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Energy reduction and improved water quality within water distribution system

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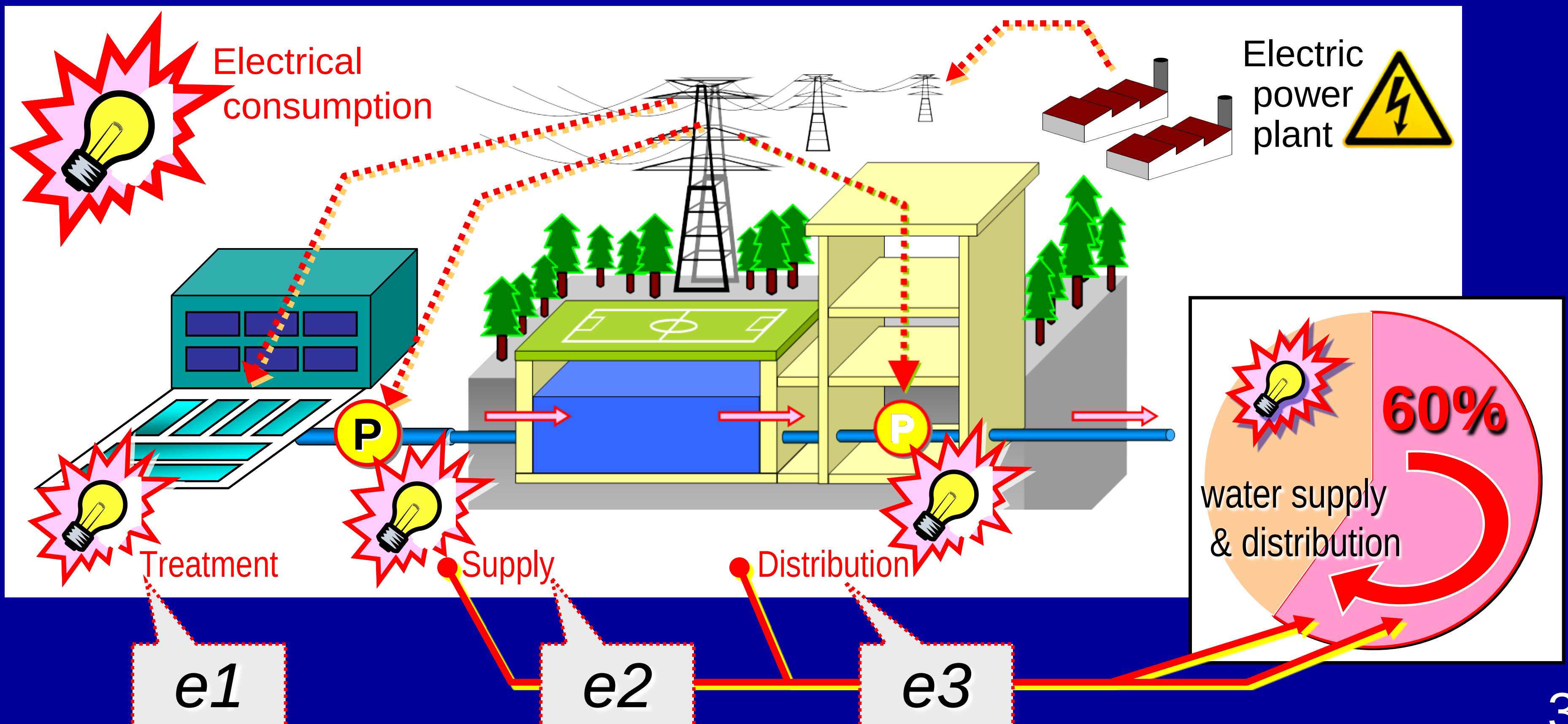
Table of contents

Introduction (1)

How can they radically reduce CO_2 Emission Amounts (Energy Usage)?

They must focus on area of the **water supply** and **distribution** that uses the most electrical consumption.



Introduction (2)

The purpose of this study is to propose an optimized solution that takes into account not only improved energy efficiency but also water quality within a water distribution system.

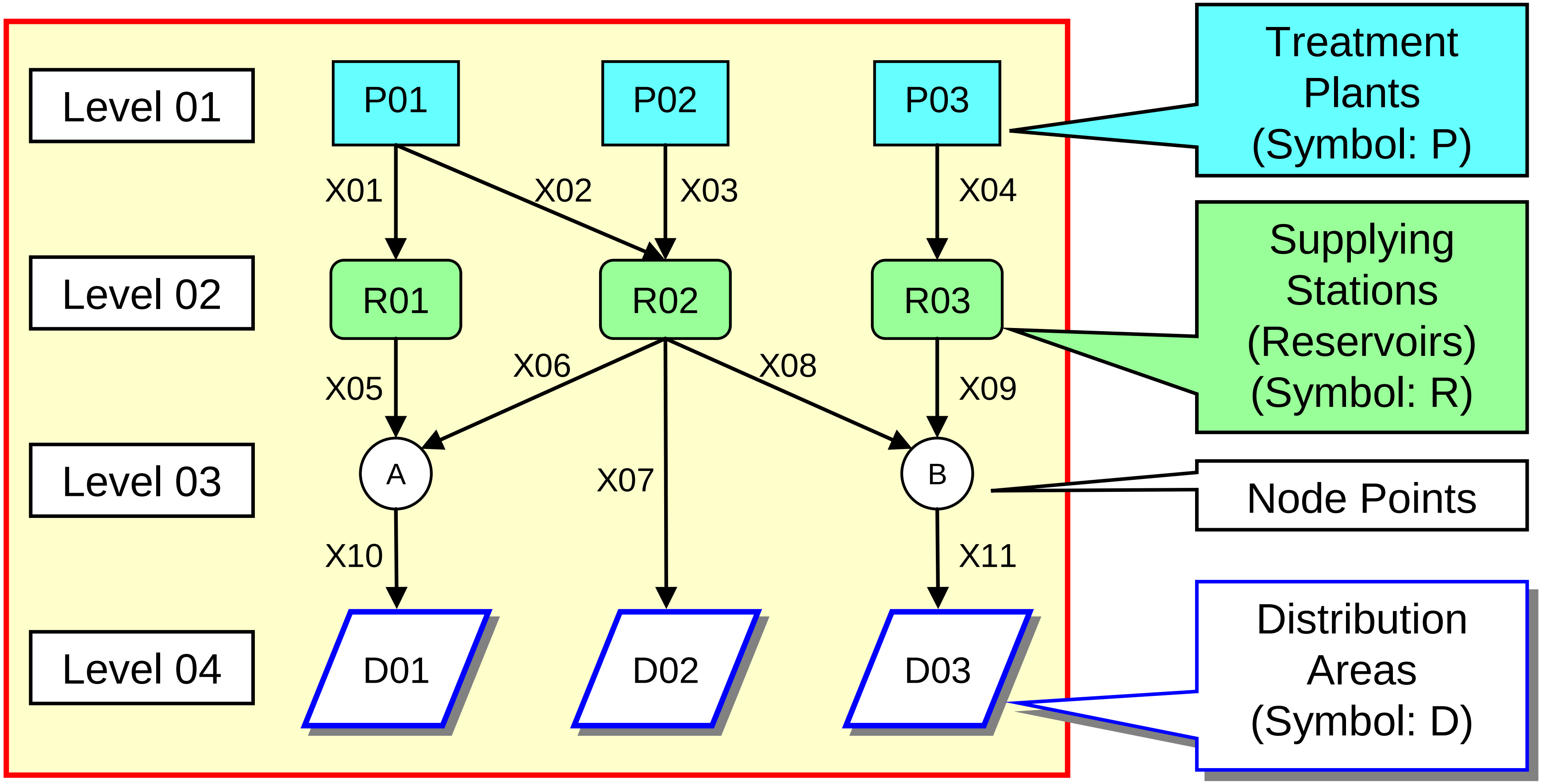
Our first objective was to make proposals for water operations in order to minimize yearly power consumption within the system.

Our second objective was to seek water supply methods from a water quality perspective, focusing on TOC (Total Organic Carbon: a value indicating the total quantity of organic substances contained in the water).

Optimized solutions for various objectives were calculated using linear programming (LP).

Our third objective was to attempt multi-objective optimization using fuzzy LP, applying optimized solutions for the previous 2 objectives.

Network model

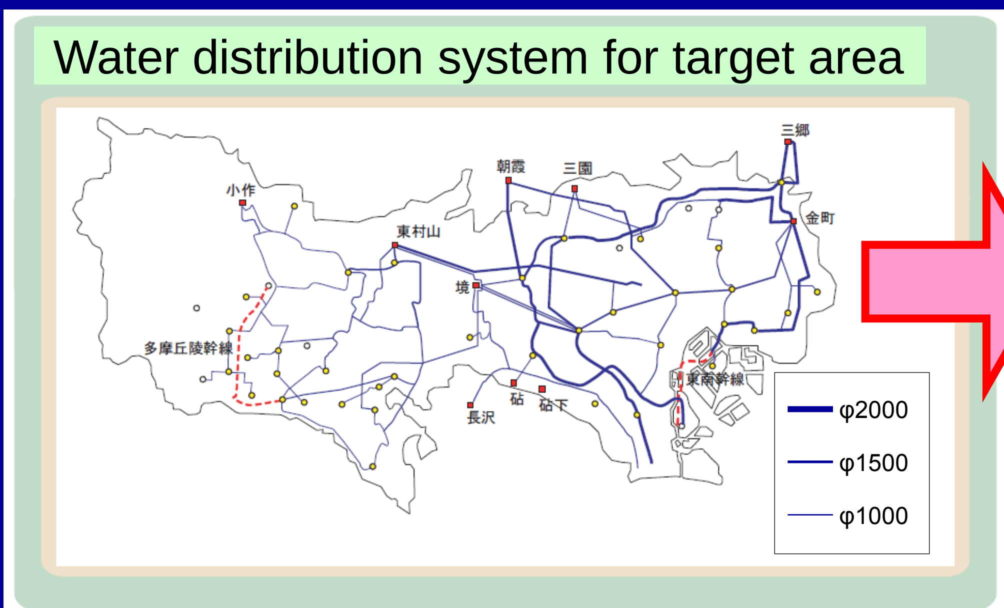


This research deals with the network model of treatment plants (P), supplying stations (R) and distribution areas (D) depicted as nodes and the lines connecting those as links.

