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# Application of networked water balance model in refined management of steel industrial park

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## ABSTRACT

Water shortages have become a major constraint on China's industrial development. Iron and steel industrial parks have a huge demand for water resources and complex production technologies. Therefore, it is very important to study the distribution, transfer and loss of water resources in industrial parks in order to improve the ability to refine water resources management. The purpose of this study was to reveal the water flow in industrial parks by using the principle of water balance and to provide a method for quantification and characteristic recognition of water resources in industrial production processes. In this research, an iron and steel industrial park in North China was chosen as the case study. In order to calculate the water balance of the whole steel production processes, the industrial park was divided into four levels and 110 water units according to the pipe network system and production processes. Based on the results of multi-level and multi-node water balance, this paper analyzed the water intake structure and water consumption structure of industrial parks, and provided the methods to optimize the allocation of water resources and reduce the consumption of fresh water in industrial production processes. The results of the study showed that the energy department accounted for 60.8% of the total water withdrawal of the industrial park. There were 6,249 m$^3$/day of fresh water in the industrial park, which could be replaced by reclaimed water from urban sewage. Evaporation and pipe network leakage were the main water consumption factors in the steel park, which contributed 91.3% of the water consumption. Under the guidance of the research results, the evaporation water consumption of the industrial park was reduced by 8,412 m$^3$/day, and pipe leakage was reduced by 600 m$^3$/day. This article demonstrates the application of the water balance principle in complex water use systems, which is helpful for water resources management based on water use processes.

**Key words:** industrial park, network of water balance, water consumption structure, water intake structure, water management

## HIGHLIGHTS

- A water balance network model based on the industrial production process is proposed.
- The model quantifies the transfer and loss of water resources during steel production, making the previously neglected water visible.
- The water intake structure evaluates the amount of fresh water that can be replaced by unconventional water resources in the industrial park and establishes the flow relationship between urban sewage and industrial water.
- Water consumption structure found the main water consumption factors, location and quantity of the industrial park. The problem of unclear characteristics of industrial water consumption has been solved.

## 1. INTRODUCTION

Industrial parks are important carriers of industrial development, and they are highly concentrated areas of water resource utilization and transformation (Liang *et al.* 2011). However, industrial activity in the park also exacerbates the problems of excessive water consumption and a worsening water environment (Yang *et al.* 2018). Social, economic and environmental aspects including water quality and quantity concerns are necessary for sustainable management of water resources (Ostad-Ali-Askari & Shayannejad 2021). Water is used as one of the important resources to support industrial development (Zhang *et al.* 2017). Water shortage, the main water problem, had become the most significant factor restricting the economic and social development of China (Xiuli *et al.* 2021), which poses a severe challenge to industrial water management and water saving. Sustainable water management in industry takes into account not only end-pipe treatment of water, but also conservation, reuse, regeneration and recycling (Jia *et al.* 2019). Lack of understanding of complex water systems may

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lead to inefficient decisions by park managers. Hence the industrial water resource management gradually develops to refinement, which requires in-depth analysis of water utilization and transfer in the industrial production processes.

The main processes of iron and steel production include coking, sintering, ironmaking, steelmaking and rolling (Na *et al.* 2021). As iron and steel industry is a typical processing industry, specific equipment and technologies are applied in different processes, and the products of upstream processes are the material of the downstream ones (Wang *et al.* 2020). Therefore, the improvement of water resource utilization efficiency is the improvement of every process. Because water is a critical heat transfer and cooling tool in steel production, steel production is one of the most water-intensive industrial processes (Tryfona-Panagopoulou *et al.* 2012). Statistics from the China Iron and Steel Association showed that the specific fresh water consumption was 2.45 $m^3$per tons of crude steel in China, whereas the number was merely 1 – 2.6 $m^3$/t-s in developed countries. There was a considerable water-saving potential due to the current inefficient use of water resources (Tong *et al.* 2018). Strengthening water resources management of the iron and steel industry is of great significance to promote the sustainable development of the industry.

The method of water balance analysis is based on the principle of material balance and can be used to study and determine the flow of various water supplies at the boundary of the system (Kenway *et al.* 2011). The equilibrium model established by the method of water balance analysis can be used as a tool for water resources evaluation and water management analysis, and it can be used at any time and scale to dynamically reflect the distribution of water in different components and the flow situation within a single system or between different systems (Modi *et al.* 2020). Water balance analysis has been applied to water resources research in watersheds (Fashae *et al.* 2019), lake (Li *et al.* 2006), water supply systems (Klingel & Knobloch 2015), soil (Pereira *et al.* 2020)and other fields, but water balance lacks research in the field of industrial water resources management. One group (Pham *et al.* 2016) constructed a water balance framework based on water volume data from 2012 to 2014 of 12 industrial parks in Dong Nai Province, Vietnam, and then analyzed the relationship between water consumption and wastewater in industrial parks. However, they did not reveal water flow within industrial parks. Although managers are aware of problems with water management, they are still unable to pinpoint the cause and location of these problems. In the absence of research on water use processes, managers are likely to make inefficient or meaningless decisions. Especially in the steel and iron industry, its water system is vast and complex. In the past, research on water balance in industrial parks was based on the data of regional water quantity and methods of water resources management were studied at the macro level. They regarded the process of industrial water consumption as a ‘black box’ and did not consider the process of industrial water consumption in detail (Liu *et al.* 2019). As a result, they could not meet the demands of refined water management.

