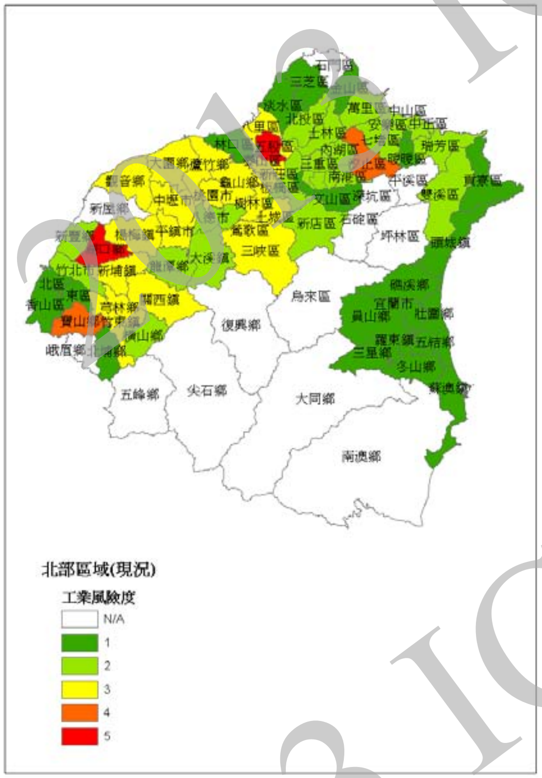


Industrial



Agricultural

Vulnerability (Risk) Maps of Industrial Water Use – Northern Region



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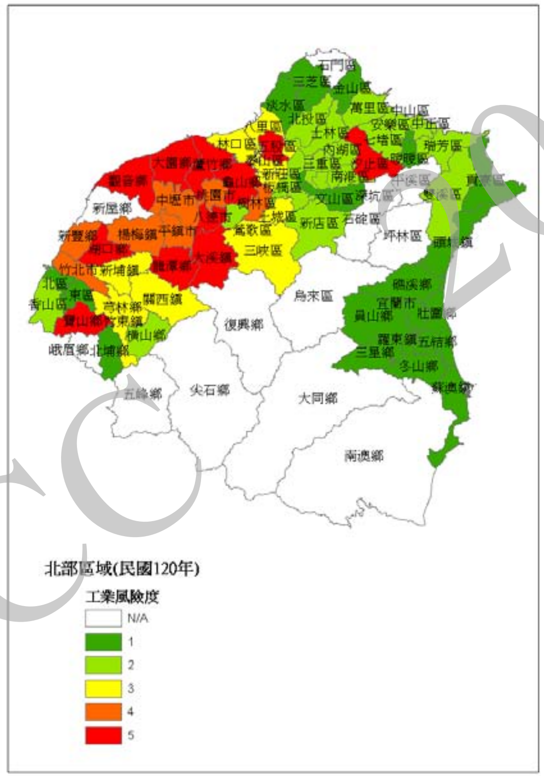
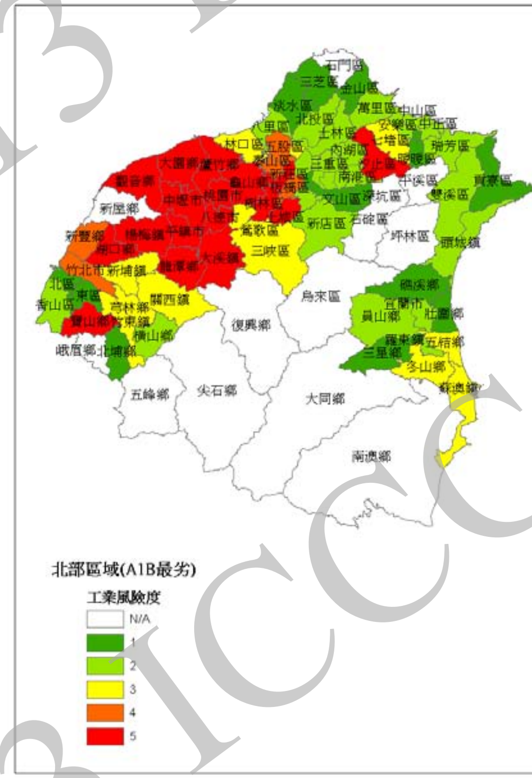
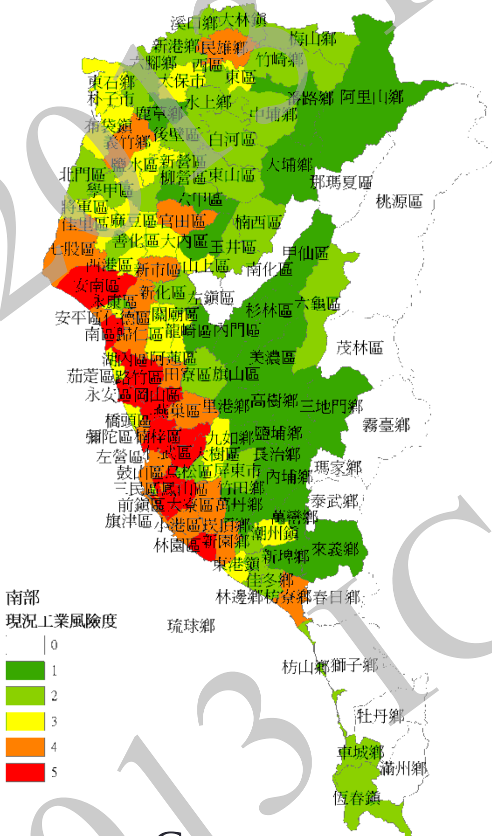


