Spectrum network optimization model for agricultural water resources management: AI agent modeling

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Irrigation Agency, Ministry of Agriculture

Introduction

停灌休耕 v.s. 環境永續發展

一.公告停灌範圍

(一)正辦理公告停灌範圍

1.苗栗水利會-明德水庫灌區

面積：1,175公頃（12%）

2.臺中水利會-大安溪流域北岸（下灌區）

面積：4,625公頃（18%）

(二)本次公告停灌範圍

1.桃園水利會-大溪溪流域灌區

面積：22,677公頃（100%）

2.新竹水利會-頭前溪流域含鳳山溪灌區4小組

面積：4,606公頃（73%）

3.嘉南水利會-曾文溪流域嘉義灌區及白水溪部分灌區

面積：8,493公頃（45%）

二.104年1月底前決定

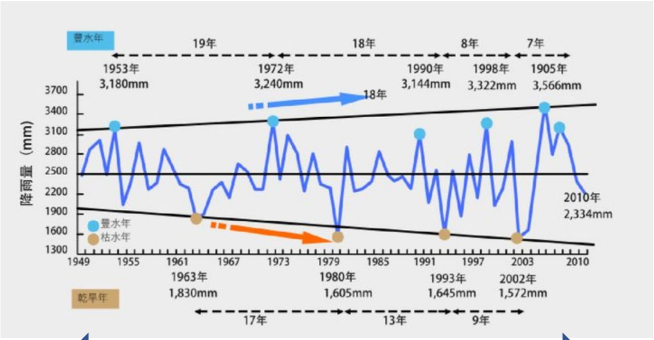
苗栗水利會-中港溪流域灌區

農民收成前遭停灌 抗議政院拒絕再被犧牲

2020/11/04 苦勞報導

張智琦 苦勞網記者

「缺水是天災，停灌是人禍！」因用水不足，經濟部及農委會日前無預警公告，自10月15日對桃竹苗地區實施停灌，受影響農民超過2萬5千人。今日（11/4）農民團體和環境團體一同前往行政院抗議，強調停灌、休耕對當地農產業及農戶將造成莫大衝擊，政府不該隨便停水，犧牲農民權益。



國立臺灣大學生物環境系統工程學系

台積電確定高雄設廠 陳其邁：完成不可能的任務

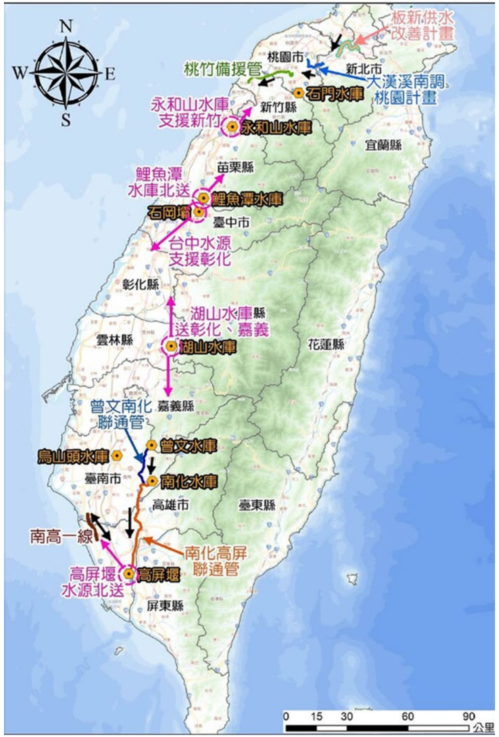
2021/11/9 21:20（11/10 10:30 更新）

台積電9日董事會決議核准公司將向高雄市政府遞件租地設廠。（中央社檔案照片）

■The purpose of the water resources system main pipe series connection is to strengthen the stable water supply, and improve the water resources scheduling and source backup capacity,

■but how to analyze the main pipe series connection that has been built or planned, the problems to be solved include:

1. How to systematically analyze the water supply capacity of the water resource system main pipe series project?
2. How to quantify the impact of water resource system main pipe series connection on dispatching and backup capacity?
3. Climate change has greatly increased the intensity and frequency of extreme events, resulting in a high degree of uncertainty in rainfall, reservoir water storage, river flow, and water supply.
4. How should uncertain water resources be allocated to improve the stability of water supply?



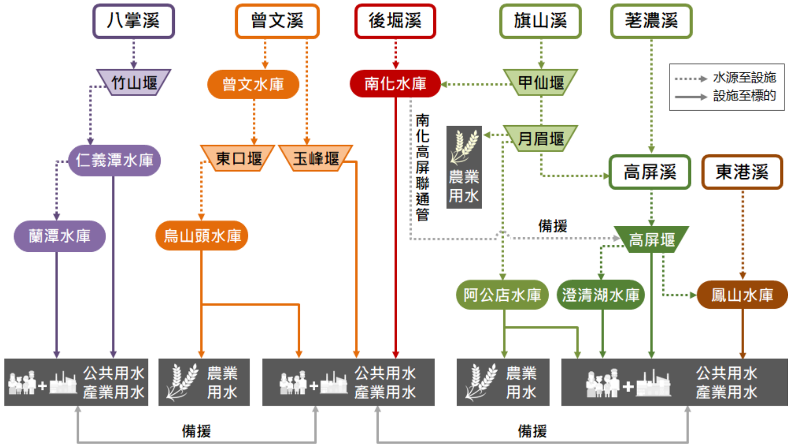
Methodology

$$\text{Minimize} \quad \sum_{i=1}^{m}\sum_{j=1}^{m} c_{ij}x_{ij}$$

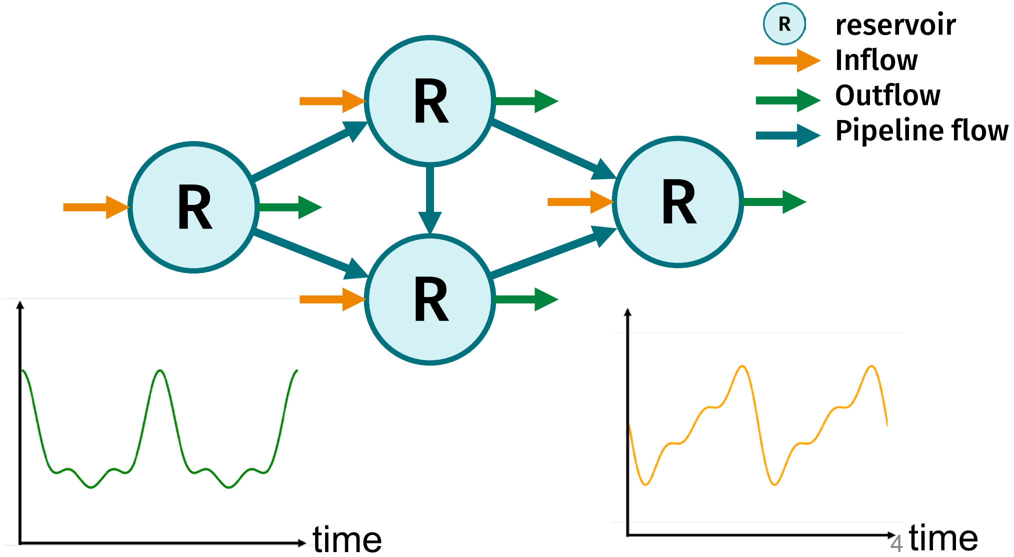
$$\text{subject to} \quad \sum_{j=1}^{m} x_{ij} - \sum_{k=1}^{m} x_{ki} = b_i, \qquad i = 1, \dots, m$$

$$x_{ij} \geq 0, \qquad i, j = 1, \dots, m.$$

time series data?



- 後堀溪為曾文溪支流
- 旗山溪及荖濃溪為高屏溪支流



a. Incorporating the temporal function into reservoir optimization（加入時間觀念的水庫最佳化模型)

$$\text{Minimize } Z = \sum_i \sum_t (f_i^{DEF}(t))^2 + (f_i^{SUR}(t))^2 \quad (1)$$

subject to:

$$\frac{dF_i^{ST}}{dt} = F_i^{IN} - F_i^{OUT} \ \forall i \quad (2)$$

$$F_i^{OUT} - F_i^{SUR} + F_i^{DEF} = F_i^{DE} \ \forall i \quad (3)$$

$$StorageCapacity_i \geq F_i^{ST} \geq 0 \ \forall i \quad (4)$$

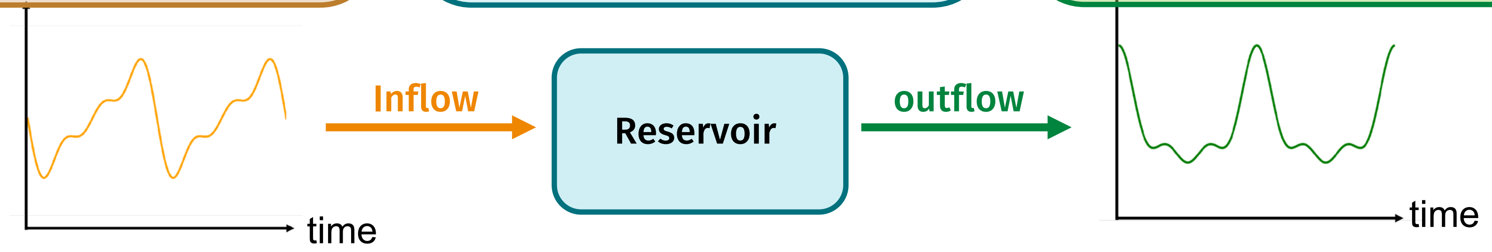
$$F_i^{OUT}, F_i^{SUR}, F_i^{DEF} \geq 0 \ \forall i \quad (5)$$

where i is index of reservoir

- Normal optimization not involving time
- Inflow and outflow are functions of time.

- Discretization in respect of time.
- Vector optimization problem such as $[f(t1), f(t2), f(t3) \ldots]^T$

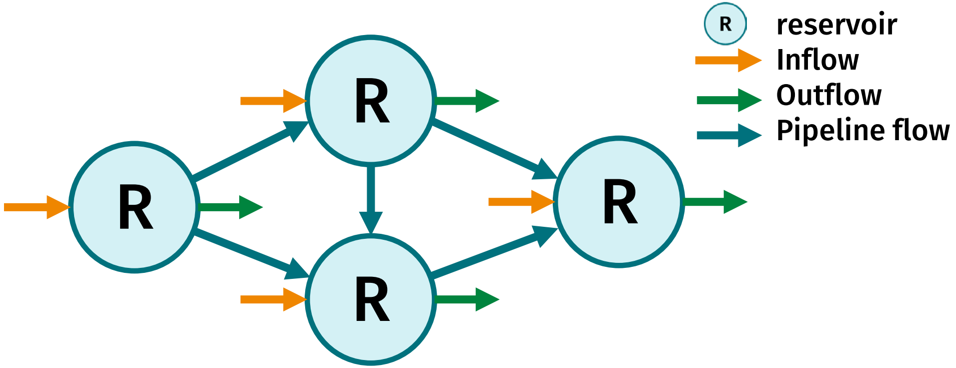
- The objective is to minimize the different between the outflow and the water demand

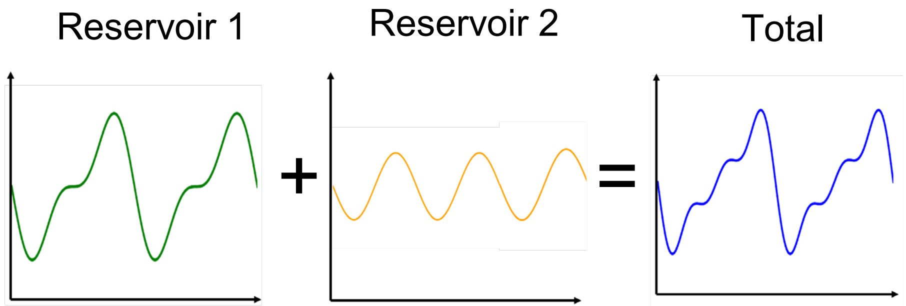


b. Connection of water resources systems (水資源系統串連的效益評估)

- Pipelines connection in "Pearl chain" plan
- Network optimization problem

- Pipelines make reservoirs have connection to other reservoirs
- Hydrograph can be superposed in respect of time.





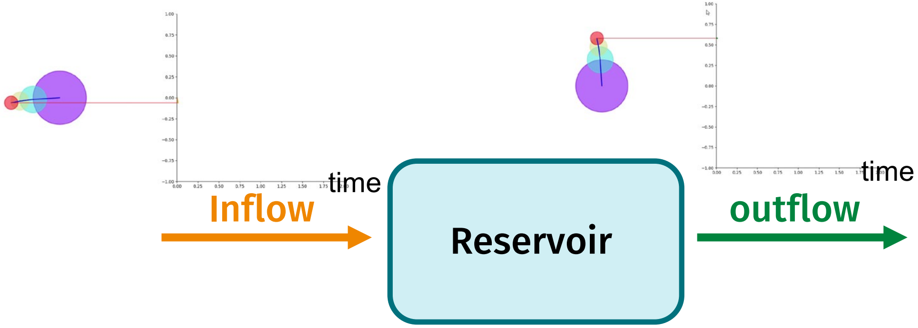
c. Water resouces network optimization on frequency domain (運用傅立葉級數的正交座標系統進行水庫串接系統頻率域最佳化)

- Time-series data lacking a describable coordinate system

- Orthogonal trait of Fourier series
- Fourier series is suitable for time data project to orthogonal coordinate system.

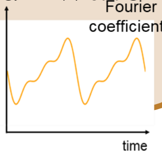
Fourier series:

$$f(t) = a_0 + \sum_{n=1}^{\infty} a_n \cos\left(\frac{n\pi t}{L}\right) + \sum_{n=1}^{\infty} b_n \sin\left(\frac{n\pi t}{L}\right)$$

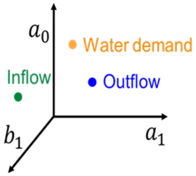


c. Water resources network optimization in Fourier frequency domain (運用傅立葉級數的正交座標系統進行水資源系統頻率網路最佳化)

- Fourier series can depict periodic functions through Fourier coefficients.
- Both hydrology and water usage are periodic.



$$\begin{bmatrix} a_0 \\ a_1 \\ \vdots \\ b_1 \\ \vdots \end{bmatrix}$$



- Use Fourier coefficients to depict the objective and constraints in optimization model.
- The simulate outflow will have **similar oscillation** of the water demand.

$$\text{Minimize } Z = {a_{0i}^{DEF}}^2 + \sum_{n,i}\left({a_{ni}^{DEF}}^2 + {a_{ni}^{DEF}}^2\right) + {a_{0i}^{SUR}}^2 + \sum_{n,i}\left({a_{ni}^{SUR}}^2 + {a_{ni}^{SUR}}^2\right) \quad (1)$$

subject to:

$$a_{0i}^{IN} - a_{0i}^{OUT} + \sum_j a_{0ji}^{FL} - \sum_j a_{0ij}^{FL} = 0\ \forall i \quad (2)$$

$$a_{ni}^{IN} - a_{ni}^{OUT} + \sum_j a_{nji}^{FL} - \sum_j a_{nji}^{FL} = \frac{n\pi}{L} b_{ni}^{ST}\ \forall n,i \quad (3)$$

$$b_{ni}^{IN} - b_{ni}^{OUT} + \sum_j b_{nji}^{FL} - \sum_j b_{nji}^{FL} = -\frac{n\pi}{L} a_{ni}^{ST}\ \forall n,i \quad (4)$$

$$a_{0i}^{OUT} - a_{0i}^{SUR} + a_{0i}^{DEF} = a_{0i}^{DE}\ \forall i \quad (5)$$

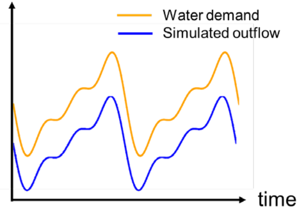
$$a_{ni}^{OUT} - a_{ni}^{SUR} + a_{ni}^{DEF} = a_{ni}^{DE}\ \forall n,i \quad (6)$$

$$b_{ni}^{OUT} - b_{ni}^{SUR} + b_{ni}^{DEF} = b_{ni}^{DE}\ \forall n,i \quad (7)$$