This paper take an iron and steel industrial park in North China as an example of water balance network analysis. The application content of the case study includes: dividing water units, constructing water balance network, calculating water balance, analyzing water intake structure and water consumption structure. The purpose of this study was to establish a water resource analysis method for industrial parks, propose a water balance network model to quantify the transfer of water resources in industrial production processes, and describe the characteristics of water intake and consumption in industrial parks. The method was used to assess the amount of fresh water that can be replaced by unconventional water sources and the potential for saving water. This method will provide decision-makers with water flow information based on the production process and help them to formulate water-saving plans effectively. This will improve the capacity of refined water management in the industrial park and promote sustainable industrial development.

## 2. MATERIALS AND METHODS

### 2.1. Case study

As is shown in Figure 1, a steel industrial park in northern China was used as a case study. Hebei province, where the park is located, is one of China’s most water-deficient provinces. Now the industrial park covers an area of about 3.03 million square meters. It has a full set of iron and steel production lines for sintering, iron making, steel making, steel rolling, vanadium products, etc. It is the most representative industrial enterprise in the area. In 2019, the park produced 7.1 million tons of pig iron, 7.05 million tons of crude steel, 6.9 million tons of steel, 0.19 million tons of vanadium slag and 20,000 tons of vanadium products. The iron and steel industrial park consumed a lot of water, with 16.16 million $m^3$ of water extracted in 2019, accounting for about 38% of the total industrial water consumption in the area.

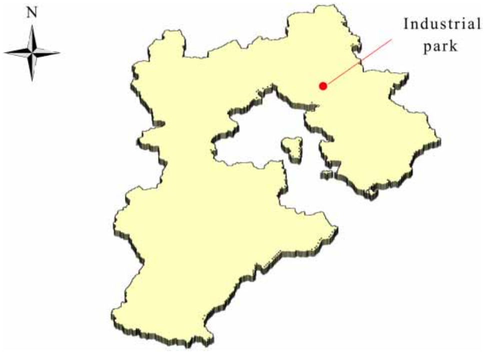

**Figure 1** | Map of Hebei Province.

### 2.2. Data acquisition

Data can be obtained from three sources: water supply companies, water meters in the park, testing and estimation. The water supply company provides surface water, incoming water and reclaimed water. There are three-level water meters in the industrial park, of which the coverage rate of the first- and second-level water meters is 100%, and the coverage rate of the third-level water meters is 95%. The industrial park carries out water quantity statistics on the water meter twice a day, and has long-term statistical data of all kinds of water. For areas where there is no water meter or where the water meters are damaged, measurement and estimation are used to determine water data. The accuracy of these data is relatively poor, but the proportion of water involved is small, and the influence on the final calculation results can be almost ignored.

### 2.3. Work procedure

As is shown in Figure 2, the working process mainly includes the following seven parts:

1. Data collection. Collect basic information of industrial park, water supply and drainage pipe network, water meter coverage rate, water meter record and park map, etc.
2. Determine system boundaries. The industrial park is a complex water system, which includes the exchange and transfer of water in the production processes The establishment of system boundary can clarify the inflow and outflow of water in the industrial park and eliminate the interference of irrelevant information to the water balance research.
3. Division of water use units. The system is divided into water units with a single production function to facilitate data statistics and calculation.
4. Modeling. According to the characteristics of each water use unit, the corresponding water balance model is constructed.
5. Calculation. Substituting the data into the balance model, the quantity and flow direction of various types of water are solved according to the basic principle of water balance.
6. Consistency comparison. The calculated results will be compared with the collected water meter data. If the data are consistent, the next step will be taken; if not, the data error will be corrected and modeling and calculation will be carried out again until the consistency comparison is passed.
7. Data analysis. Draw the water flow trend chart in the industrial park, analyze the water intake structure and water consumption structure, and quantify the feasible water-saving space.

### 2.4. Water balance network

According to the principle of water balance, for a determined research unit, the inflow water is equal to the sum of the outflow water and the storage water in a certain period of time. Figure 3 shows the water balance model for a single water unit. In order to satisfy the study of water intake structure and water consumption structure, the water balance model was modified appropriately in this article. Water entering the industrial park includes fresh water, reclaimed water and soft water. The water consumption was further decomposed according to water consumption factors.

Equations (1)–(3) are the basic equations of the unit water balance model:

