Power of City driven by Power of Nature

"To the Era of Green Infrastructure"

Green Infrastructure Research Institute

CONTENT

Landscape in the City of Portland where attractive urban development with green infrastructure is progressed
(Photo: Mike Houck, Urban Greenspaces Institute)

Chapter 01. Green Infrastructure: Why now?

1.What is green infrastructure?

Green infrastructure is an infrastructure or land use plan which contributes to sustainable social and economic development using a variety of natural functions[1]. However, the methods and viewpoints depend on nations and organizations. For instance, the European Union defines green infrastructure as "a strategically planned network of natural and semi-natural areas" and implements conservation and restoration of ecosystems, generation of ecosystem networks, urban development using ecosystem services, disaster countermeasures etc. On the other hand, the United States recognizes green infrastructure as " a simultaneous method to achieve rainwater management, stormwater countermeasures and environmental conservation", and focuses on human-made buildings (rainwater management facilities) reinforced with ecosystem functions[2].

Both strategies aim to solve urban issues utilizing natural (green) potentials, and they are implemented as a new concept that can facilitate integrating various components such as environmental conservation, urban and regional development, and disaster prevention and mitigation. This brochure focuses on the green infrastructure from a viewpoint of rainwater management based on the concept in the US.

2. Urban issues on disaster risks are urgent issues

In recent years, urban heat island effects and localized heavy rain which may trigger urban water disasters have become more serious globally year by year. When we think about a "good environment" in future cities, technology that can solve the issues persistent in urban infrastructures, such as "safety" against natural disasters or "cities that can cool" even under severe heat, are thought to be unquestionably necessary. Japan has taken countermeasures against stormwater using excellent construction technology. However, these systems are ineffective against recent which are exceed their capacity. **Photo 1-1** shows a situation of localized heavy rain, and **Figure 1-1** shows an upward trend of heavy rain frequency[3], which demonstrates that the countermeasures against heavy rain are an urgent issue.

Photo 1-1 Situation of localized heavy rain (Photo: Japan Meteorological Agency)

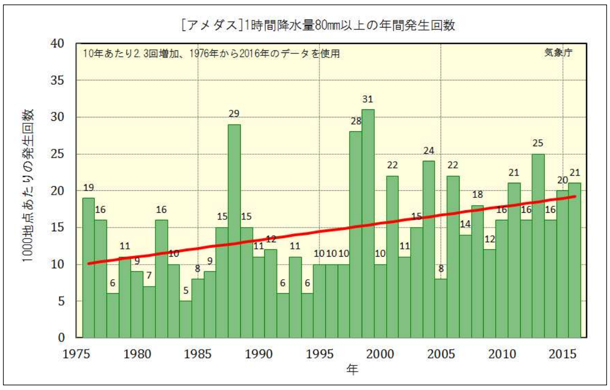


Figure 1-1 Annual frequency of heavy rain (>80 mm/hour) The annual frequency of heavy rain (>80 mm/hour) increases year by year (Photo: Japan Meteorological Agency)

3. Green Infrastructure that solve the Urban issues

In the world's megacities, they find an answer for their urban issues using green infrastructure, because many benefits are produced by utilizing the green potentials as an urban infrastructure. That is, rainwater retention and infiltration, reduction of surface runoff, removal of pollutants, improvement of water cycle including rainwater reuse and groundwater recharge, and improvement of microclimate in cities can be achieved by taking advantage of natural functions possessed by plants and soils, which results in new urban developments that are safe and comfortable to live in.

A major reason for the global trend of green infrastructure is its "multi-functions." As opposed to the single-purpose gray infrastructure that can work only during rain events, like conventional civil engineering methods, green infrastructure can provide many benefits, which is its most important point. United States Environmental Protection Agency (USEPA) describes the advantage of green infrastructure as "Benefits of Green Infrastructure[4]" (**Table 1-1**).

