Water-efficient cities
Evaluating urban water management using a water metabolism framework

Jooyoung Park
Graduate School of Energy and Environment
Korea University
<table>
<thead>
<tr>
<th>Water in SDGs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>6.1</strong> By 2030, achieve universal and equitable access to safe and affordable drinking water for all</td>
</tr>
<tr>
<td><strong>6.1.1</strong> Proportion of population using safely managed drinking water services</td>
</tr>
<tr>
<td><strong>6.2</strong> By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations</td>
</tr>
<tr>
<td><strong>6.2.1</strong> Proportion of population using safely managed sanitation services, including a hand-washing facility with soap and water</td>
</tr>
<tr>
<td><strong>6.3</strong> By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally</td>
</tr>
<tr>
<td><strong>6.3.1</strong> Proportion of wastewater safely treated</td>
</tr>
<tr>
<td><strong>6.3.2</strong> Proportion of bodies of water with good ambient water quality</td>
</tr>
<tr>
<td><strong>6.4</strong> By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity</td>
</tr>
<tr>
<td><strong>6.4.1</strong> Change in water-use efficiency over time</td>
</tr>
<tr>
<td><strong>6.4.2</strong> Level of water stress: freshwater withdrawal as a proportion of available freshwater resources</td>
</tr>
<tr>
<td><strong>6.5</strong> By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate</td>
</tr>
<tr>
<td><strong>6.5.1</strong> Degree of integrated water resources management implementation (0-100)</td>
</tr>
<tr>
<td><strong>6.5.2</strong> Proportion of transboundary basin area with an operational arrangement for water cooperation</td>
</tr>
<tr>
<td><strong>6.6</strong> By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes</td>
</tr>
<tr>
<td><strong>6.6.1</strong> Change in the extent of water-related ecosystems over time</td>
</tr>
</tbody>
</table>
Water and Circular Economy

As a service
- Consumptive use
- Production use
- Process use

As a source of energy
- Kinetic
- Thermal
- Bio-thermal

As a carrier
- Nutrients
- Chemicals
- Minerals

Fig. 3. Results of the plastics budget for Austria in 2010 (exports of plastics include also their chemical or thermal utilization). Flow values are given by their mean value (two significant digits) and relative standard deviation.

Source: Van Eygen et al. 2017
Socio-economic Metabolism

Source: Graedel et al. Work in Progress
EU’s Raw Material Initiative

- Critical Raw Materials

<table>
<thead>
<tr>
<th>2017 CRMs (27)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antimony</td>
</tr>
<tr>
<td>Fluorspar</td>
</tr>
<tr>
<td>LREEs</td>
</tr>
<tr>
<td>Phosphorus</td>
</tr>
<tr>
<td>Baryte</td>
</tr>
<tr>
<td>Gallium</td>
</tr>
<tr>
<td>Magnesium</td>
</tr>
<tr>
<td>Scandium</td>
</tr>
<tr>
<td>Beryllium</td>
</tr>
<tr>
<td>Germanium</td>
</tr>
<tr>
<td>Natural graphite</td>
</tr>
<tr>
<td>Silicon metal</td>
</tr>
<tr>
<td>Bismuth</td>
</tr>
<tr>
<td>Hafnium</td>
</tr>
<tr>
<td>Natural rubber</td>
</tr>
<tr>
<td>Tantalum</td>
</tr>
<tr>
<td>Borate</td>
</tr>
<tr>
<td>Helium</td>
</tr>
<tr>
<td>Niobium</td>
</tr>
<tr>
<td>Tungsten</td>
</tr>
<tr>
<td>Cobalt</td>
</tr>
<tr>
<td>HREEs</td>
</tr>
<tr>
<td>PGMs</td>
</tr>
<tr>
<td>Vanadium</td>
</tr>
<tr>
<td>Coking coal</td>
</tr>
<tr>
<td>Indium</td>
</tr>
<tr>
<td>Phosphate rock</td>
</tr>
</tbody>
</table>