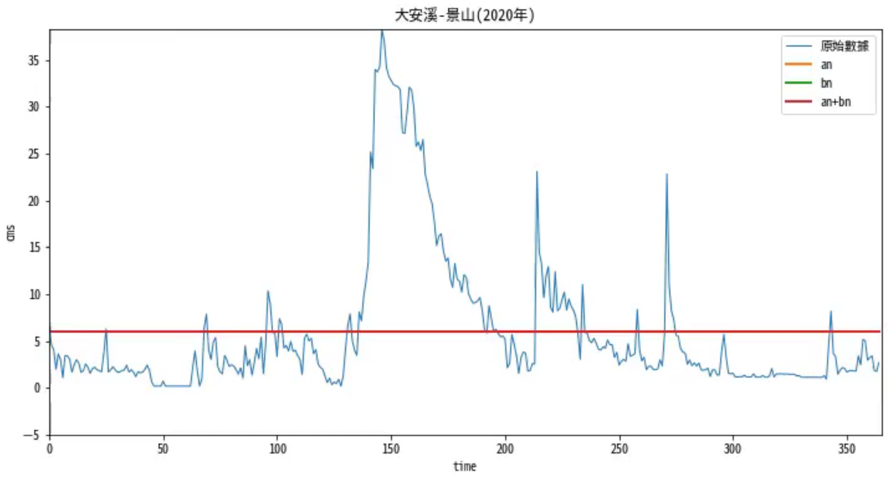
$$StorageCapacity_i \geq a_{0i}^{ST} + \sum_{n=1}^{\infty} a_{ni}^{ST} \cos\frac{n\pi t}{L} + \sum_{n=1}^{\infty} b_{ni}^{ST} \sin\frac{n\pi t}{L} \geq 0\ \forall i \quad (8)$$

$$FlowCapacity_{ij} \geq a_{0ij}^{FL} + \sum_{n=1}^{\infty} a_{nij}^{FL} \cos\frac{n\pi t}{L} + \sum_{n=1}^{\infty} b_{nij}^{ST} \sin\frac{n\pi t}{L} \geq 0\ \forall i,j \quad (9)$$

$$f_i^{OUT}(t),\ f_i^{SUR}(t),\ f_i^{DEF}(t) \geq 0\ \forall i \quad (10)$$

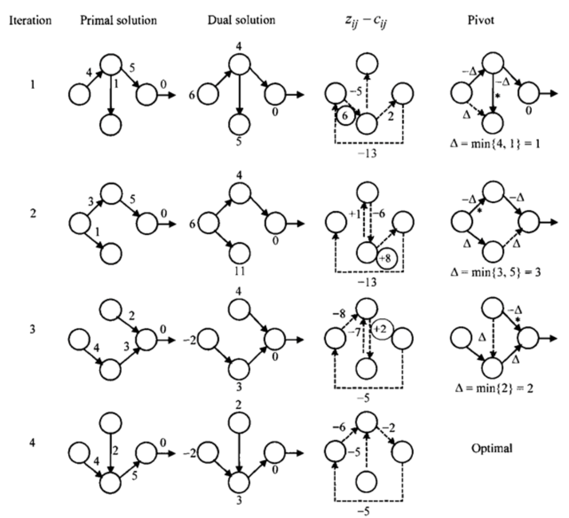


1. A network flow model for the series connection of main pipes in water resources system
2. Fourier Spectrum Analysis of Hydrological Time Series Data
3. Spectrum Optimum Analysis of Trunks in Water Resources System
4. Case study: data collection and analysis of pipeline connection in water resources system

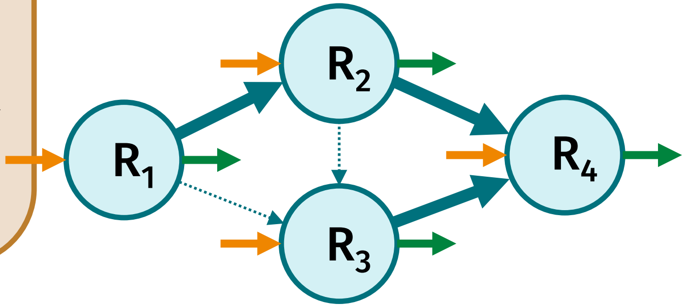


d. Optimization using network simplex method (在時域或頻率域下運用網路單形法分析幹管最佳流線)-

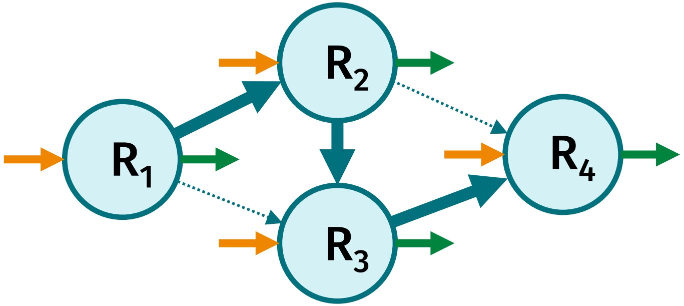
- The network simplex method is applied simplex method in network flow problem.
- Determine the optimal flow network solution (spanning tree) in network optimization.
- The result will exhibit **variation over time** in time domain and **over frequencies** in frequency domain



(a) Optimal spanning tree 1



(b) Optimal spanning tree 2



Case study

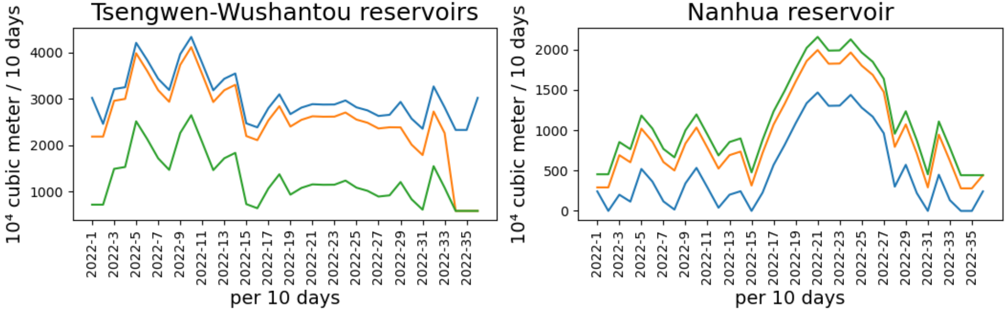
- Agricultural policy can adjust the agricultural water demand.
- In "Tsengwen-Nanhua Interconnection Pipeline Project" as known as "Pearl chain" plan in Southern region water resources system, the connecting pipeline is constructed between Tsengwen Reservoir and Nanhua reservoir, aiming to transmit the surplus water and alleviate the regional water shortage.
- With the existing Nanhua-Gaoping Interconnection Pipeline, the interconnection system can integrate the water allocation system of mainly Tainan and Kaohsiung and enhance the water supply backup system in the Southern area.

Results and discussion

(1) Scenario with one existing pipeline between Nanhua Reservoir and Gaoping River Weir

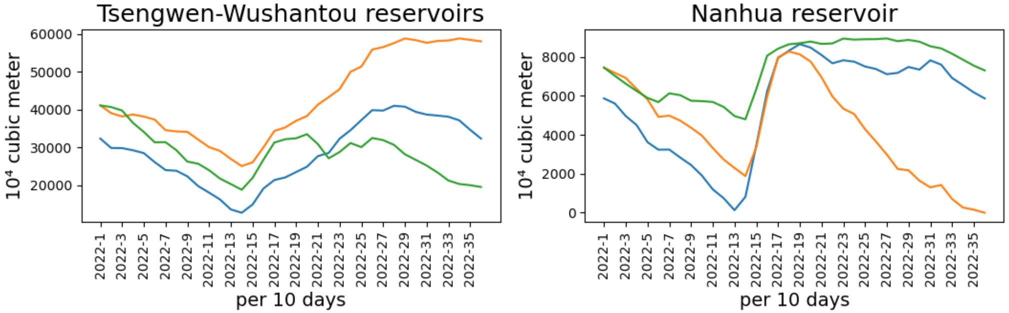
Simulated outflow

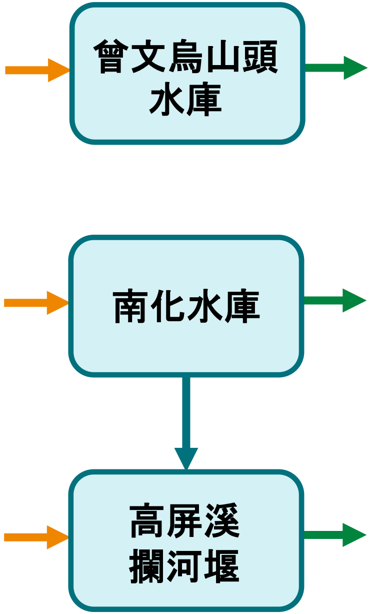
- frequency optimization
- time optimization
- observed water demand



Simulated storage

- frequency optmization
- time optimiation
- observed storage



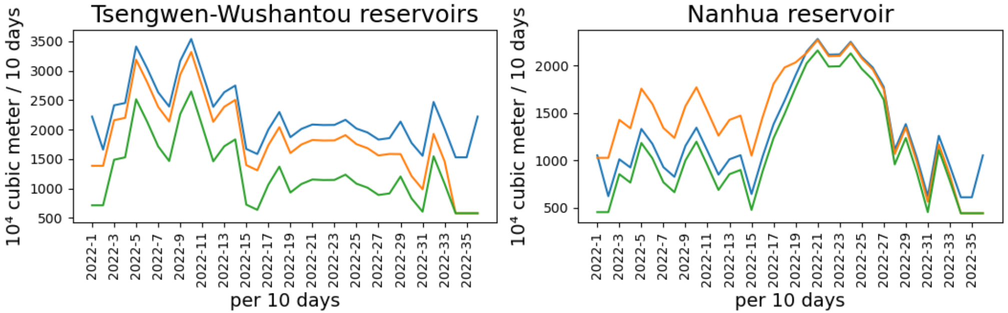


Results and discussion

(2) Scenario with two existing pipelines connecting reservoirs

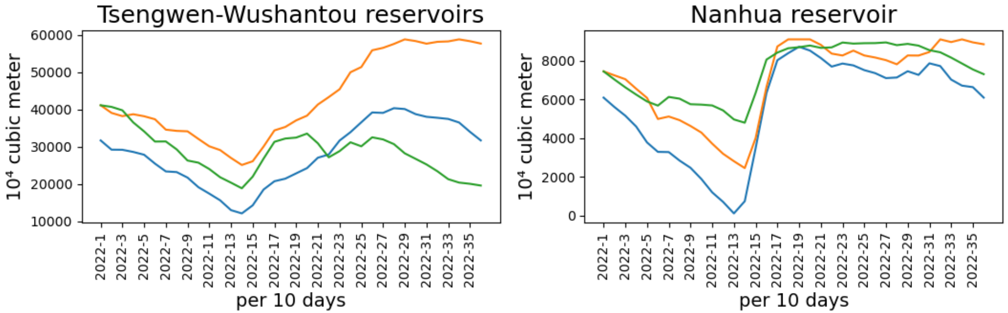
Simulated outflow

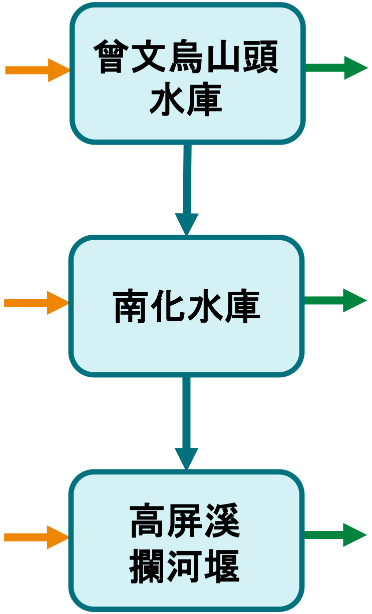
- frequency optimization
- time optimization
- observed water demand



Simulated storage

- frequency optmization
- time optimiation
- observed storage



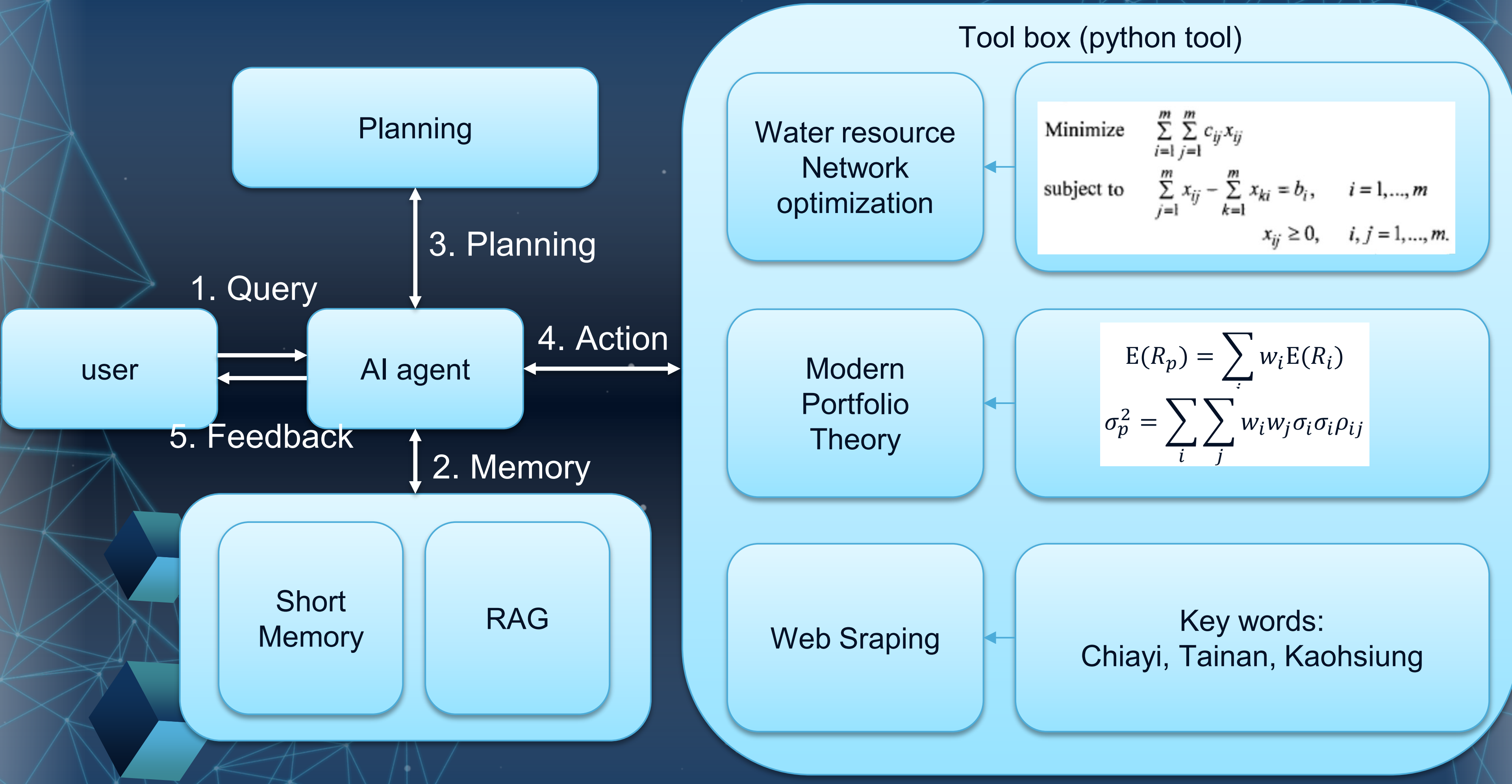


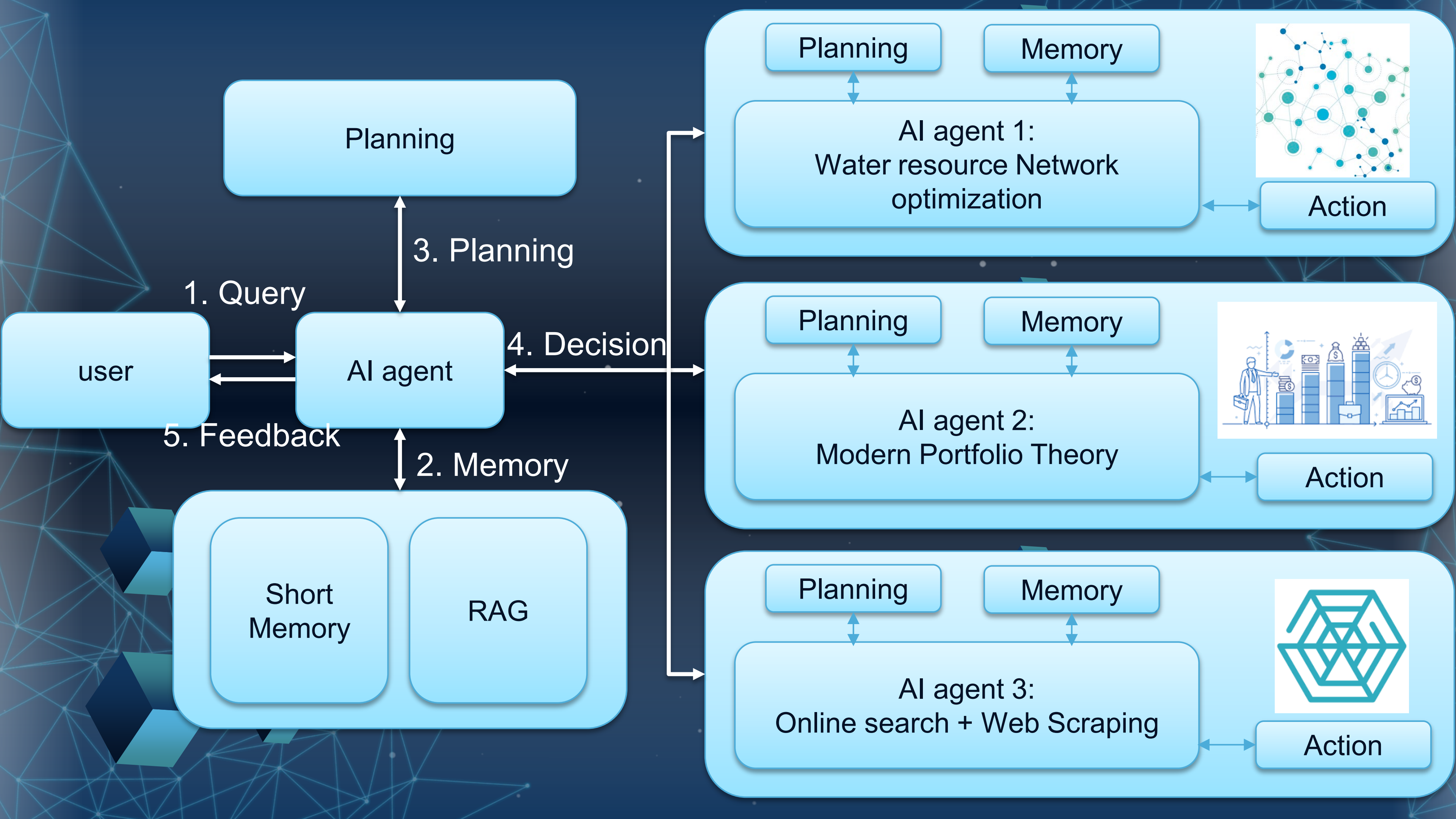
Results and discussion

- Agricultural policy, and connectivity of water resources systems really can alleviate the regional imbalanced water allocation.