Table 1-1 Various benefits of green infrastructure

Category	Merit	Function
Water Quality & Quantity	Water quality improvement	Reduce pollutant loads; Reduce stormwater discharge into combine sewers and rivers
	Surface runoff mitigation	Delay and reduce stormwater discharge
	Water supply	Facilitate rainwater harvesting and infiltration; Increase groundwater recharge; Improve water cycle
Air Quality	Particle pollution reduction	Absorb and filter particulate matters
	Health effects	Reduce respiratory ailments
	Grand-level ozone improvement	Reduce air temperatures; Reduce nitrogen oxides; Reduce smog
Climate Resiliency	Water disaster reduction	Infiltrate rainwater; Reduce flood risk by open space preservation
	Drought mitigation	Replenish groundwater reserve; Relieve stress on water supplies
	Heat island mitigation	Reduce temperature by evapotranspiration; Reduce temperature with green roofs
	Lower building energy demands	Reduce indoor temperature by shading building surfaces
	Lower energy usage for water management	Reduce rainwater flows into sewer systems; Reduce pumping and treatment demands for municipalities
Habitat & Wildlife	Habitat improvement	Reduce erosion and sedimentation; Provide water and food; Provide places for hiding, relaxing and mating
	Habitat connectivity	Facilitate wildlife movement; Connect wildlife populations between habitats
Communities	Green jobs	Create construction and maintenance jobs
	Health benefits	Encourage outdoor physical activity; Reduce chronic diseases
	Recreation space	Facilitate recreational activity for urban residents
	Property values	Increase property values with more vegetation and tree cover; Benefit both developers and homeowners

Chapter 02. Urban Development enhanced by Green Infrastructure

1. Attract people and companies through urban development using green infrastructure

The City of Portland is the most popular “destination city” in the US, and it is globally renowned as a winner of the world city’s competition. More people have moved from centralized cities with IT companies in California (such as Silicon Valley), and some major sporting goods companies also have moved to the city. The movement is reflected by the transition of work style along with IT development, as well as the attractive city development of Portland with green infrastructure.

Young and highly productive people work with outstanding concentration to achieve their high performance. On the other hand, it is said that once work is finished, they forget all about work and go to play outside in nature to recharge and gain energy to accomplish their next big goal. As such, cities like Portland, which provide a rich natural environment suitable for this charge and recharging of modern life, as well as a living environment that is enriched by greenery, they attract more high potential people, which then leads companies to come to hire such excellent workers, which up generating a positive spiral. As a consequence, such cities will gain more tax revenue, become more vibrant, and transform into more popular cities. Thus, green infrastructure plays an important role in urban development (see Photos from 2-1 to 2-3).

Photo 2-1 Tanner Springs Park, built on a former industrial site (2012); **Photo 2-2** Trekking – environmental education in nature (2012); **Photo 2-3** Pioneer Courthouse Square, at a public viewing (2014)

2. Vibrant and attractive remodeling of parks using green infrastructure

The role of parks changes with the time. The "existence" of parks used to be important, while parks are deemed to "be utilized" by many people as well as "create vibrant spaces" in today's society. Parks should be a place to provide comfortable spaces whenever we go, and therefore they don't meet the role if the environment is uncomfortable such as "parks without any shade from trees" or "parks that are always humid". Thus, there is need for public spaces that people want to go, and parks where people can relax even on hot summer days.

So what tools are available to cool down the public places? Misting systems and sunshades are the most popular artificial facilities used in many places. They provide the direct cooling effects, however they will be constant labor and maintenance costs and they may not be used in the future as the needs of society change.

On the other hand, parks originally possess various natural elements such as soils, trees and water as basic natural components. If these elements can be utilized effectively and parks can be transformed into attractive spaces where many people can gather and enjoy themselves, then that is an ideal park development which is sustainable and provides values continuously into the future. In fact, the Grand Mall Park (Minato Mirai 21) in the City of Yokohama has been transformed into an "innovative park leading matured urban development" using green infrastructure technology[5)] **(Photo 2-4)**

Photo 2-4 Grand Mall Park in the City of Yokohama vibrant with many people (Minato Mirai 21) "Bijutsu no Hiroba"

Example: Grand Mall Park in the City of Yokohama

The Grand Mall Park in the City of Yokohama was renovated as a core of new urban development, and “Bijutsu no Hiroba” was constructed in the Japanese fiscal year 2015. In order to create a vibrant space in the park, a large water circulation system was installed using green infrastructure technology (**Figure 2-1**). A “cool space even in summer” was created with not only green shades but also evaporation of rainwater occurred from underground by capillary action, as well as evapotranspiration from progressively growing trees. This microclimate effect has been verified and a technical report was published in Journal of the Japanese Society of Revegetation Technology (volume 42, issue 3, February 2017) (**Figures 2-2 and 2-3**). The Grand Mall Park has become a showcase of environmental future city, literally along with a concept of “the second urban development” held by the city of Yokohama.