Hierarchization using ISM* method

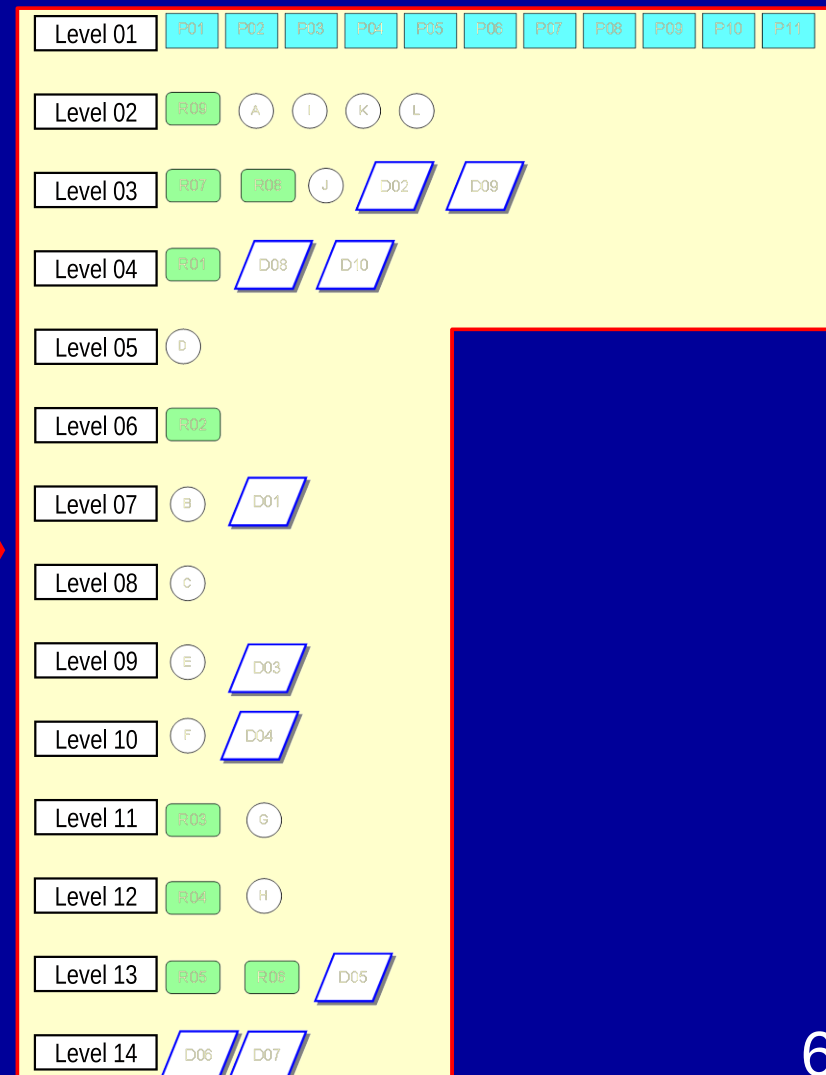
* Interpretive Structural Modeling

The current network is shown below. In order to perform LP Formulization, we need to clarify the mutual link among water treatment plant, supplying station, nodes and distribution areas.



Treatment plant

Supplying station



Minimizing energy consumption

Objective function_1

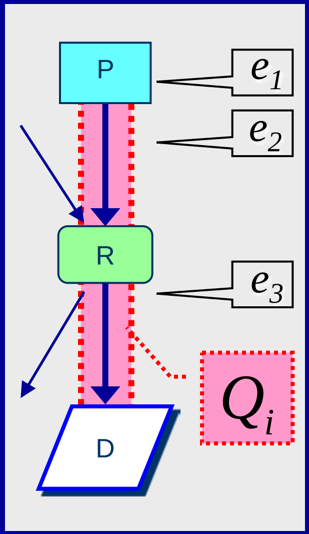
Σ (Energy Consumption [Electricity Usage] rate) × (Water Volume)

$$TE = \sum_{i} \left(\sum_{n} e_{n@Yj\sim k} \times Q_i \right) \rightarrow \min \quad \ldots(1)$$

TE : Total energy consumption (Electricity Usage) [Wh]

Q_i : Water volume [m^3] (Variables)

$e_{n@Yj\sim k}$: Energy consumption rate [Wh/m^3]
(based on 2006 actual values)



The purpose of this research is to plan water supply operation that the aggregate total of **electrical consumption** of treatment, supply and distribution of the water (objective function) is **minimized**. In another words, the purpose is **to obtain the value 'Q_i' when equation (1) is minimized**.

Evaluation indicator for water quality

Water quality within the water distribution network is another important objective for consideration.

TOC* multiplied by route length

* **Total Organic Carbon**:
a value indicating the total quantity of organic substances contained in the water.

Objective function_2

$$WL = \sum_{i} \left(C_i \times Q_i \times L_i \right) \quad \ldots(2)$$

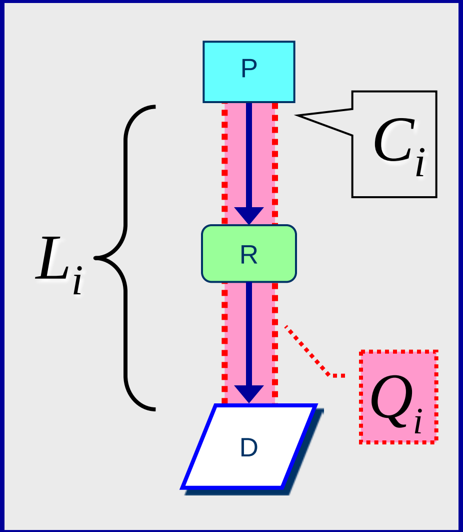
WL : Water quality distance

C_i : TOC concentration [mg/m³]

Q_i : Water volume [m³] (Variables)

L_i : Route length [km]

Smaller value for ***WL*** is the most desirable.



Logical constraints for LP

Treatment Plants

$$\sum_{i \in J} Q_i \leq Pj \quad \ldots(3)$$

Pj: Treatment Plant ***Capacity*** [m^3]
(obtained by "maximum" actual value of from 1999 to 2006)

J: Set of routes from a water treatment plant (j)

Supplying Stations

$$\sum_{i \in K} Q_i \leq Rk \quad \ldots(4)$$

Rk: Reservoir ***Permissible*** Volumes [m^3]
(obtained by "maximum" actual value of from 1999 to 2006)

K: Set of routes via a supplying station (k)

Distribution Areas

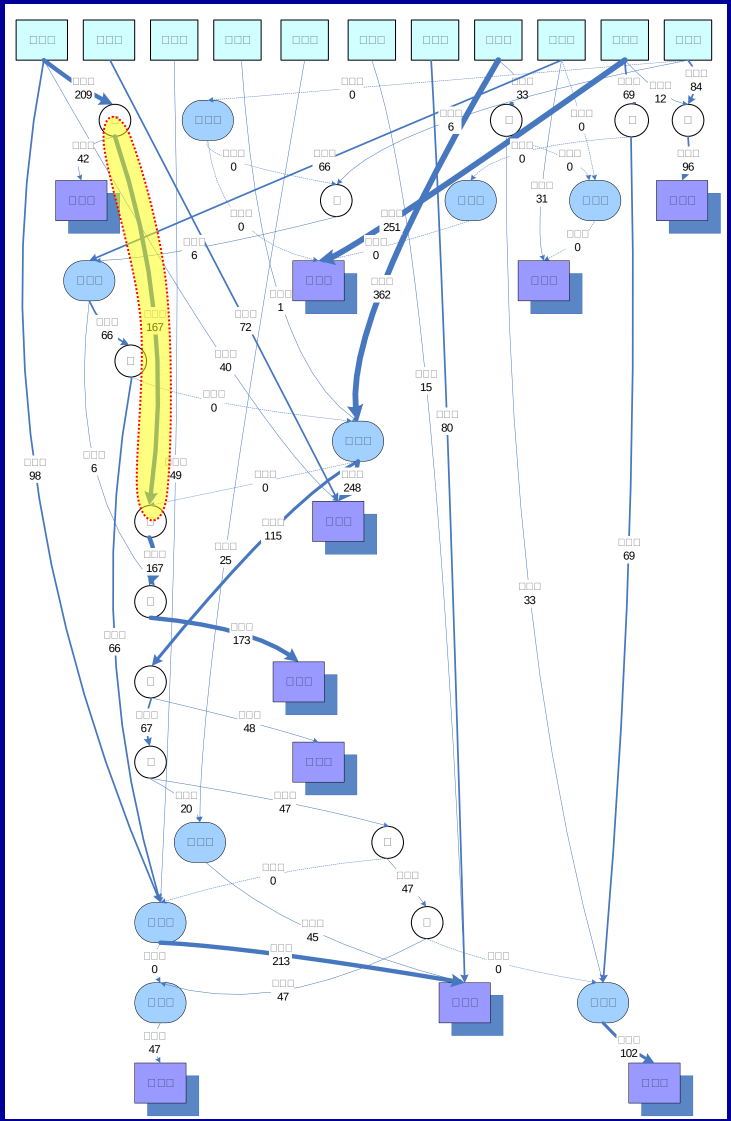
$$\sum_{i \in L} Q_i \geq Dl \quad \ldots(5)$$

Dl: Distribution Area ***Demand*** Volumes [m^3]
(2006 Data is used)

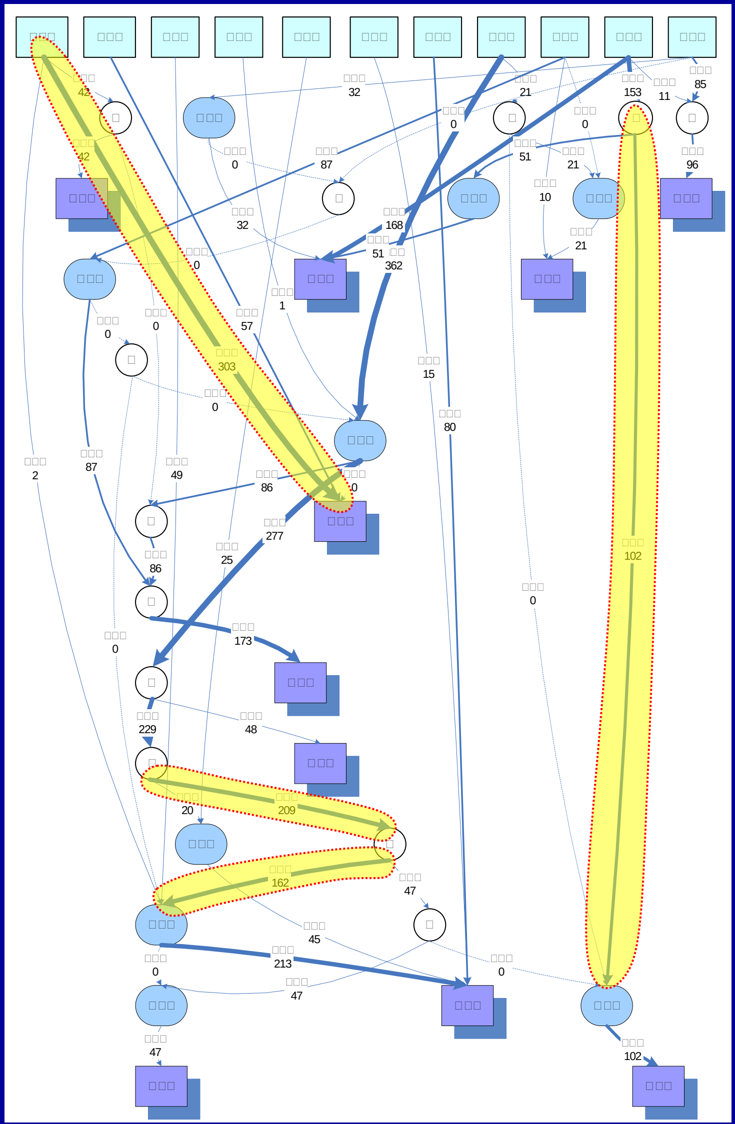
L: Set of routes into a distribution area (l)

