4-2-1 A New O&M Approach for both Improvement of Water Quality and Reduction of Greenhouse Gas Emissions in Wastewater Treatment Plants

Takumi Morikawa[1*], Norihisa Kashihara[1], Kenichi Umeda[1]

1 Bureau of Sewerage, Tokyo Metropolitan Government, Japan
*** Email: Takumi_Morikawa@member.metro.tokyo.jp**

ABSTRACT

Since approximately 1% of power consumption of the Tokyo metropolitan area is consumed for the sewage treatment, Bureau of Sewerage, Tokyo Metropolitan Government has been putting its efforts into reducing the power consumption to reduce greenhouse gas emissions. Furthermore, further power reductions are required because of the significant increases of electricity rates due to the shut down of nuclear power plants and increase in the cost of the fuel for thermal power generation after the Great East Japan Earthquake. However, an excessive power reduction may lead to the deterioration of the water quality. Thus, the bureau of sewerage has devised and implemented the "Two Axis Management Method" as a tool to achieve both the water quality improvement and power consumption reduction which are in trade-off relationship.

KEYWORDS: operation, total nitrogen concentration, electric power concentration

INTRODUCTION

Since nitrogen is one of the prime causes of eutrophication of closed public water, nitrogen concentration in the effluent water from the wastewater treatment plant (hereinafter referred to as "WWTP") should be reduced actively. In order to remove the nitrogen biologically, the nitrification of ammonia to nitric acid in sewage system is necessary and this process requires a large amount of air. The blower operations for the nitrification require a large amount of power consumption and this leads to a large amount of greenhouse gas emissions. The electricity consumption of the Bureau of Sewerage, Tokyo Metropolitan Government amounts to approximately 1% of power usage of the metropolitan area (approximately 980 million kWh/year)(Bureau of Sewerage, TMG, 2014a), a reduction of the power consumption (i.e., greenhouse gas emissions) together with the water quality improvement shall be promoted strategically. In addition, the significant increases of electricity rates by the shut down of nuclear power plants and increase in the cost of the fuel for thermal power generation after the

Great East Japan Earthquake, a further power reduction is required.

Each WWTPs have been taking measures for water quality improvement and energy saving by introduction of energy saving equipment, optimum operation management, and introduction of advanced treatment. By advancement of both improvements, the concerns of the deterioration of effluent quality are expressed when energy conservation measures have been excessively promoted. A delicate management technique is required to balance between the water quality improvement and energy savings. The “two axis management method” is implemented to address the difficult issue of achieving further reduction in power consumption for air flow volume while securing a certain level of water quality and to correspond to various volume and load of inflow water (Bureau of Sewerage, TMG, 2013). Here we report, the operation method and outcomes of the two axis management method.

OUTLINE AND UTILIZATION OF THE TWO AXIS MANAGEMENT METHODS

Overview of two axis management method

The two axis management method uses the graph with plotting effluent quality and power consumption of the treatment plant along the vertical and horizontal axis respectively (Seiichi *et al*, 2014b). This graph visualizes the results of operating improvements and upgrading facilities. As a representative of effluent quality and power usage from the treatment plant, total nitrogen concentration of discharged water (regulation items) and specific power consumption of blowers were used for the two axis management method. In this method, vector is drawn by plotting the actual value for previous year (or previous month) as the starting point and the actual value for the current year (or current month) as the end point. Both the introduction of energy-saving equipment and the improvement of operation management are monitored so that vector points to the bottom left.