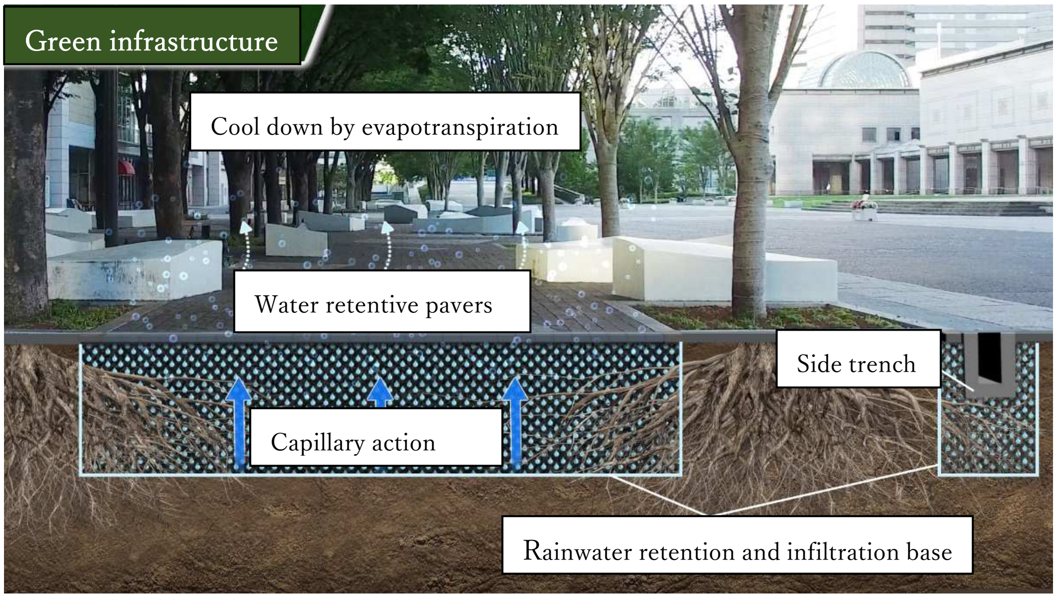


Figure 2-1 Sectional diagram of the Grand Mall Park
Rainwater infiltrated from water retentive pavers or side trench moves up through the rainwater retention and infiltration base by capillary action and reaches out to the water-retentive pavers. A temperature reduction effect occurs by evaporation of rainwater from the water-retentive pavers as well as evapotranspiration from trees.

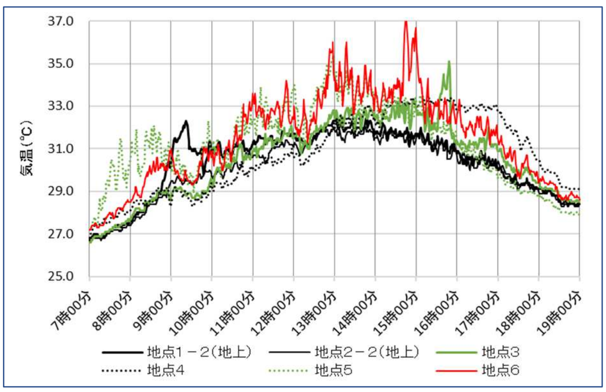


Figure 2-2 Results of temperature measurement at a site installed with rainwater retention and infiltration base (at a 1.5 m height)[6)]

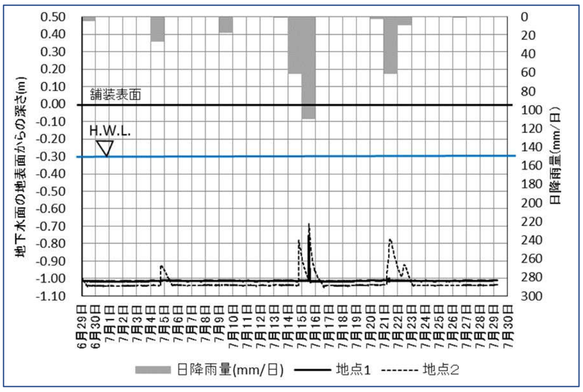


Figure 2- 3 Precipitate and groundwater level change
A heavy rain (110 mm/day) was observed on July 15, 2016, but the groundwater level at rainwater retention and infiltration base only increased by 30 cm. There was no flood occurred from the catchment area during the monitoring of groundwater level[6)].