Results of applying LP (1)

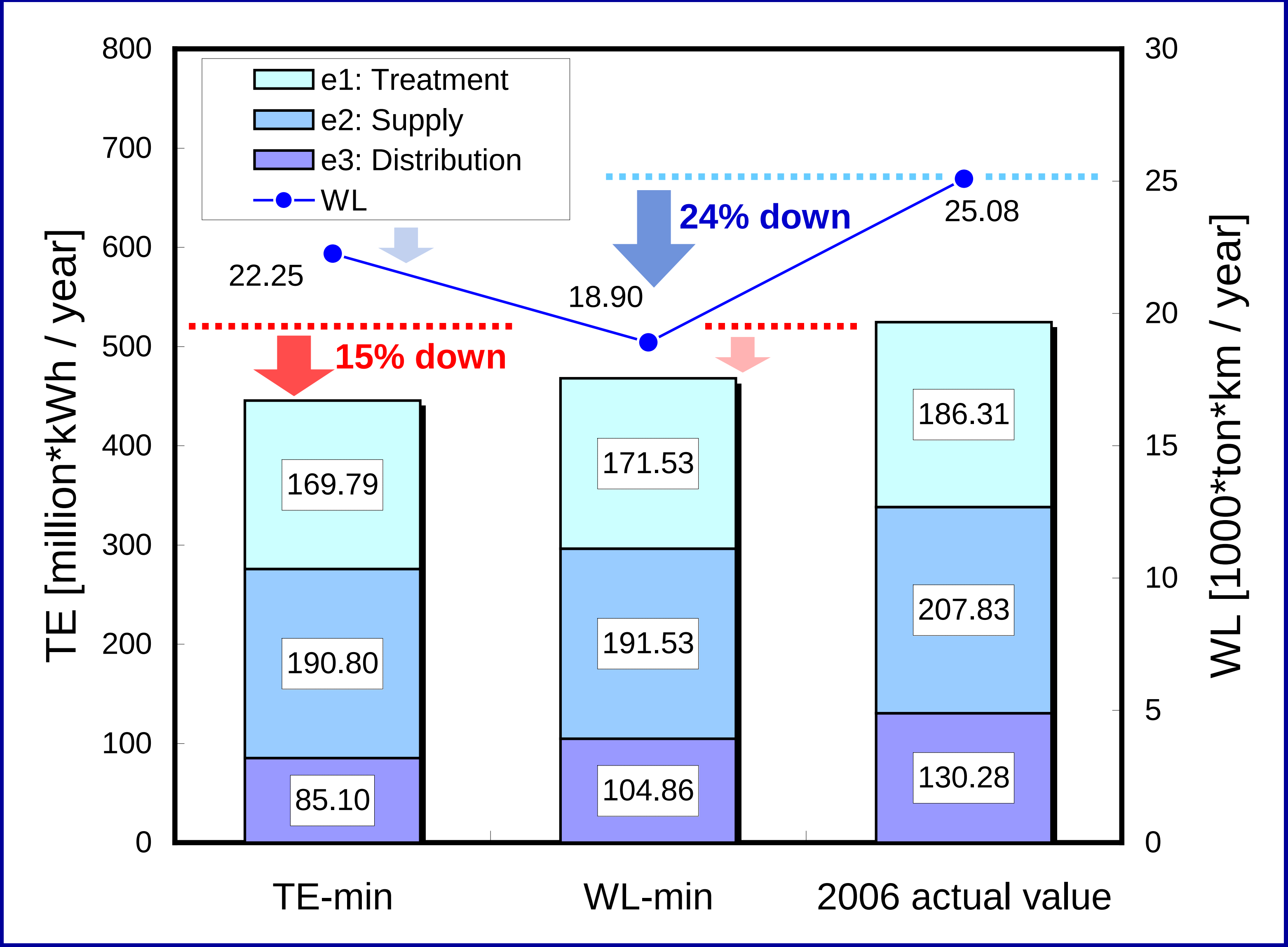
TE-min



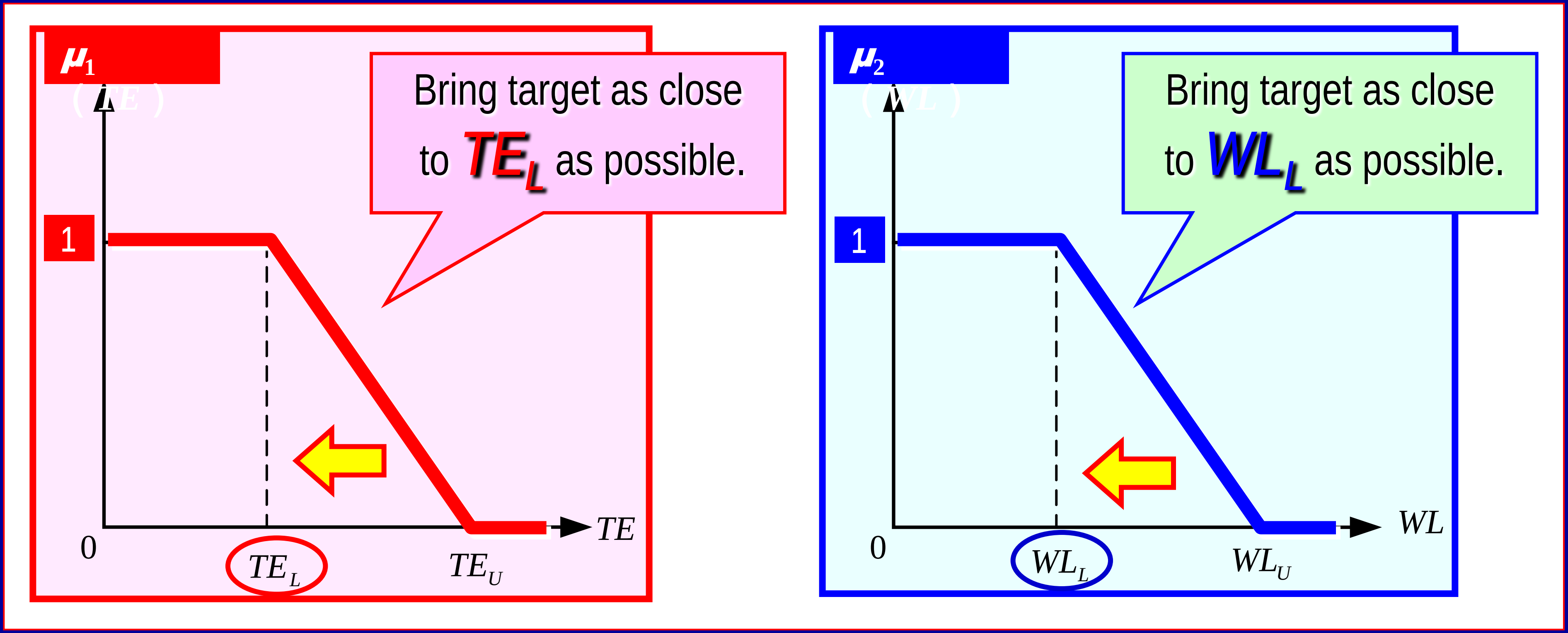
WL-min



Results of applying LP (2)



Expanding on multipurpose fuzzy LP (1)



TE	:	Electrical Consumption	WL	:	Water quality distance
$\mu_1(TE)$	:	*TE* Membership Function Value	$\mu_2(WL)$	:	*WL* Membership Function Value
TE_L	:	*TE* Minimum Value (LP returned value)	WL_L	:	*WL* Minimum Value (LP returned value)
TE_U	:	Maximum Possible *TE* (Set to *TE* when WL_L is obtained)	WL_U	:	Maximum Possible *WL* (Set to *WL* when TE_L is obtained)

Expanding on multipurpose fuzzy LP (2)

[Multipurpose fuzzy LP Formula]

$$\text{maximize} \quad \lambda$$

$$\text{subject to} \quad \lambda \le \mu_i, \quad i = 1, 2$$

$$\sum_{i \in J} Q_i \le Pj \quad \ldots(3)$$

$$\sum_{i \in K} Q_i \le Rk \quad \ldots(4)$$

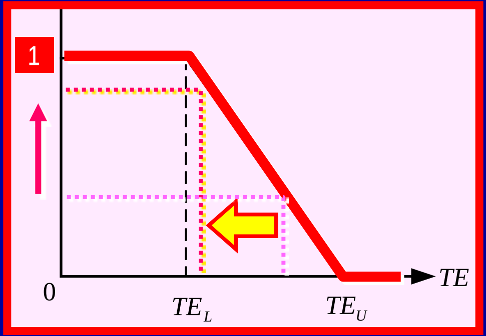
$$\sum_{i \in L} Q_i \ge Dl \quad \ldots(5)$$

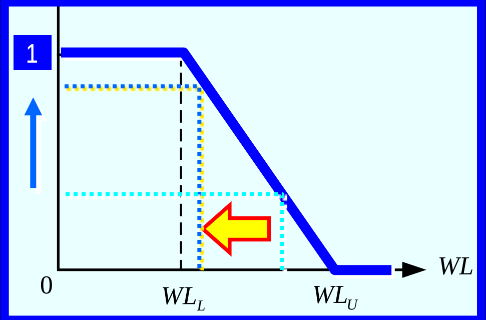
$(i = 1)$
$$\lambda \le 1 - \frac{TE - TE_L}{TE_U - TE_L}$$