- Time and frequency optimization models both can simulate the water outflow from reservoirs to oscillate in response to water demand. But only frequency optimization can ensures that the water storage maintains an appropriate level after a period.

- Though not applied in our study, network simplex method in the frequency perspective can identify the primary frequency components of the interconnected flow, and thus much reasonable to filter the noise which could result from climate extreme events.


Tool box (python tool)
Planning
3. Planning
1. Query
user
AI agent
4. Action
5. Feedback
2. Memory
Short Memory
RAG
Water resource Network optimization
Minimize $\sum_{i=1}^{m}\sum_{j=1}^{m} c_{ij}x_{ij}$
subject to $\sum_{j=1}^{m} x_{ij} - \sum_{k=1}^{m} x_{ki} = b_i, \quad i = 1,\ldots,m$
$x_{ij} \geq 0, \quad i, j = 1,\ldots,m.$
Modern Portfolio Theory
$E(R_p) = \sum_i w_i E(R_i)$
$\sigma_p^2 = \sum_i \sum_j w_i w_j \sigma_i \sigma_i \rho_{ij}$
Web Sraping
Key words:
Chiayi, Tainan, Kaohsiung


Planning
3. Planning
1. Query
user
AI agent
4. Decision
5. Feedback
2. Memory
Short Memory
RAG
Planning
Memory
AI agent 1:
Water resource Network optimization
Action
Planning
Memory
AI agent 2:
Modern Portfolio Theory
Action
Planning
Memory
AI agent 3:
Online search + Web Scraping
Action

https://colab.research.google.com/drive/1HLvwEnKCiXUAk6dmSJRVd41T0FDpBsrw?usp=sharing

Llama3 only

```
from langchain_community.llms import Ollama

llm = Ollama(model="llama3")
question = """
            how to study the relationship between spectrum network optimization and water resource mangement?
            if you have used the document i provided,
            please told me the document name and the related original text in the document.
            """
response = llm.invoke(question)

formatted_response = response.replace(",", ",\n").replace(".", ".\n\n")
#print("question:\n")
#print(question, "\n")
print("LLM response:\n")
print(response)
#print(formatted_response)
```

```
LLM response:

A fascinating topic!

Studying the relationship between spectrum network optimization and water resource management requires a multidisciplinary approach, combining insights from telecommunications engineering, computer science, and environmental studies. Here's a suggested framework to explore this connection:

1. **Understand the basics**:
	* Spectrum: The range of electromagnetic frequencies used for wireless communication.
	* Network optimization: Techniques to improve the performance, efficiency, and reliability of wireless networks.
	* Water resource management: The planning, development, and management of water resources (e.g., supply, demand, quality) to ensure sustainability.
2. **Identify potential connections**:
	* Spectrum sharing: Coexistence of different wireless systems on the same frequency band, which can impact water resource management.
	* Energy consumption: Wireless networks require energy, which can be generated by water-dependent power plants or contribute to greenhouse gas emissions affecting water cycles.
	* Environmental monitoring: Wireless sensor networks can monitor water quality and quantity, influencing water resource management decisions.
3. **Analyze relevant literature**:
	* Search for research papers, articles, and books that discuss the intersection of spectrum network optimization and water resource management.
	* Review studies on wireless communication systems, such as cellular networks, satellite communications, or IoT devices, and their impact on water resources.

If you have provided a document related to this topic, please share it with me. I'll be happy to help you identify specific sections or texts that relate to the connection between spectrum network optimization and water resource management.

Some potential documents you might have included:

1. "Spectrum Sharing for Wireless Communications: A Survey" by J. M. de la Vega et al. (2020) - This paper discusses various spectrum sharing techniques, including those relevant to water resource management.
2. "Water-Resource-Based Optimization of Wireless Networks" by Y. Liu et al. (2019) - This study explores the relationship between wireless network optimization and water resources, considering factors like energy consumption and environmental monitoring.

Please let me know if these are the documents you're working with, or if I can help you find other relevant texts!
```

Llama3 + RAG

```
tion = """
        how to study the relationship between spectrum network optimization and water resource mangement?
        if you have used the document i provided,
        please told me the document name and the related original text in the document.
        """
onse = rag_chain(question)
t(response)
```

ry specific question!

tudy the relationship between spectrum network optimization and water resource management, you can refer to the article "Network Spectrum Optimization of Agricultural Water Resource Management" by Ming-Che Hu et al.

his abstract, it is mentioned that:

evaluate the agricultural water resource dispatching capability and the purpose of the study is to evaluate how agricultural water resource management affects water supply stability and drought resistance."

suggests that the authors aim to investigate how optimizing network spectrum (i.e., frequency allocation) can impact water resource management, specifically in terms of water supply stability and drought resilience.

can further explore this topic by looking into the references provided in the article, such as:

eyszig, E. 2011. Advanced Engineering Mathematics, Tenth Ed, Wiley, London.
mtahen, S., and A. B. Dariane. 2007. Direct search approaches using genetic algorithms for optimization of water reservoir operating policies. Journal of water resources planning and management, 133(3), 202-209.

e references may provide insights into the mathematical frameworks and methods used in optimizing network spectrum for agricultural water resource management.

pe this helps!

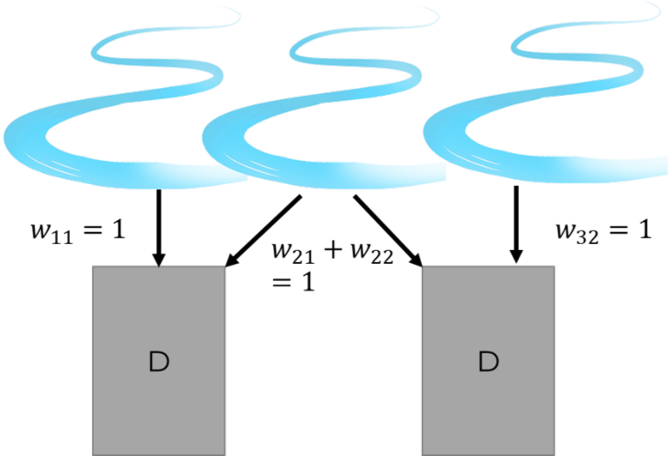
Abstract

Under climate change, extreme hydrological events have a serious impact on the water supply of the agricultural water resource system. This study will provide systematic analysis methods and tools to evaluate the agricultural water resource dispatching capability and the purpose of the study is to evaluate how agricultural water resource management affects water supply stability and drought resistance. The research uses the network programming model to simulate and analyze the agricultural water supply

Modern Portfolio Theory for water resources management

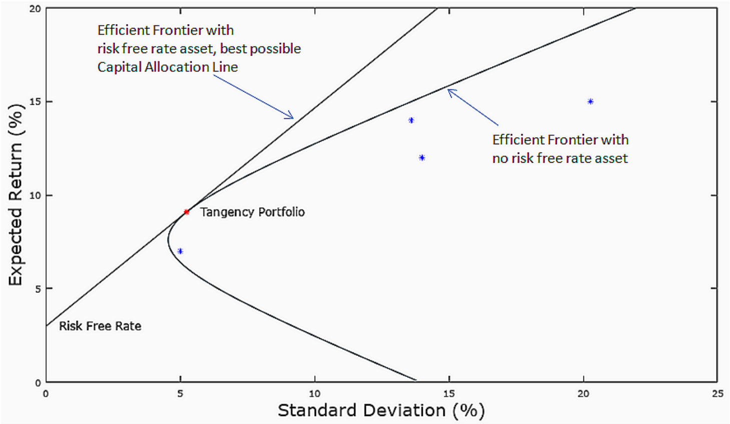
Economist Harry Markowitz introduced MPT in a 1952 essay, for which he was later awarded a Nobel Memorial Prize in Economic Sciences.

Modern portfolio theory is a mathematical framework for assembling a portfolio of assets such that the expected return is maximized for a given level of risk.



Modern Portfolio Theory

- The MPT is a mean-variance theory, and it compares the expected (mean) return of a portfolio with the standard deviation of the same portfolio.
- A portfolio lying on the efficient frontier represents the combination offering the best possible expected return for given risk level.



(Markowitz Model)

$$\mathrm{E}(R_p) = \sum_i w_i \mathrm{E}(R_i)$$

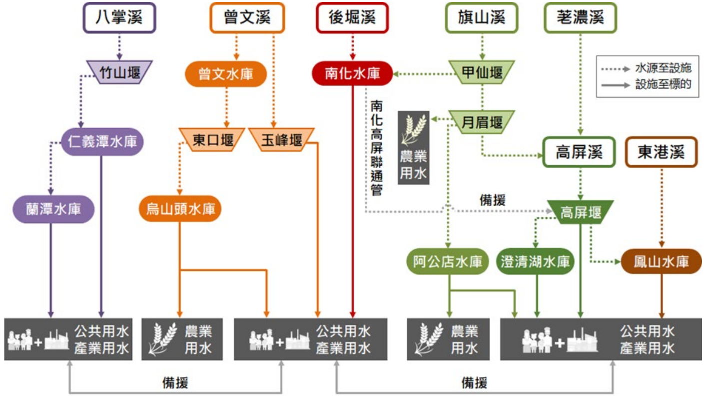
$\mathrm{E}(R_i)$：組合中個標的期望回報率
w_i ：各標的所占資金權重，且$\sum_i w_i = 1$

$$\sigma_p^2 = \sum_i \sum_j w_i w_j \sigma_i \sigma_i \rho_{ij}$$

$\mathrm{E}(R_i)$：w_i、w_j為組合中第i、j個標的所占總資金的權重
w_i ：σ_i、σ_j為組合中第i、j個標的標準差
ρ_{ij}為組合中第i、j個標的間的相關係數

研究方法—數學模型

權重**W**為分配 **X** 流量與需求量的方式，第 i 個流量分配至第 j 個子系統（需求）的權重。



- 後堀溪為曾文溪支流
- 旗山溪及荖濃溪為高屏溪支流

$$\mathbf{W} = \mathbf{W}_{ij} = \begin{bmatrix} w_{11} & w_{12} & \cdots & w_{1q} \\ w_{21} & w_{22} & & w_{2q} \\ \vdots & \ddots & & \vdots \\ w_{p1} & & & \\ w_{p+1,1} & & & \\ \vdots & & & \\ w_{p+q,1} & w_{p+q,2} & \cdots & w_{p+q,q} \end{bmatrix}_{(p+q)\times q}$$

$$\sum_j w_{ij} = 1 \text{ 且}$$

$$w_{ij} \geq 0 \; for \; i \leq p$$

則任一時間段之$\mathbf{W}_n$

$$\mathbf{W}_n \in \mathbf{W}, n = 1,2,\ldots,k$$

Modern Portfolio Theory for water resources management

$$\min \sum_{n=1}^{k} (\sum (diag(\mathbf{W}_n^T (\mathbf{X}_n \mathbf{X}_n^T) \mathbf{W}_n)))$$

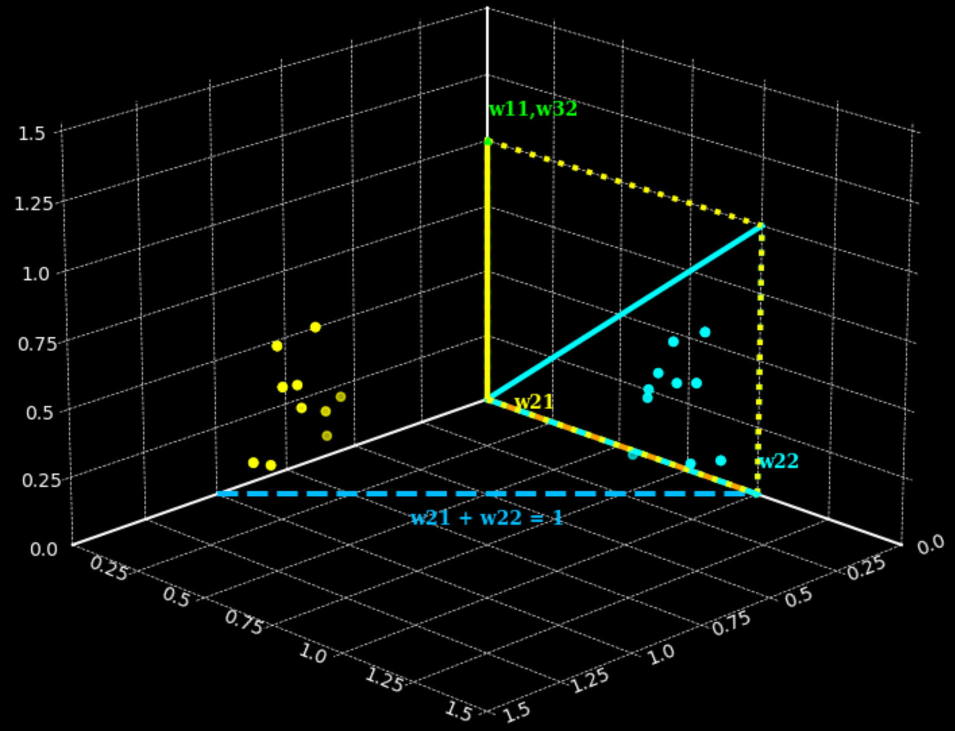
$$s.t. \mathbf{W}_n \in R, R \; is \; the \; feasible \; region$$

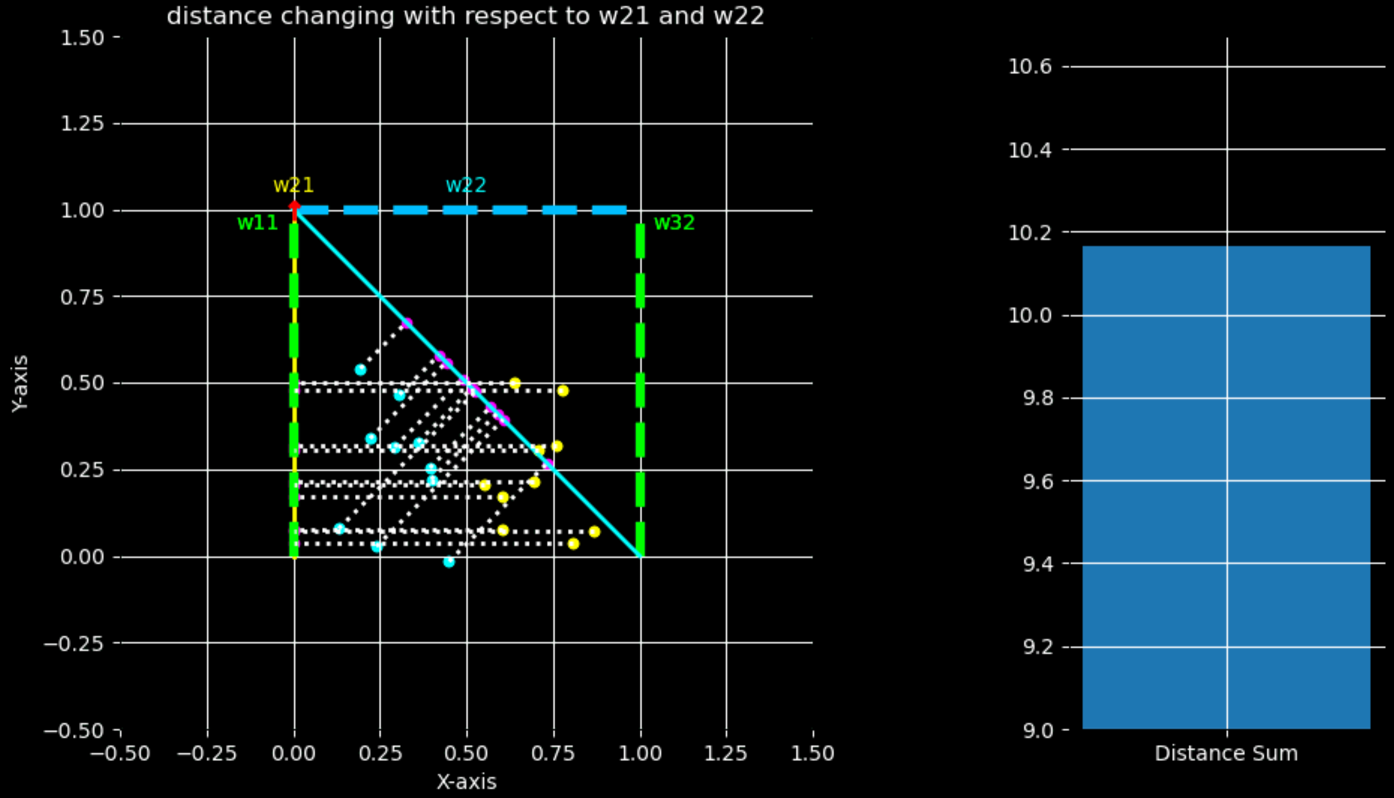
$$W_n^T (X_n X_n^T) W_n = \begin{bmatrix} w_{11} & w_{21} & w_{31} & w_{41} & w_{51} \\ w_{12} & w_{22} & w_{32} & w_{42} & w_{52} \end{bmatrix} \begin{bmatrix} Q_1 \\ Q_2 \\ Q_3 \\ D_1 \\ D_2 \end{bmatrix} \begin{bmatrix} Q_1 & Q_2 & Q_3 & D_1 & D_2 \end{bmatrix} \begin{bmatrix} w_{11} & w_{12} \\ w_{21} & w_{22} \\ w_{31} & w_{32} \\ w_{41} & w_{42} \\ w_{51} & w_{52} \end{bmatrix}_{n=1,\ldots k}$$

$$Risk \equiv \sum_{n=1}^{k} \left(\sum (diag(\mathbf{A}^T \mathbf{A})) \right)$$

where $\mathbf{A} = \min(0, \mathbf{X}_n^T \mathbf{W}_n)$

$\mathbf{A} = \min(0, \mathbf{X}_n^T \mathbf{W}_n)$ 表示缺水的情況才會被計入風險


w11,w32
w21
w22
w21 + w22 = 1

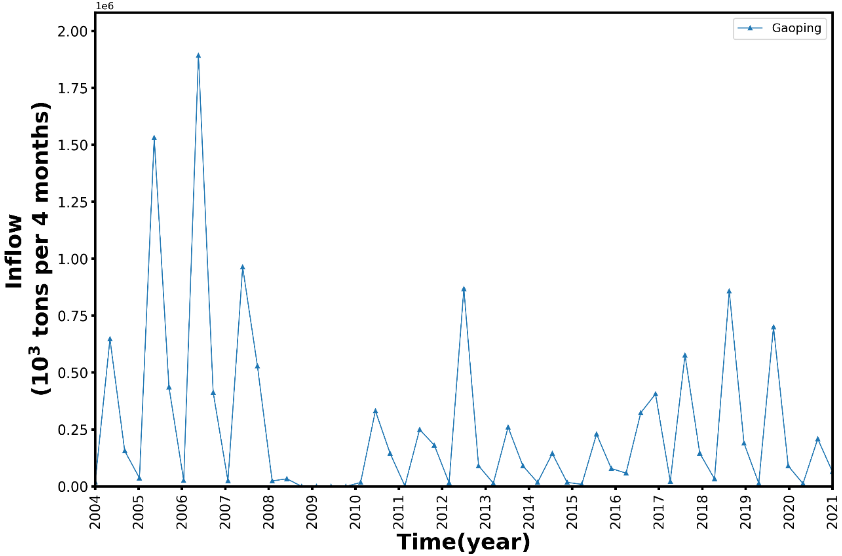

distance changing with respect to w21 and w22
w21
w22
w11
w32
Y-axis
X-axis
1.50
1.25
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.50
−0.25
0.00
0.25
0.50
0.75
1.00
1.25
1.50
10.6
10.4
10.2
10.0
9.8
9.6
9.4
9.2
9.0
Distance Sum