3. Urban development adapted to the future mobility style

(1) Reduce driveway lanes and utilize walkway for green zone

In recent years, street designs have been gradually transformed from car-centered to human-centered, cyclists and pedestrians. In the City of Portland, which is the most environmentally friendly city in the US, people often use bikes and it has become normal to bring their bikes onto trams. In Japan, car sharing is becoming more popular and renovation of streets is planned along with bikeway installation in major cities that reduces driveway lanes and expands walkways. Conceptual diagrams are shown in **Figures 2-4**. As such, urban development changes corresponding to the change of people's lifestyle.

To reduce driveway lanes and accommodate green spaces for human wellbeing, the planting base also has to be maintained properly. However, conventional roadbeds which are often hard and compact are not suitable for healthy plant growth because plant roots cannot be extended in such a nonporous soil base, which results in the inhibition of plant growth. On the other hand, considering that urban flooding has become more frequent in recent years, it is desirable that the spaces under walkways are utilized effectively as a rainwater retention and infiltration facility. Thus, the needs of urban development are changing along with the transition of our society.

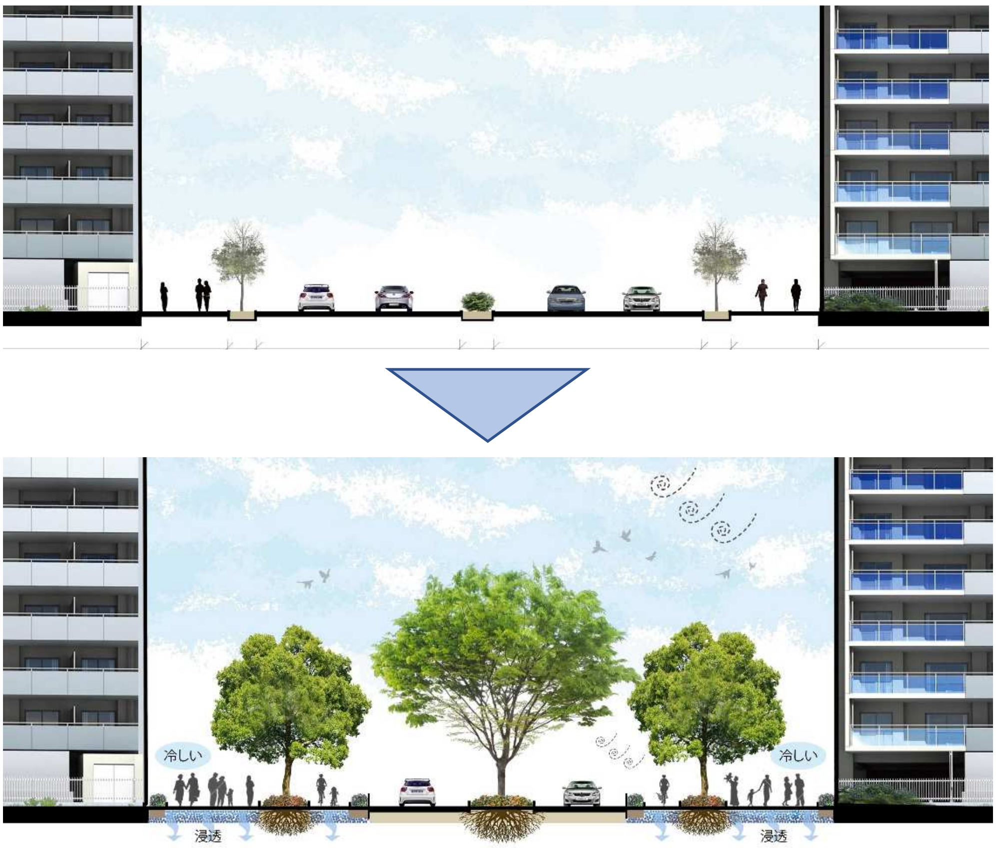


Figure 2-4 Human-centered street design
The 2 driveway lanes are reduced to a single lane, while bikeways and vibrant spaces (flower beds) are installed, along with the anticipated lower needs of car transportation. (Conceptual diagram)

(2) Prevent tree roots rising for safe walkway

Tree roots rising up from walkways is a phenomenon where tree roots have no extension space in tree pits and end up reaching out to the bottom layers of pavements (such as interlocking blocks) which results in the pushing up of the pavements (**Photos 2-5 and 2-6**). Therefore, if an enough space of good planting base is accommodated for tree roots, this can be avoided.