$(i = 2)$
$$\lambda \le 1 - \frac{WL - WL_L}{WL_U - WL_L}$$

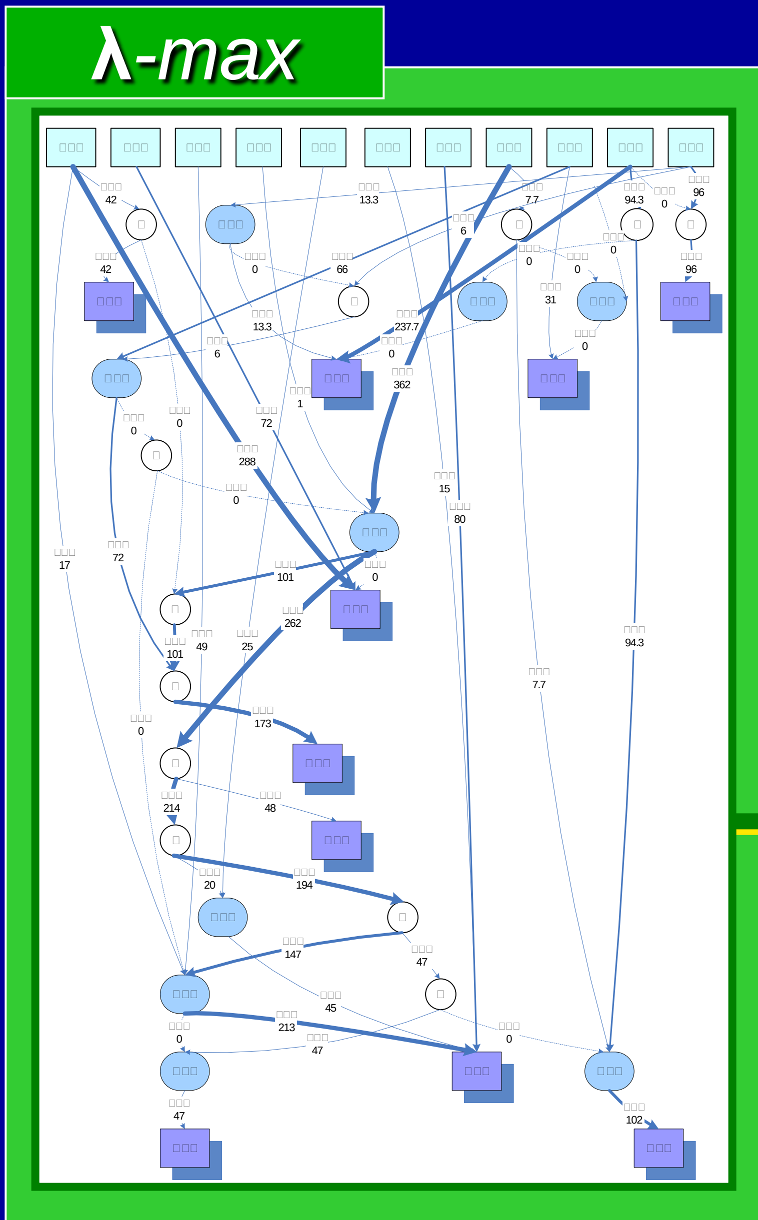
Using Linear Membership Function, we can standardize a value based on the original objective function.

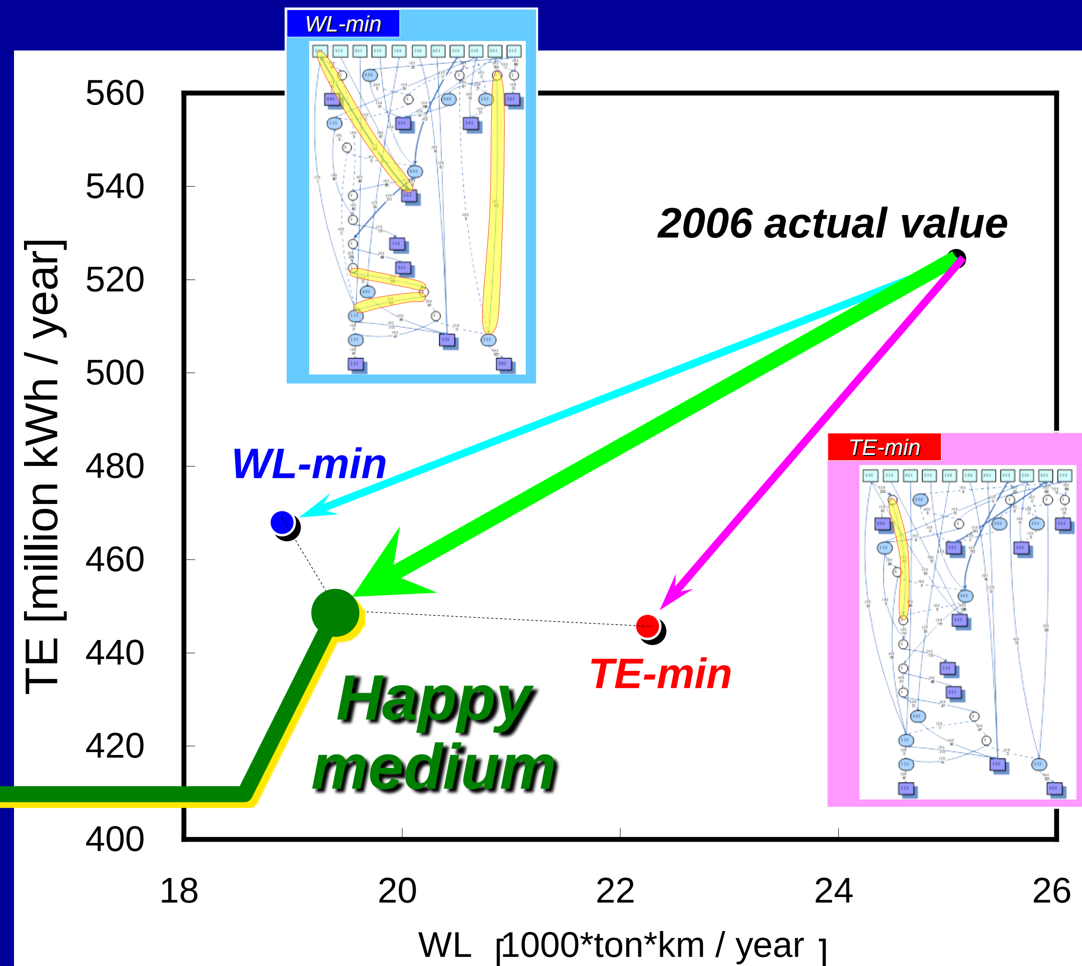
Furthermore, a ***supplementary variable "λ"*** has enabled us to arrive at a standard LP problem.





Results of applying *fuzzy LP*





The optimized solution obtained with ***multi-objective fuzzy LP*** represented a happy medium between the 2 single-objective alternatives.

Conclusion

We mathematically formulated problems with water operation planning, while focusing on *energy reduction* and *improved water quality* within water distribution system.

We tried *multipurpose optimization* to achieve a perfect balance between the various objectives .

Acknowledgements

We would like to thank ***Ms. Suehiro*** (master's course student) whose meticulous supports were invaluable.

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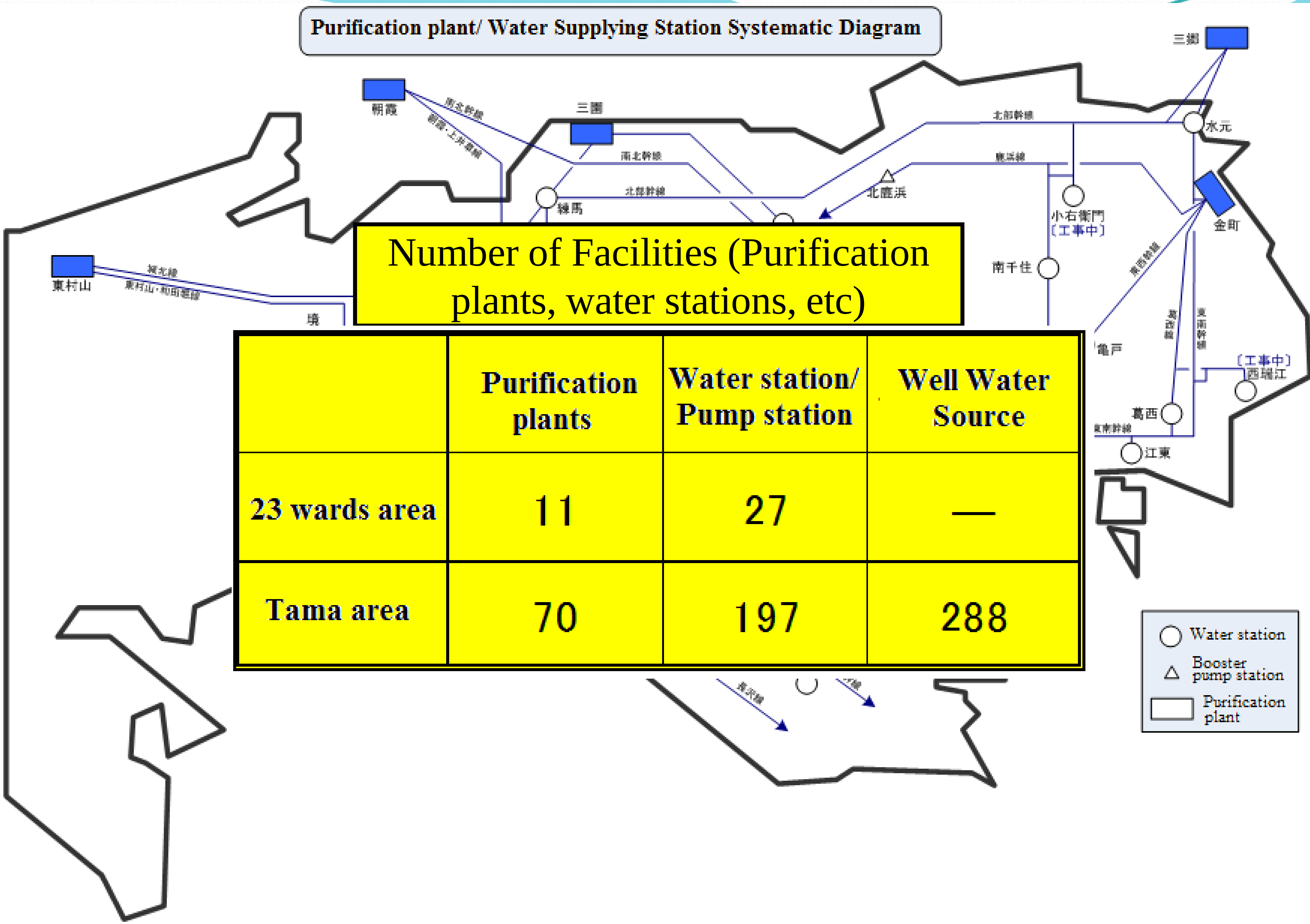
References

A. Koizumi, T. Inakazu, J. Koo, Y. Sakakibara
Monthly Water Distribution Control Planning by Multiobjective Fuzzy Linear Programming
Journal of Japan Water Works Association, Vol.66, No.5, 1997