Results and discussion

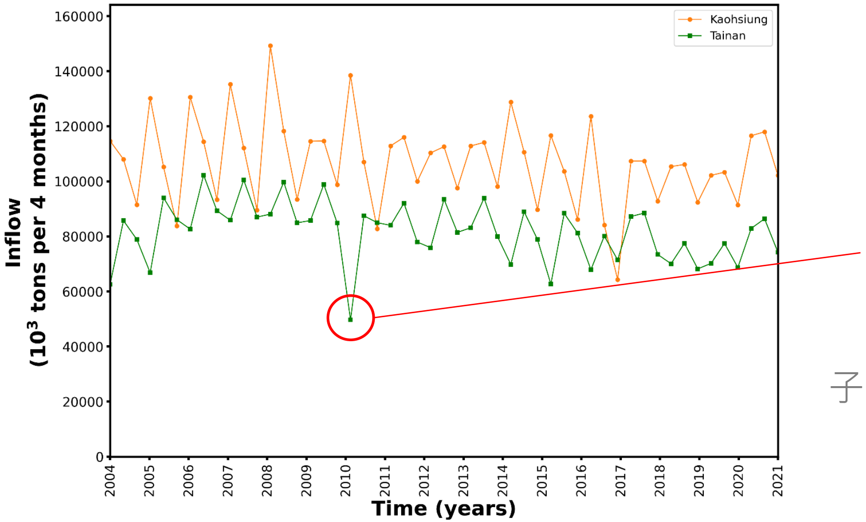
曾文 - 烏山頭、南化水庫及高屏攔河堰

供給至台南與高雄子系統之分配權重：

$$[w_{11}, w_{21}, w_{31}, w_{12}, w_{22}, w_{32}]$$



Historical data



Drought

子系統之歷史需水量

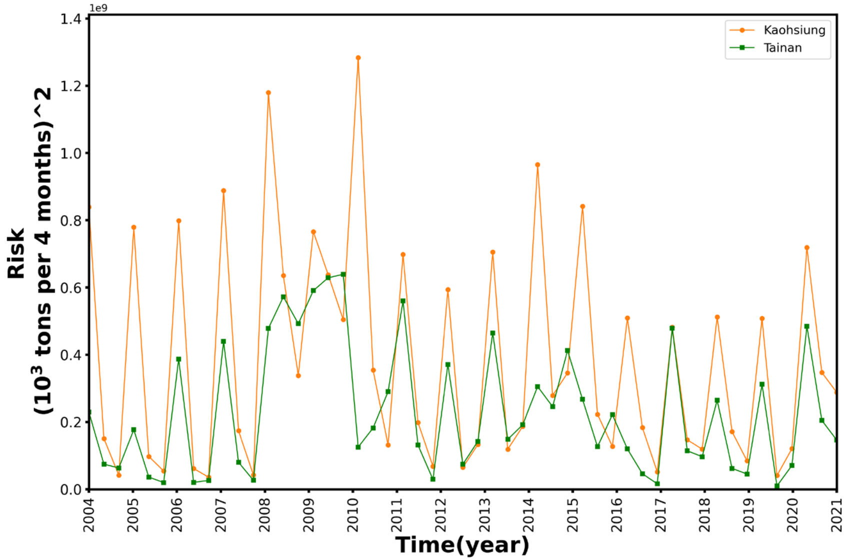
結果與討論 - 時間變化對權重的影響

不分段的歷史資料最佳分配權重為：

$$w_{11}, w_{21}, w_{31}, w_{12}, w_{22}, w_{32} = 0.15, 0.60, 0.50, 0.85, 0.40, 0.50$$

n 值	1	2	3	4	6	12	18	36	68
Risk	3.138×10^{10}	3.138×10^{10}	3.139×10^{10}	3.134×10^{10}	3.128×10^{10}	3.128×10^{10}	3.128×10^{10}	3.081×10^{10}	4.640×10^{10}
w_{11}	.15	.17	.19	.19	.27	.02	.28	0	0
w_{21}	.60	.62	.61	.51	.39	.51	.39	1	0
w_{31}	.50	.50	.50	.50	.51	.50	.50	.25	0
w_{12}	.85	.83	.81	.81	.73	.98	.72	1	1
w_{22}	.40	.38	.39	.49	.61	.49	.61	0	1
w_{32}	.50	.50	.50	.50	.49	.50	.50	.75	1

不同分段數n對應權重及風險變化



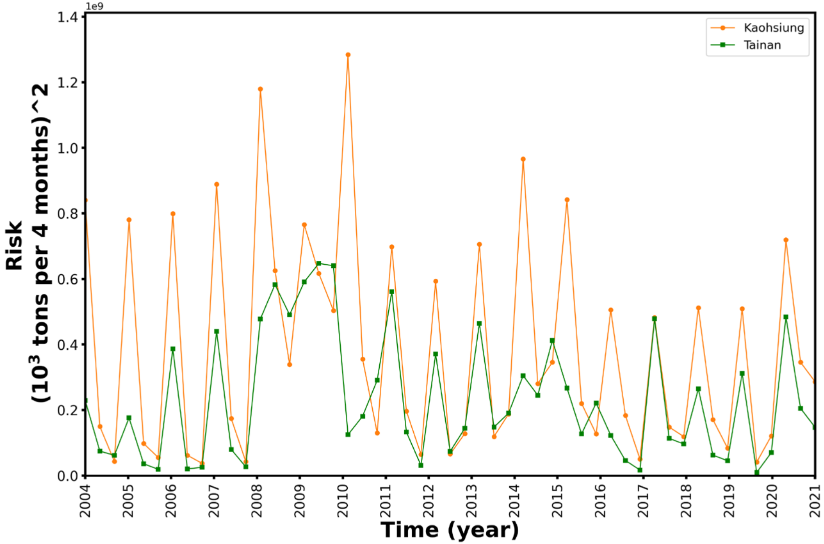
歷史資料不分段進行最佳化結果

結果與討論 - 特定時間區間對權重的影響

探討季節性等不同時間段對權重的影響

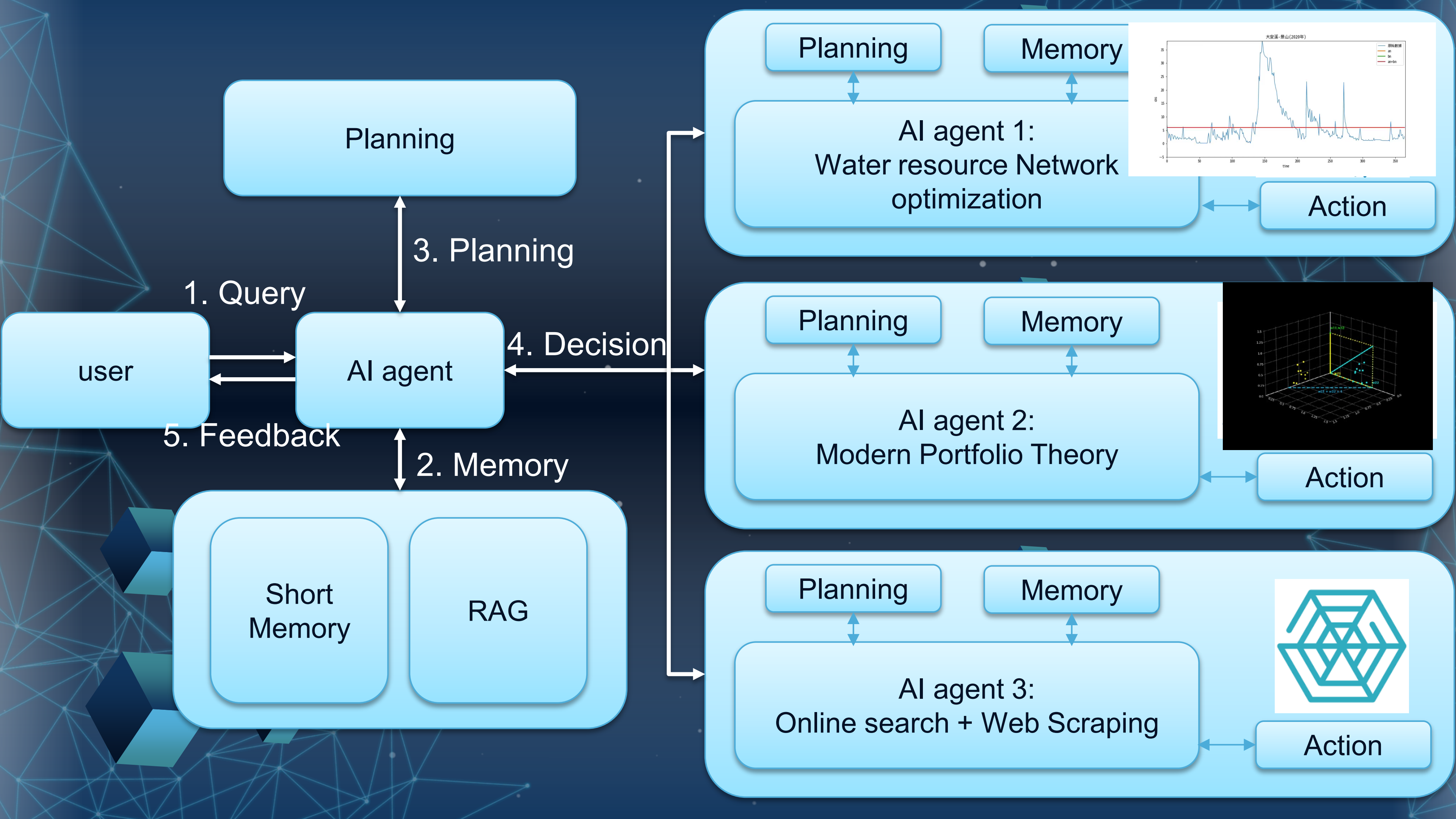
將時間序列以灌溉（2-5月, 7-10月）及休耕（其餘時段）來分段

n 值	1	2	3	4	6	12
Risk	3.136×10^{10}	3.136×10^{10}	3.137×10^{10}	3.134×10^{10}	3.132×10^{10}	3.122×10^{10}
w_{11}	.15	.17	.19	.18	.25	0
w_{21}	.61	.63	.62	.45	.25	.66
w_{31}	.50	.50	.50	.51	.51	.50
w_{12}	.85	.83	.81	.82	.75	1
w_{22}	.39	.37	.38	.55	.75	.34
w_{32}	.50	.50	.50	.49	.49	.50



依灌溉時間分段之風險圖

不同分段數n對應權重及風險變化



Planning
3. Planning
1. Query
user
AI agent
4. Decision
5. Feedback
2. Memory
Short Memory
RAG
Planning
Memory
AI agent 1:
Water resource Network optimization
Action
Planning
Memory
AI agent 2:
Modern Portfolio Theory
Action
Planning
Memory
AI agent 3:
Online search + Web Scraping
Action

Questions and comments?

mchu@ntu.edu.tw

TAIWAN INT'L WATER WEEK

Sep. 10 ▸ 11
TICC台北國際會議中心

Water Towards Safety、Sustainable Environment and Prosperity 水與安全、環境、發展

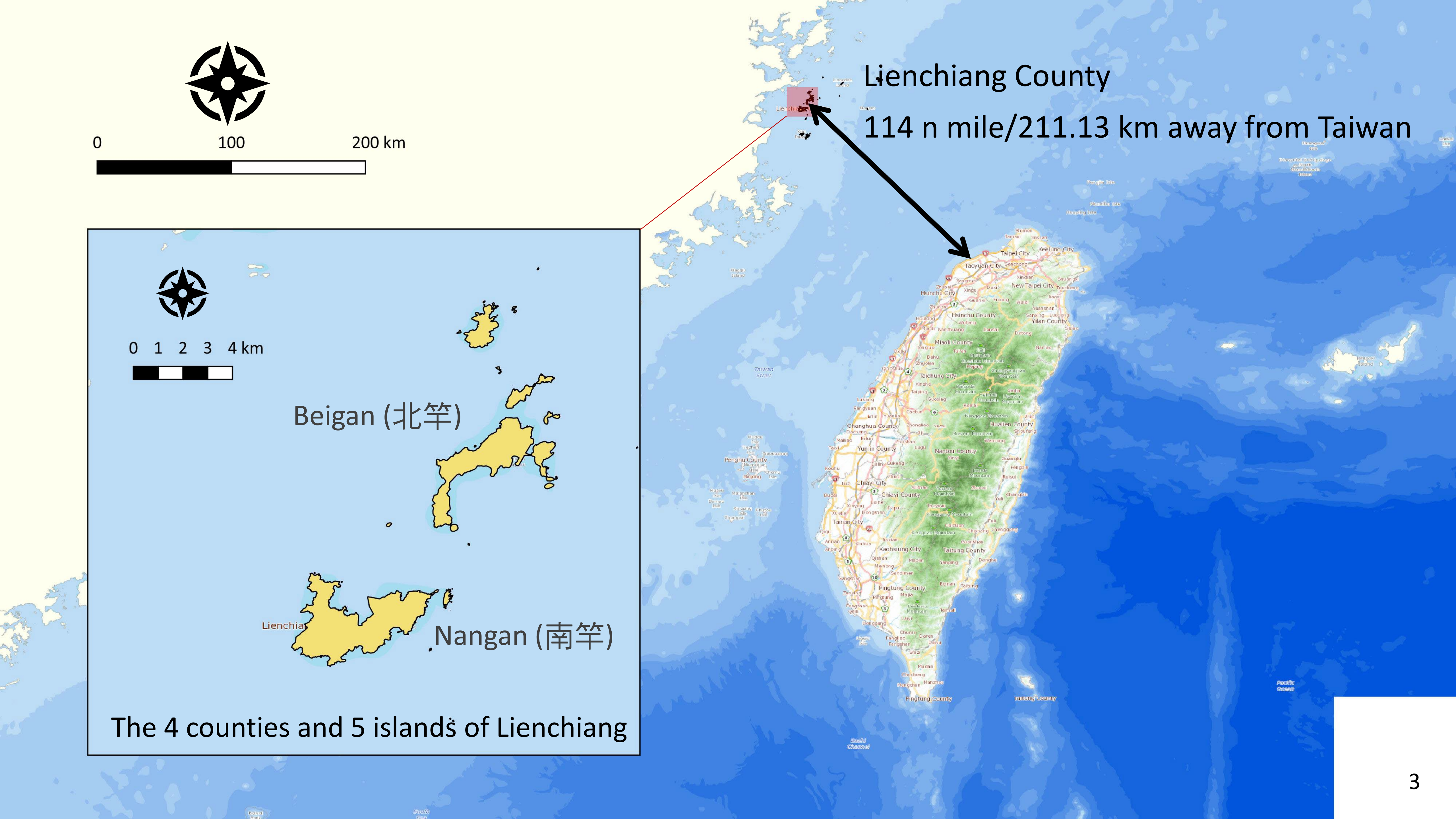
International Forum 2024

Transforming for Smart and Resilient Water Systems

Paul Chuo

Dr. Paul Chuo

- Executive Deputy General Manager, Stantec Consulting Services Inc., Taiwan Branch
- PhD in Civil Engineering
- Stantec Consulting Services Inc.
- Sydney Water Corporation


Lienchiang County
114 n mile/211.13 km away from Taiwan
0
100
200 km
0 1 2 3 4 km
Beigan (北竿)
Nangan (南竿)
Lienchiang
The 4 counties and 5 islands of Lienchiang
Taipei City
Taoyuan City
Keelung City
New Taipei City
Hsinchu City
Hsinchu County
Yilan County
Miaoli County
Taichung City
Changhua County
Hualien County
Nantou County
Yunlin County
Penghu County
Chiayi City
Chiayi County
Tainan City
Kaohsiung City
Taitung County
Pingtung County

Water supply challenges on island

Water Towards Safety Sustainable Environment and Prosperity 水與安全、環境、發展

Characteristics	Challenges
Natural Boundaries	Uneven precipitation
Widely distributed residents	Challenging terrain for water retention
Multiple water sources	High OPEX

O&M Pain points

Unstable Water Sources

- Unstable traditional water resources due to climate change
- Desalination alone cannot meet demands
- Multiple water sources integrated for operation

Aging Infrastructure

- Existing facilities/ system are gradually aging
- Lack of informatized water management facilities
- Key operational data remains analog

Human Resource Shortage

- Difficulty in recruiting professional personnel
- Lack of standardized operational experience
- Limited human resources leading to challenges in improving user services

Digital Transformation:

The Key to Resolving Water Management Pain Points

Water Towards Safety Sustainable Environment and Prosperity 水與安全、環境、發展

- Automates complex data analysis
- Improves operational efficiency
- Enables real-time monitoring and decision-making
- Addresses human resource constraints

Leakage Management

- Real-time monitoring
- Leakage hotspot identity
- Prioritise leak repair area

Water Supply Management

- Optimizing water distribution

Energy Consumption Analysis

- Monitoring power usage efficiency
- Identifying energy-saving opportunities

Asset Management

- Equipment Transportation Management
- Optimizing maintenance schedules
- Predictive maintenance

Demand Analysis

- Tracking water usage patterns
- Capture internal line leakage

Lienchiang's Smart water journey

Water Towards Safety
Sustainable Environment
and Prosperity 水與安全、環境、發展

Digitalisation | Automation | Intelligence

START

2017 | Planning

2018 | System Engineering

- Monitoring Equipment Installation (reservoir, WTPs, Networks)

2020 | Phase 1 Construction completion

The era of Smart Water Management starts.