Year 2031 without Climate Change



Worst Case
Year 2031 under
Climate Change A1B

Vulnerability (Risk) Maps of Industrial Water Use – Southern Region



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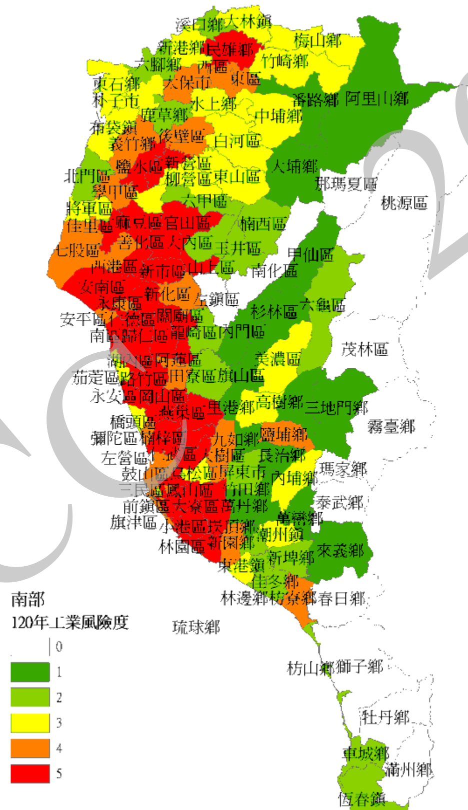
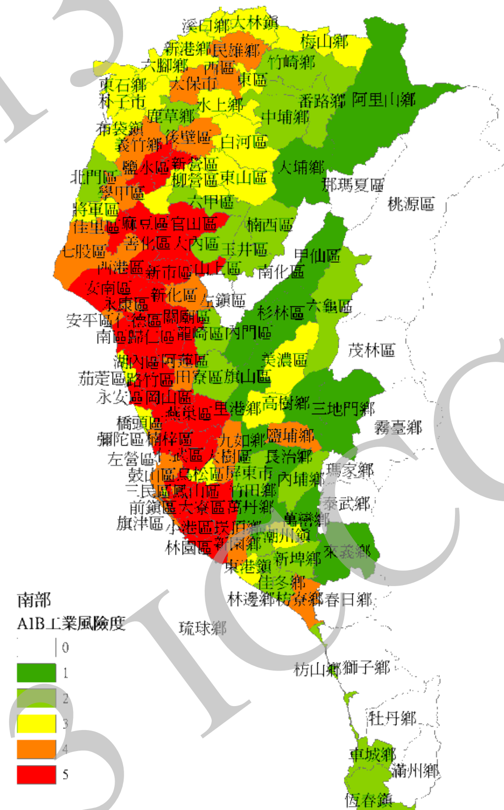
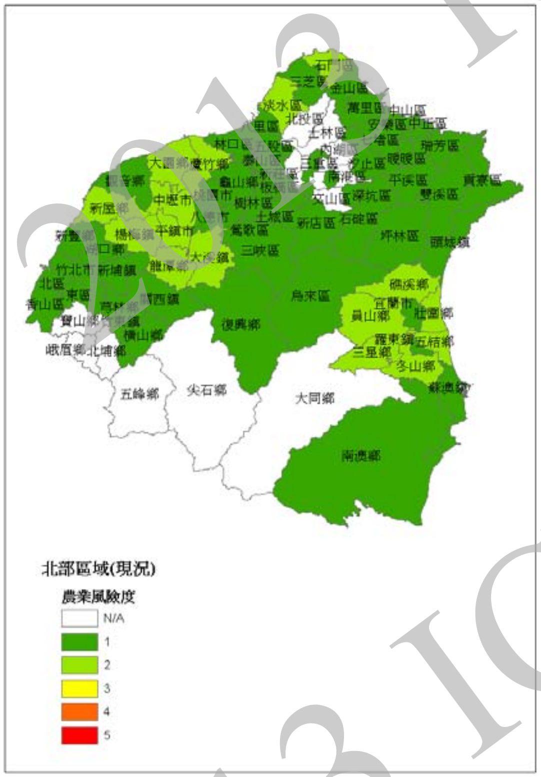


Year 2031 without Climate Change



Worst Case Year 2031 under Climate Change A1B

Vulnerability (Risk) Maps of Agricultural Water Uses – Northern Region

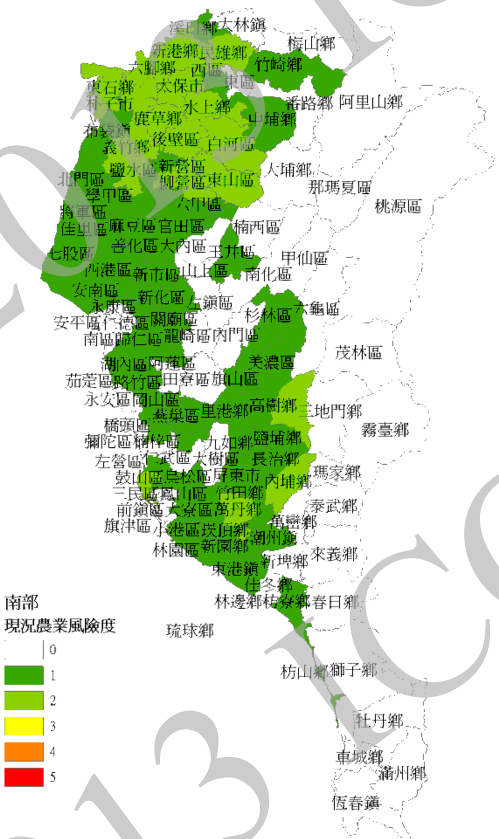


Current

Year 2031 without Climate Change

Worst Case Year 2031 under Climate Change A1B

Vulnerability (Risk) Maps of Agricultural Water Uses – Southern Region



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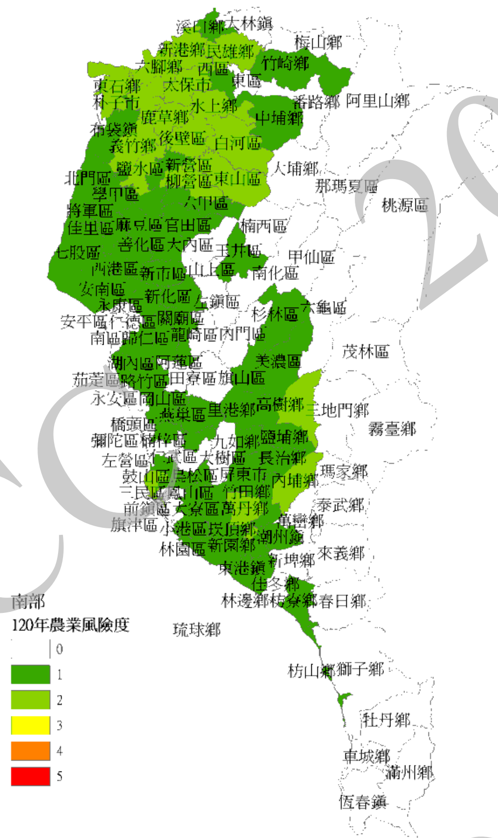