$$V_q + V_s + V_{cy} = V'_{cy} + V_{co} + V_d + V'_s + V_t \tag{1}$$

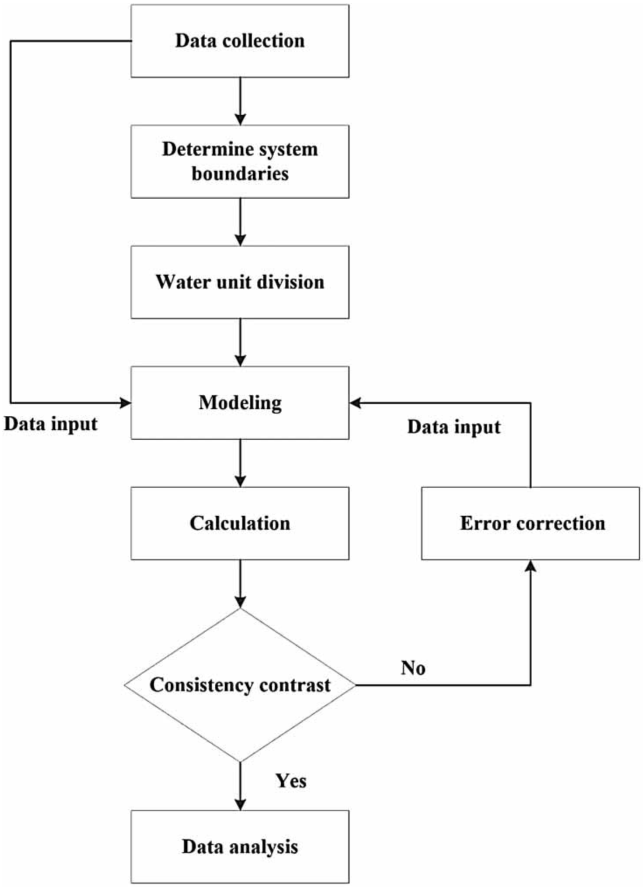

**Figure 2** | Work flow diagram.

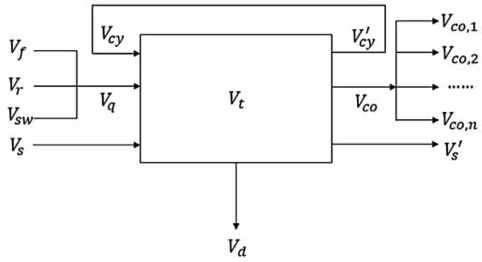

**Figure 3** | Water balance model.

$$V_q = V_f + V_r + V_{sw} \tag{2}$$

$$V_{co} = V_{co,1} + V_{co,2} + \ldots + V_{co,n} \tag{3}$$

Here: $V_{cy}$ and $V'_{cy}$ are the amount of circulating water, $V_q$ is the amount of water flowing into the water unit, excluding $V_s$ and $V_{cy}$. $V_s$ is the amount of water flowing into the water unit from other units. $V'_s$ is the amount of water discharged from this water unit to other water units. $V_{co}$ is the amount of water consumption. $V_d$ is the amount of drainage, and $V_t$ is the variation in the amount of water stored. $V_f$ is the amount of fresh water. $V_r$ is the amount of reclaimed water. $V_{sw}$ is the amount of soft water. $V_{co,i}$ are the water consumptions generated by different water consumption factors.

The industrial park was divided into several water use units, which together formed the water balance network. The water balance network realized the quantification of water resources in the process of water consumption, which was the basis to meet the refined water management in industrial parks. The establishment of water balance network mainly consisted of two steps: dividing water units and constructing a water balance network:

1. Dividing water units. Figure 4 shows the brief water balance network. This research divided the complex water use system into four levels, including 110 water use units. Firstly, the water system was divided into seven two-level units according to the production function and layout. The two-level units were then divided into 26 three-level units with smaller boundaries. Finally, the three-level units were divided into 76 four-level units with single function and simple technology.

Take the ironmaking department as an example, it is a two-level water unit, which can be divided into six three-level units, including 1# sintering, 2# sintering, 1# blast furnace, 2# blast furnace, stock yard and office. 1# sintering can be divided into six four-level water units, including circulating water system, dust and humidification, primary mixing, secondary mixing, and flue gas desulfurization.

2. The construction of the unit water balance includes the water balance within a single water unit and between different water units. According to the water balance model in Figure 3, The water balance of a single unit can be completed. In addition, different production processes and equipment in the park have different requirements for water quality, and water reuse between units is common. Therefore, series water ($V_s$ and $V_s'$) was used to simulate the flow of water between water consumption units, which realized the water balance of any combination of water consumption units and formed a water balance network.

## 3. RESULTS

### 3.1. Water balance in industry

Figure 5 shows the water balance of the industrial park. In 2019, the amount of water taken from four water sources in the industrial park was 180,634 $m^3$/day, of which the fresh water and outsourced reclaimed water ($V_{or}$) belong to the purchased water, accounting for 31.8%, and the reclaimed water and soft water belong to the self-produced water, accounting for 68.2%. The water was allocated by the water management department, with 91.7% of the water taken flowing into seven production departments and 8.3% going to external companies. In the production and operation of the industrial park, due to evaporation, leakage of water supply network, loss of sewage treatment, external loss and other factors, the water consumption was 50,838 $m^3$/day, and the direct reuse was 13,020 $m^3$/day. The amount of waste water discharged into the sewage treatment plant was 74,403 $m^3$/day, and the soft water produced was 39,249 $m^3$/day. The sewage treatment plant produced 71,040 $m^3$/day of water, accounting for 95.5% of the total waste water volume, while the loss of water was 3,363 $m^3$/day, accounting for 4.5% of the total waste water volume. The result of water balance shows that the industrial park does not discharge waste

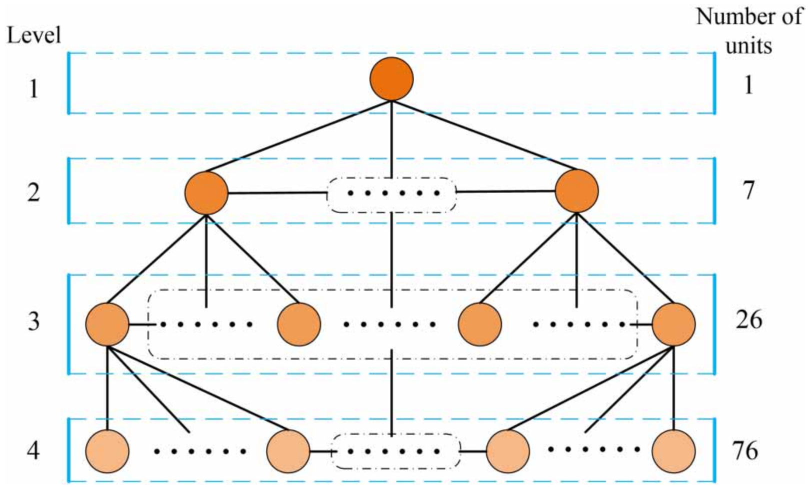

**Figure 4** | Water balance network. Please refer to the online version of this paper to see this figure in colour: http://dx.doi.org/10.2166/ws.2021.449.