2022 | Performance Analysis

- Spatial analysis
- Dynamic real-time calculation
- Decision support tool

2025 | Smart Water Network

Stantec

Project Achievements

- **Scope of work**
  - From raw water end to customer end.
  - Project coverage area: 4 counties and 5 islands of Lienchiang county
- **Key Infrastructure**
  - 2,006 × Smart meters
  - 3,330 × NB-IoT
  - 111 × Water meters
  - 71 × Water pressure monitoring stations
  - 142 × Lightning protection facilities
  - 2 × Smart Water Monitoring System Platform

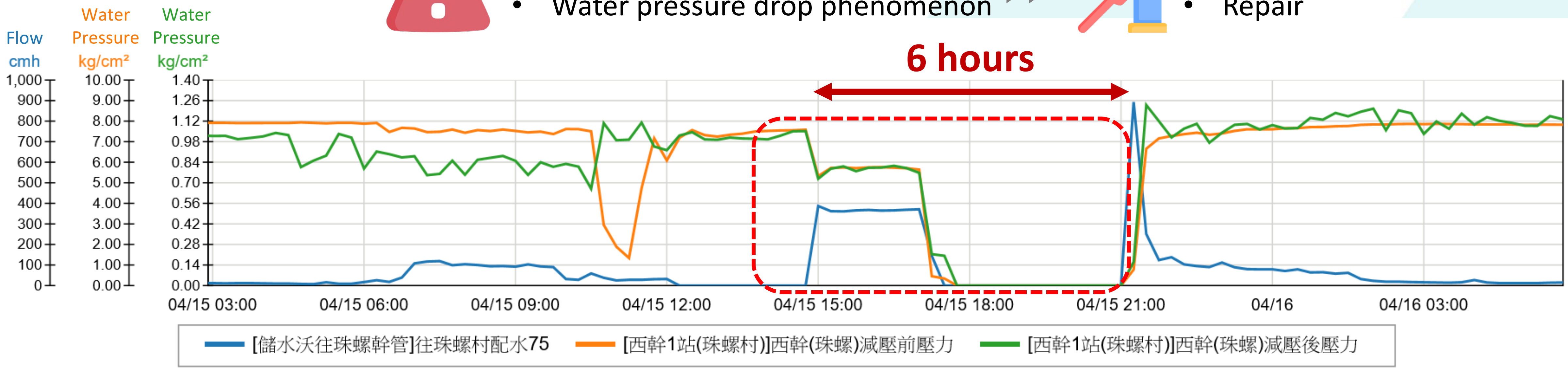
Water Towards Safety Sustainable Environment and Prosperity

Insight – Pipe break detection

Key Location Flow/Water Pressure Anomaly Analysis

- Abnormal flow rate
- Water pressure drop phenomenon

- Confirm pipe break location
- Repair



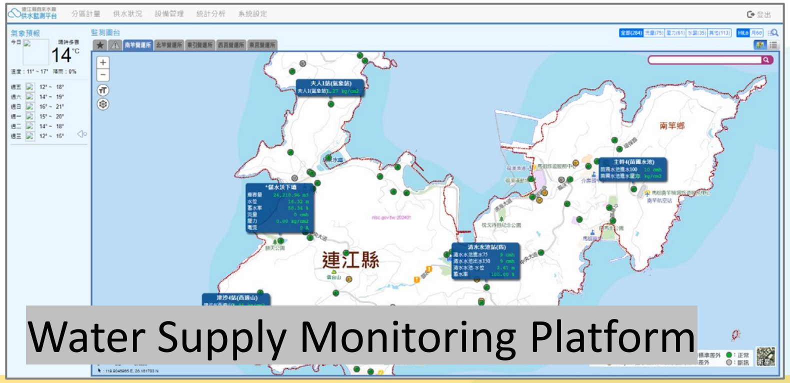
- Real-time flow monitoring information enables immediate detection of anomaly locations
- Effectively shortens response time, location, and repair duration for pipe breaks, reducing impact on users

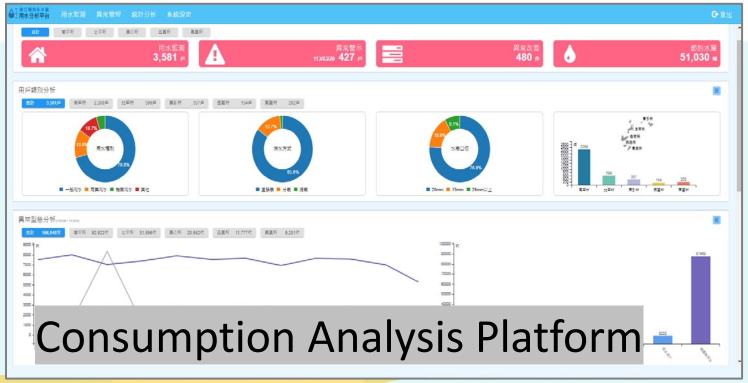
Insight – Better Service Quality

Increasing Operational Efficiency

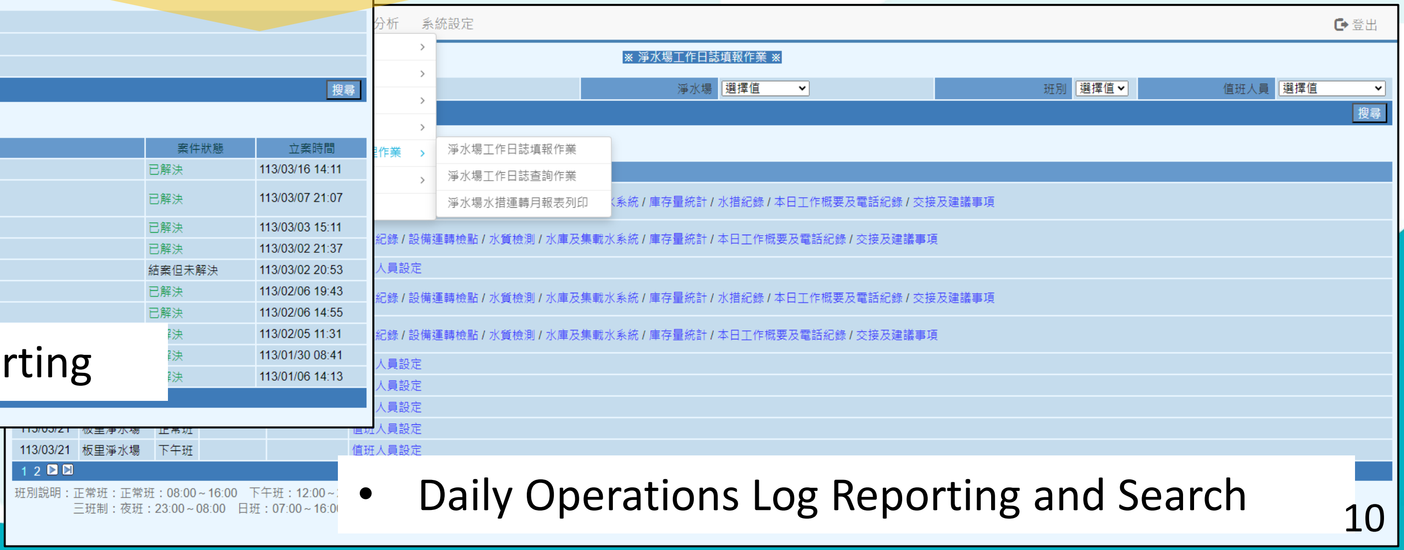
- Past: 5 hours/person/month spent on paperwork
- Now: 2.5 hours/person/month spent on platform


SWN Dashboard


Water Supply Monitoring Platform


Consumption Analysis Platform

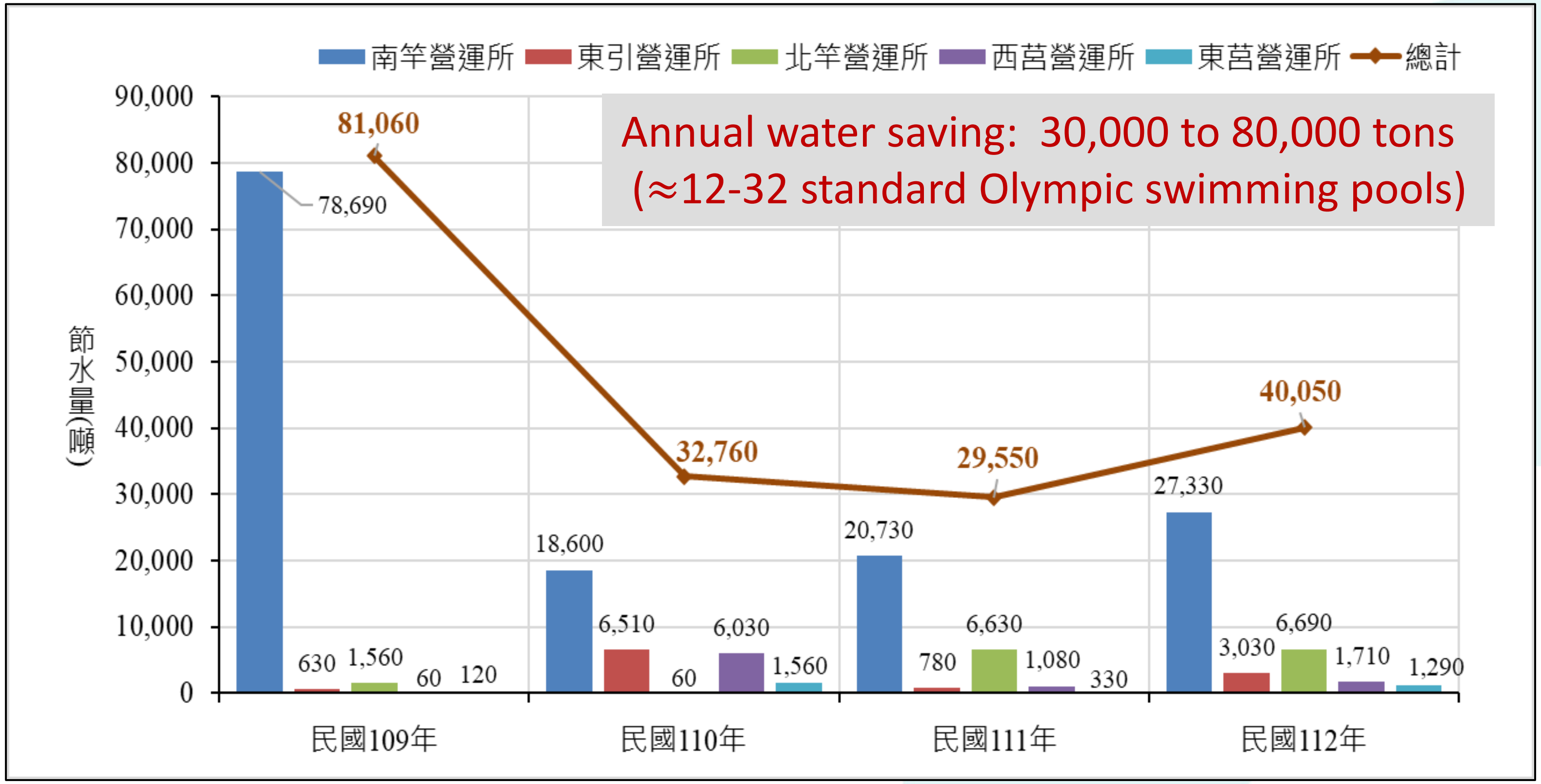
- Online complaint and leak registration and reporting



- Daily Operations Log Reporting and Search

Insight – Strengthening Water Management Efficiency

Smart water meter + Internal line leak analysis



- Conditionals:
  Weekly water consumption increase and continuous flow for more than 1 day (24 hours) with unusual 0.05CMD
- Notify users automatically

Smart network × ESG

- **Environmental**
  - Smart water metering and leak detection to reduce water waste.
  - Optimise pump operations to minimize energy use
  - Monitor and reduce energy consumption in water treatment and distribution.
- **Social**
  - Real-time water quality monitoring to safeguard public health
  - Community Engagement by well-design user app
  - Fair water pricing structure
- **Governance**
  - Provide open data
  - Predictive analytics to anticipate and mitigate water-related risks
  - Public private partnetship

Future Landscape of Smart Network

Optimal Water Supply Mode

- Climate change adjustment
- Water resource management
- User water demand analysis and prediction

Hydraulic model-based water distribution digital twins

- Asset management
- Optimizing maintenance schedules
- Predictive maintenance
- Identifying energy-saving opportunities

Questions?

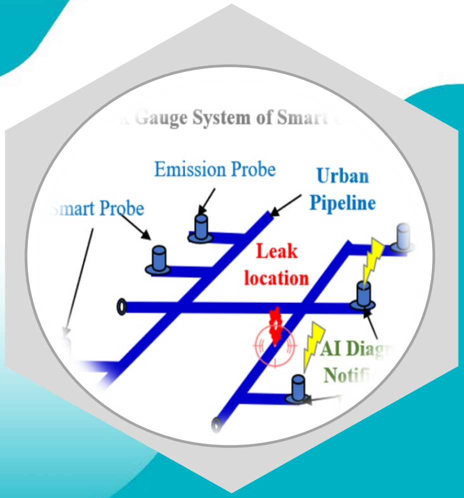
Title

Mobile Smart Leakage Rapid Screening and Early Warning System in Pipeline Networks

Speaker : Tsai Yao-Long

Department : ITRI MCL

Email : YLtsai@itri.org.tw



Outline

1. BACKGROUND
2. QUICK LEAGAGE SCREEN STRATEGY
3. PRODUCT AND CLOUD MONITOR PLATEFORM
4. ACOUSTIC AND VIBRATIOB DIAGNOSIS THEORY
5. FIELD VERIFICATION

BACKGROUND

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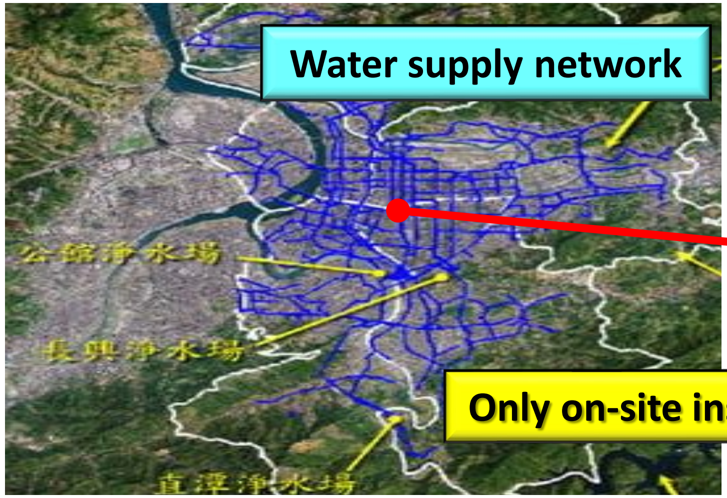
- **Water leakage rate is high (13.59%) and increases by 1.56% every year.** The annual increase in losses is 327 million NTD.
- Water restrictions reduce the production capacity of the facility by half and **result in a daily loss of 3 billion NTD.**
- The replacement of old pipelines with new ones is too slow **(cycle of 38 years).**
- **Water resource waste, foundation erosion, collapse**, and other public dangers.