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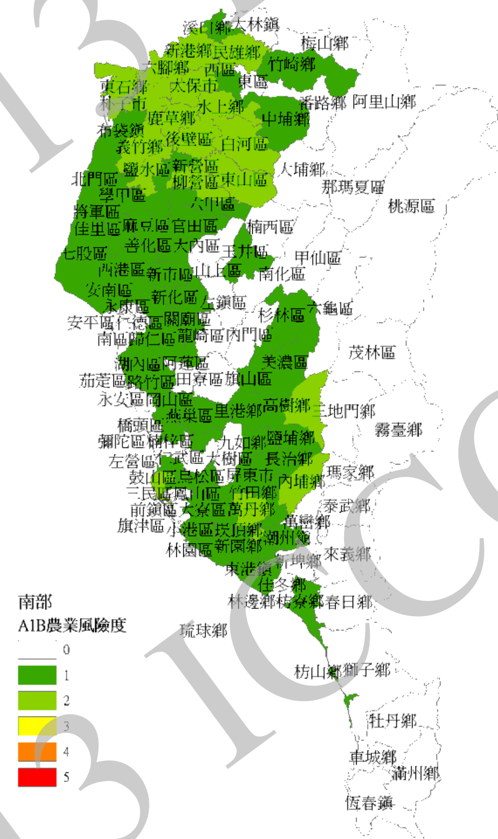
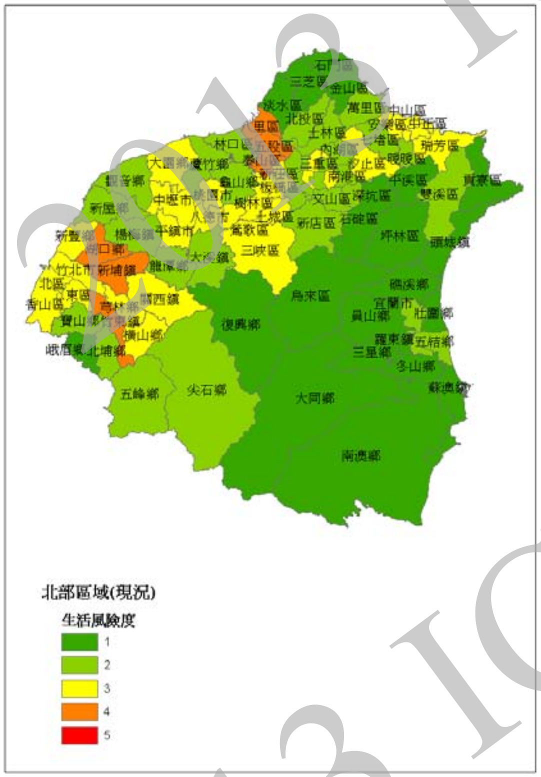


Worst Case
Year 2031 under Climate Change A1B

Vulnerability (Risk) Maps of Domestic Water Uses – Northern Region



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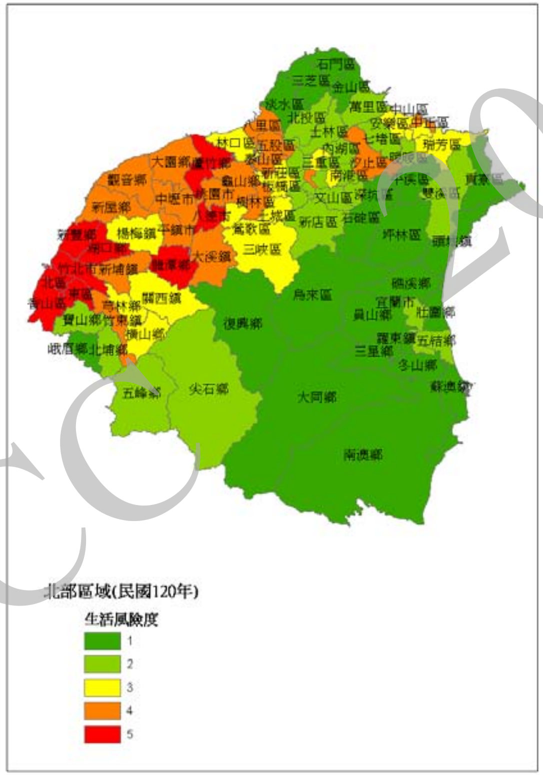
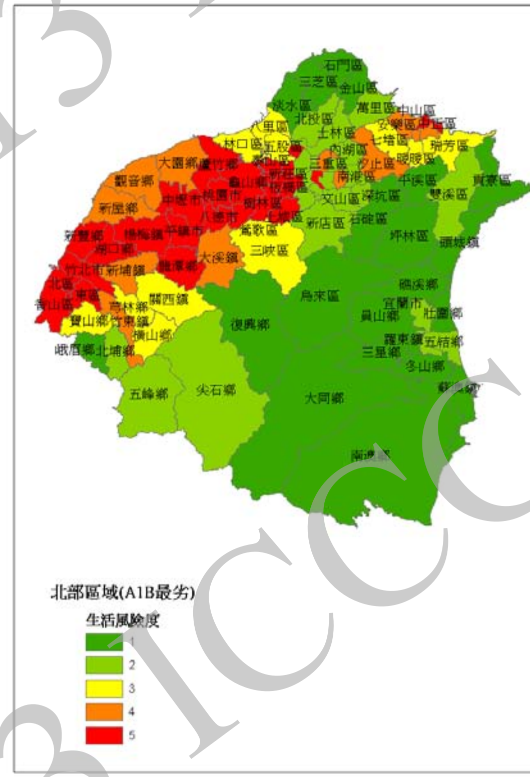
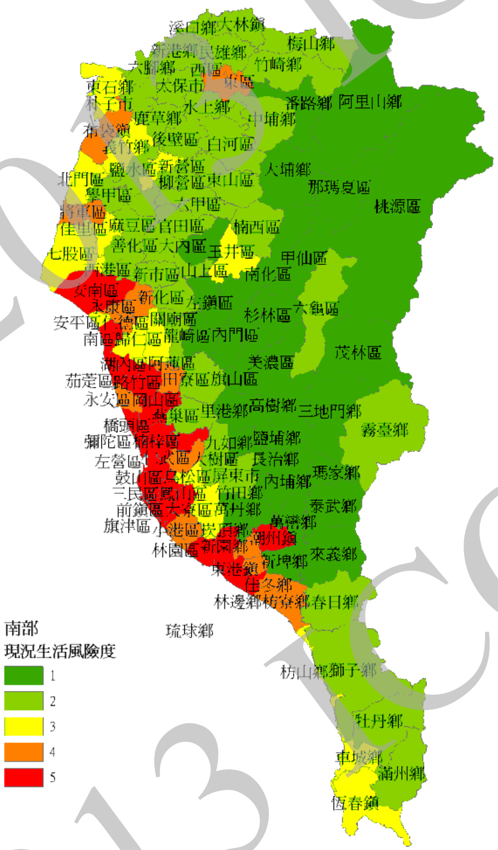