Root guide and pressure-resistant base material (Power Mix) is a technology to provide good planting base adaptable in narrow tree pit as well as to prevent tree roots rising. The Power Mix is installed around the tree pits, whereas rainwater retention and infiltration base is installed under the entire walkway in order to accommodate an enough infiltration area.

These planting bases are a beneficial green infrastructure technology for road authorities that can minimize the risk of pedestrian accidents followed by lawsuits due to rising tree roots.

Photos 2-5 and 2-6 Phenomenon of tree roots rising and its cause
If soils around trees are compacted, their roots extend towards the road surface and causes tree roots rising. Countermeasures are necessary to prevent lawsuits caused by pedestrian accidents.

Chapter 03. Promotion of living environment by Green Infrastructure

1. Increase property resale values with green infrastructure

Apartment exteriors enriched by greenery have become common in recent years. People tend to choose their properties by looking at not only properties themselves but also the quality of greenery and state of greenery maintenance. Apartment exteriors which have been guaranteed with the quality of green for the next couple of decades will result in increasing the property values as well as a source of pride for the residents.

Lands for large housing developments are often within ecologically preserved sites. Therefore, it is possible to create ecologically friendly, green-enriched, and space that are cool even in summer by using green infrastructure technology. In addition to the hardware aspects, developers have to be aware that the maintenance of green spaces is also an important key factor for the satisfaction of residents. Also, soft aspects such as the maintenance plan has to be clear from the designing phase. This is a big opportunity for developers to differentiate product offering and therefore a firm and high-quality maintenance plan has to be developed (**Figure 3-1**).

Figure 3-1 Comfortable apartment life supported by green infrastructure technology (Conceptual diagram) Possible to provide enriched green shades and cool spaces even in summer
(Please contact us for further details of the road base system)

Photo 3-1 An example of green infrastructure which works for temporarily retaining rainwater as well as providing a green space for a rooftop party

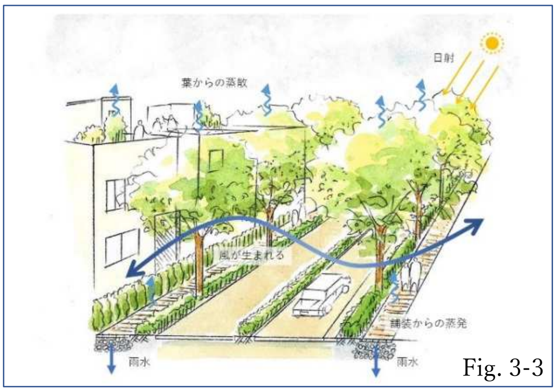
2. Urban green infrastructure that makes use of empty space

In Japan, 433.8 ha of green rooftops have been created since 2000 until 2015[7)]. In Chicago, green rooftops are installed progressively because an ordinance that enforces to the installation of a temporal retention system on rooftops for a half-inch of rainwater has been enacted. If the same ordinance is enacted in Japan, 56,000 m^3 of rainwater can be additionally retained on rooftops, which is equivalent to about 10% of retention volume in a large underground tunnel (Kanda River Underground Regulating Reservoir Under the Loop Road 7, approximately 540,000 m^3) constructed by the Tokyo Metropolitan Government for as an urban flooding prevention method. When the rainwater retention at rooftop spaces is recognized as an effective countermeasure for stormwater capture in Japan, the construction of green rooftops will be increasingly expected as a new and effective rainwater retention system.

There are a number of rooftops left abandoned without any usage. It is also expected that new communication sites are created by installing the latest green infrastructure technology in there (**Photo 3-1**).