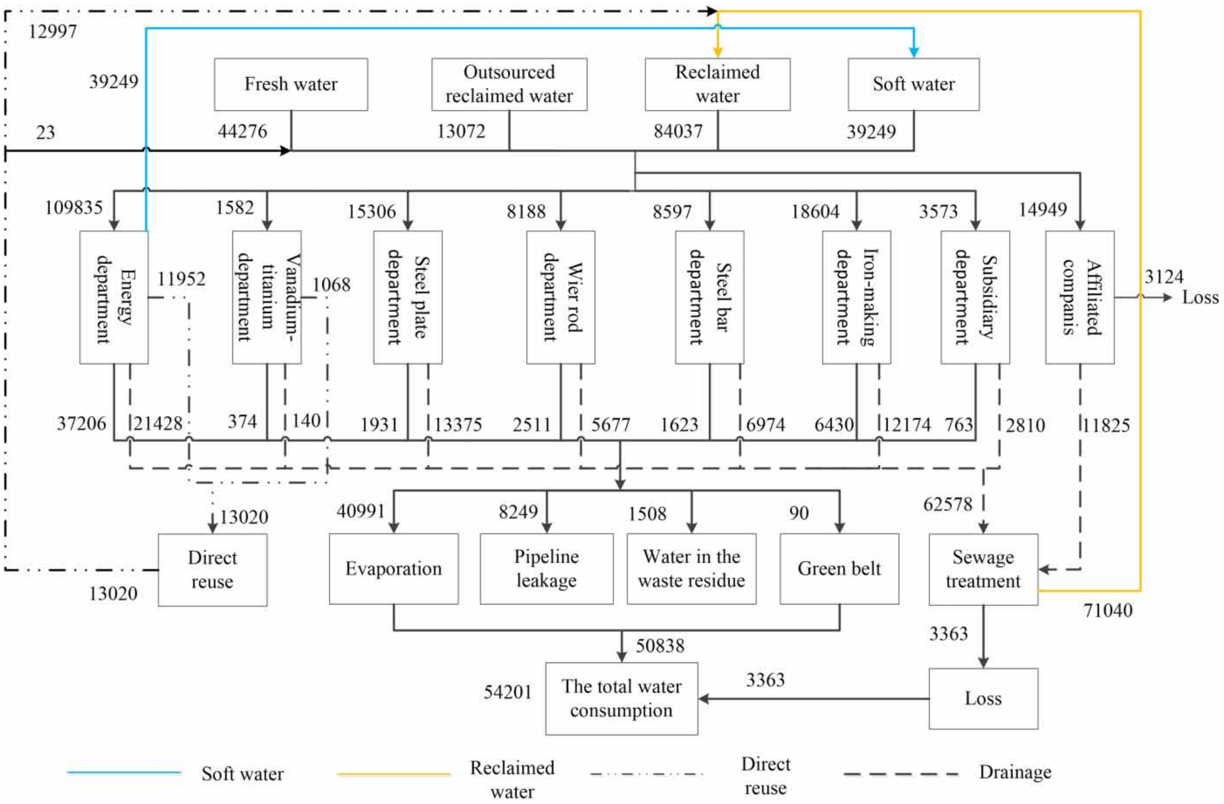

**Figure 5** | Water balance in industry.

**Table 1** | Water balance of two-level water units

| | Water inflow (m$^3$/day) | | | | Water outflow (m$^3$/day) | | | |
|---|---|---|---|---|---|---|---|---|
| **Two-level units (departments)** | $V_f$ | $V_{or}$ | $V_r$ | $V_{sw}$ | $V_s$ | $V_{osw}$ | $V_{co}$ | $V_d$ |
| Ironmaking | 5,068 | 1,518 | 9,761 | 2,257 | | | 6,431 | 12,174 |
| Steel bar | 1,069 | 675 | 4,336 | 2,517 | | | 1,623 | 6,974 |
| Steel plate | 1,683 | 721 | 4,635 | 8,267 | | | 1,931 | 13,375 |
| Wier rod | 2,328 | 386 | 2,484 | 2,989 | | | 2,511 | 5,677 |
| Vanadium–titanium | 411 | 102 | 656 | 412 | 1,068 | | 374 | 140 |
| Energy | 28,961 | 8,245 | 53,005 | 19,624 | 11,952 | 39,249 | 37,206 | 21,428 |
| Subsidiary | 1,753 | 16 | 100 | 1,705 | | | 764 | 2,810 |
| Affiliated companies | 3,003 | 1,409 | 9,060 | 1,477 | | | 3,124 | 11,825 |
| Total | 44,276 | 13,072 | 84,037 | 39,249 | 13,021 | 39,249 | 53,963 | 74,402 |

water outward, and basically realizes the resource utilization of sewage. In this way, the water environment pollution and water ecological damage caused by pollutants in the industrial park waste water can be eliminated from the source.