Basic data of Tokyo Metropolitan Waterworks

fiscal year 2009

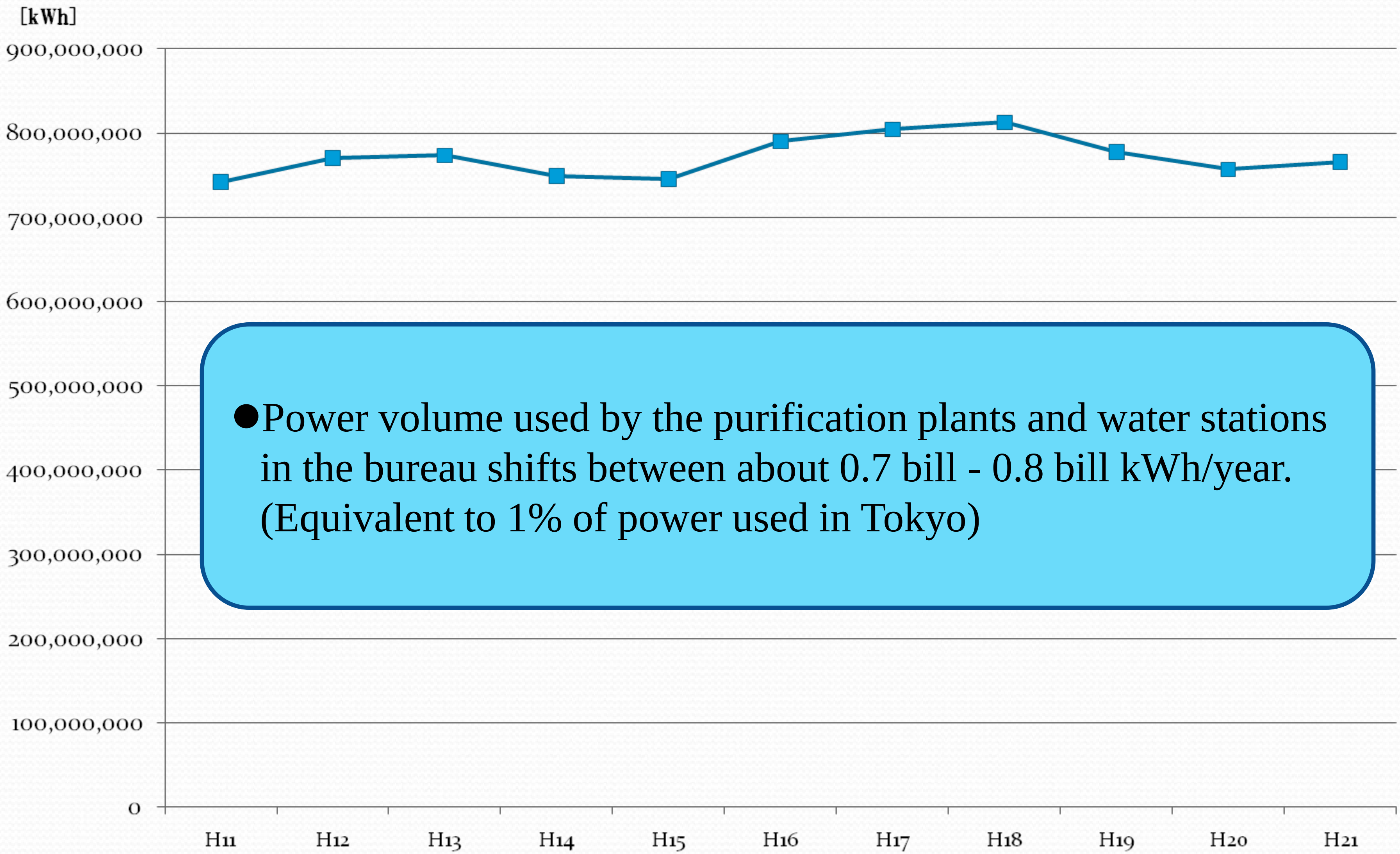
Service area	(km^2)	1,222.8
Population served	(10^3 people)	12,643
Service coverage rate	(%)	100
Number of service connection	(10^3 cases)	6, 891
Total length of distribution pipes	(km)	25,969
Total facility capacity	(10^3 m^3/day)	6,860
Total annual water distribution volume	($10^3 m^3$)	1,567,900
Average daily distribution volume	($10^3 m^3$)	4,296
Maximum daily water distribution volume	($10^3 m^3$)	4,847



Number of Facilities (Purification plants, water stations, etc)

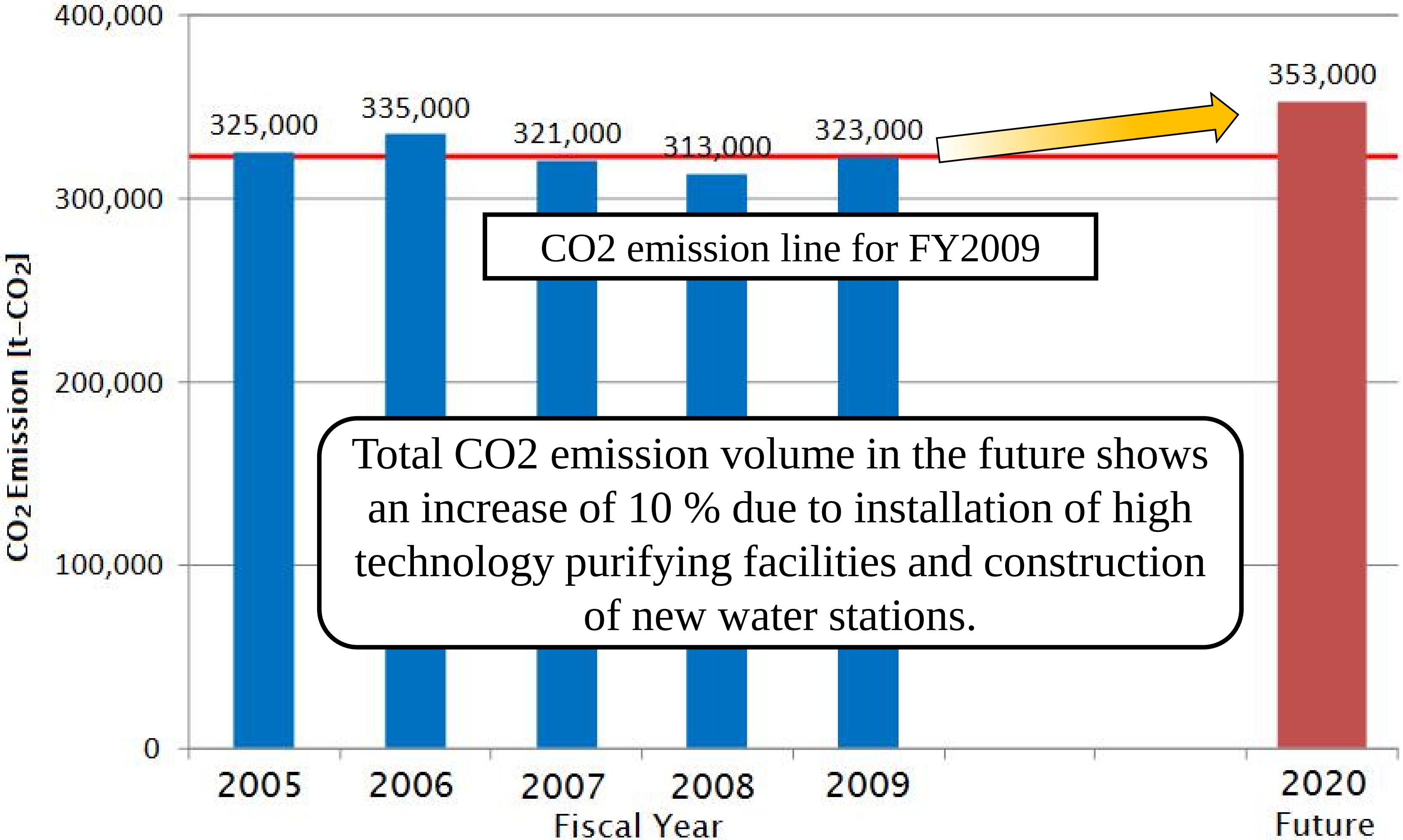
	Purification plants	Water station/ Pump station	Well Water Source
23 wards area	11	27	—
Tama area	70	197	288

Total Power Usage Volume of Purification Plants and Water Stations



- Power volume used by the purification plants and water stations in the bureau shifts between about 0.7 bill - 0.8 bill kWh/year. (Equivalent to 1% of power used in Tokyo)

Total CO_2 Emission Volume



Total CO2 emission volume in the future shows an increase of 10 % due to installation of high technology purifying facilities and construction of new water stations.

※Future water distribution is assumed to be equivalent to that of FY2008.

Guideline for Measures Against Global Warming (Dec 25, 2008) All-day figures are used for emission figures.

Aiming for New Water Supply System

■Background

○Growing social interest towards energy-saving countermeasures

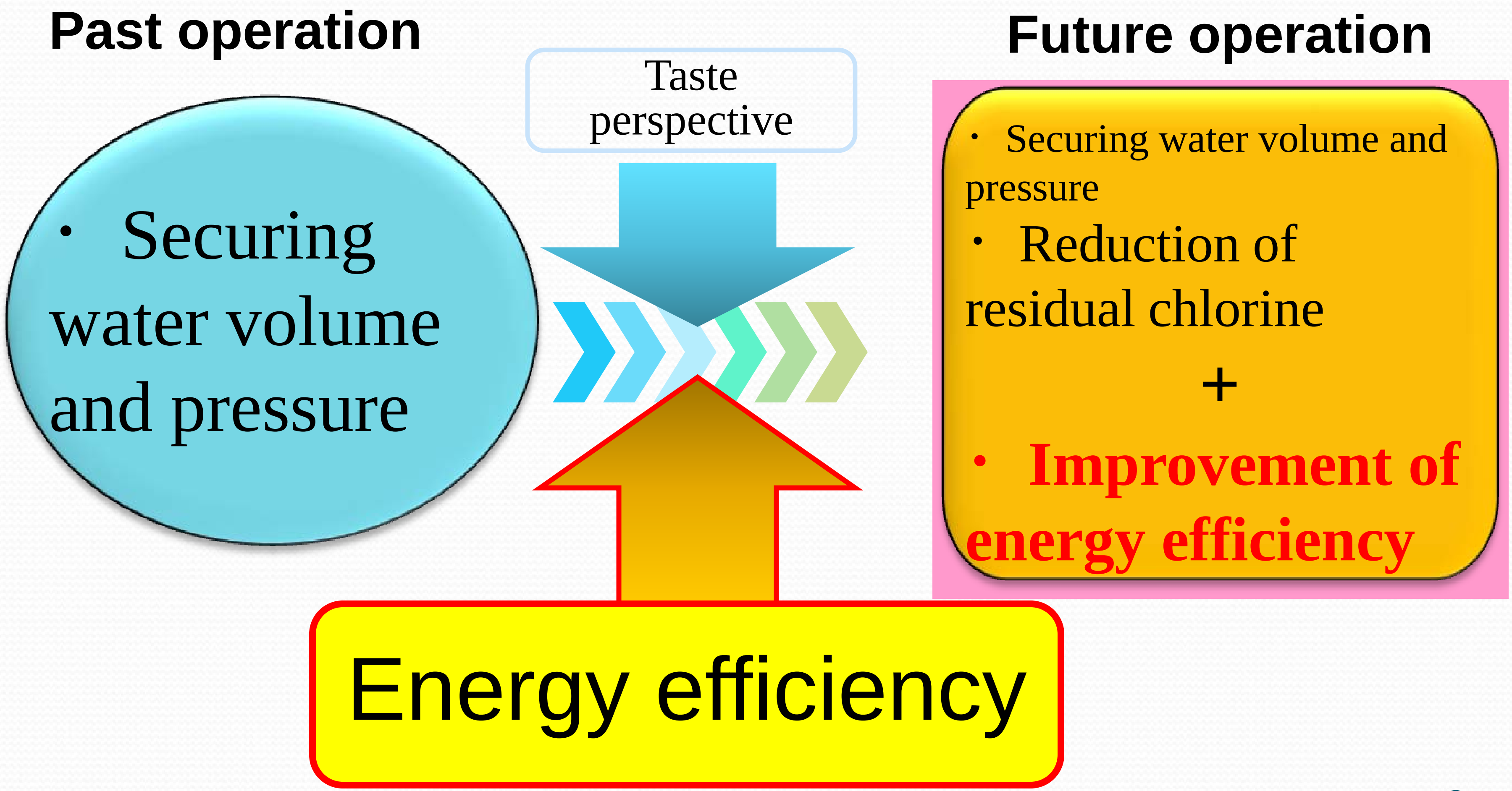
・ Emission reduction has become mandatory for large businesses, due to revision of **the Rationalization in Energy Use Law** and **Tokyo Metropolitan Ordinance of Environment Preservation**, and strengthened efforts for reduction of emission.