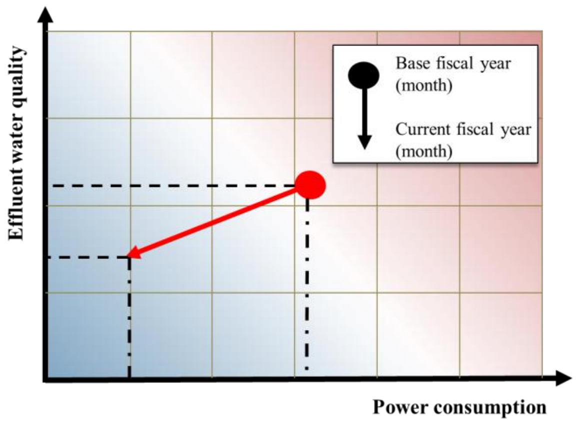

Figure 1. Image of two axis management graph

Operation and evaluation of two axis management

The PDCA cycle was incorporated to develop improvement measures and take into consideration of the current state of WWTPs and the results of both the water quality improvement and energy saving. In particular, continuous operation improvements,

improvements of equipment and spiral up of the both have been pursed in accordance with the flow chart shown in Figure 2.

In order to maximize the update effect and operation improvement of each WWTP, set a goal of specific power consumption of blowers and total nitrogen concentration was set at the start of each fiscal year. In each WWTP, both total nitrogen concentration and specific power consumption of blowers were planned to reduce so that the vector in the graph points to the bottom left. The results were analyzed, evaluated and counter measures were improved. For evaluation, the length and direction of the vector of each WWTP was focused and the effects such as weather conditions, seasonal variation, improvements, and upgraded facilities and the operations at each plant was examined. The deviation between the target value and actual value were calculated as a percentage and used for modification of the measures.

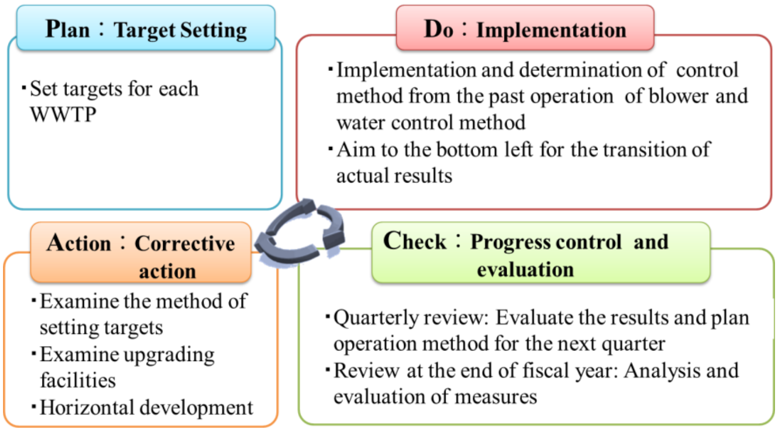

Figure 2. Procedure of two axis management

Preparation of two axis graph

The efforts at 13 WWTPs in the Tokyo wards area are reported. Monthly total, 6 months total and yearly total of effluent total nitrogen concentration from each outlet and specific power consumption of blowers for the entire treatment are aggregated and the weighted average of total nitrogen concentration of the entire treatment plant and power consumption per volume of treated water are calculated. Calculated total nitrogen concentration and changes in specific power consumption of blowers are connected by vectors and the length and direction of the vector of each treatment plant are evaluated. Also, data for all treatment plants are integrated into one sheet of paper and evaluated for their positional relationship.

SETTING TARGET VALUES AND EFFORTS TO ACHIEVE THE TARGETS

Set of target values

In order to maximize the effects of operational improvements and upgrading of equipment for each WWTP, targets for specific power consumption of blowers and total nitrogen concentration was set at the start of each fiscal year. For example, deteriorations by special circumstances during the fiscal year of 2013 such as construction works, equipment failure which affects (improvement) of the total nitrogen concentration and specific power consumption of blowers were quantified and adjusted for setting the goal of the fiscal year of

2014. In addition, improvement of total nitrogen concentration and specific power consumption of blowers by the operational improvement and upgrading of equipment and deterioration due to construction works that are expected in the fiscal year of 2014 are reflected to set the specific target value.