3. Green infrastructure will enhance economic values in (developing) residential areas

In future urban development, it is important to establish maintenance methods that make residents feel comfortable and keep their property values stable in the long run. To achieve this, urban planning based on residents' point of view, the installation of green infrastructure technology, and sustainable maintenance planning are important. In addition to "beautiful", "rich", "vibrant" and "proud" which used to be recognized as "good living conditions", sustainable urban design which can provide "cool in summer" and "safe" environment is also to be anticipated in the future (**Figures 3-2 and 3-3**). Also, development of monitoring technology to verify the effects of green infrastructure will be advanced.



Figures 3-2 and 3-3 Application of green infrastructure for comfortable urban development

Chapter 04. Activities of green infrastructure in major cities of the United States

1. The most environmentally friendly city in the US: City of Portland

The City of Portland is a middle-sized city in the US with a population of about 600,000 people. The main industry of the city used to be forestry, and thereafter the city was industrialized with many steel factories and shipyards along Willamette River, which ended up becoming the dirtiest river in the US. The sewer system in the City of Portland is a combined sewer system which releases wastewater into rivers when its amount exceeds the capacity of wastewater treatment plants due to heavy rain. In 1993, the federal government filed a lawsuit to restrict the amount of wastewater discharge into rivers because the discharged wastewater polluted the river water further. As the river water became polluted, steelhead and Coho salmon which are a vital part of the ecosystem in the City of Portland were listed as endangered species. Therefore, the city started to take actions for stormwater management as well as watershed restoration.

The city determined an urban growth boundary between land development areas and nature conservation areas in order to restrict chaotic land development and the expansion of impervious area. Green infrastructure used to be installed for the purpose of natural stormwater purification, but the application was expanded as a countermeasure for the overflow of wastewater from sewers due to heavy rain, such as rain gardens and green streets with bioswales (**Photos 4-1 to 4-4**). Furthermore, in the city's infrastructure development project "Tabor to the river", 60% of the cost for sewer pipes repair was saved using green infrastructure, which resulted in further promoting the application of green infrastructure.

The City of Portland has become the world's model city of green infrastructure and many people visit the city to see the green infrastructure. The city has been ranked as "the most environmentally friendly city in the US," and hence more talented people have moved in there and related companies corresponded to them and built their offices there. Thus, the City of Portland has built a resilient city base using green infrastructure.

Photos 4-1, 4-2, 4-3, 4-4 Raingardens and bioswales in Portland City

2. The green infrastructure that New York City is actively developing

New York City held a competition "Rebuild by Design" for disaster prevention against hurricanes since a serious urban flooding occurred on the east coast of the US by Hurricane Sandy in 2012. The characteristics of the competition was that a mix of sectors got involved with projects at specific land areas. The BIG U, which is one of the participants in the competition, proposed a comprehensive plan at the lower Manhattan Island that not only mitigates the risk of flooding and downpour but also improves the issues of climate change and environmental problems, ecological network and recreation, and economic values. The rebuild design proposed in the plan corresponds to a question of what new and multi-purpose infrastructure is (**Photo 4-5**)[8)].

The High Line in New York City is a linear park (2.3 km) that uses former freight railroads and attracts people as greenery on artificial ground. The freight railroads have been abandoned and used to be a poor landscape, but it has been transformed to be an attractive sky garden with full of greenery, and the economic values around the park have increased to 300 billion JPY annually. The park is also functionalized as a green infrastructure facility as rainwater is retained and slowly infiltrated into underground during rainfall.

Figure 4-1 Sectional diagram of rain garden (2016) Rainwater infiltration base is installed under the rain garden (Ref: New York City)

Green Infrastructure Research Institute visited New York City on July 2016 and interviewed a representative of the city's green infrastructure division. There are more than 2,300 rain gardens (rainwater retention and infiltration facility) built in New York City, particularly in the Brooklyn borough. The rainwater retention capacity is 2,200 gallons (about 8.3 m^3) per rain garden (**Figure 4-1**), and hence the burden of rainwater discharge into sewers decreases by 19,000 m^3. The stormwater management will be implemented with a budget of $1.5 billion by 2030.

According to NYC Green Infrastructure Plan by Michael R. Bloomberg (a part of the preface), advanced street-pits mentioned in the preface means rain gardens which infiltrate rainwater. Also, economic rationality was pursued in the plan as Bloomberg mentions "we can achieve all of these benefits for billions of dollars less than the cost of the traditional tanks and tunnels that are useful only when it rains". Streets and residential areas are rebuilt in accordance with the plan.