External sensing probe

- Pipe pressure : **LOW** (<1.5kg/cm2)
- Signal attenuation : **FAST** (< 5m)
- Current leak monitoring system is **not suitable**

- Inspectors : **FEW** (87 person)
- Inspection speed : **SLOW** (0.5 km/hr)
- Diagnostic accuracy : **POOR** (74%)

- Mobile probe deployment : **High density**
- AI-assisted leak detection speed : **HIGH** (2 km/hr)
- AI-assisted diagnostic accuracy : **Good** (>90%)

Quick leakage screening strategy

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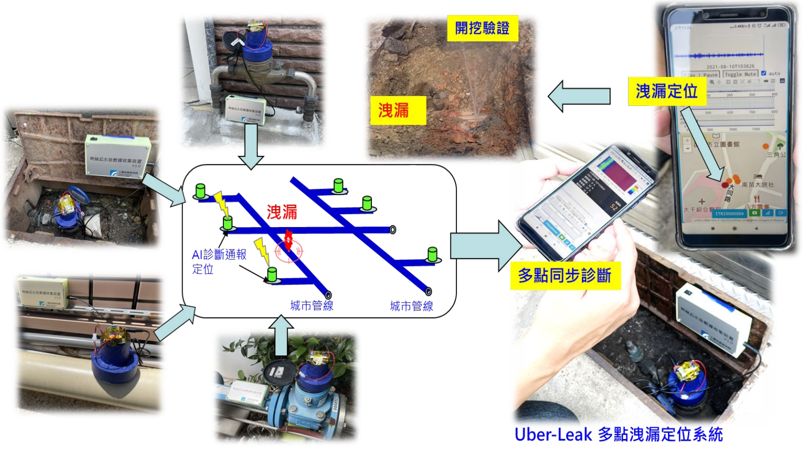
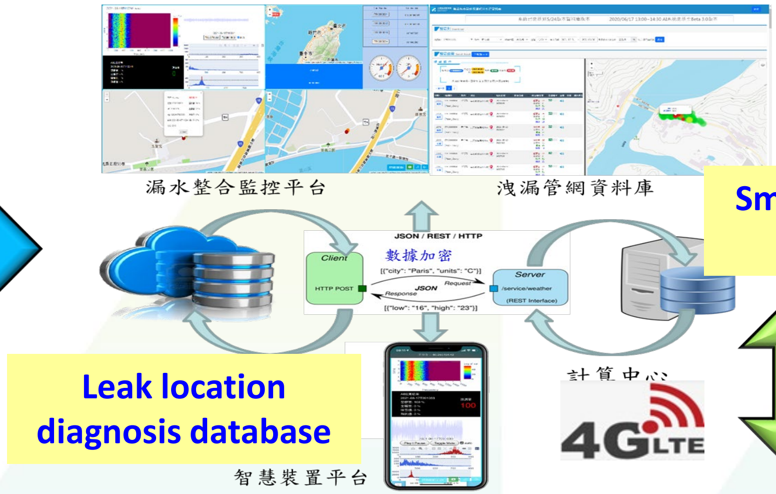
Sustainable Environment
and Prosperity 水與安全、環境、發展

Mobile pipe network smart leakage and abnormal sound positioning system



Cloud Intelligent Deterioration Diagnosis Service Platform



Leak location diagnosis database

Smart environment noise recognition module

Plug-in smart water leakage sensing device

1	2	3
4	5	6
7	8	9

Smart water leak sound auxiliary identification system

Mobile pipe network rapid leakage area reduced

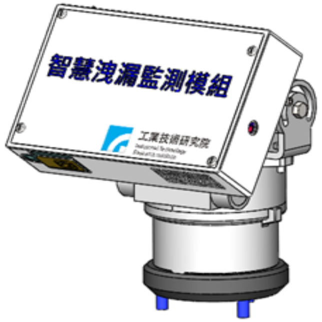
Smart water leakage inspection locates leakage points

Intelligent leakage and abnormal sound positioning system

Water Towards Safety Sustainable Environment and Prosperity

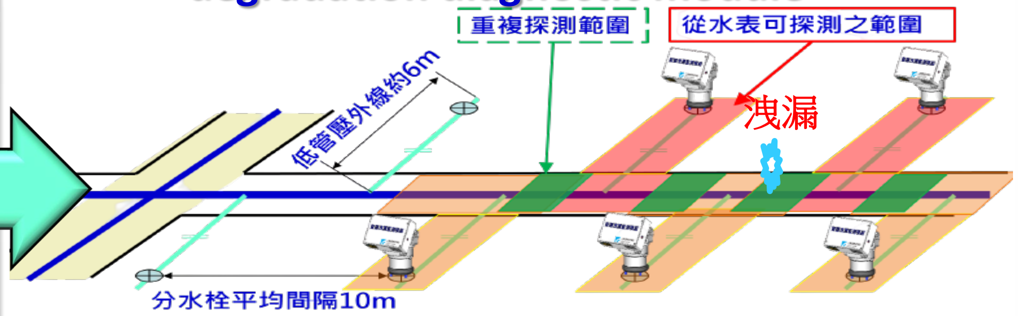
Active sensing in the cloud

■ **Ultra-low frequency and high sensitivity sound transceiver probe**



- Transceiver bandwidth：**20Hz ~ 2KHz**
- Enhanced detection range **> 150m**

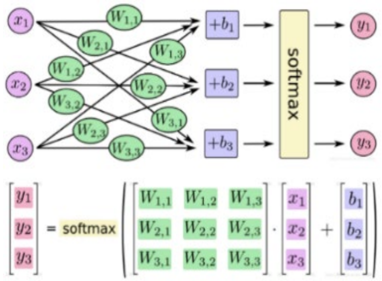
■ **Multi-point active sound field degradation diagnostic module**

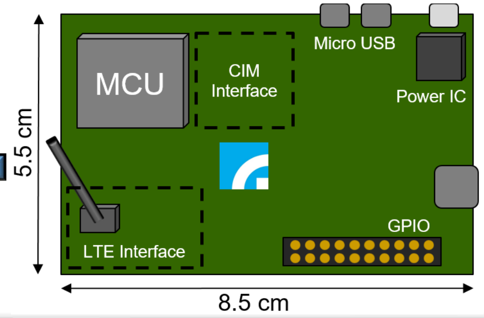


- Development of multi-point pipeline acoustic and vibration degradation module
- Smart pipe network leakage location **< ± 1m**

Front-end passive sensing

■ **Ultra-low power consumption AI computing module**





- Dynamic event AI recognition **< 3 sec**
- Ultra-low computing power consumption **≥ 1000 TOPs/W**

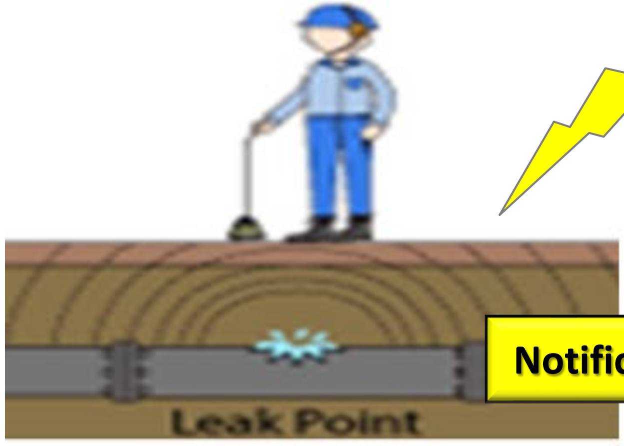
Smart water leak sound auxiliary identification system

Water Towards Safety Sustainable Environment and Prosperity

◆ **Schematic diagram of AI technology supporting underground pipe network leak detection**

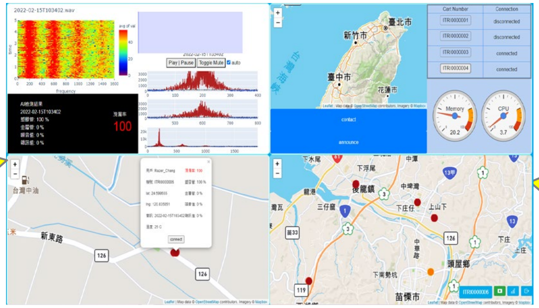
◆ Traditional inspection

Quick screen leakage range < 10m²



Targeting range

◆ ITRI Cloud Diagnosis Service Platform



Notification

Position

Synchronous analysis of big data in the cloud

◆ AI-assisted positioning

Accurately locate leak points

Targeting range

■ **Sensor module cell :**

1. Radio time 3 secs
2. Smart sound leakage diagnosis
3. Ambient noise separation
4. GPS leak location
5. 16bit compression technology
6. AI-IOT cloud platform transmission

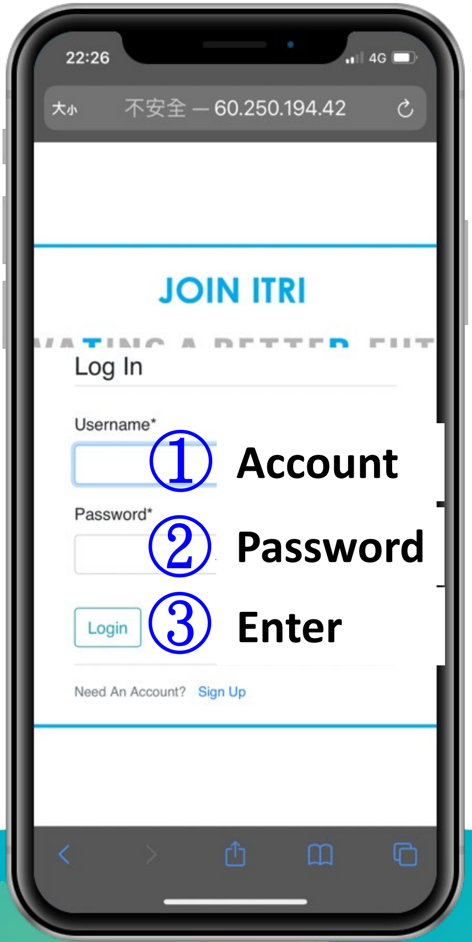
■ It is convenient for personnel to carry it to various places for data collection and cloud AI leak detection and diagnosis.

Handheld smart device operation interface

Water Towards Safety Sustainable Environment and Prosperity

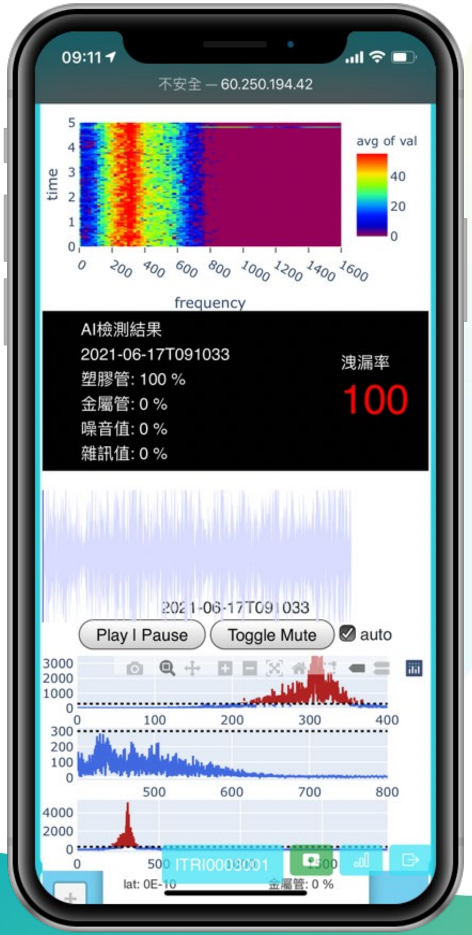
Smart device platform interface

- **Login**



① Account
② Password
③ Enter

- **Analyze screen**



- **Diagnostic screen**

Cloud leakage pipe network database

Water Towards Safety Sustainable Environment and Prosperity

Leakage database interface

- **Leak probability photosphere definition :**

- < 50% : No leakage
- 50~55% : Suspicious leakage
- 56~69% : Micro-leakage
- > 70% : Massive leakage

New leak detection mode

Water Towards Safety Sustainable Environment and Prosperity

AS IS

TO BE

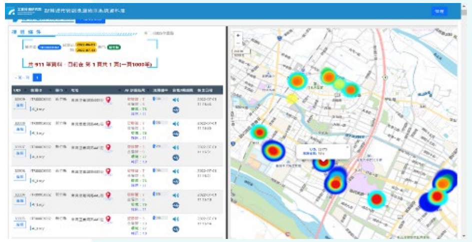
Single person

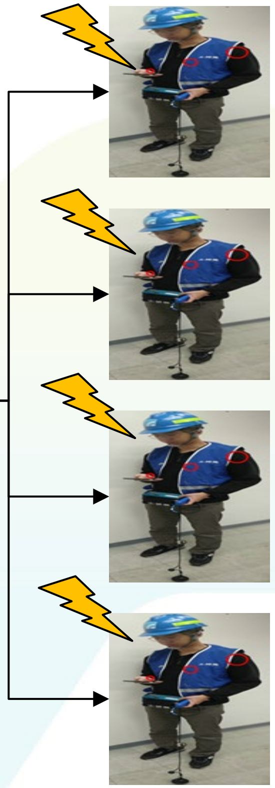
Step by step

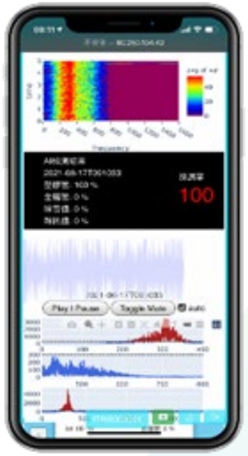
Professionals

Local or remote

Cloud command







AI inspection diagnosis

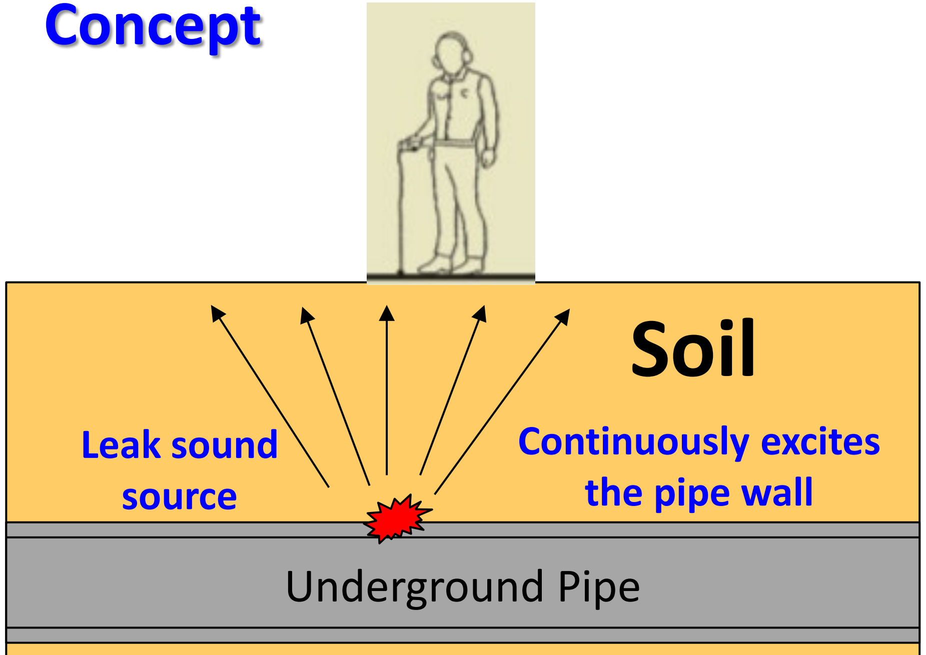
Synchronous multi-person online diagnosis

- Requires repeated confirmation and takes a long time
- Limited personal experience
- No testing evidence, unstable quality
- Wrong excavation rate >26%
- Low maintenance efficiency

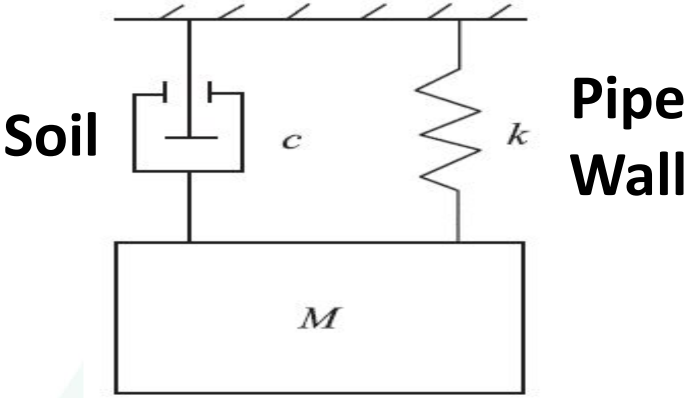
- Requires repeated confirmation and takes a long time
- Limited personal experience
- No testing evidence, unstable quality
- Wrong excavation rate >26%
- Low maintenance efficiency

Acoustic and vibration smart diagnosis theory [1]

■ Passive Noise Leak Detection Diagnosis Concept



Local vibration (sound source) model



$$F = M\ddot{X}^2 + C\dot{X} + KX$$

$$f_n = C\sqrt{\frac{EI}{\overline{m}L^4}}$$

- f_n ： Natural frequency
- C ： Boundary factor
- E ： Young's coefficient
- I ： moment of inertia
- m ： Pipeline unit mass
- L ： Length of pipeline

管路質量損失/增加 → 影響 → $\overline{m}$

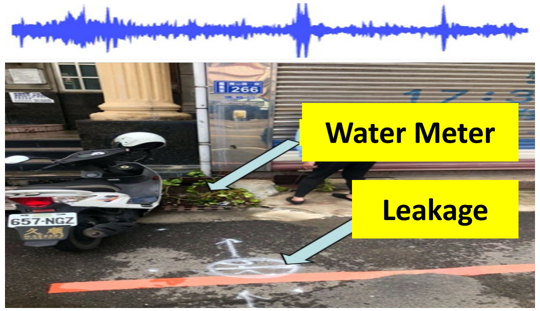
管路截面幾何改變 → 影響 → I

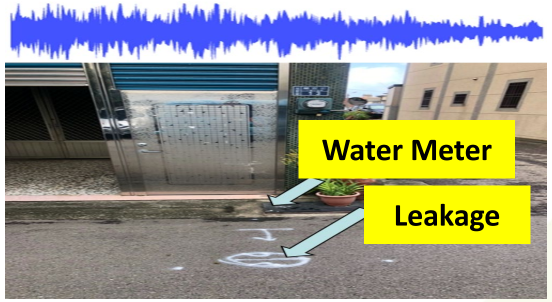
支撐架腐蝕或螺栓鬆脫 → 影響 → C

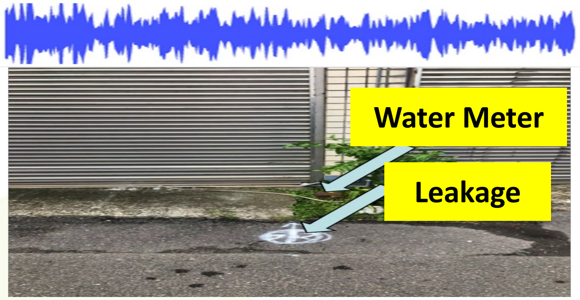
Master the characteristic frequency changes of pipeline systems