Table 1 shows the water balance of seven departments within the industrial park. In terms of water inflow, 89.7% of water resources in industrial parks were used for production. The department with the largest inflow of water was the energy department, which take 109,835 m$^3$/day of water, accounting for 60.8% of the total. In terms of water outflow, the vanadium–titanium department and energy department produced 1,068 m$^3$/day and 11,952 m$^3$/day series water, respectively, which was used for blast furnace slag flushing. The energy department generated 39,249 m$^3$/day soft water and supplied it to

**Table 2** | Water balance of steel bar department

| | Water inflow ($m^3$/day) | | | | | Water outflow ($m^3$/day) | |
|---|---|---|---|---|---|---|---|
| **Three-level units** | $V_f$ | $V_{or}$ | $V_r$ | $V_{sw}$ | $V_{cy}$ | $V_{co}$ | $V_d$ |
| 100T Converter | 463 | 357 | 2,296 | 1,771 | 191,289 | 820 | 4,067 |
| 1# Steel bar | 325 | 240 | 1,536 | 609 | 97,459 | 564 | 2,146 |
| 1# Wier rod | 253 | 78 | 504 | 137 | 39,490 | 231 | 741 |
| Office | 28 | | | | | 8 | 20 |
| Total | 1,069 | 675 | 4,336 | 2,517 | 328,238 | 1,623 | 6,974 |

other production departments. The water consumption of the park was 53,963 $m^3$/day, and that of the energy department was 37,206 $m^3$/day, accounting for 68.9% of the total water consumption.

Table 2 shows the water balance results of steel bar department. The steel bar department is a two-level unit in the industrial park, and its three-level water units include 100 T converter, 1# steel bar, 1# wire rod and office. It can be seen that the water withdrawal of the three production units accounted for 99.7% (8,569 $m^3$/day) of the total water withdrawal of the department. The main types of water were fresh water, reclaimed water and soft water. Circulating water was the key in the steel production process. It was mainly used for cooling equipment and products. Circulating water was repeated between the cooling tower and the production line, so the amount of circulating water was huge compared to the amount of water extracted.

Table 3 shows the water balance of the 100 T converter, which is a three-level unit attached to the steel bar department, and it consisted of seven four-level units. It is worth noting that water flow exists in different production processes. For example, the refining furnace and crystallizer provided an average of 900 $m^3$/day of water to the oxygen lance. This water was discharged directly into the oxygen lance after the use of the refining furnace and crystallizer, indicating that there was a step utilization of water resources in the industrial park. However, only four-level units in the industrial park had stepped utilization between them, and two-level and three-level units lacked stepped utilization of water resources.

### 3.2. Water intake structure

The production of the steel industrial park mainly includes five processes: sintering, ironmaking, steelmaking, steel rolling and vanadium production. Figure 6 shows the water intake structure of each process in the industrial park. It can be seen that there are significant differences in the water intake structure of different processes. There are three types of water intake in industrial parks: fresh water, reclaimed water and soft water, of which reclaimed water can be divided into reclaimed water and outsourced reclaimed water according to its source.

Outsourced reclaimed water is the reclaimed water produced by a municipal sewage treatment plant, which is a common unconventional water resource in the city. The use of reclaimed water in industrial parks can effectively improve the utilization efficiency of urban water resources and give play to the social responsibility of industrial parks. In addition, increased

**Table 3** | Water balance of the 100 T converter

| | Water inflow ($m^3$/day) | | | | | | Water outflow ($m^3$/day) | | |
|---|---|---|---|---|---|---|---|---|---|
| **Four-level units** | $V_f$ | $V_{or}$ | $V_r$ | $V_{sw}$ | $V_s$ | $V_{cy}$ | $V'_s$ | $V_{co}$ | $V_d$ |
| Converter | | 89 | 574 | | | 35,368 | | 663 | |
| Refining furnace | | | | 212 | | 17,469 | 182 | 30 | |
| crystallizer | | | | 744 | | 51,352 | 718 | 26 | |
| Oxygen lance | 153 | | | | 900 | 14,747 | 1,023 | 30 | |
| Clean circulation | 310 | | | 815 | | 39,098 | 1,093 | 32 | |
| Turbid circulation | | 243 | 1,561 | | 2,116 | 33,254 | | 27 | 3,893 |
| Braised slag | | 25 | 161 | | | | | 12 | 174 |
| Total | 463 | 357 | 2,296 | 1,771 | 3,016 | 191,289 | 3,016 | 820 | 4,067 |