- Tracking Supply Chains

(2) Aluminium
MFA in Korea

Source: Korea National Material Flow Analysis
Energy Flow Analysis

Estimated U.S. Energy Consumption in 2018: 101.2 Quads

Sources: LLNL, March 2019. Data is based on DOE/EIA MER (2019). If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports consumption of renewable resources (i.e., hydro, wind, geothermal, and solar) for electricity in Btu-equivalent values by assuming a typical fossil fuel plant heat rate. The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential sector, 45% for the commercial sector, 22% for the transportation sector, and 49% for the industrial sector, which was updated in 2017 to reflect DOE’s analysis of manufacturing. Totals may not equal sum of components due to independent rounding. LLNL-TR-619027
\[ P + C + D + Re = ET + SW + WW + G + Re + \Delta S \]

Source: Kenway et al. 2011; Farooqui et al. 2016; Renouf et al. 2018
Seoul’s Water Reuse Masterplan

❑ Rainwater harvesting

<table>
<thead>
<tr>
<th></th>
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<th></th>
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<th></th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>물재이용(천m³/년)</td>
<td>393.4</td>
<td>1,737</td>
<td>2,006</td>
<td>2,223</td>
<td>2,400</td>
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<tr>
<td>물재이용관리계획(천m³/년)</td>
<td>50,496</td>
<td>133,870</td>
<td>142,010</td>
<td>180,688</td>
<td>208,820</td>
<td></td>
</tr>
<tr>
<td>비율(%)</td>
<td>0.78</td>
<td>1.30</td>
<td>1.41</td>
<td>1.23</td>
<td>1.15</td>
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❑ Greywater reuse

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</thead>
<tbody>
<tr>
<td>중수도시설 재이용량(천m³/년)</td>
<td>2,837</td>
<td>11,786</td>
<td>13,771</td>
<td>15,897</td>
<td>18,351</td>
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<tr>
<td>물재이용관리계획(천m³/년)</td>
<td>50,496</td>
<td>133,870</td>
<td>142,010</td>
<td>180,688</td>
<td>208,820</td>
<td></td>
</tr>
<tr>
<td>비율(%)</td>
<td>5.62</td>
<td>8.80</td>
<td>9.70</td>
<td>8.80</td>
<td>8.79</td>
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❑ Wastewater recycling

<table>
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</tr>
</thead>
<tbody>
<tr>
<td>하수처리장 재이용률(천m³/년)</td>
<td>47,266</td>
<td>120,347</td>
<td>126,234</td>
<td>182,565</td>
<td>188,089</td>
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<tr>
<td>물재이용관리계획(천m³/년)</td>
<td>50,496</td>
<td>133,870</td>
<td>142,010</td>
<td>180,688</td>
<td>208,820</td>
<td></td>
</tr>
<tr>
<td>비율(%)</td>
<td>93.60</td>
<td>89.90</td>
<td>88.89</td>
<td>88.97</td>
<td>90.06</td>
<td></td>
</tr>
</tbody>
</table>

서울시 물재이용 관리계획(2013-2020)
• “물의 재이용 촉진 및 지원에 관한 법률“(‘11.6.9)
• 향후 물부족에 대한 선제적 대응을 위해 친환경 수자원 확보
• 2020년 총 용수사용량의 14.4%

Source: 서울특별시, 2013. 서울특별시 물재이용 관리계획
서울특별시 물재이용 관리계획

서울특별시, 2013.

서울의 물 재이용을 보고하는 다이어그램.

2010년 기준 연도
- 상수사용량: 1,120.3
- 기타용수사용량: 63.1
- 중발산량: 191.1
- 강우량: 938.5

2020년 목표 연도
- 상수사용량: 1,101.8
- 기타용수사용량: 63.1
- 중발산량: 191.1
- 강우량: 938.5

주: 하수처리 수재이용은 하천유지용수 공급량을 제외한 값입니다.