Year 2031 without Climate Change



Worst Case
Year 2031 under Climate Change A1B

Vulnerability (Risk) Maps of Domestic Water Uses – Southern Region



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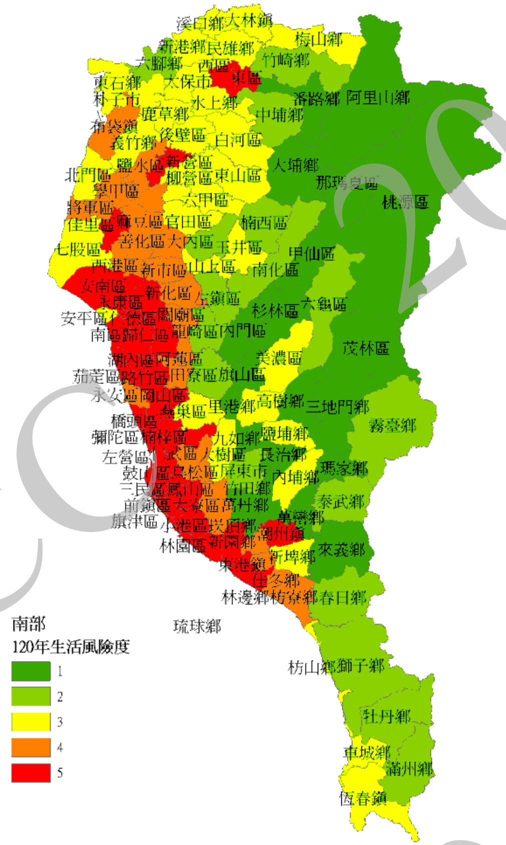
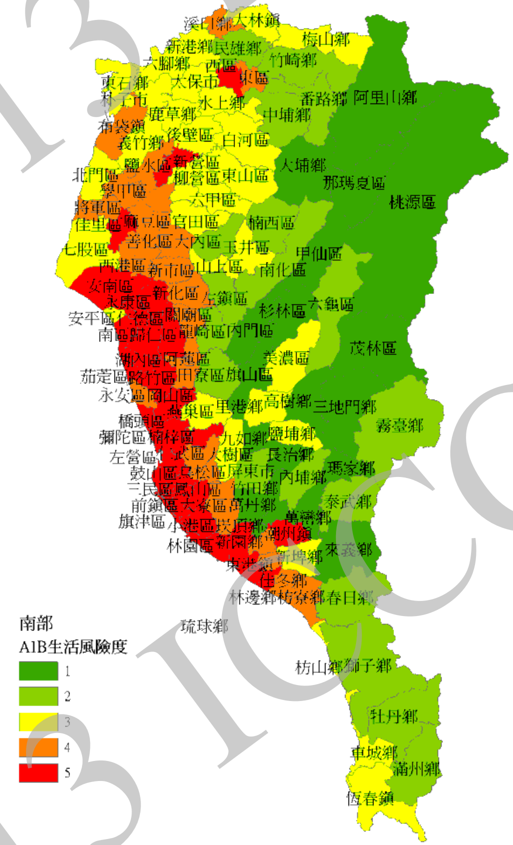
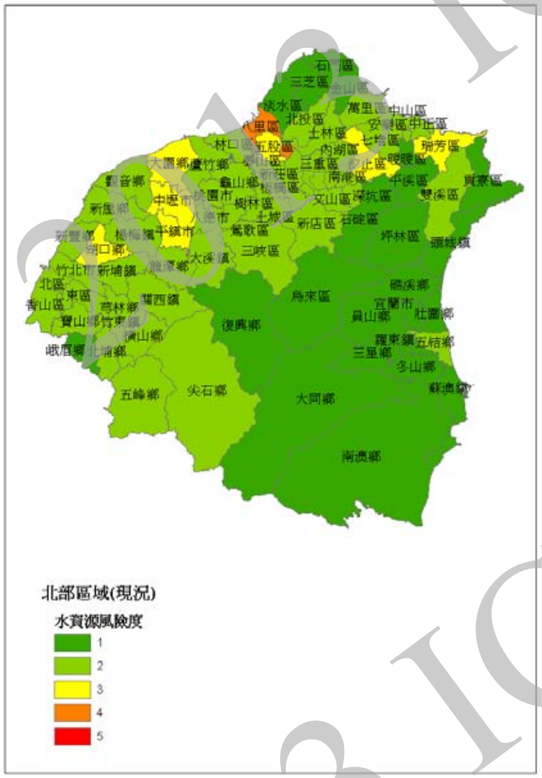


Year 2031 without Climate Change



Worst Case Year 2031 under Climate Change A1B

Vulnerability (Risk) Maps of Water Resources– Northern Region



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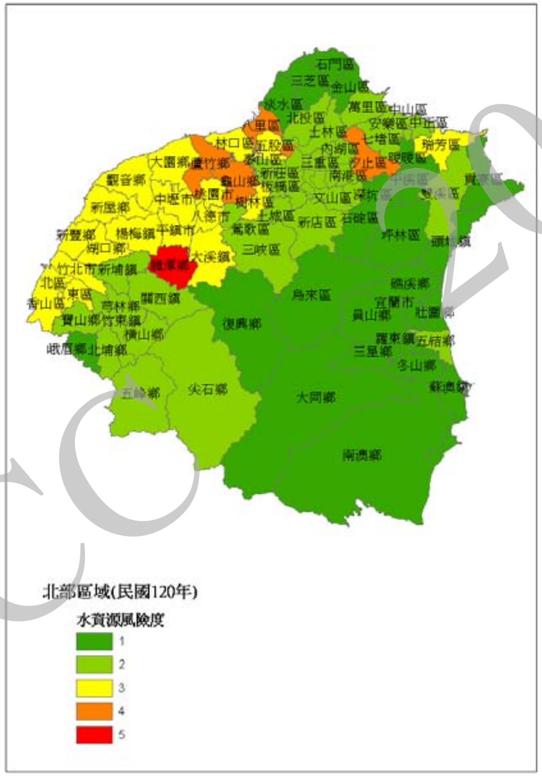
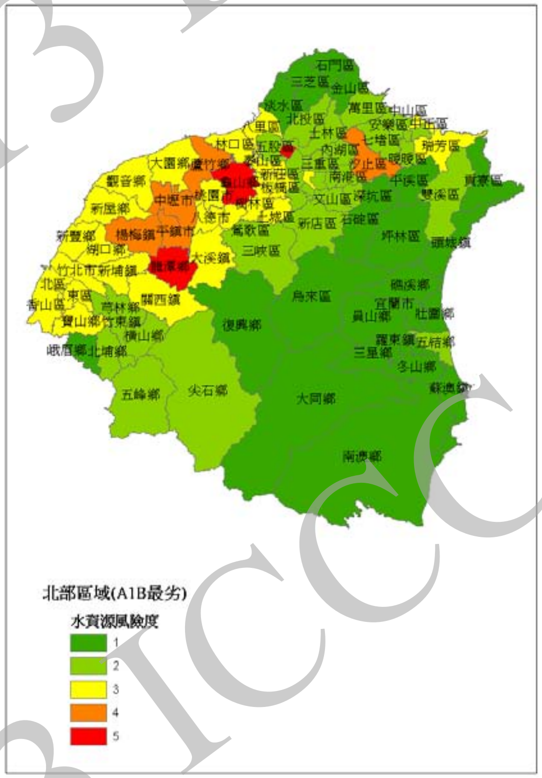
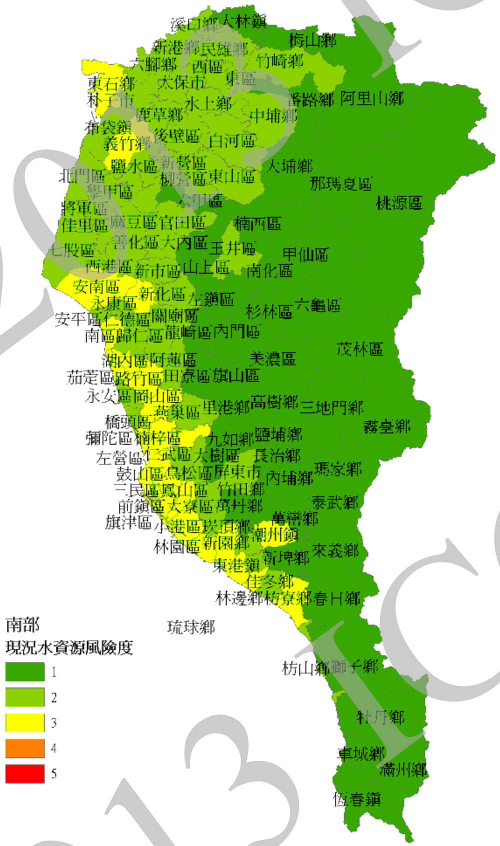