・ Due to the installation of **high technology purification facilities**, increase in energy usage volume is inevitable for us.

○ Customer needs towards tap water has developed and become highly diversified.

・ Customer satisfaction towards taste of water has been increasing year by year. However, one out of four customers are still unsatisfied.
(From Customer Satisfaction Survey FY2009)

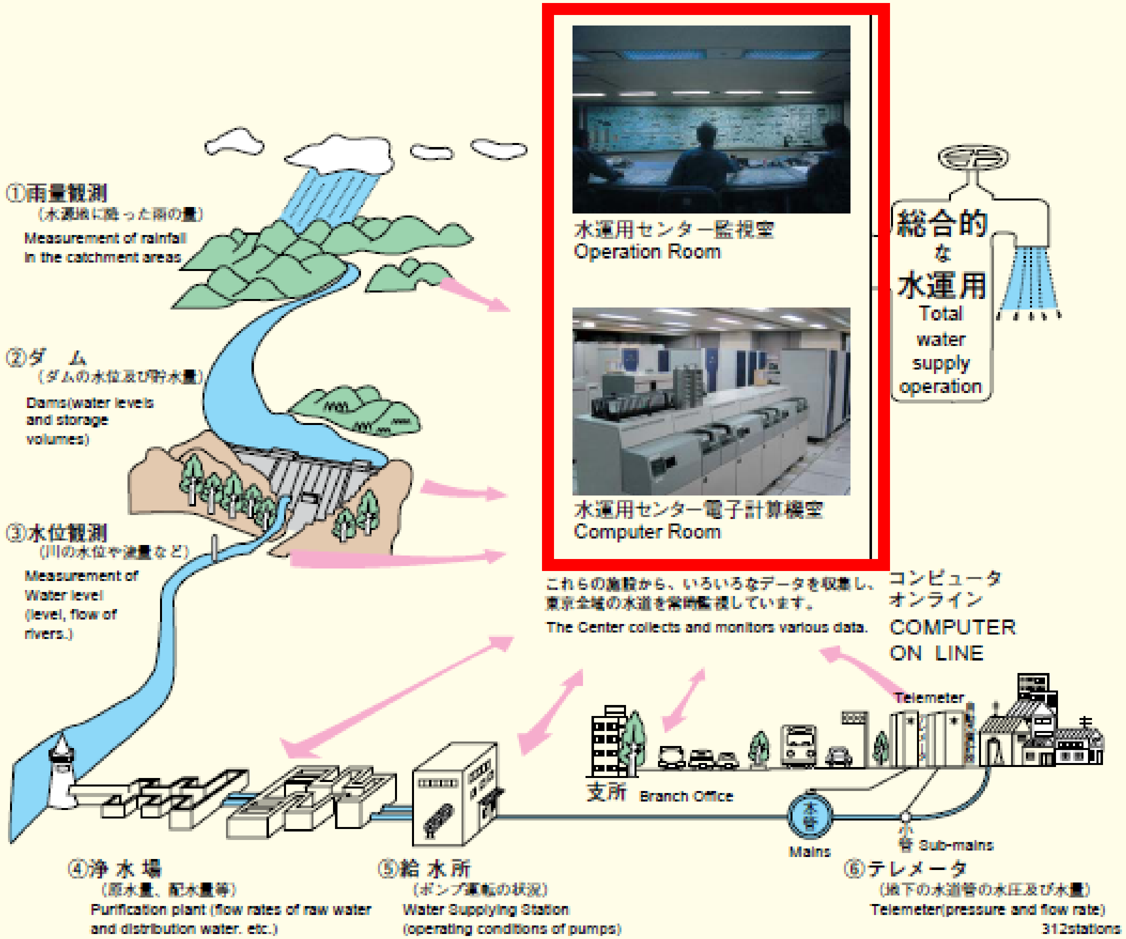
New Water Supply System (image)



WATER SUPPLY OPERATION CENTER

①雨量観測（小河内貯水池管理事務所雨量観測設備）
Measurement of rainfall
（Ogochi Weather Observatory）

②ダム（小河内ダム）
Dams（Ogochi Dam）



④浄水場（東村山浄水場）
Purification Plant
（Higashimurayama Purification Plant）

⑤給水所
（本郷給水所配水ポンプ）
Water Supplying Station
（Hongo Water Supplying Station Distribution Pumps）

⑥テレメータ
（練馬区旭町）
Telemeter
(Asahicho, Nerima Ward)

配水本管テレメータ

区部　257箇所

（圧力計115、圧力・流量計142）

多摩　55箇所

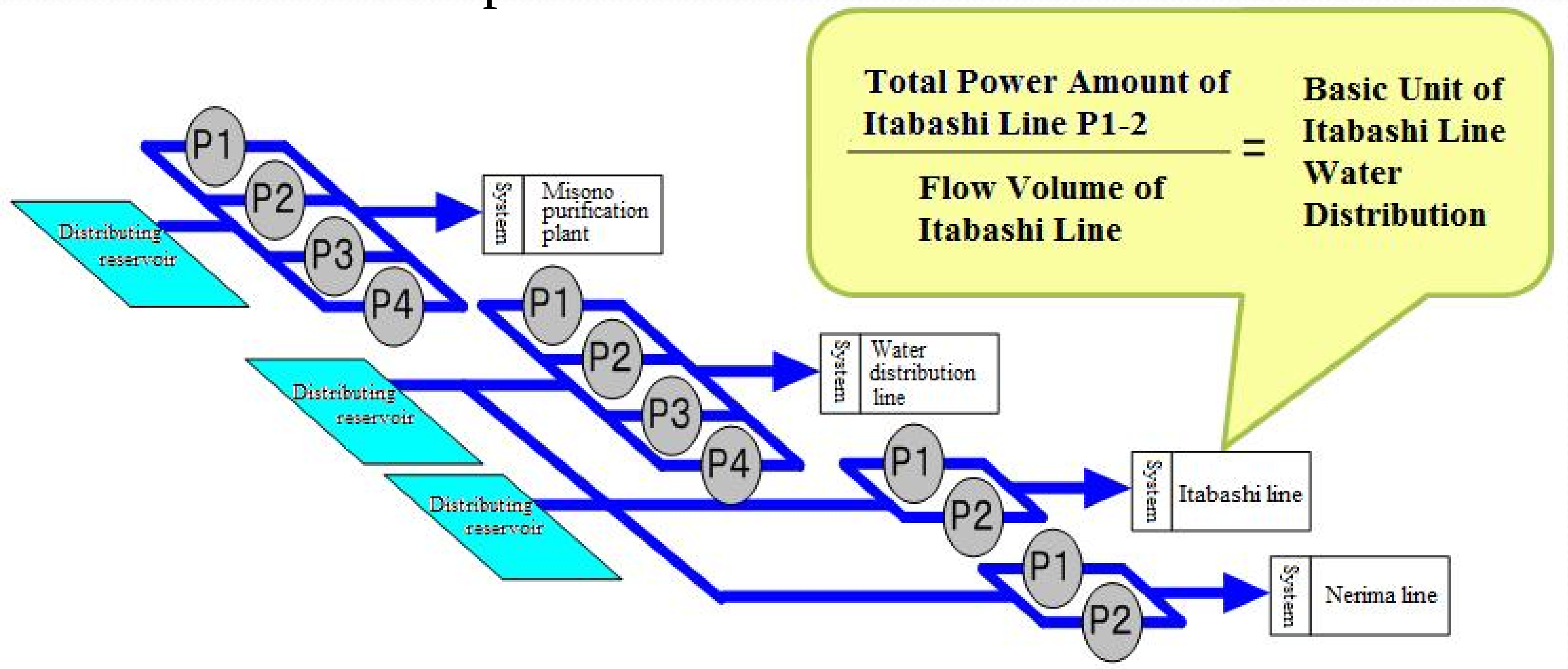
（圧力・流量計27）

（圧力計26、流量計２）

計　312箇所

Collection of Water Distribution Basic Units for each Systems

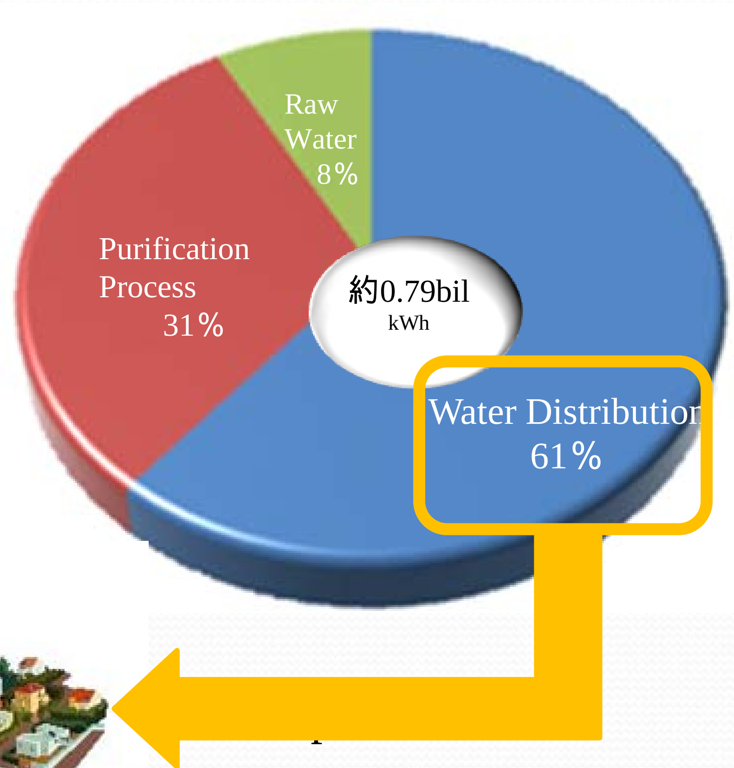
- Collection example of data

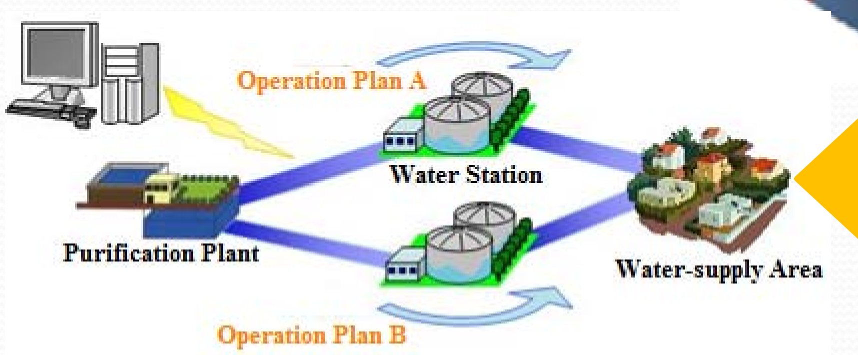


"Basic unit for each water distribution system" will be calculated based on the total power used for pumps in each systems.