Example of target setting is shown in Table 1. In this WWTP, there was suspension of reaction tanks by construction works in the fiscal year of 2013 and total nitrogen and specific power consumption of blowers were worsen by 0.1mg/L and 0.004kWh/m3 respectively. As the construction works were completed during the fiscal 2013, adverse effects due to the construction work is no longer required to take into account in the target setting of the fiscal year of 2014. Target values are established based on the actual annual values of the fiscal 2013 (total nitrogen 10.6 mg/L and specific power consumption of blowers 0.111 kWh/m3) with the deduction for the above (i.e. total nitrogen 10.6 - 0.1 mg/L and specific power consumption of blowers 0.111 - 0.004kWh/m3). In addition, the aeration equipment of the reaction tank in this WWTP is upgraded to the energy-saving type of fine bubble diffuser in 2013. In the fiscal 2014, it was estimated that deduction of 0.001 kWh/m3 specific power consumption of blowers from that of the fiscal 2013 is possible by this upgrading. As such, the target values are further subtracted with the calculated value of the above (specific power consumption of blowers 0.107 - 0.001 kWh/m3). On the other hand, the total nitrogen concentration is expected to be reduced 0.5 mg/L by promoting denitrification by controlling the air volume of a part of the aerobic tanks, but the increase of 0.2mg/L due to the suspension of reaction tanks for reconstruction works was also expected. As such, the target value is set by taking into account of these adjustments (total nitrogen is 10.5 - 0.5 + 0.2 mg/L).

Table 1. Example of Setting Target

<table>
<tr><th colspan="3" rowspan="2">Item</th><th colspan="2">Effect and Results</th></tr>
<tr><th>specific power consumption of blowers (kWh/m^3)</th><th>Total nitrogen (mg/L)</th></tr>
<tr><td rowspan="3">Fiscal year 2013</td><td colspan="2">Average</td><td>0.111</td><td>10.6</td></tr>
<tr><td>Factor such as constraction works and breakdown of equipment that affect the results</td><td>Suspension of reaction tank due to construction works</td><td>-0.004</td><td>-0.1</td></tr>
<tr><td colspan="2">alues excluding special circumstances</td><td>0.107</td><td>10.5</td></tr>
<tr><td rowspan="3">Fiscal year 2014</td><td>Upgrade to energy saving equipment</td><td>Introduction of micro bubble diffusion device</td><td>-0.001</td><td></td></tr>
<tr><td>New operational management</td><td>Limited partial aeration of aerobic tank</td><td></td><td>-0.5</td></tr>
<tr><td>Construction works and breakdown of equipment that are considered for target setting</td><td>Suspension of reaction tank due to construction works</td><td></td><td>+0.2</td></tr>
<tr><td colspan="3">Target value</td><td>0.106</td><td>10.2</td></tr>
</table>

Application results of two axis management method

In order to achieve the target values, a two axis management graphs were prepared for each month at each treatment plant and these were used for the evaluation of efforts made. The change history of operating conditions of each treatment plant and the content of efforts made are summarized on a quarterly basis and these are used as a reference for evaluation of vectors. Based on this, vector directions are evaluated and the causes are reviewed.

Analysis of efforts made in each treatment plant

In order to grasp the management status (results) for the current fiscal year, each values was compared with the past average value, and if the positions of vector of the fiscal 2014 are significantly different, it was presumed that there were special processing conditions and effects. Distinctive examples are shown in Figure 3 to 5. Red portions represent the actual value of the total nitrogen concentration and the blower power consumption for each month of the fiscal 2014, and blue portions represent the average value of the previous five fiscal years (from 2009 to 2013) and the dotted line shows the year-end target value.