Year 2031 without Climate Change



Worst Case
Year 2031 under
Climate Change A1B

Vulnerability (Risk) Maps of Water Resources – Southern Region



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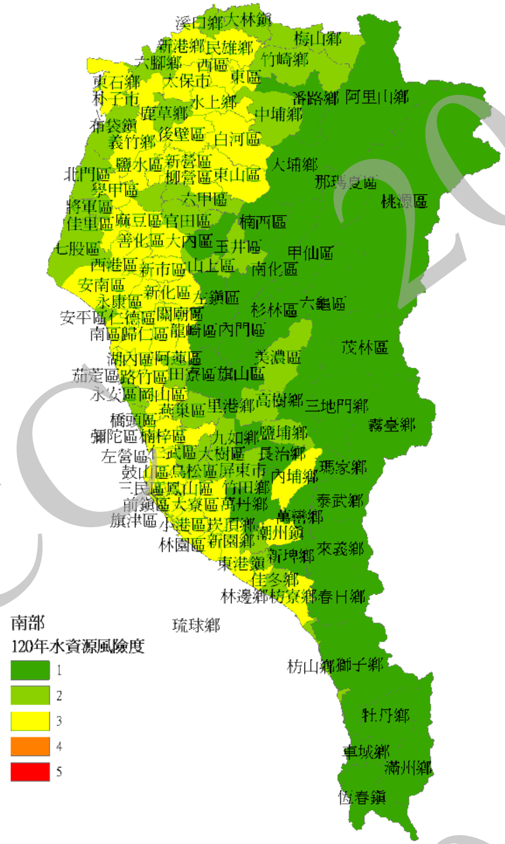
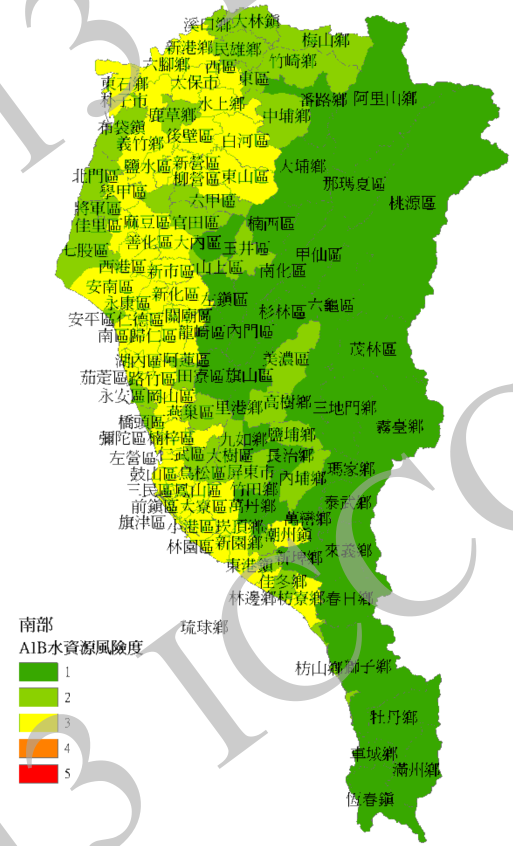