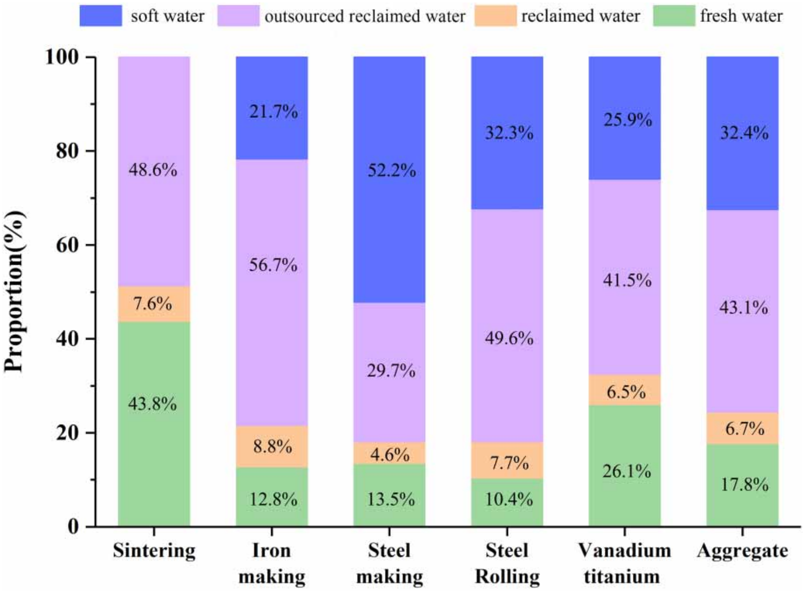

**Figure 6** | Water intake structure of each process.

use of reclaimed water can reduce new water consumption, which has a positive impact on the conservation of regional water resources. The proportion of outsourced reclaimed water in total water withdrawal was 4.6%–8.8%, indicating that industrial parks were trying to use urban water as production water, thus reducing the demand for new water.

Soft water was an essential resource in steel production. Only the sintering process does not require soft water. In other production processes, the proportion of soft water in the water intake structure was more than 20%, especially in the steelmaking process, where the proportion reached 52.1%. The industrial park used fresh and reclaimed water to make soft water. However, the low efficiency of soft water conversion in the park led to a large amount of funds spent on soft water production, equipment maintenance and sewage treatment every year. Updating related equipment and technologies required a large investment, so buying soft water from outside might be a better approach.

The low proportion of fresh water indicates that the water intake structure is advanced, otherwise it indicates that the process needs to be improved. This study compared the water-taking structure of the same process. The amount of fresh water that can be replaced by medium water was calculated according to the difference of the proportion of fresh water between similar processes. The advantage of this comparison method was that it does not exceed the upper limit of water-saving technology in the industrial park, so the analysis results were achievable.

The water balance analysis results of energy department showed that 0.60 $m^3$ fresh water and 0.63 $m^3$ reclaimed water are consumed for each 1 $m^3$ soft water production. According to this ratio, the soft water was reduced to fresh water and medium water, and the water intake structure containing only fresh water and medium water was obtained. Figures 7–10 were the comparison of water intake structures in sintering, ironmaking, steelmaking and steel rolling processes respectively. As there was only one production line in vanadium production process, it cannot be compared horizontally, so it was not discussed in this paper.

There were two production lines in the sintering process. The proportion of fresh water in the water intake structure of the 1# sintering machine is 77.0%, and that of the 2# sintering machine is 15.3%. There were significant differences in water intake structure between them. If the fresh water consumption of 1# sintering machine was reduced to the level of 2# sintering machine, the fresh water consumption can be reduced by 2,254 $m^3$/day. Similarly, 2,417 $m^3$/day of fresh water can be reduced in steelmaking process, and 1,578 $m^3$/day of fresh water can be reduced in steel rolling process. The water intake structure of the two production lines in the ironmaking process was basically the same. Considering the errors in the statistical data, it will not be estimated here. In conclusion, the amount of fresh water that can be replaced by reclaimed water in the steel industrial park was about 6,249 $m^3$/day, which can reduce the amount of fresh water taken by 22.81 million $m^3$ every year. It will increase the disposable water resources in the region, and the extra water can be used to repair the water environment and increase the ecological flow.

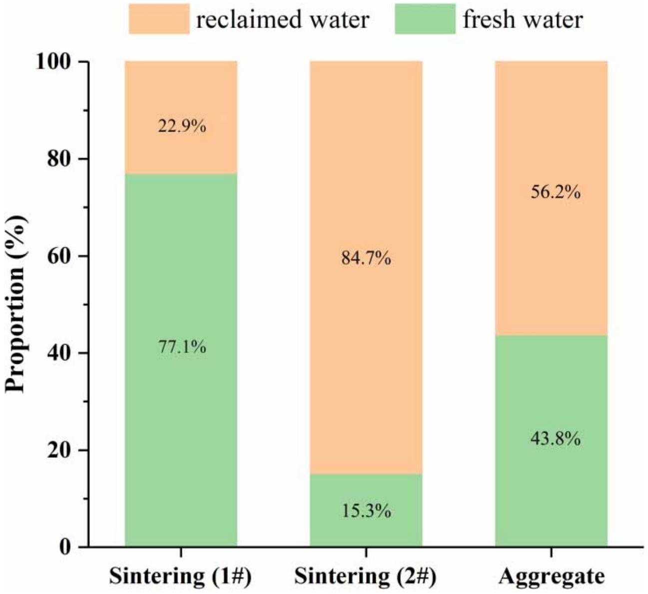

**Figure 7** | Sintering process.

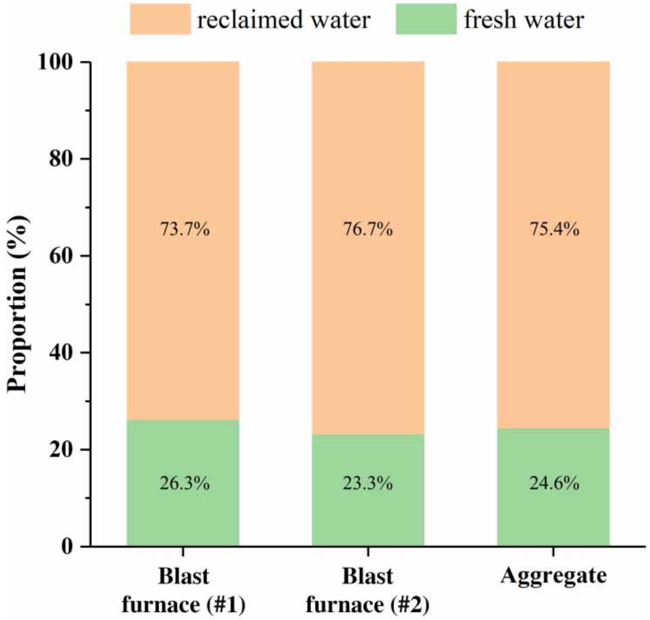

**Figure 8** | Ironmaking process. Please refer to the online version of this paper to see this figure in colour: http://dx.doi.org/10.2166/ws.2021.449.