Timely diagnosis of pipeline corrosion and deterioration

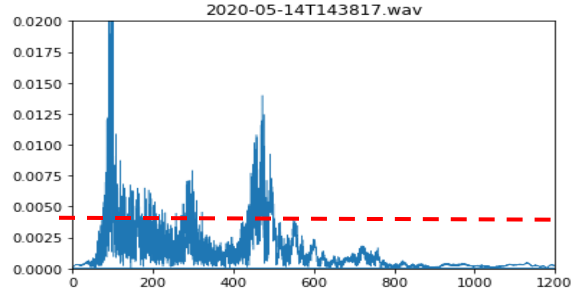
Acoustic and vibration smart diagnosis theory [2]

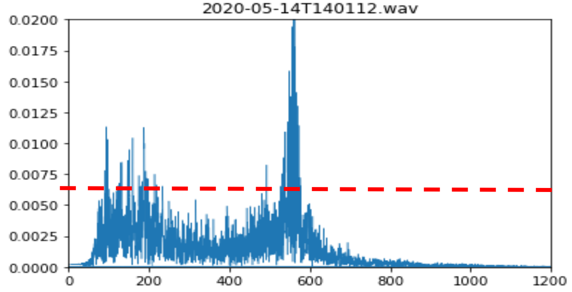


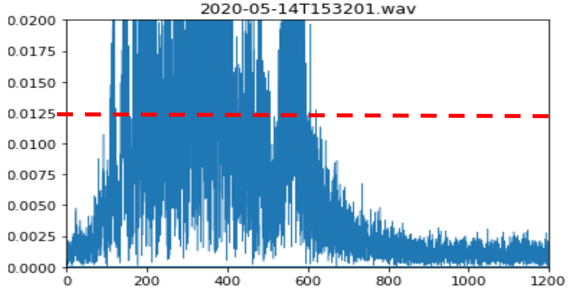




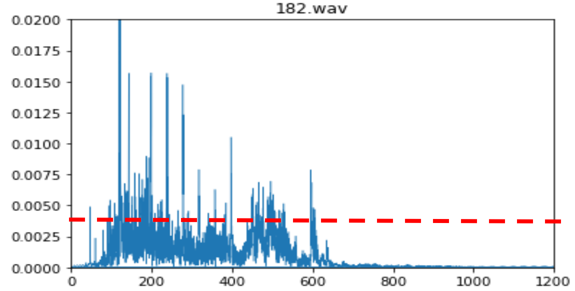
■ **Water leakage signal**

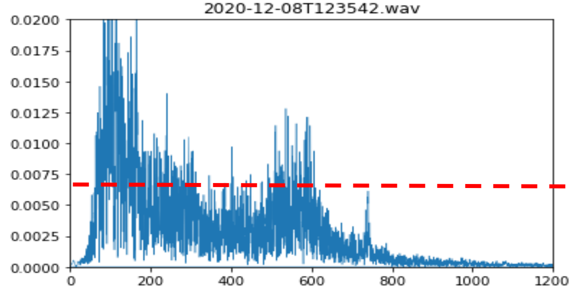


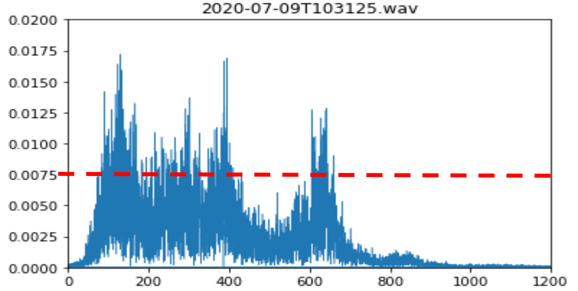




■ **Non water leakage signal (random event)**

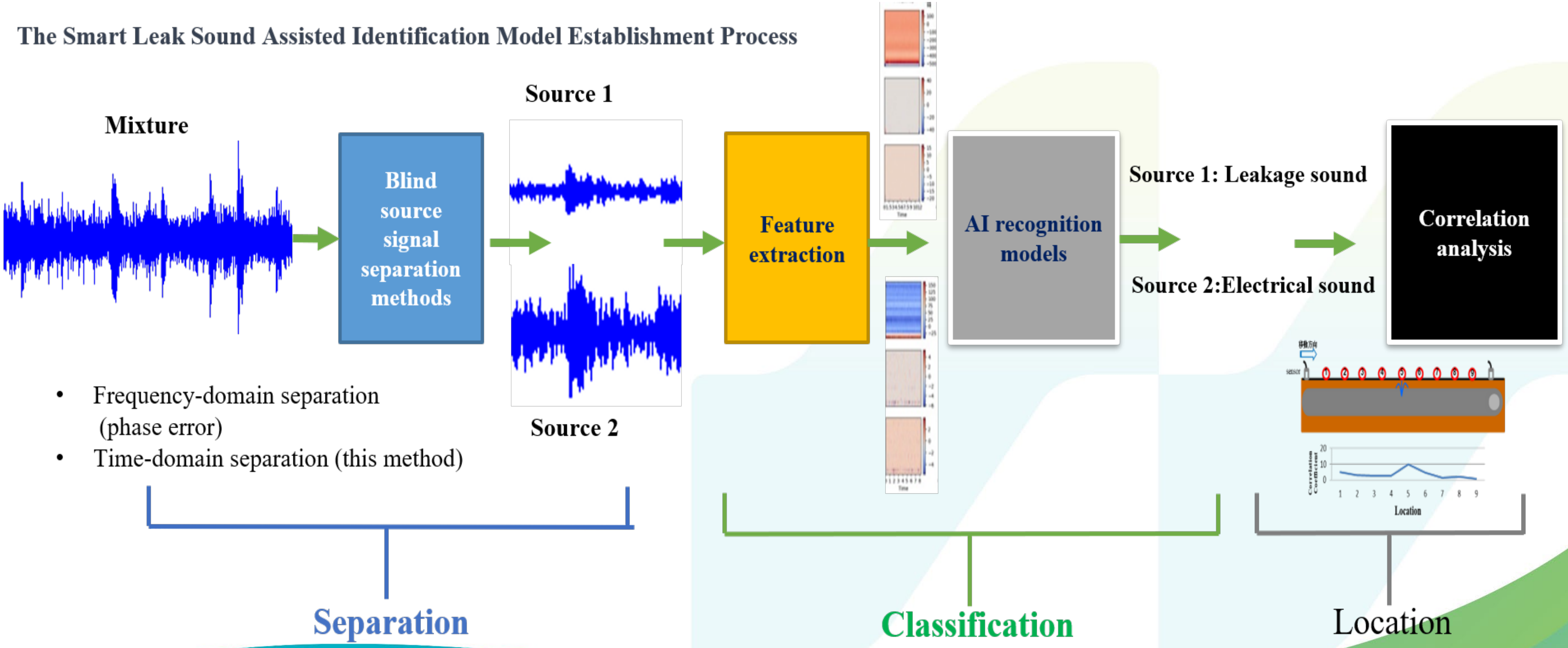






■ **The signal spectrum is similar and it is difficult to effectively distinguish water leakage event.**

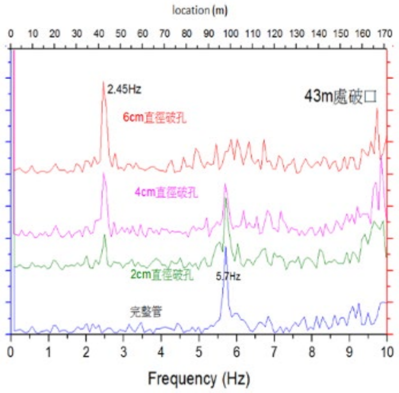
Acoustic and vibration smart diagnosis theory [3]

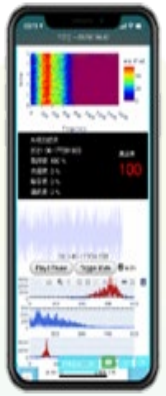


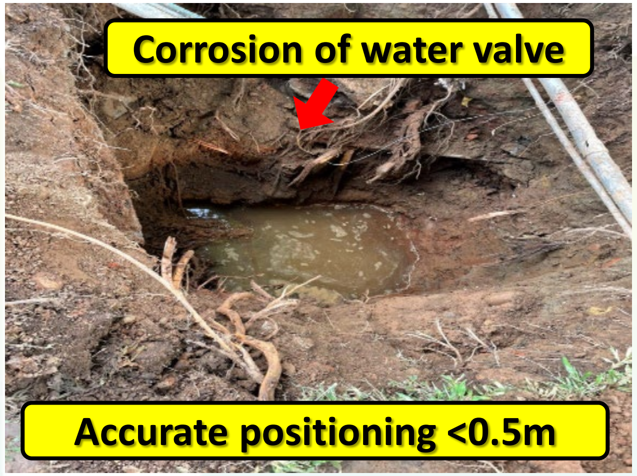
Field verification case [1]

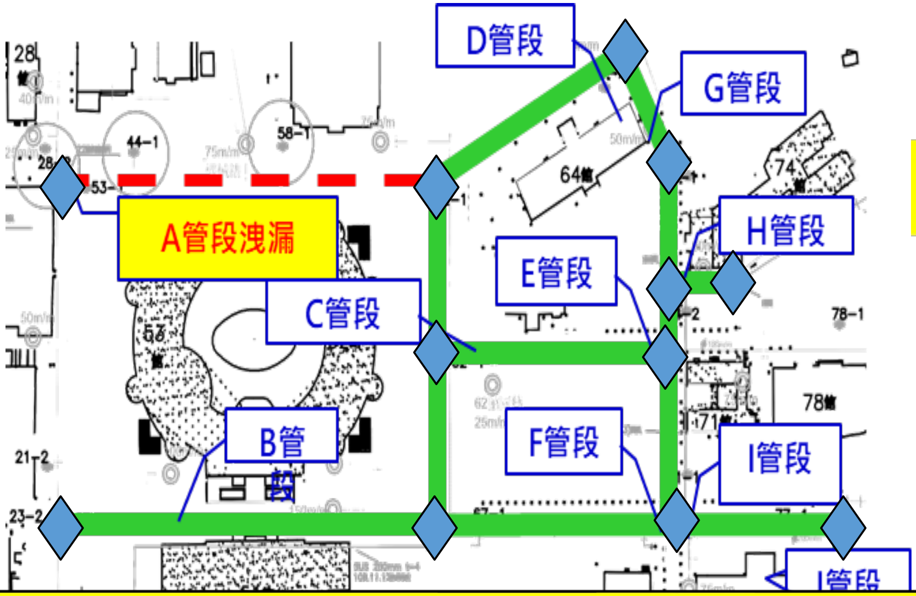
Surface : Pipe network probe placement → **Line : Active Sound Detection** → **Point : On-site leak confirmation** → **Excavation verification and pipe repair**

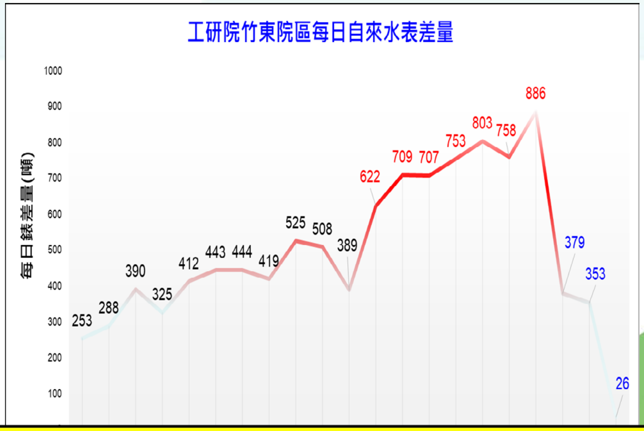






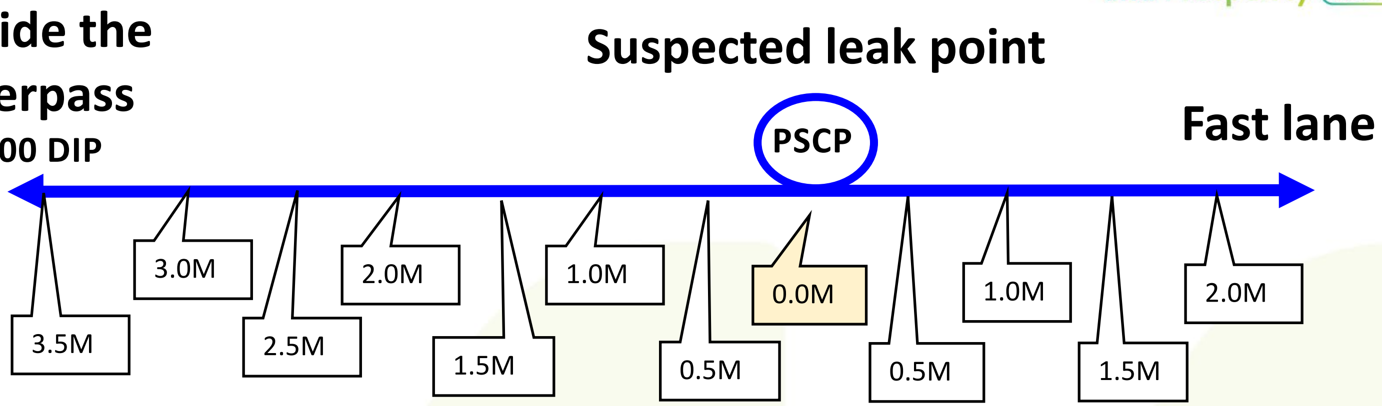


Successfully located and repaired pipeline leaks in Zhongxing Branch, **improving the maximum leakage volume from 886 tons to 26 tons per day**.

Field verification case [2]

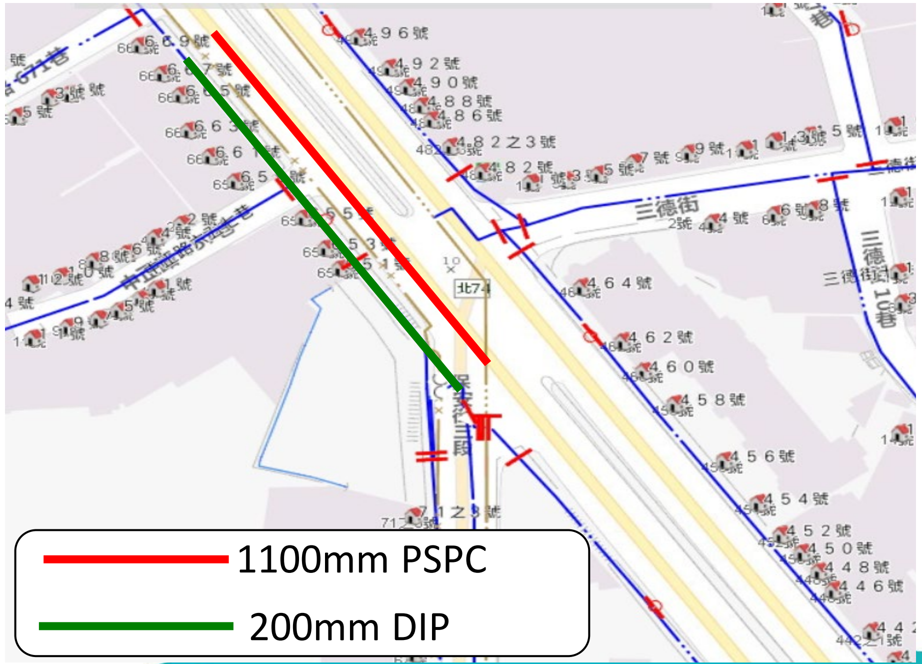
Water Towards Safety Sustainable Environment and Prosperity

◆ **Large pipe 1100mm non-steel lined prestressed concrete pipe (PSCP) field**



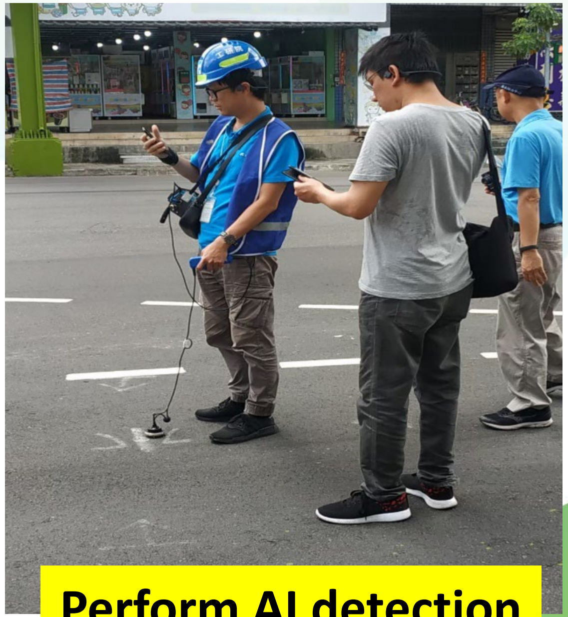
Date : 2020.08.07
Area : New Taipei City/Shulin District
Pipe Type :
1100mm prestressed concrete pipe without steel lining (PSCP)
200mm ductile iron pipe (DIP)
Detection range : 20m²

Mark the location of the leakage point and take a signal point every 50 centimeters for leakage point diagnosis.