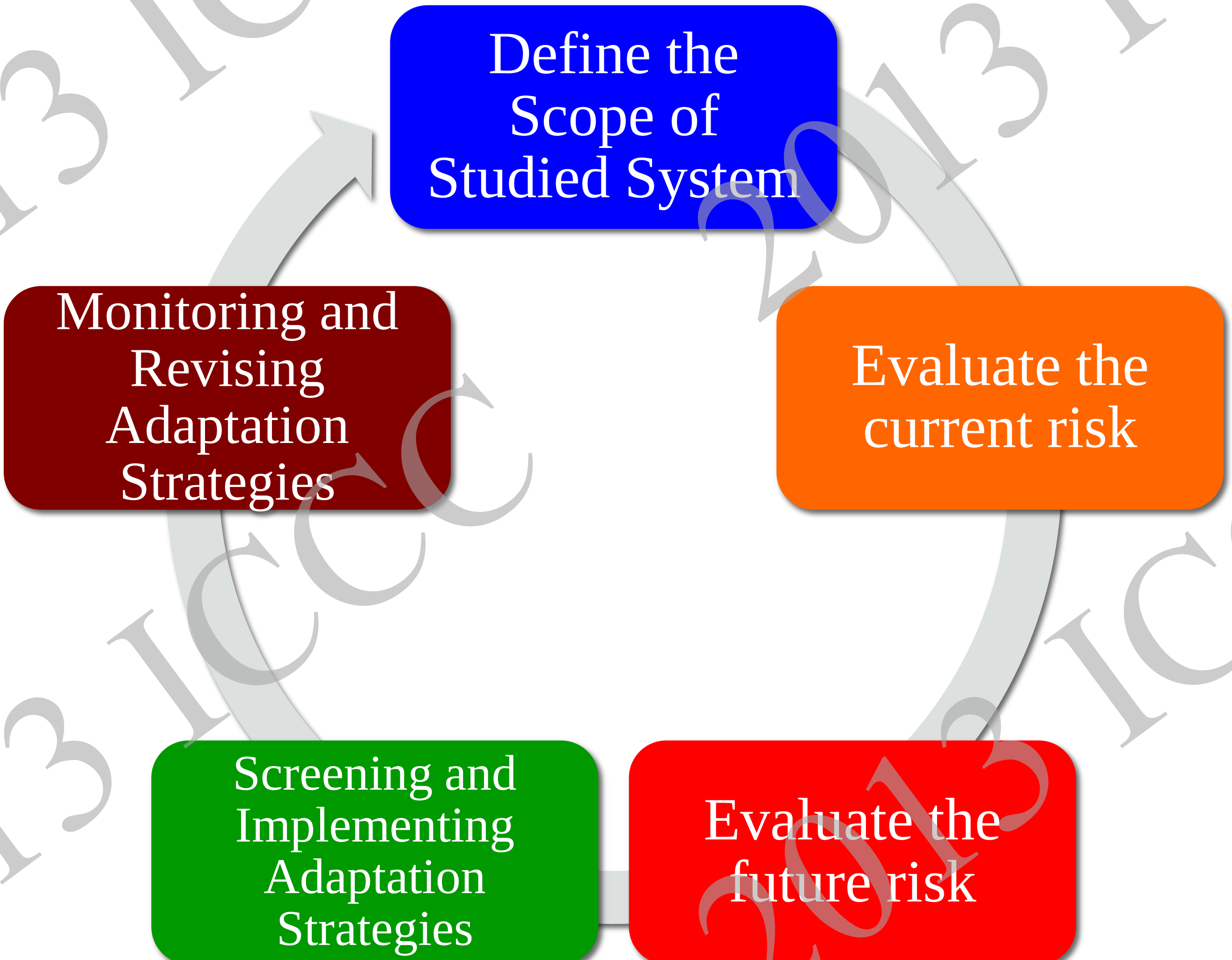
Year 2031 without Climate Change



Worst Case Year 2031 under Climate Change A1B

Adaptive Capacity Building

Procedure based on UK Adaptation Wizard



Procedure to develop strategies and action plans

Possible Problem	Strategies	Action Plans
Insufficient Carrying Capacity of Water Supply – Water Sources	Stabilizing Water Supply	**Groundwater** **Rainwater** **Reuse**
Insufficient Carrying Capacity of Water Supply – Facility		**Existing Plans** **New Plans**
Over-Loading – High Water Demand	Reasonable Water Uses	Water Saving
Lack of Flexibility of Water Resources Management	Strengthening Flexible Water Management	Conduct Pipe
Lack of Ability to Make Decisions with Considering Uncertainty	1. Quantifying uncertainty and enrich information related to climate change 2. Decision making under uncertainty	:
Improper land use planning	Land use planning	:
Public awareness	Education and others	:

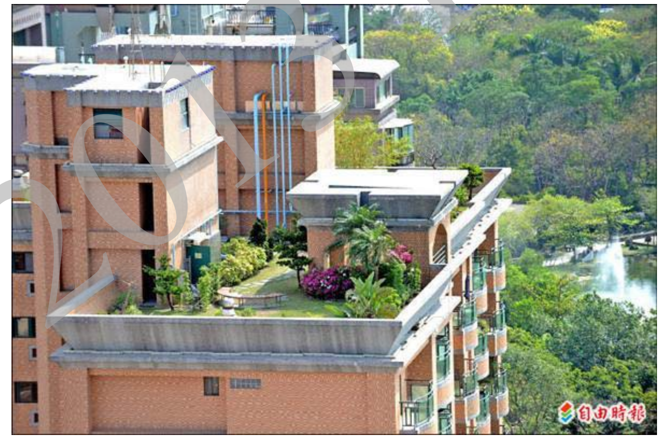
Adaptive capacity building

- Traditional Measures, such as reservoir
  - Effectiveness for larger area
  - Huge costs and high impact to ecosystem
  - Not flexible
  - Not easy to promote
  - Longer time to plan and build

- Distributed response system
  - Effectiveness for smaller area
  - Low costs and Low impact
  - Flexible
  - Shorter time to plan and implement

Distributed response facilities

Groundwater Well

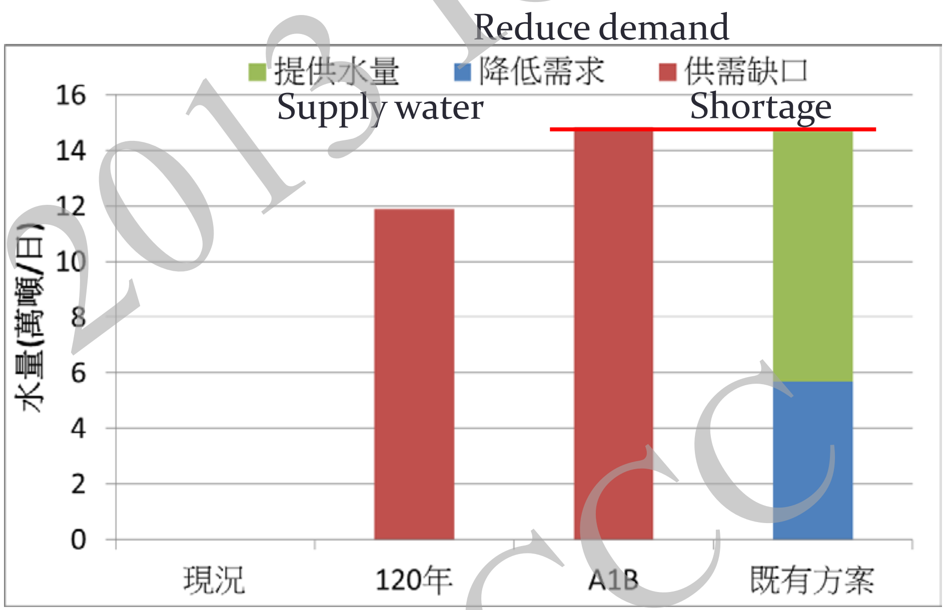


Rainfall Harvesting

Artificial Lake & Pond

Sea water desalinization

Analysis of implementing planned measures - Hsinchu (新竹)



