Effectiveness of reconstruction of water supply system from the economic viewpoint and affecting factors – case study of a city
Hayato Nakazono, Okinari Dodo and Kinya Kataishi

ABSTRACT
To solve the issues of decreasing revenue of waterworks caused by population decline and increasing renewal cost caused by ageing facilities, it is necessary to strengthen the financial base of the waterworks by undertaking efficient reconstruction of water supply system, and the cost of future renewal demands and anti-seismic upgrading need to be reduced. This paper evaluates the effectiveness of the reconstruction of water supply system from the economic viewpoint and identifies affecting factors. Assessments show it is more effective to terminate 60% of plants. The following factors were taken into account; intake water amount, length of conveyance pipe, diameter of conveyance pipe, difference in elevation between the abolished and integrated plants, and ratio of hourly maximum amount of water distribution, treatment capacity ratio, the anti-seismic capacity of abolished plants. Out of these factors, the intake water amount from abolished plant to merged plant has the highest correlated factor affecting the reconstruction of water supply system from the economic viewpoint.

INTRODUCTION
In Japan, the water supply coverage ratio exceeds 97% of population. On the other hand, management circumstances for waterworks are growing increasingly severe year by year, due to decreasing revenue on water supply caused by population decline and increasing renewal cost caused by ageing of facilities. To solve these issues, it is necessary to strengthen the financial base of the waterworks by more effective reconstruction of water supply system, and by reducing the cost of future renewal demands and anti-seismic upgrading (Ministry of Health, Labour and Welfare 2004). Many waterworks in the United States struggle with accurate long-term financial forecasting for reconstruction and renewal (David 2010; David & Ivan Velez 2010).

This paper evaluates the effectiveness of reconstruction of water supply system from the economic viewpoint and identifies factors affecting the effectiveness of reconstruction.

TARGET AREA
Targeted A city’s served population was approximately 350,000 in 2009 and is expected to decrease in the future. As shown in Figure 1, it is predicted that average daily amount of water distribution and accounted-for water will decrease by 20% until 2040, with the falling population.

The ratio of aged treatment plant and mechanical and electrical equipment, and the ratio of earthquake-resistant treatment plant, pumping station and reservoir (Japan Waterworks Association 2005) are shown in Table 1, and these ratios of the waterworks in the A city are compared with those of same scale waterworks in Japan. The ratio of aged treatment plant was 0% in 2009, but the oldest facility in the A city’s waterworks is almost 56 years old, compared with 60 years as the statutory lifetime (Ministry of Internal Affairs and Communication 2008). In addition, because the ratio of
Aged mechanical and electrical equipment was 63%, it is necessary to renew the treatment plants as scheduled, considering the service lifetime of mechanical and electrical equipment.

The ratios of earthquake-resistant pumping stations and reservoirs are 56% and 70%, respectively which indicates the ratios of the A city’s waterworks are higher than those of same scale waterworks in Japan. However, the ratio of earthquake resistant treatment plants, was 0%. It is necessary to enhance anti-seismic strength of treatment plant as scheduled for the A city’s waterworks in order to ensure the protection of water supply functions in case of earthquake that has frequently occurred (Ministry of Health, Labour and Welfare 2008), although the presence of active fault zones beneath A city has not been reported.

The A city’s waterworks has two water sources: wholesale water and groundwater. As shown in Figure 2, the percentage of wholesale water amount was 91% in 2009. The A city’s waterworks total treatment capacity is to secure approximately 50,000 m³/day, because water supply by wholesale water is restricted during periods of drought, although the actual groundwater amount of intake being used at present is only 10,000 m³/day. As shown in Figure 3, A city waterworks has eight plants in two water supply zones. A2 zone has six plants and A1 zone has two plants. Both zones have water source supplied from wholesale water and wells. In the A1-1, A1-2 and A2-6 plants, groundwater is purified by filtration facilities and supplied after chlorination. From other plants, groundwater is supplied after only chlorination.

Topographically, the A city does not undulate. The northwestern to central part of the A city is flat, the southwestern part is hilly and the northern to eastern part is low alluvial plains.

### METHODOLOGY

The effectiveness of the reconstruction of water supply system was examined from the economic viewpoint by comparing the costs in case of with-reconstruction and without-reconstruction. In the costs, the initial cost and operation cost were included.

The initial cost items in case of with-reconstruction and without-reconstruction are shown in Table 2. The merged plant is defined as the plant to be utilized after

![Figure 1](https://i.imgur.com/3Q1.png) Actual and predicted values of accounted-for water, average daily amount of water distribution, served population.

![Figure 2](https://i.imgur.com/3Q1.png) Total water distribution amount and percentage of wholesale water amount.