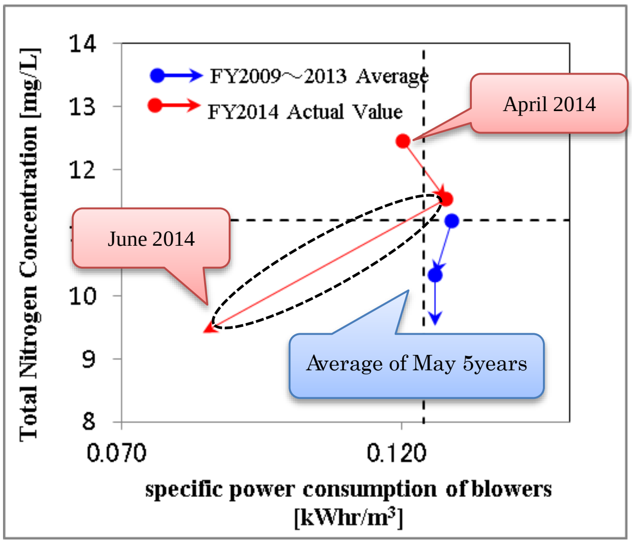

Figure3. The example which is considered to be influenced by rainfall

Figure 3 shows an example which is considered to be influenced by rainfall. The red portions show results from April to June in 2014 and blue portions show the past five-year average from April to June. The trend of the past five years shows that the total nitrogen concentration from April to June decreased and that the specific power consumption of blowers (blue arrow) didn't change significantly. On the other hand, as the blower power consumption from May to June in 2014 is reduced significantly, the vector points to the bottom left and both direction and length of vectors are significantly different from the average of past years (red arrow). This shows that the changes are due to the rainfall in June 2014 which is equivalent to 3.8 times of average rainfall. Combined sewer system is mainly adopted in the Tokyo ward area and a large volume of rainwater flows into the treatment plant at the time of rainfall. It was confirmed that the specific power consumption of blowers was significantly reduced by this effect.

Figure 4 shows the case that the effect of denitrification promoting operation was clearly visible. The red portions show results from October to December in 2014 and blue portions show the past five-year average from October to December. The trend of the past five years shows that specific power consumption of blowers and total nitrogen concentration from October to December increased and the vector moved top right corner (blue arrow). In the fiscal 2014, the total nitrogen concentration was reduced and the overall vectors located comparatively low (red arrow). In this treatment plant, the air volume to the certain part of aerobic tanks was limited to enhance denitrification. As a result, the total nitrogen concentration is reduced. This example of good practice has been deployed to other treatment plants.

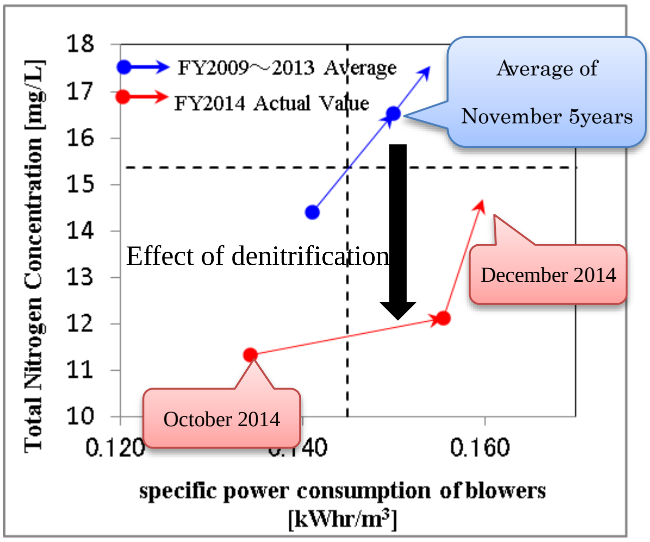

Figure 4. The example which was affected by the effect of denitrification

Figure 5 is an example which is considered to have influenced by construction works. The red portions show results from October to December in 2014 and blue portions show the past five-year average from October to December. The trend of the past five years shows that the increases of specific power consumption of blowers and total nitrogen concentration from October to December and the vector moved top right corner (blue arrow). On the other hand, the comparison of results of the fiscal 2014 with the results of usual years shows significant differences in the length, direction, and positions of the vectors. In particular, total nitrogen concentration from November to December in the fiscal 2014 was significantly increased (red arrow). The capacity of this treatment plant was dropped and nitrification was stagnant due to reduction of the treatment ability because of construction works. Therefore, although the stagnation of nitrification reduced the blower power consumption compared with the results of the previous years, the water quality deteriorated