加入既有方案後，在A1B情境下便可滿足用水需求

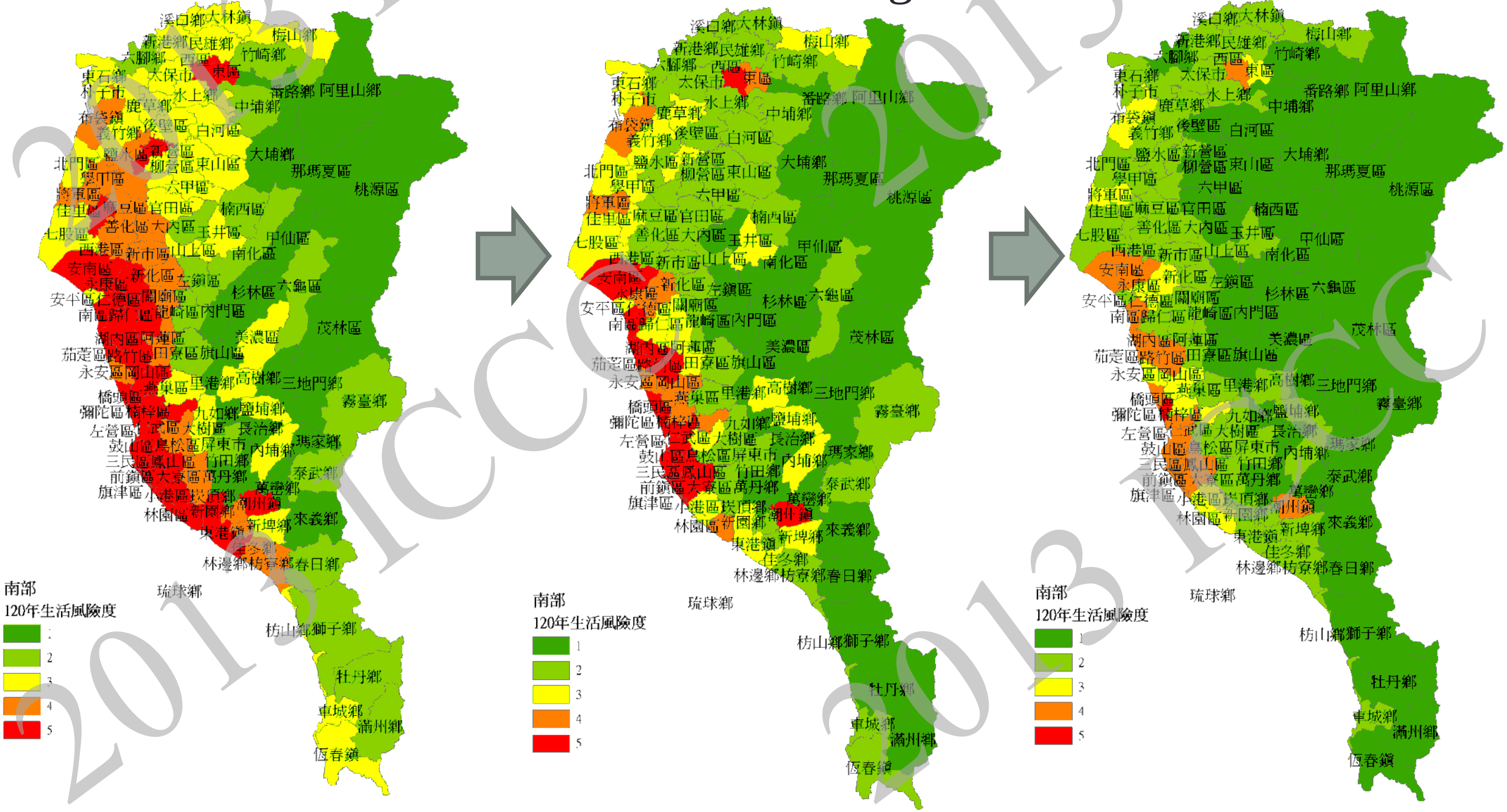
- 1.Seawater desalination plant
  - For the high-tech industry
  - Supply water: about **9×10^4 tons/day**
- 2. Domestic water saving
  - Reduce demand: **2.1×10^4 tons/day**
- 3. Industrial water saving
  - Reduce demand: **3.6×10^4 tons/day**

The Analysis of Planned Strategies

2031		No Climate Change	The Worst Case of A1B
Loadings (Demand)	No Strategy	64.17	64.27
	Planned Strategies	57.73	57.84
Carrying Capacity (Water Supply)	No Strategy	52.27	49.44
	Planned Strategies	64.77	59.82
Deficits	No Strategy	-10.75	-14.83
	Planned Strategies	-	-

Vulnerability Maps of Domestic Water Uses with strategies

No strategies | +Planned strategies | +Strengthening strategies



Evaluation of Resilience

Definition of Resilience

Resilience

Ecological Resilience

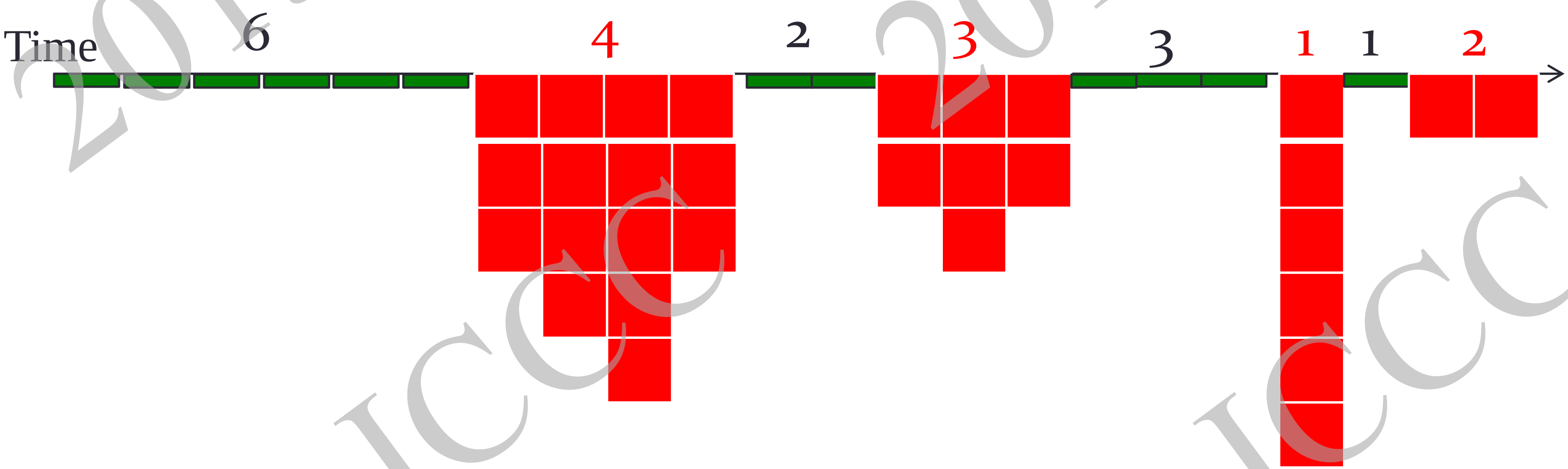
How far (Threshold) a system can go without totally collapse.

Engineering Resilience

How fast a system can back to normal state.