### Table 1 | Ratio of aged treatment plant, mechanical and electrical equipment and earthquake resistance ratio of treatment plant, pumping station and reservoir

<table>
<thead>
<tr>
<th>Item</th>
<th>Value for A city</th>
<th>Average value for same scale waterworks in Japan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age ratio</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Treatment plant</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Mechanical and electrical</td>
<td>63%</td>
<td>58%</td>
</tr>
<tr>
<td>equipment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Earthquake resistance ratio</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Treatment plant</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Pumping station</td>
<td>56%</td>
<td>29%</td>
</tr>
<tr>
<td>Reservoir</td>
<td>70%</td>
<td>67%</td>
</tr>
</tbody>
</table>

- Age ratio: Treatment plant = (the capacity of the treatment plants that have passed the statutory lifetime / the capacity of all treatment plants) * 100.
- Age ratio: Mechanical and electrical equipment = (the number of equipment that have passed the statutory lifetime / the number of all equipment) * 100.
- Earthquake resistance ratio: Treatment plant = (the capacity of the treatment plants that have anti-seismic performance / the capacity of all treatment plants) * 100.
- Earthquake resistance ratio: Pumping station = (the capacity of the pumping stations that have anti-seismic performance / the capacity of all pumping stations) * 100.
- Earthquake resistance ratio: Reservoir = (the capacity of the reservoirs that have anti-seismic performance / the capacity of all reservoirs) * 100.
reconstruction and abolished plant is defined as the plant not to be utilized after reconstruction. In case of with-reconstruction, as for the merged plant, the costs of the renewal of existing equipment, anti-seismic upgrading of existing facility, expansion of existing facility and installation of distribution facility are required, and for the abolished plant the cost of the installation of water conveyance facility is required. From the viewpoint of ensuring stable water source during periods of drought, the conveyance pipes should be installed to convey the maximum available intake water amount by keeping all groundwater sources of the abolished plants operational. On the other hand, in case of without-reconstruction, the costs of the renewal of existing equipment and anti-seismic upgrading of existing facility are required. The initial cost is estimated during 15 to 20 years that is the renewal cycle of mechanical and electrical equipment (Japan Waterworks Association 2005).

The operation cost is estimated as electrical power cost, repairs and maintenance costs. The electrical power cost per unit water amount by each plant was calculated using actual intake amount and distributed amount in 2009 and the actual power consumption. Multiplying the estimated future intake amount and distributed amount by the unit electrical power cost at each plant, future electrical power cost is calculated.

In this paper, it is studied that two plants are merged into one plant in A1 zone, and six plants are merged into two plants in A2 zone, in which five out of eight plants are abolished. The present facility location in case of without-reconstruction is shown in Figure 3, and the facility location in case of with-reconstruction is shown in Figure 4.

In case of with-reconstruction, groundwater of the abolished plants is conveyed to the merged plants.

### Table 2 | Initial cost items in case of with-reconstruction and without-reconstruction

<table>
<thead>
<tr>
<th>Plant</th>
<th>Case of with-reconstruction</th>
<th>Case of without-reconstruction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Merged plant</td>
<td>Renewal of existing equipment</td>
<td>Intake pump</td>
</tr>
<tr>
<td></td>
<td>Anti-seismic upgrade of existing facility</td>
<td>Mechanical and electrical Distribution pump Structure Pipe</td>
</tr>
<tr>
<td></td>
<td>Expansion of existing facility</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Installation of distribution facility</td>
<td>Pipe in plant</td>
</tr>
<tr>
<td>Abolished plant</td>
<td>Installation of water conveyance facility from abolished to merged plant</td>
<td>Booster pump Distribution main</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 3 | Present facility location (in case of without-reconstruction).
RESULTS AND DISCUSSIONS

As shown in Table 3, the assessments show it is more effective to terminate 60% of plants, because the cost ratio is more than 1.

In this study, to convey intake water from abolished plant to merged plant, the intake water amount (conveyance), the length of conveyance pipe, the diameter of conveyance pipe and the difference in elevation between abolished and merged plants were considered as factors affecting the effectiveness of the reconstruction. As the diameter of conveyance pipe is related to the intake water amount, the intake water amount could be used as an affecting factor instead of the diameter of conveyance pipe. It was reported that the water supply system is costly, in case the intake facility is far from treatment plant (Bijlee Deshmukh 2006).

Furthermore, the construction of distribution main (ratio of hourly maximum amount of water distribution), the expansion of the merged plant (treatment capacity ratio) and anti-seismic capacity of the abolished plants, were considered as affecting factors.

In case of with-reconstruction, the amount of water distribution from the merged plant increases, which increases the cost of installation of distribution main to a great degree. Therefore, it was considered that the ratio of hourly maximum amount of water distribution is one of the affecting factors. If this ratio is bigger, the need to install distribution main in the area covered by the merged plant after reconstruction is lower, in other words the effectiveness of reconstruction is higher.