Pipeline map information

Mark the location of suspected leaks

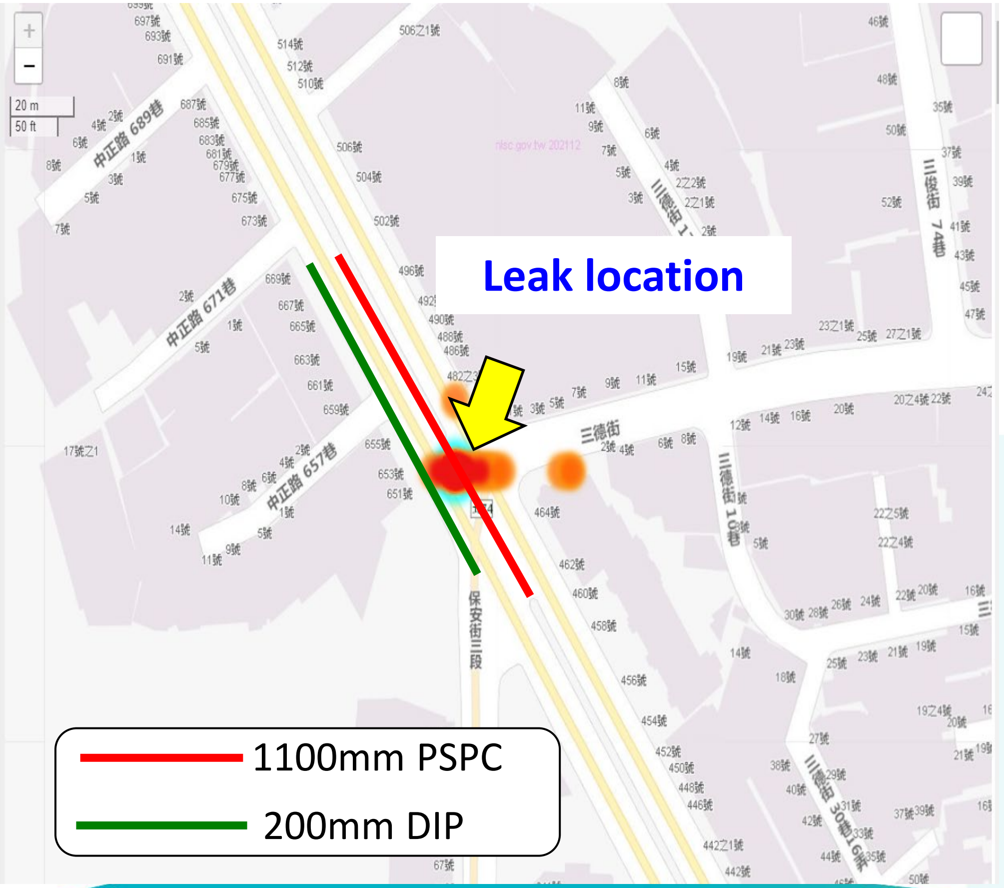


Perform AI detection around leak points

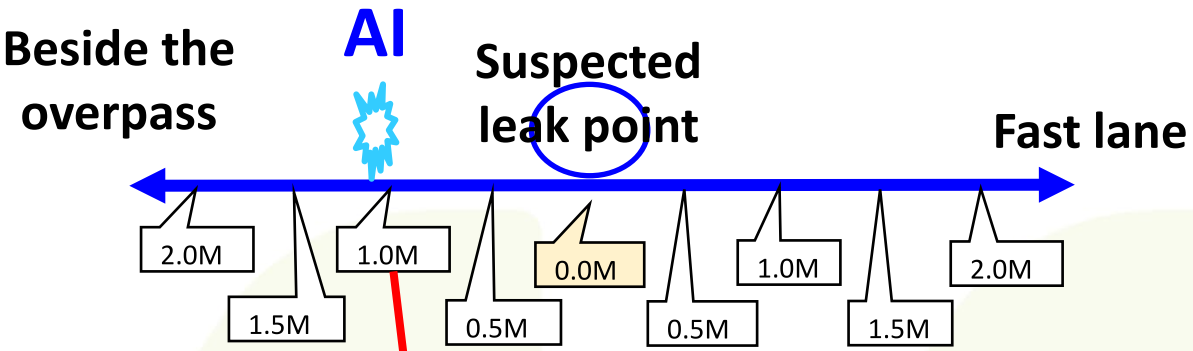
Field verification case [3]

◆ 1100mm PSCP excavation repair

Test results: AI is located the leak point above the 1100mm PSCP pipe and is offset by 1.0M, so it is ruled out as a leak in the 200mm DIP pipe.



Locate leakage range



AI locates leakage points

Field verification case [4]

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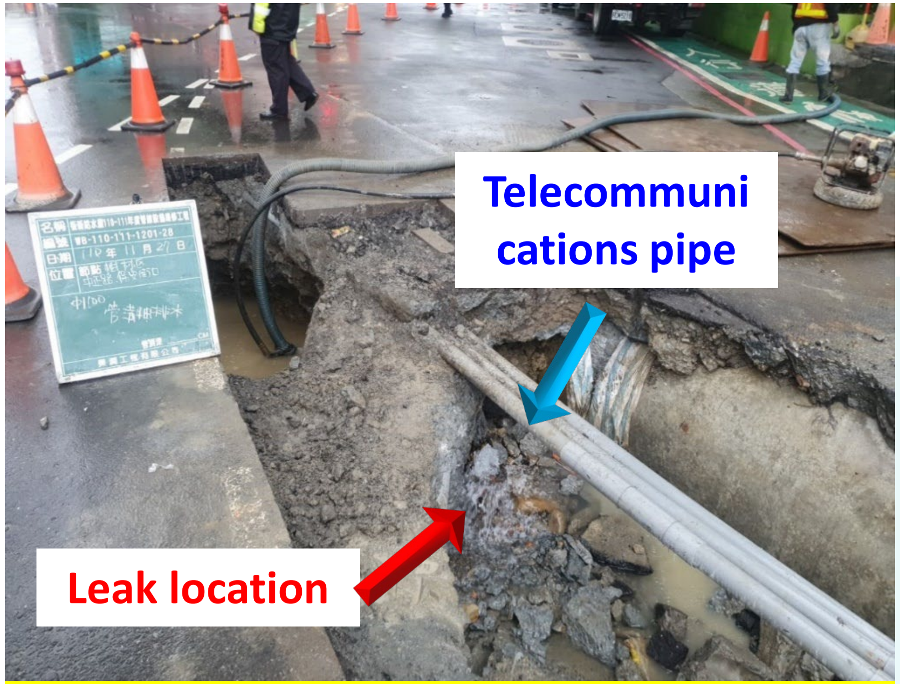
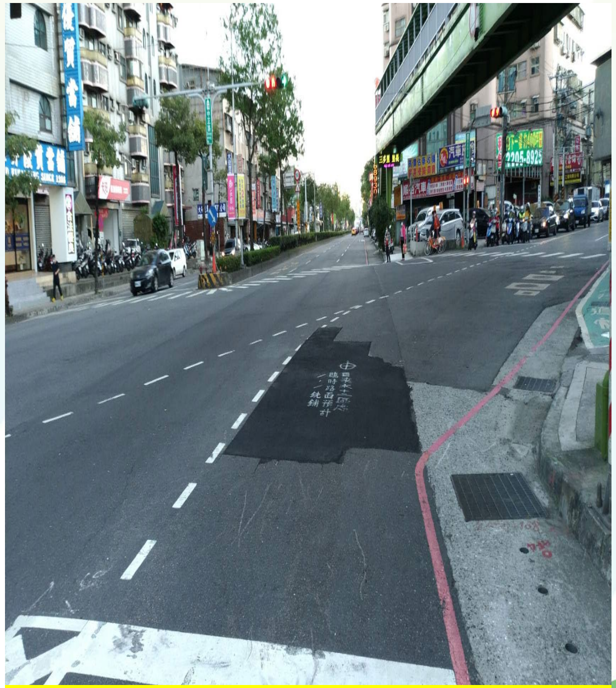
◆ 1100mm PSCP inspection leak detection case

Detection Date : 2020.08.07
Excavation Date : 2021.11.26
Excavation Result : Abandoned fire hydrant metal valve corroded and leaking
AI marks the suspected leak point within 0.5M of the excavation range
Excavation leakage volume : 76.9CMD



Fire hydrant metal valve corroded and leaking

Leak point status

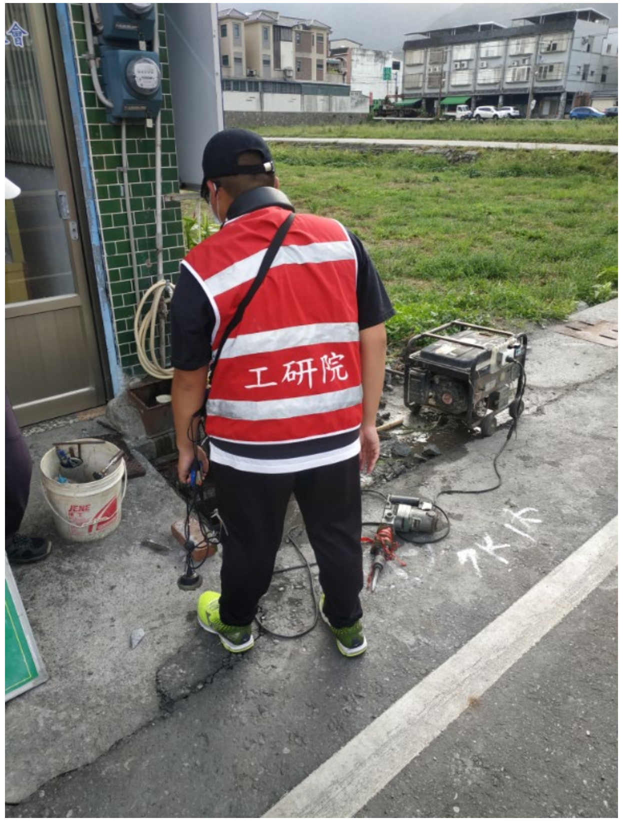


Repair construction scope

Field verification case [5]

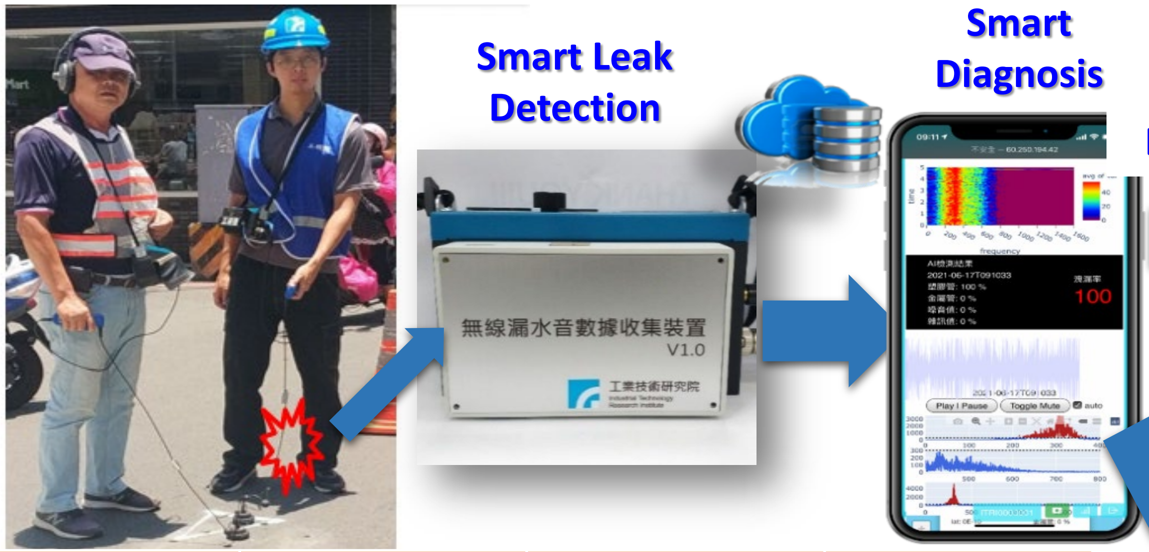
Water Towards Safety Sustainable Environment and Prosperity 水與安全、環境、發展

◆Assisting Taishui District 9 Management Office in post-earthquake inspection and diagnosis of water leakage in Hualien (2020/9/18~2020/9/22)



檢漏案號	巡檢日期	地址	AI診斷結果	類別
1	2020/9/21	花蓮縣玉里鎮中山路一段26號之間	洩漏	地下
2	2020/9/21	花蓮縣玉里鎮城東三街31號	洩漏	地下
3	2020/9/21	花蓮縣玉里鎮光復路與大同路交叉口	洩漏	地下
4	2020/9/21	花蓮縣玉里鎮仁愛路一段17之1號周圍	洩漏	地下
5	2020/9/21	花蓮縣玉里鎮和平路146號	洩漏	地下
6	2020/9/21	花蓮縣玉里鎮民權街70巷1號	洩漏	地下
7	2020/9/21	花蓮縣玉里鎮富國街15號	空管	地下
8	2020/9/21	花蓮縣玉里鎮新生街省道(23.343234507, 121.310560)	洩漏	地下
9	2020/9/21	花蓮縣玉里鎮忠智路59號周圍	未洩漏	地下
10	2020/9/21	花蓮縣玉里鎮忠勇路與中山路一段交叉路口	未洩漏	地下
11	2020/9/22	花蓮縣玉里鎮后庄路2之1號	洩漏	地下
12	2020/9/22	花蓮縣玉里鎮大同路(東都商務汽車旅館圍牆邊)	洩漏	地下
13	2020/9/22	花蓮縣玉里鎮大同路35號	洩漏	地下
14	2020/9/22	花蓮縣玉里鎮松浦里樂德公路36之1號(23.415038, 121.372052)	洩漏	地下
15	2020/9/22	花蓮縣玉里鎮福音部落聚會所旁143號(23.435691, 121.382367)	洩漏(竊水)	地下
16	2020/9/22	花蓮縣玉里鎮松浦橋	空管	地下

Field verification case [6]



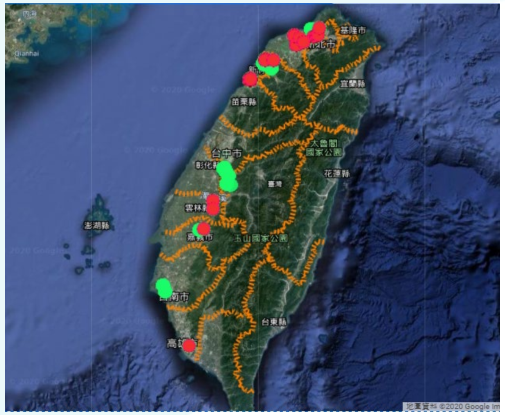
Excavation

Monitor

Administrative District	Excavation Test Event	Manual Classification Diagnosis	ITRI Smart Diagnosis
Hsinchu	133	71%	99%
Miaoli	132	72%	99%
Others	69	61%	79%

AI diagnosis accuracy is 15% higher than manual detection

- Accurate diagnosis : **simultaneous multi-person online AI interaction**
- Precise positioning: accuracy <±1m, **saving the cost of accidental excavation**

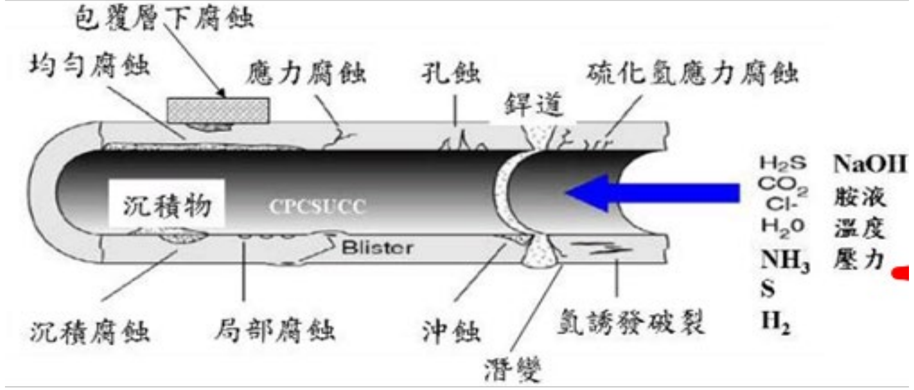


Taiwan-wide excavation verification results >95% accuracy.

Future applications and expectations

Water Towards Safety Sustainable Environment and Prosperity

- Specific benefits : **Leakage Prevention and Monitoring**
- Technology management : Research data analysis shows that many **micro-leak signals** can still be diagnosed by the AI system, **with continuous database archiving and tracking**. In the future, we can further analyze and **predict the pipeline leak time**, which will help to arrange repair schedule and save leak detection costs.
- Combination of pipe networks and digital transformation : Underground pipes are not just water pipes. **Gas pipelines and petrochemical pipelines** also affect the management of surrounding underground pipe networks. **Big data risk prediction and interconnection reporting** will help to make the future more accurate. Diagnose the situation and even expand the service territory.



Any corrosion deterioration
=> pipe wall integrity compromised

Technology management, water leakage prediction

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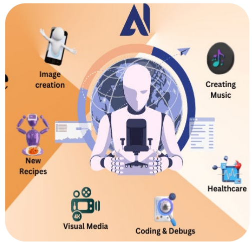
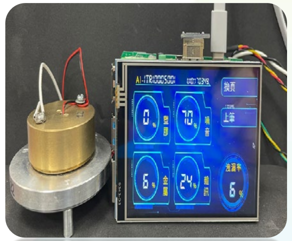
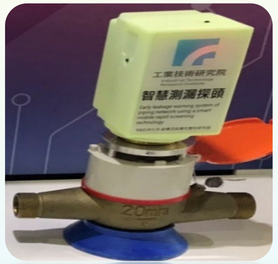
The End

Let's do something for the future…

Thanks For Your Attention .