### 3.3. Water consumption structure

Table 4 shows the calculation results of water consumption of each department in the industrial park. This result was obtained by summarizing the water consumption data of four-level units The energy department was responsible for supplying steam and soft water to other departments, and the park lacks effective steam recycling measures. Therefore, the energy department was the most water-consuming sector, accounting for 64.9% (37,206 $m^3$/day) of the total water consumption of the industrial park. As shown in Figure 11, the horizontal comparison of water consumption factors from the perspective of industrial parks showed that the contribution of evaporation, pipe network leakage, waste residue carrying, greening and

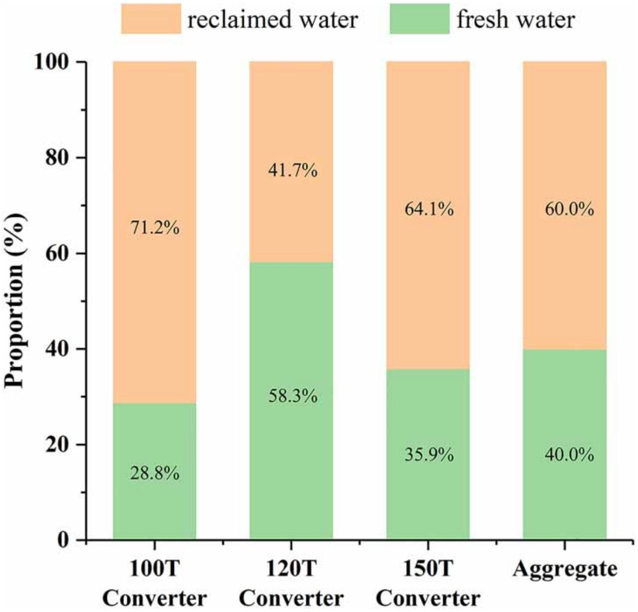

**Figure 9** | Steelmaking process. Please refer to the online version of this paper to see this figure in colour: http://dx.doi.org/10.2166/ws.2021.449.

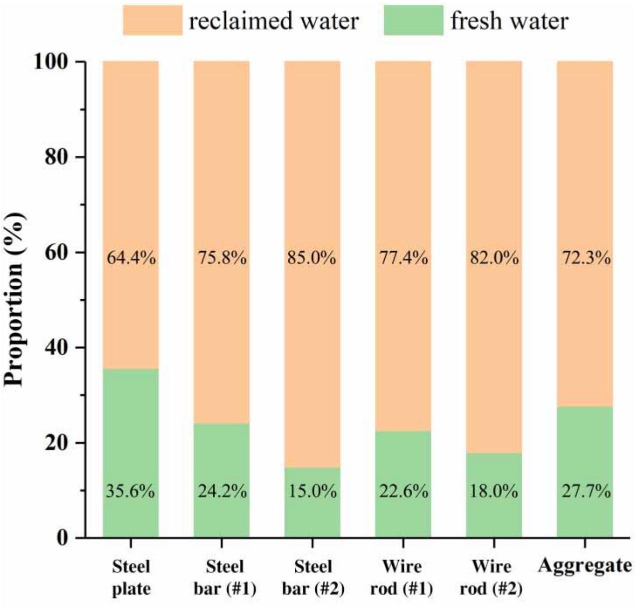

**Figure 10** | Steel rolling process. Please refer to the online version of this paper to see this figure in colour: http://dx.doi.org/10.2166/ws.2021.449.

sewage treatment to water consumption are 72.8%, 18.5%, 5.9%, 2.6% and 0.2% respectively. According to the statistical results in Table 4, evaporation water consumption and pipe network leakage were the main water consumption factors in industrial parks. The two accounted for 91.3% of the total water consumption. As the industrial park produces steel, the amount of water carried in the product was ignored.

The water balance results showed where there was abnormal water consumption in the park. After investigation in the industrial park, it was found that the water collector of the cooling tower of the circulating water system was damaged to varying degrees, among which the efficiency of the water collector of the energy department was less than 56% of the designed efficiency. The restoration of the collector was expected to reduce evaporation losses by 8,412 $m^3$/day, which is

**Table 4** | Results of water consumption by department (m$^3$/day)

| No. | Department | $V_{co,1}$ | $V_{co,2}$ | $V_{co,3}$ | $V_{co,4}$ | $V_{co,5}$ | Total |
|---|---|---|---|---|---|---|---|
| 1 | Ironmaking department | 5,204 | 1,027 | 195 | 4 | | 6,431 |
| 2 | Steel bar department | 1,299 | 271 | 47 | 5 | | 1,623 |
| 3 | Steel plate department | 1,465 | 390 | 53 | 23 | | 1,931 |
| 4 | Wier rod department | 1,998 | 430 | 72 | 11 | | 2,511 |
| 5 | Vanadium-titanium department | 279 | 80 | 10 | 6 | | 374 |
| 6 | Energy department | 30,285 | 5,804 | 1,116 | 0 | | 37,206 |
| 7 | Subsidiary department | 461 | 247 | 15 | 40 | | 764 |
| 8 | Affiliated companies | 747 | 2,332 | 0 | 45 | | 3,124 |
| 9 | Sewage treatment plant | | | | | 3,363 | 3,363 |
| 10 | Total | 41,739 | 10,582 | 1,508 | 134 | 3,363 | 57,326 |