그림 6: 2020년 물재이용에 따른 서울시 물순환 변화

Source: 서울특별시, 2013. 서울특별시 물재이용 관리계획
## Urban Water Performance

### Urban Water Goals and Performance Evaluation

<table>
<thead>
<tr>
<th>Urban water goals</th>
<th>Supply security</th>
<th>Risk management</th>
<th>Functionality</th>
<th>Resource efficiency</th>
<th>Environmental protection</th>
<th>Economic sustainability</th>
<th>Global water sustainability</th>
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</thead>
<tbody>
<tr>
<td><strong>Evaluation approach</strong></td>
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<tr>
<td>Integrated water system modeling</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<td>Water metabolism</td>
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<td>Life cycle assessment</td>
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<td>Water footprint</td>
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<td>Environmentally-extended input-output</td>
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<td>Ecological network analysis</td>
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<tr>
<td>System dynamics</td>
<td>X</td>
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<td>X</td>
</tr>
</tbody>
</table>

Source: Renouf et al. 2017
Evaluating urban water management using a water metabolism framework: A comparative analysis of three regions in Korea

Seongpil Jeong\textsuperscript{a,}\textsuperscript{b}, Jooyoung Park\textsuperscript{c,}\textsuperscript{*}

\textsuperscript{a} Water Cycle Research Center, Korea Institute of Science and Technology, Republic of Korea
\textsuperscript{b} Division of Energy & Environment Technology, KIST School, Korea University of Science and Technology, Republic of Korea
\textsuperscript{c} Graduate School of Energy and Environment (KU-KIST Green School), Korea University, Republic of Korea

Abstract

As climatic and societal changes increase the prominence of water insecurity, sustainable urban water management focusing on water efficiency and reuse is an increasingly significant issue in Korea and elsewhere. This study uses the urban water metabolism framework to examine patterns of water flows in urbanized areas and evaluate water management performance in three Korean regions: Seoul (a metropolitan city), Ulsan (an industrial city), and Jeju (an urbanized agricultural province). Constructed water metabolism models showed distinct water use patterns and performance across each region in 2015. Seoul largely relied on surface water, while the residential sector’s dominant use of water implies high greywater use and wastewater recycling potential. Ulsan relied on abstracting river water, with lower water availability of the river making Ulsan’s water system less self-sustaining and more vulnerable to climatic risks than Seoul’s. Facing higher water use intensity due to high industrial demand, Ulsan actively promotes industrial wastewater recycling. Jeju showed the highest water use intensity because of the presence of intensive agricultural activities. Nonetheless, Jeju sourced 76% of its water from internal sources, with its water system considered to be the most self-sustaining. These results suggest that the water metabolism framework helps facilitate more holistic understandings and evaluations of the water performance of cities.
Study Regions

Han river
(1,488 m³/yr/capita)

Taehwa river
(614 m³/yr/capita)

Groundwater
(730 million m³/yr)
### Table 2
Water flow data and their sources.

<table>
<thead>
<tr>
<th>Type</th>
<th>Flows</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cs</td>
<td>River water (domestic), Tap water, Water imported from other region, Water distributed to other region, River water (industrial), Reservoir water</td>
<td>Korea Ministry of Environment Statistics of Waterworks (MOE, 2016b), Water Resources Management Information System (Han River Flood Control Office, 2019b)</td>
</tr>
<tr>
<td>Dp</td>
<td>Rainwater harvesting (domestic), Rainwater (agriculture)</td>
<td>Korea Ministry of Environment Statistics of Sewerage (MOE, 2016a), Water Resources Management Information System (Han River Flood Control Office, 2019b)</td>
</tr>
<tr>
<td>Re</td>
<td>Greywater, Wastewater reuse, River maintenance</td>
<td>Korea Ministry of Environment Statistics of Sewerage (MOE, 2016a)</td>
</tr>
<tr>
<td>Cg</td>
<td>Groundwater</td>
<td>Korea Ministry of Land, Infrastructure and Transportation Groundwater report (MOLIT, 2016b)</td>
</tr>
<tr>
<td>Dg</td>
<td>Bore water</td>
<td>Surveys by local governments, Water Resources Management Information System (Han River Flood Control Office, 2019b), Korean Statistical Information Service (Statistics Korea, 2019), Korea Meteorological Administration Open Database Portal (Korea Meteorological Administration, 2019)</td>
</tr>
<tr>
<td>P</td>
<td>Precipitation</td>
<td>Estimated based on hydro-partitioning data from literature (Jeju Special Self-Governing Province, 2013; Kim and Jin, 2018; Ulsan Metropolitan City, 2018) Calculated from mass balance</td>
</tr>
<tr>
<td>ET, G, SW</td>
<td>Evaporation, Groundwater infiltration, Surface runoff</td>
<td>Estimated based on hydro-partitioning data from literature (Jeju Special Self-Governing Province, 2013; Kim and Jin, 2018; Ulsan Metropolitan City, 2018) Calculated from mass balance</td>
</tr>
<tr>
<td></td>
<td>Balancing flows: Water loss, Discharge, Other wastewater, Infiltrated water, Infiltration</td>
<td>Estimated based on hydro-partitioning data from literature (Jeju Special Self-Governing Province, 2013; Kim and Jin, 2018; Ulsan Metropolitan City, 2018) Calculated from mass balance</td>
</tr>
<tr>
<td></td>
<td>Land area</td>
<td>Korea Ministry of Environment Statistics of Waterworks (MOE, 2016b), Korean Statistical Information Service (Statistics Korea, 2019)</td>
</tr>
</tbody>
</table>
Seoul’s Water Metabolism, 2015