In addition, in case of with-reconstruction, the treatment capacity of the merged plant increases; therefore, it was considered that the treatment capacity ratio is one of the affecting factors. In case of without-reconstruction, anti-seismic capacity of the abolished plant is required to be enhanced; therefore, it was considered that anti-seismic capacity of the abolished plants is one of the affecting factors.

This paper focuses on affecting factors in terms of topography and water amount without the treatment capacity ratio and the anti-seismic capacity of the abolished plants, and

<table>
<thead>
<tr>
<th>Abolished plant</th>
<th>Merged plant</th>
<th>Cost ratioa</th>
<th>Evaluation for with-reconstructiona</th>
<th>Water amount for intake (conveyance) (m$^3$/day)</th>
<th>Conveyance pipe Length (m)</th>
<th>Diameter (mm)</th>
<th>Difference in elevation (m)</th>
<th>Treatment capacity ratioa</th>
<th>Ratio of hourly maximum amount of water distributiona</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1-2</td>
<td>A1-1</td>
<td>1.38</td>
<td>✓</td>
<td>2,000</td>
<td>6,000</td>
<td>150–350</td>
<td>−12</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>A2-2</td>
<td>A2-1</td>
<td>1.07</td>
<td>✓</td>
<td>4,000</td>
<td>6,000</td>
<td>150–600</td>
<td>−13</td>
<td>0</td>
<td>22</td>
</tr>
<tr>
<td>A2-3</td>
<td>–</td>
<td>0.97</td>
<td>–</td>
<td>9,000</td>
<td>11,000</td>
<td>150–700</td>
<td>−19</td>
<td>0</td>
<td>13</td>
</tr>
<tr>
<td>A2-5</td>
<td>A2-4</td>
<td>0.97</td>
<td>✓</td>
<td>6,000</td>
<td>4,000</td>
<td>200–600</td>
<td>5</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>A2-6</td>
<td>–</td>
<td>1.00</td>
<td>✓</td>
<td>9,000</td>
<td>4,000</td>
<td>200–600</td>
<td>4</td>
<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>

a (the cost in case of without-reconstruction / in case of with-reconstruction).

b Legend ✓: should be reconstructed, –: should not be reconstructed.
c (difference in elevation of the abolished plant - the merged plant).
d (capacity of the merged plant + the abolished plant) / the abolished plant.
e (water amount of distribution in the merged plant + the abolished plant) / the abolished plant, actual value on 15 July 2009.

Figure 4 | Facility location scenario (in case of with-reconstruction).
considered the factors affecting effectiveness of the reconstruction of water supply system from the economic viewpoint.

As shown in Figure 5, intake water amount from the abolished plant to the merged plant has higher correlation with the cost ratio. In other words, if the intake water amount of the abolished plant is small, the effectiveness of the reconstruction is higher. As shown in Figure 6, the length of conveyance pipe does not have any correlation with the cost ratio. Although the length from A2-5 and A2-6 to A2-4 plant is shorter, the reconstruction cost becomes higher to a great degree due to installation of distribution main in the area covered by A2-4 plant. As shown in Figure 7, the difference in elevation of plants does not have any correlation with the cost ratio. In fact, there are differences in elevation among the plants, but it is not the main factor for the effectiveness of the reconstruction. As shown in Figure 8, the ratio of hourly maximum amount of water distribution does not have any correlation with the cost ratio. Although the ratio of A1-2 plant was low, A1-1 distribution main has the capacity to cover entire A1 zone at present, so in case of with-reconstruction, it does not cost to install distribution main of A1-1 plant.

The observations of the results are shown as follows.

- The intake water amount is the highest correlated factor affecting the reconstruction of water supply system from the economic viewpoint in this paper.
- It is necessary to confirm the distribution capacity of the merged plant under the future water demand. In case of less distribution capacity, the effectiveness of the reconstruction is lower because it is necessary to install additional distribution main.

CONCLUSIONS AND CHALLENGES FOR THE FUTURE

This paper evaluates the effectiveness of the reconstruction of water supply system from the economic viewpoint and identifies affecting factors. Assessments show it is more effective to terminate 60% of plants. The following factors were taken into account; intake water amount, length of conveyance pipe, diameter of conveyance pipe, difference in elevation between the abolished and integrated plants, and ratio of hourly maximum amount of water distribution, treatment capacity ratio, the anti-seismic capacity of
abolished plants. Out of these factors, the intake water amount from abolished plant to merged plant has the highest correlated factor affecting the reconstruction of water supply system from the economic viewpoint.

To clarify the effectiveness of the reconstruction from the economic viewpoint easily, it is important to consider the affecting factors. Through accumulating more knowledge and information, the accuracy of this study will be enhanced.

REFERENCES


Ministry of Internal Affairs and Communications 2008 revision, Local Public Enterprise Law.

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