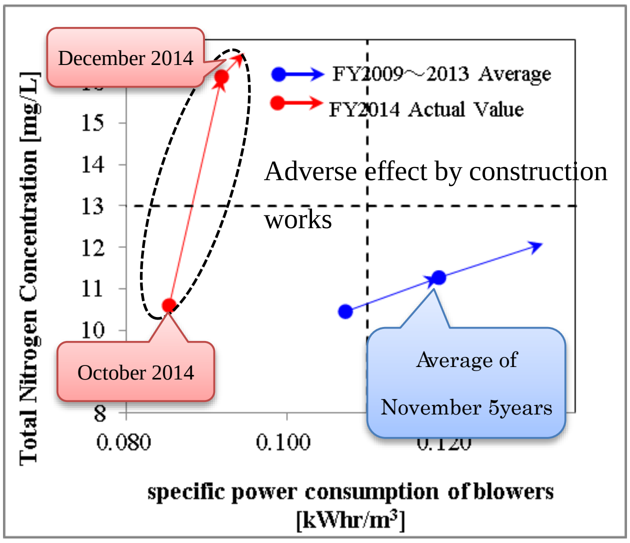

Figure 5. The example which was affected a by construction works

significantly. As a result of this, it could be analyzed that the orientation of vector tuned upward sharply.

Figure 6 is the case that the improvement is clearly seen as a result of upgrading facilities. The red portions show results from October to December in 2014 and blue portions show the past five-year average from October to December. Both the total nitrogen concentration and specific power consumption of blowers from October to December are increased and the tendency that the vector moves toward the top right direction has not changed in the fiscal 2014 as well as past five-year average (blue and red arrows). When comparing the results of the same month of the previous five-year average to the results of the fiscal 2014, the results of fiscal 2014 show the reduction of specific power consumption of blowers and shifting of vector position to the left direction. The aeration equipment of this treatment plant had been changed sequentially to energy-saving type equipment from the spring of this fiscal year. Two reaction tanks out of four were re-commissioned from late August and one more tank was re-commissioned from November. It was concluded that the improvement was achieved by the upgrading of facilities. This effect made the reduction of specific power consumption of blowers by 0.007kWh/m^3.

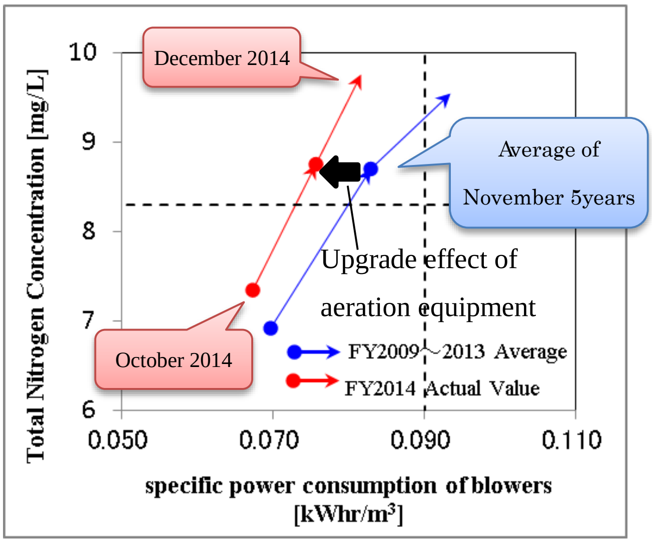

Figure 6. The example that upgrading facilities improved performance

Results of efforts toward target values

The operational improvements have been progressed in each treatment plant by observing the movement of the two axis management graph and checking the target values. Figure 7 to 11 show the deviations in percentage between the target values and cumulated values of total nitrogen and specific power consumption of blowers, plotting the target values to the point of origin. Figure 7 shows the deviation from the target values at the end of the fiscal 2013. Although the treatment plant "A" shown in the Figure was able to reduce 4.0% of specific power consumption of blowers from the target value at the end of the fiscal year, the total nitrogen becomes 17% higher than the target at the same time. Thus the plant was not able to maintain the balance between the water quality improvement and the power reduction. From this, the target of further improvement of the water quality was set for the fiscal 2014 and operational improvements were implemented. Deviations between the target values and the cumulated values as of the end of April 2014, September 2014, and March 2015 are shown in Figure 8, Figure 9, and Figure 10 respectively. Although both data at the end of April and September 2014 show relatively high specific power consumption of blowers, it was able to minimize the increase of blower power usage per unit and maintaining nitrification and denitrification appropriately, by the reduction of DO set values and setting MLSS higher than usual. As a result, 3.8% of total nitrogen and 4.0% of blower energy were able to reduce compared with the target values and the balance between the water quality improvement and energy-saving were achieved at the end of the fiscal year (Figure 8 to 10).