Time to Failure and Time to Repair

- Function : Loading ≤ Carrying Capacity
- Failure : Loading > Carrying Capacity



- Time to Failure, TTF : Duration of function = 6, 2, 3, 1
- Time to Repair, TTR : Duration of failure = 4, 3, 1, 2
- Total Cumulative Deficits of three events = 15, 7, 6, 2
- Max. Deficit of a time period = 6

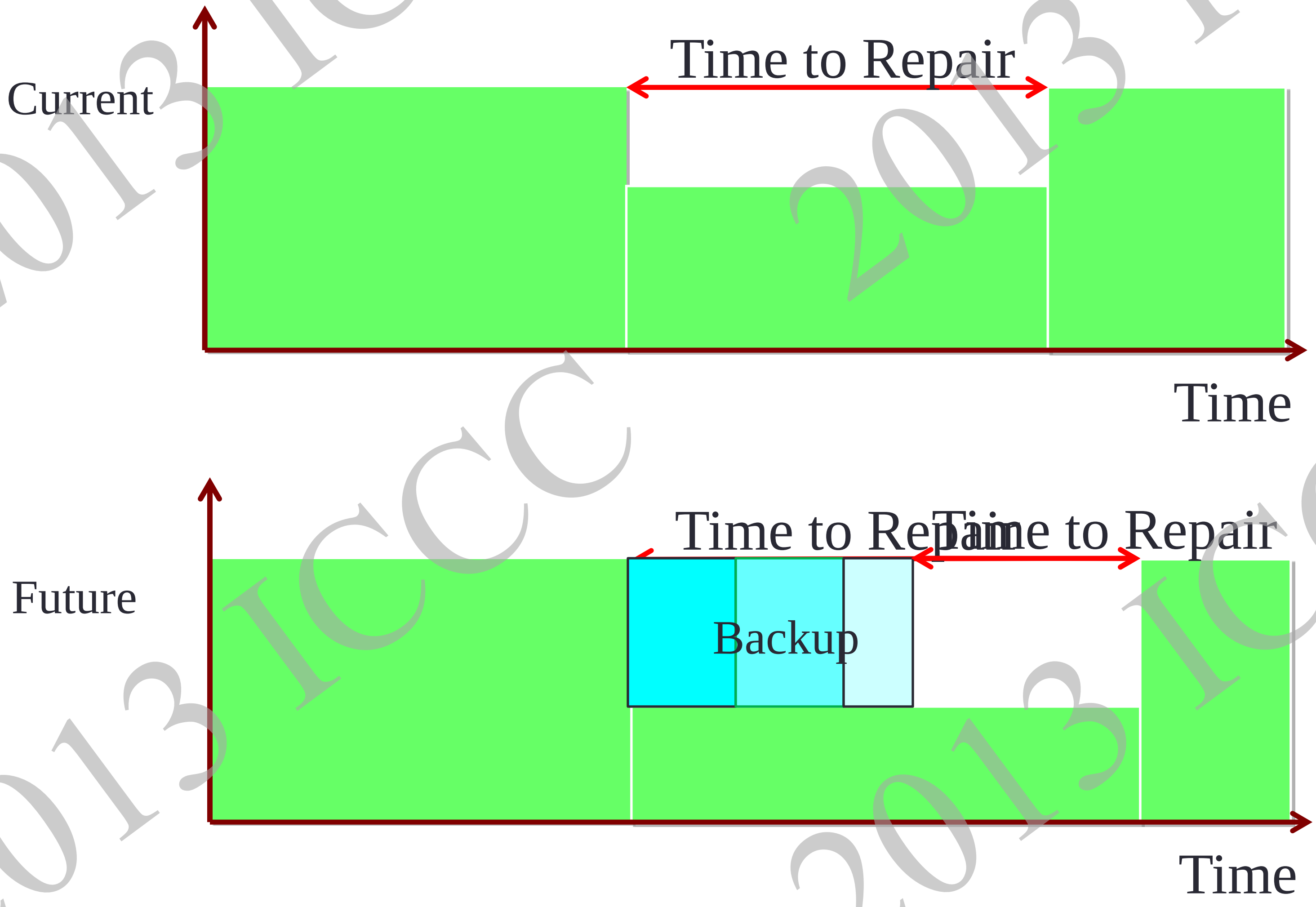
Design of Vulnerability and Resilience Indicators

Resilience	Definition	Example
Res_Indicator 1	Mean Time to Repair, MTTR	Average(4, 3, 1, 2) = 2.5
Res_Indicator 2	Max. TTR	Max(4, 3, 1, 2) = 4
Availability	Definition	Example
Ava_Indicator	MTTF/(MTTR+MTTF)	3/(3+2.5) = 0.545
Vulnerability	Definition	Example
Vul_Indicator 1	Max. total cumulative deficits	Max(15, 7, 6, 2) = 15
Vul_Indicator 2	Max. deficits for a time step	6

Example of Hsinchu (新竹)

Baseline	MaxTTR	10					
	MTTR	4.70					
	MTTF	88.87					
	Availability	0.95					
Future		CSMK35	GFCM21	MIMR	MPEH5	MRCGCM	Worst
A1B	MaxTTR	21	20	18	15	17	21
	MTTR	6.23	6.26	6.42	5.88	5.27	6.42
	MTTF	34.25	34.22	30.31	43.44	36.38	30.31
	Ava_Indicator	0.85	0.85	0.83	0.88	0.87	0.83
A2	MaxTTR	42	15	20	17	19	42
	MTTR	8.91	5.07	7.62	5.96	6.08	8.91
	MTTF	26.91	36.58	29.34	35.45	35.10	26.91
	Ava_Indicator	0.75	0.88	0.79	0.86	0.85	0.75
B1	MaxTTR	21	19	23	11	18	23
	MTTR	6.08	4.62	6.76	4.06	5.64	6.76
	MTTF	37.33	56.44	31.95	67.98	45.11	31.95
	Ava_Indicator	0.86	0.92	0.83	0.94	0.89	0.83

Resilient Capacity Building



Final Remarks

- Study of climate change impacts and adaptations should relate to sustainable development.
- Climate change may result in different spatial distribution of risk maps due to the characteristics of both sensitivity and exposure to hazard.
- Climate change may not only influence the sustainability (e.g. balance between water supply and demand), but also influence the resilience.
- Adaptive capacity building should consider to keep sustainability, decrease vulnerability, and increase resilience.

Final Remarks

- Both centralized traditional water resources measures and distributed emerging measures are important.
- Integrated water resources management (IWRM) should be applied to integrate both measures.
- Higher future risk may result from improper social and economic development.
- Uncertainty still constrains adaptation actions, which requires further studies. Besides, smart decision making process is required.

Smart Living with Changing Climate!

Thank you for your Attention!

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