Photo 4-5 Countermeasure plan for disaster prevention against hurricanes along the U-shaped region of lower Manhattan Island (Ref: ©The Big Team/Rebuild by Design)

3. Green infrastructure that is used for heat island mitigation in the City of Chicago

The City of Chicago faces to Lake Michigan and is located in a geographically harsh region as the weather dramatically changes between summer (42℃) and winter (-17℃). Also, the city has many heat island countermeasures because many skyscrapers worsen the phenomenon. Of the city's countermeasures, green infrastructure application on rooftops is characteristic. Millennium Park which is the world's largest rooftop garden built-in 2004 plays a role in rainwater retention and as an infiltration facility. Railways, large parking lots and concert halls have been constructed under the 10-ha park as if it were a city park built on natural ground. The park close to skyscrapers provides a natural atmosphere within the megacity.

Also, a large green roof is constructed on the top of the city office. Temperature in the maintenance-free greening section has found to be 30℃ lower than that in the remaining concrete section, and therefore the cool environment is provided even on the rooftop. The cost savings of air conditioning at the floor below the rooftop are estimated to be $3,600 annually due to the green roof. Bee farms are also installed on the rooftop garden which almost makes you forget that it is a rooftop. The green roof also provides unexpected advertisement effects and a number of people from all over the world visit there.

Thus, the green roof has become a place which allows us to realize that green rooves have great potential for green infrastructure in urban areas.

Regarding heat island countermeasure of the City of Chicago, Complete Street Project[9)] and Green Alley Project[10)] are a part of the countermeasures currently being progressed. **Photo 4-6** shows a conventional alley which is dark with puddles due to impervious road surface. **Photo 4-7** shows an alley renovated under the Green Alley Project which was installed with recycled aggregates under the ground in order to functionalize as rainwater retention and infiltration as well as heat island mitigation. The road surface is covered with pervious pavers, and maintenance methods have been developed by the City of Chicago. Thus, the new alleys are rapidly developed for heat island mitigation.

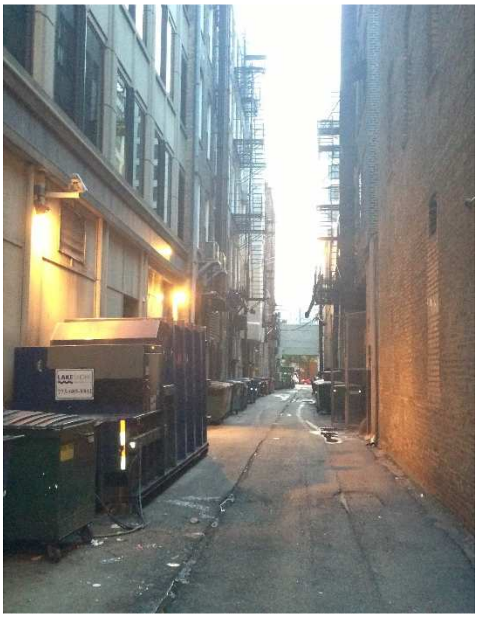


Photo 4-6 Conventional alley
It is dark even during daytime and puddles remain due to the impervious road surface

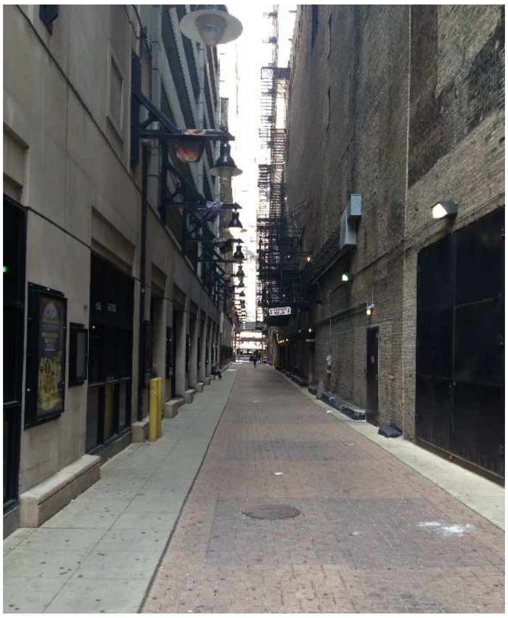


Photo 4-7 Alley after renovation
Road surface is covered with pervious interlocking blocks and recycled aggregates are installed under the ground which play a role as a rainwater retention and infiltration base (2014)