Improvement of Energy Efficiency (image)

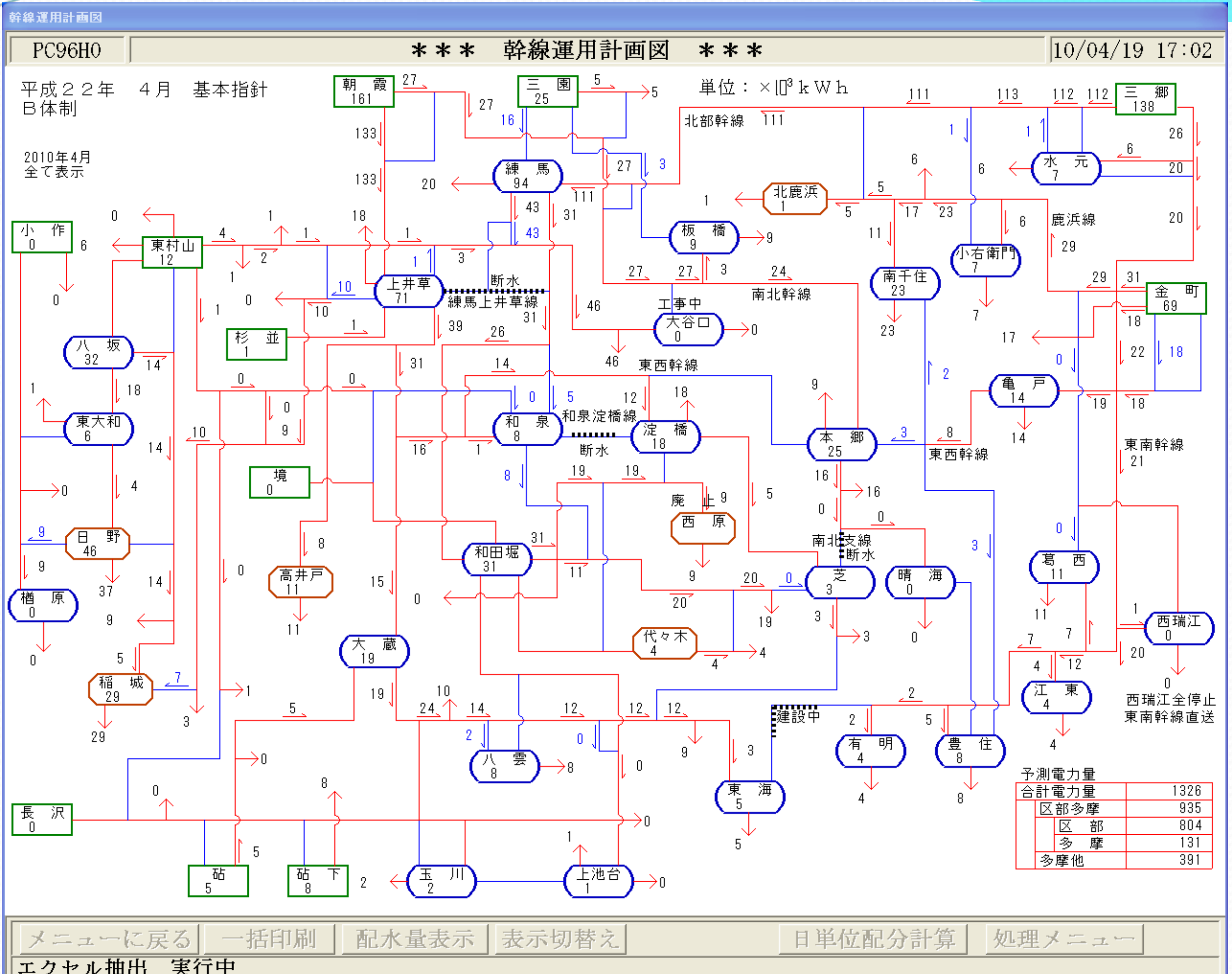
Which is better, plan A or B?

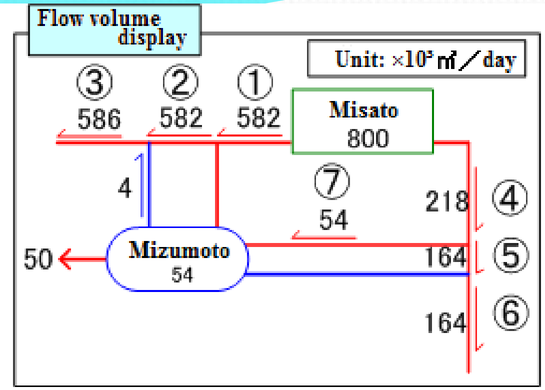




Ratio chart of power used within the bureau FY2009

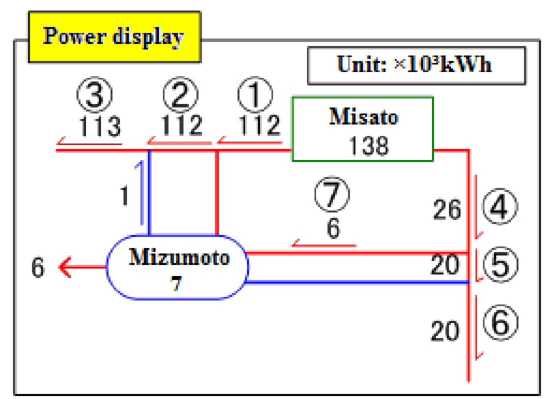
Function 1 "Mainline Management Map" Power Volume Display Function





Power volume display

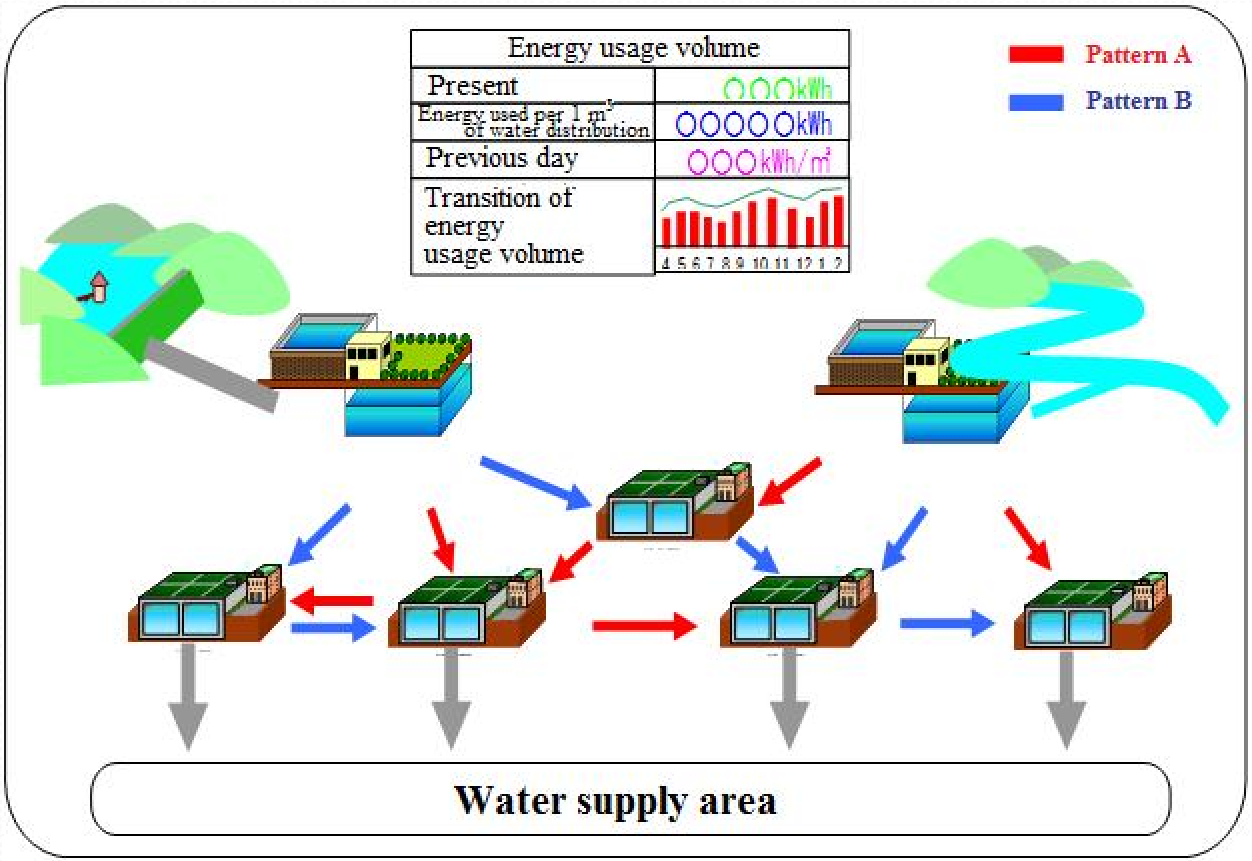
Sys-tem	Flow volume m³	Basic unit kwh/m³	Power volume kwh
①	582000	0.193	112000
②	582000	0.193	112000
③	586000	0.193	113000
④	218000	0.122	26000
⑤	164000	0.122	20000
⑥	164000	0.122	20000
⑦	54000	0.122	6000

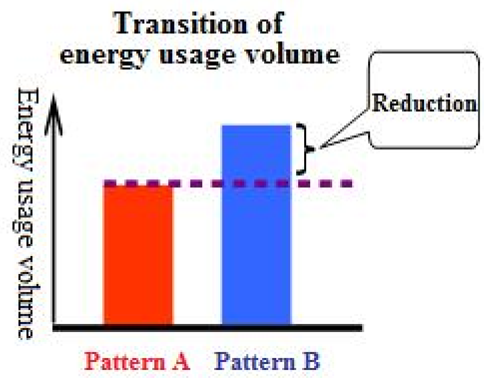


The screen goes back to flow volume indication by pressing the "Water Distribution Display" button.