Import: 1,717.6 million T/y
Evaporation: 123.7
Run-off: 279.1
Export: 2,042 million T/y

Rainwater Harvesting
Greywater Use
Water distributed to other region
Wastewater Treatment Plant
River
Wastewater Reuse System
Aquifer
Reservoir
Water Production Plant
Tap Water
Domestic Use
Industrial Use
Other Uses
Agricultural Use
Groundwater
Reservoir
Reservoir

Rainwater
Greywater
Domestic Wastewater
Industrial Water
Treated Water
Wastewater Reuse
Other Wastewater
Industrial Wastewater
Rainwater
Infiltrated Water
Infiltration
Water Loss
Water Loss
Jeju’s Water Metabolism, 2015

Import: 4,426.3

Precipitation 3,899.5

Rainwater Harvesting

Greywater Use

Domestic Wastewater

Hydrological Cycle

Evaporation 757.1

Run-off 500.5

Water Production Plant

Tap Water 77.8

Groundwater 150.1

Bore

Industrial Wastewater 32.6

Water Reuse System

Wastewater Treatment Plant 5.3

Treated Wastewater 70.3

Seacoast 583.4

Discharge 1,007

Groundwater Infiltration 1,007

Aquifer

Groundwater 254.9

Reservoir

Reservoir 271.8

Agricultural Use 1,963.9

Water Loss 66.6

Water Loss

Infiltration 3,089.6

Export: 4,431
## Performance Indicators

### Comparisons of Urban Water Performance Indicators

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Seoul</th>
<th>Ulsan</th>
<th>Jeju</th>
<th>MEL</th>
<th>BAN</th>
<th>DEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water use intensity (m³/capita/yr)</td>
<td>142</td>
<td>134</td>
<td>136</td>
<td>133</td>
<td>546</td>
<td>3425</td>
</tr>
<tr>
<td>Domestic</td>
<td>78</td>
<td>133</td>
<td>114</td>
<td>110</td>
<td>144</td>
<td>374</td>
</tr>
<tr>
<td>Industrial</td>
<td>2.4</td>
<td>2.5</td>
<td>4.9</td>
<td>4.6</td>
<td>267</td>
<td>22</td>
</tr>
<tr>
<td>Agricultural</td>
<td>3.8</td>
<td>2.4</td>
<td>1.9</td>
<td>0.8</td>
<td>114</td>
<td>3062</td>
</tr>
<tr>
<td>Water extraction intensity (m³/capita/yr)</td>
<td>140</td>
<td>133</td>
<td>135</td>
<td>120</td>
<td>478</td>
<td>821</td>
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<tr>
<td>Water supply internalization (%)</td>
<td>1.2</td>
<td>0.8</td>
<td>0.9</td>
<td>9</td>
<td>13</td>
<td>76</td>
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<tr>
<td>Rainfall potential (%)</td>
<td>68</td>
<td>68</td>
<td>59</td>
<td>35</td>
<td>170</td>
<td>178</td>
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<tr>
<td>Wastewater potential (%)</td>
<td>81</td>
<td>143</td>
<td>128</td>
<td>97</td>
<td>28</td>
<td>3</td>
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<tr>
<td>Water import rate (%)</td>
<td>-</td>
<td>33.5</td>
<td>6.2</td>
<td>5.9</td>
<td>21.3</td>
<td>-</td>
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</tbody>
</table>
Thank you