By visualizing the deviations from the target values, it was clarified whether to focus on either water quality improvement or reduction blower power consumption. Thus, the motivation for the simultaneous achievement of water quality improvement and energy savings is easily promoted.

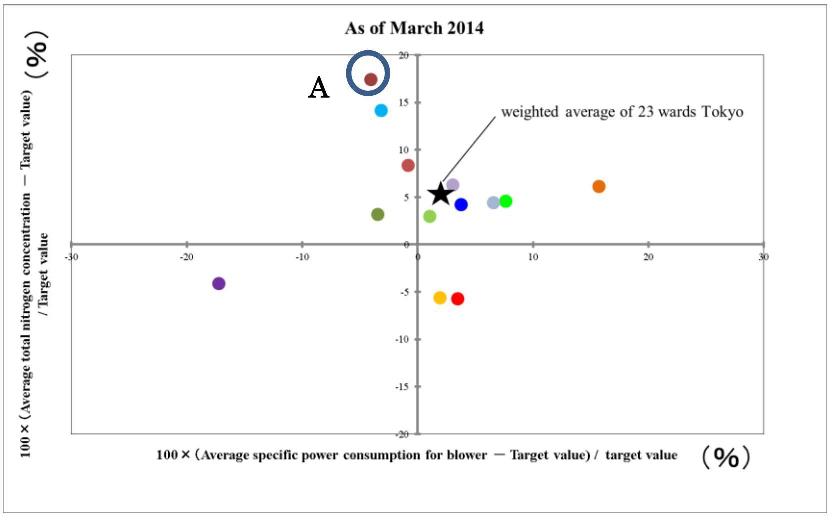

Figure 7. Deviation from the target value as of March 2014

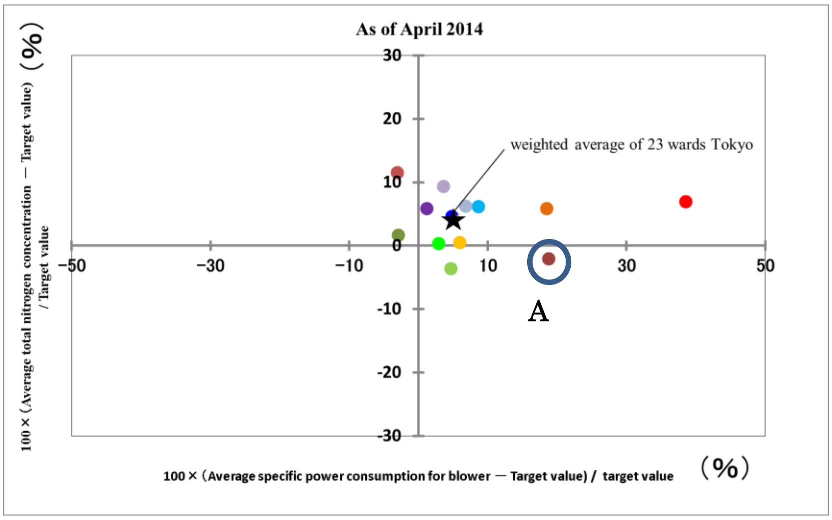

Figure 8. Deviation from the target value as of April 2014

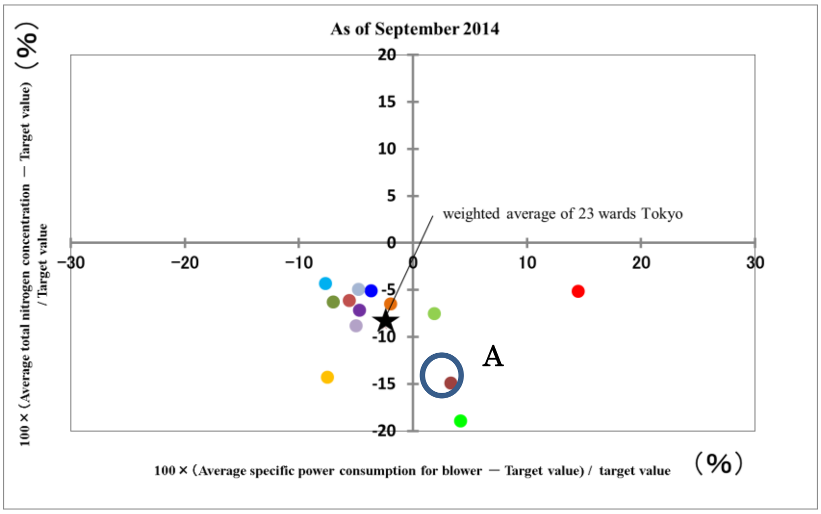

Figure 9. Deviation from the target value as of September 2014

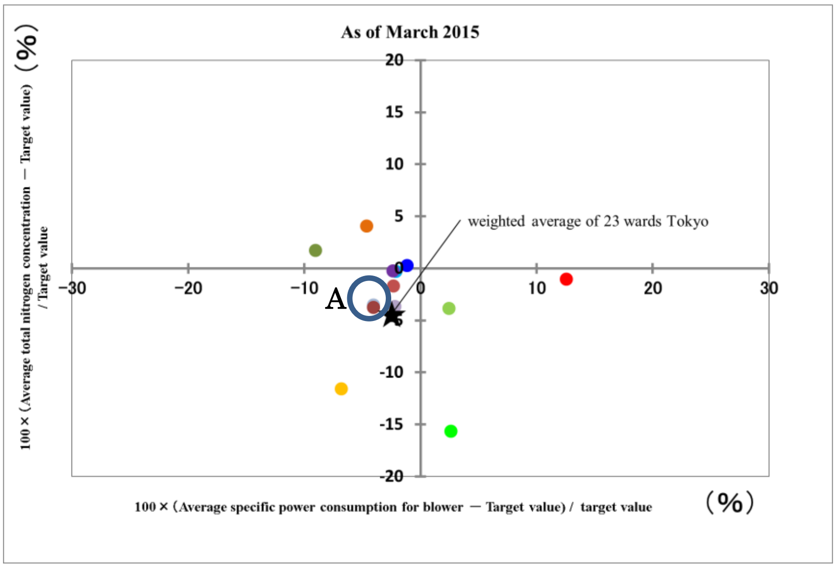

Figure 10. Deviation from the target value as of March 2015

Comparison between treatment plants

A list of the results of each treatment plant for the fiscal 2014 was prepared and comparison using this list was carried out. In Figure 11, the result of the total nitrogen concentrations and the specific power consumption of blowers are shown by plotting the results of the fiscal 2013 as the starting points and the results of the fiscal year of 2014 as the end points. Starting point varies in each WWTP which indicates the distinctive features of each treatment plant. The differences in these positions are considered to reflect differences in the scale, the inflow water quality, the structure and equipment, and reaction time of each treatment plant. The yearly efforts resulted in the reduction in specific power consumption of blowers from 0.117 kWh/m3 to 0.109 kWh/m3 and the improvement of total nitrogen concentration from 11.9 mg/L to 11.3 mg/L in the weighted average of the 23 wards of Tokyo. Reviewing the results of treatment plants individually, it should be noted that vectors are directed in various directions. For example, "A" in Figure 5 shows the good example of software measure that the water quality was improved by facilitating denitrification by avoiding excessive nitrification which was achieved by the improvement of operational management. Also, "B" is the case of hardware measure that the specific power consumption of blowers are improved by replacement of the air diffuser plates.