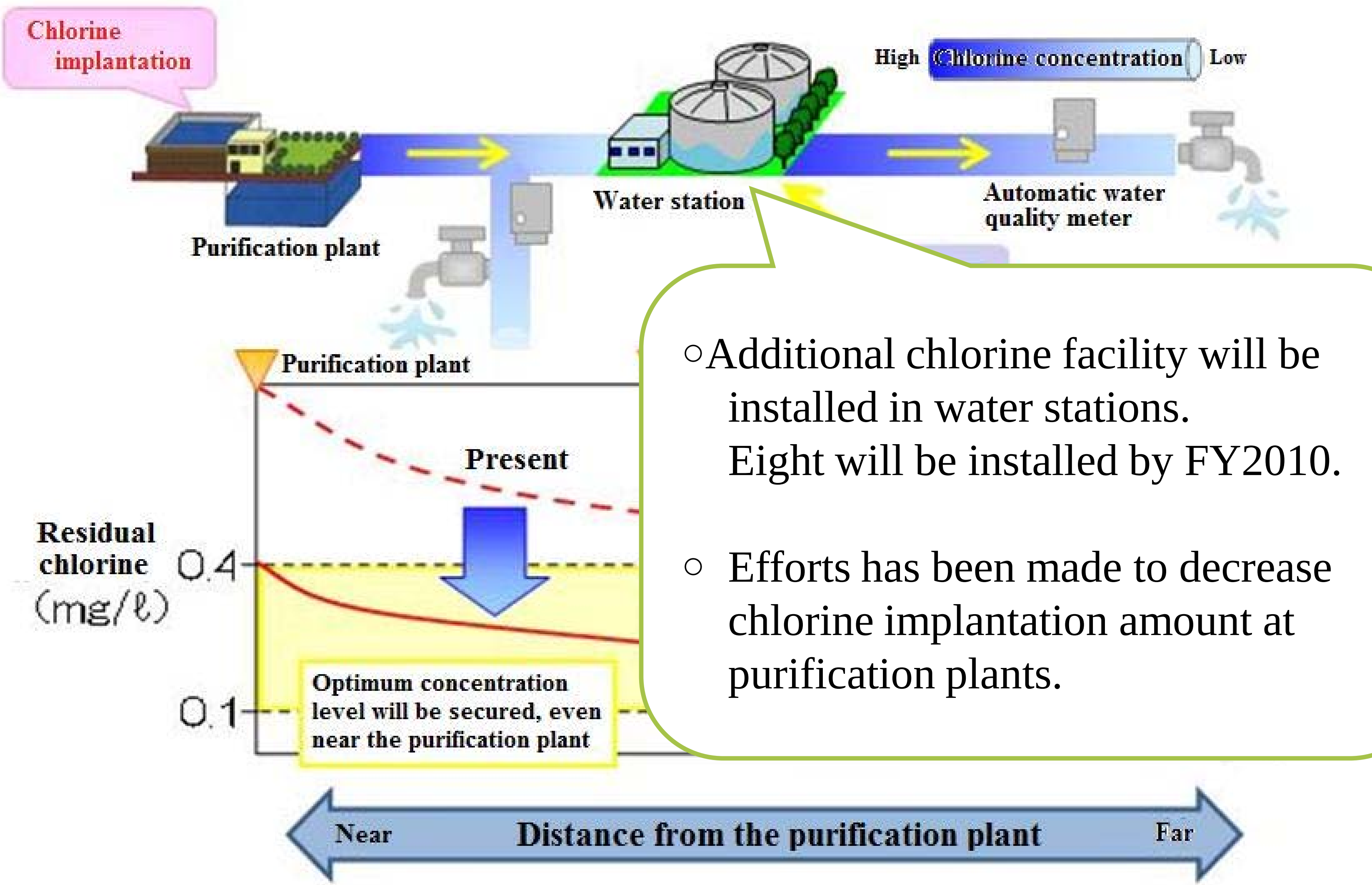
Optimization of Water Supply

Implementation of efficient water management, more in relation to energy efficiency.





New Water Supply System
(Reducing Residual Chlorine)



- ○Additional chlorine facility will be installed in water stations.
  Eight will be installed by FY2010.

- ○ Efforts has been made to decrease chlorine implantation amount at purification plants.

Other Energy Countermeasures

Our Main Energy Countermeasures

- Installment of energy saving instruments

・ To make speed-control device for pumps run with inverters.
Change about 50% of water distribution pumps.

- Adoption of Natural Energy etc.

・ Installment of photovoltaic generation and small hydroelectric generation facility.

・ Installment of 7,500kW worth power generating scale by end of FY2009.

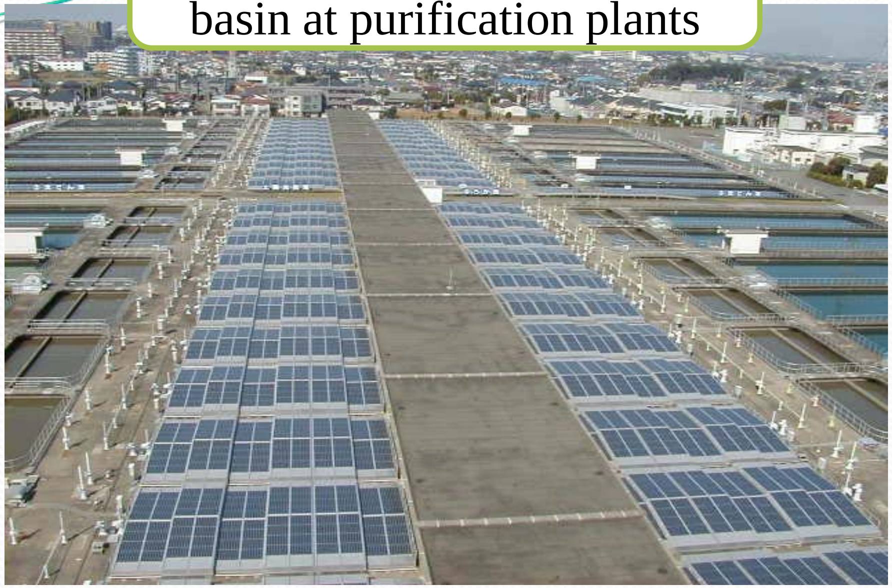
- Installment of Co-Generation system

・ Generation facility will be installed in four purification plants for common use, and exhaust heat will be utilized for humidifying polluted mud.

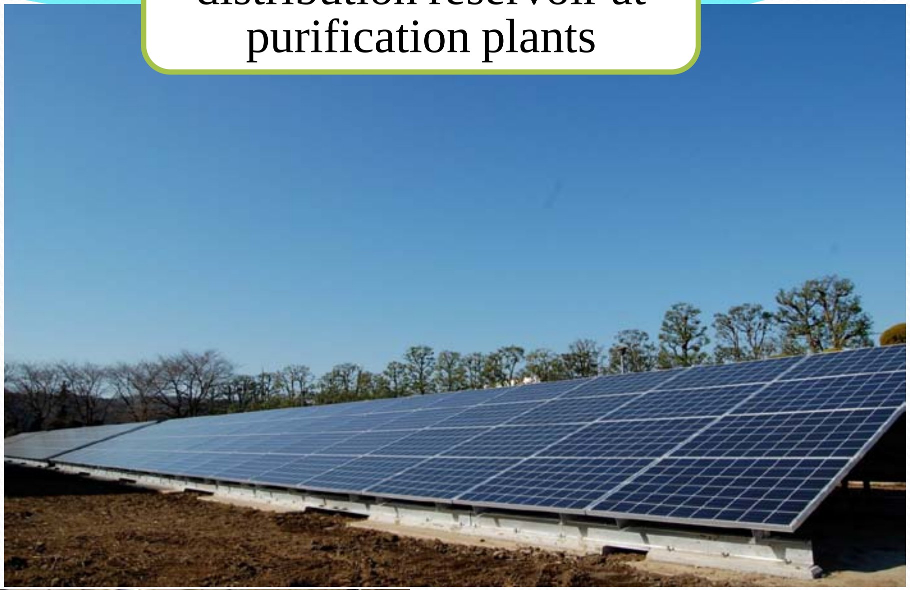
- Installment of power storage system

・ NaS battery facility will be installed in two water stations.

Upper overdeck of filter basin at purification plants



Upper part of water distribution reservoir at purification plants



Small hydroelectric generation facility at water stations

Installment of Direct Water Distribution System

Energy will be saved by utilizing water pressure to water stations, expanding direct operation, and installing direct water distribution pumps.

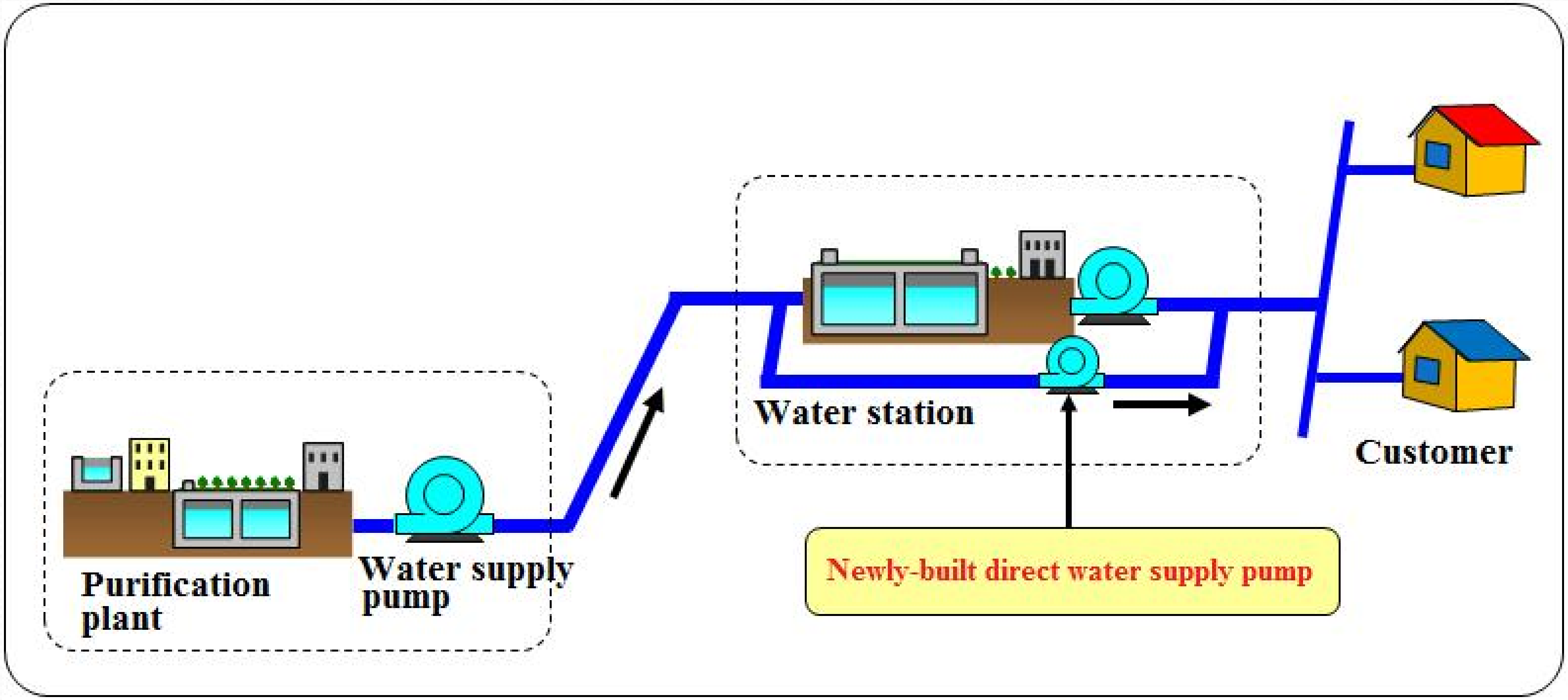


Image of direct water supply method at water

Thank you for your attention!