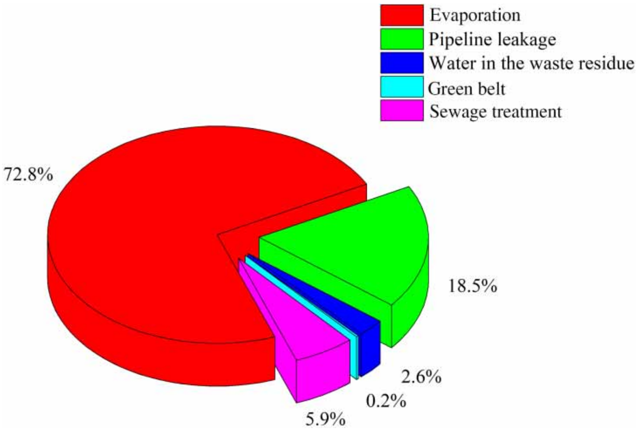

**Figure 11** | Water consumption structure of industrial park. Please refer to the online version of this paper to see this figure in colour: http://dx.doi.org/10.2166/ws.2021.449.

equivalent to 19% of evaporation in 2019. The leakage volume of pipe network was 10,582 m$^3$/day, which was also one of the main water consumption factors. Because the industrial park had been in operation for a long time, the water supply and drainage pipe network were damaged to varying degrees. According to the water balance results of four water units, 112 pipe network leakage points were repaired in the industrial park, reducing water loss by 600 m$^3$/day. In the industrial park, water consumption caused by waste residue carrying, road greening and sewage treatment accounted for 8.7% of the total water consumption. This fraction of water was an inevitable loss in industrial production, so it could be considered as not water-saving value.

## 4. DISCUSSION

The water balance method has advantages in dealing with the quantification of water resources in complex water systems. The method makes visible large flows of water that have previously been unaccounted for and ignored (Pham *et al.* 2016). Previous studies have focused mostly on the amount of water in the water intake and drainage stages of industrial parks. However, the flow of water during production is often ignored. In this article, the water balance network model was applied in the steel industrial park, and the balance model was established on each four-level unit, which made the water in the production processes clearly visible.

The water intake structure can be used to analyze the utilization efficiency of conventional and unconventional water resources. Conventional water resources include: groundwater, surface water, tap water, soft water, etc. Unconventional water resources include: reclaimed water, rainwater, etc. Industrial water demand increasingly competes with municipal and agricultural water demand, often resulting in the limitation of industrial expansions (Wagner *et al.* 2020). In the area of water shortage, the use of municipal wastewater for industrial production may be an effective way to improve the efficiency of water resource utilization (Bauer *et al.* 2020). The water intake structure can be used to assess the potential of unconventional water resources in industrial parks, thereby reducing fresh water consumption.

Water consumption structure can help water managers to clearly identify key water consumption factors. The water obtained from the outside of the industrial park is used to make up for the loss in the production process. Therefore, the water consumption structure is of great guiding value to the water-saving work. Water is an important cooling agent in the production process of industrial parks. It directly or indirectly contacts high temperature equipment and completes heat exchange, such as blast furnace, continuous casting machine, mold and other equipment. Steam is an essential tool in the production of steel. Blast furnace blower, basic oxygen furnace (BOF) vacuum treatment, cold rolling and other processes need to consume a lot of water steam.

## 5. CONCLUSION

The water balance results of the industrial park showed that the energy department was the largest water consumption sector, accounting for 64.9% (37,206 $m^3$/day) of the total water consumption. Therefore, priority should be given to improving water resource management capacity in the energy department to reduce water resource loss. There were differences in water intake structure between the same production processes in the park. Through horizontal comparison, it was found that fresh water could be replaced by reclaimed water in sintering, steelmaking and rolling processes of 2,254 $m^3$/day, 2,417 $m^3$/day and 1,578 $m^3$/day respectively. The water intake structure established a relationship between industrial water use and municipal wastewater and provided a means of assessing the potential of unconventional water use. The consumption of fresh water was reduced, and conversely, the utilization rate of urban water resources was improved. The water consumption structure showed that evaporation and pipe network leakage are the main water consumption factors in industrial parks. Their contribution to water consumption was 72.8% and 18.5% respectively. With the help of the network water balance results, the industrial park checked the water use units with abnormal data one by one. Crews repaired damaged water collectors and leaks in water supply and drainage lines. Evaporation water consumption reduced by 8,412 $m^3$/day. Pipe network leakage water consumption reduced by 600 $m^3$/day.

The research results provided a theoretical and methodological basis for the refined water management of industrial parks. Although good application results have been achieved, there are areas to be improved in this study. Industrial parks are gradually moving towards a sustainable and environmentally friendly development model, and more and more scholars are paying attention to the impact of industrial pollution on the ecological environment. However, the flow of pollutants was not considered in this study. Future work will consider the relationship between pollutants and water flow and identify the transfer of pollutants during production.

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## DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

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