Although the individual ratings of treatment plant "A" show the improvement, when compared with the other treatment plants, both the total nitrogen concentration and blower power consumption exceeds the weighted averages of all WWTP. Therefore, both hard and soft measures should be aggressively promoted.

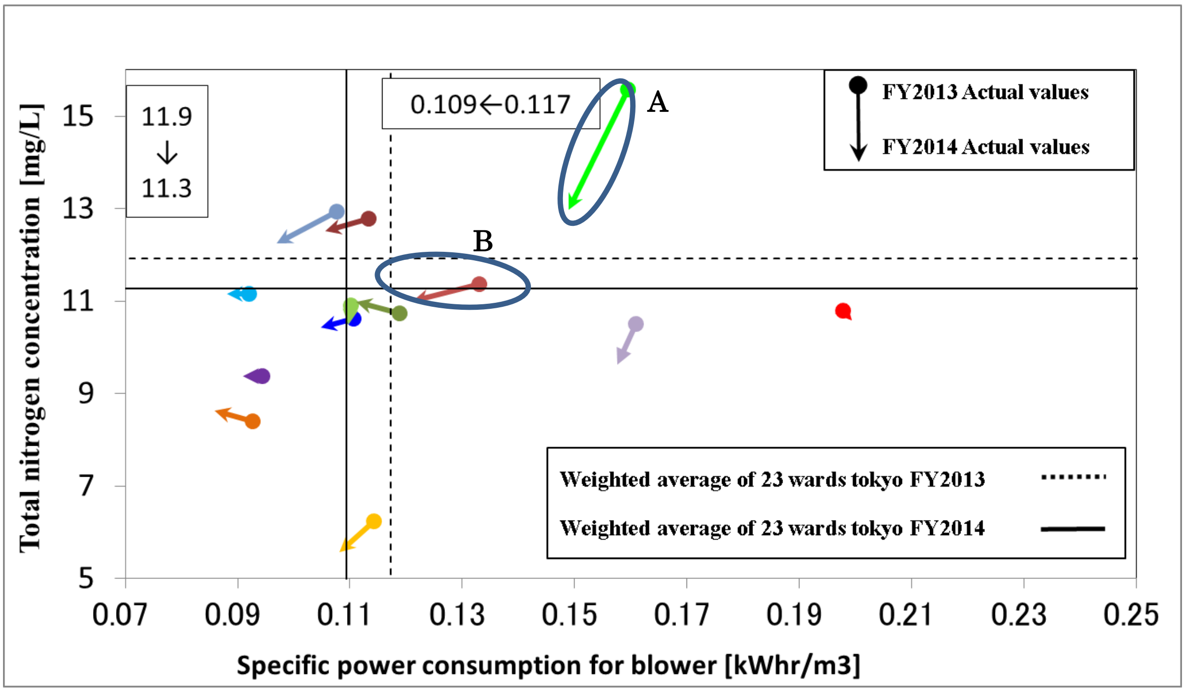

Figure 11. Comparison of the fiscal year of 2013 and 2014

CONCLUSION

As described above, it was possible to clearly grasp the effects of facilities upgrading and operational improvements by visualizing the trend of total nitrogen concentration and the specific power consumption of blowers with vectors. In addition, by setting a target value for each treatment plant and making appropriate changes in operating conditions, motivation to achieve both water quality improvement and energy saving was promoted and it became easy to tackle the issue

.

In Bureau of Sewerage TMG, will further improve and develop the two axis management methods in order to continue the contribution to the realization of good water quality with less environment impacts by both water quality improvement and power saving which is simultaneous pursuit of water quality and reduction of green gas emissions.

REFERENCES

Bureau of Sewerage, Tokyo Metropolitan Government (2014a) *Smart Plan 2014*

Bureau of Sewerage, Tokyo Metropolitan Government (2013) *2013 Management Plan*

Seiichi, S; Teru, Y; Youhei, A; Mayuko, T (2014b); New O&M approach for reduction of the power consumption by two axis management. *The 51th Annual Technical Conference on Sewerage*, 604-606 (in Japanease)