Chapter 05: Development of green infrastructure in Japan

In foreign countries, new urban development that makes effective use of green infrastructure is being progressed to improve the work and living environment. Then, is it possible to develop safe and rich cities and towns in Japan using the same technology? The answer is no. Urban structure, culture, geographic situation, and/or social situation vary amongst countries or regions, and hence the best green infrastructure technology is different accordingly. In the case of Japan, green infrastructure technology unique Japan is necessary which is adapted to the current national issues such as narrow city spaces, limited investments for public works, and increased management costs.

1. Fourteen elements of green infrastructure: Technological elements and situational elements

The organization promoting green infrastructure in the US is the United States Environmental Protection Agency (EPA). The EPA defines 11 items as green infrastructure elements[11]. To apply the green infrastructure to Japan, green parks, wall greenery and lawn square ground were added as technological elements and the 14 elements were categorized by either technological elements or situational elements[12]. Creation of various and multi-purpose infrastructure is important through combining the technological elements in various situations of urban development.

Technological elements

(1) Downspout Disconnection

Rooftop drainage pipes are rerouted from draining rainwater into the storm sewer to draining it into rain barrels, cisterns, or permeable areas. Downspout disconnection could be especially beneficial to cities with combined sewer systems (Photo: City of Portland)

(2) Rainwater Harvesting

Rainwater harvesting systems collect and store rainfall for later use. They slow and reduce runoff and provide a source of water for miscellaneous use in buildings as well as for emergency use during natural disasters. (Photo: Water level measurement in rainwater retention base)

(3) Rain Garden

Rain gardens collect and absorb runoff from rooftops, sidewalks and streets which can be installed in almost any unpaved space. They infiltrate the runoff into underground and treat it. They also can be natural habitats. (Photo: Kyoto Gakuen University, Uzumasa Campus, provided by Yukihiro Morimoto)

(4) Planter Boxes

Planter boxes are urban rain gardens with vertical walls and either open or closed bottoms. They collect and absorb runoff from sidewalks, parking lots and streets, and are ideal for space-limited sites in dense urban areas. (Photo: Portland State University)

(5) Bioswales

Bioswales are vegetated, mulched or xeriscape channels that provide treatment and retention as they move stormwater from one place to another. As linear features, they are particularly well suited to being placed along streets and parking lots. (Photo: City of Portland)

(6) Permeable Pavement

Permeable pavements infiltrate treat and/or store rainwater where it falls. They can be made of pervious concrete, porous asphalt or permeable interlocking pavers. (Photo: Morton Arboretum, City of Chicago)

Situational elements

(7) Green Alleys and Streets

Green streets and alleys are created by integrating green infrastructure elements into their design to store, Infiltrate, and evaporate stormwater. Permeable pavement, bioswales, planter boxes, and trees are among the elements that can be woven into street or alley design. (Photo: City of Chicago)

(8) Green Parking

Many green infrastructure elements can be seamlessly integrated into parking lot designs. Permeable pavements can be installed in sections of a lot and rain gardens and bioswales can be included in medians and along the parking lot perimeter. (Photo: Morton Arboretum, City of Chicago)

(9) Green Parks

Green parks can improve microclimate by previous pavers and evapotranspiration of trees through integrating green infrastructure elements into their design. They also enable rainwater circulation within the parks. (Photo: Grand Mall Park, City of Yokohama)

(10) Green Roofs

Green roofs are covered with artificial soil or natural soil and vegetation that enable rainfall infiltration and evapotranspiration of stored water as well as cooling effects. (Photo: Millennium Park, City of Chicago)

(11) Wall Greenery

Wall greenery reduces and slows downflow of rainwater hit to the walls. In case of planter types, they can slow and reduce runoff by retaining and infiltrating rainwater temporarily. Also, they provide temperature reduction effects by plants. (Photo: City of Portland)

(12) Lawn Square Ground

Lawn Square ground infiltrates rainwater effectively and can slow runoff as well as reduce and treat rainwater. They also can provide temperature reduction effects on road surface. (Photo: Shoemaker Plaza, City of Philadelphia)

(13) Urban Tree Canopy

Trees reduce and slow stormwater by intercepting precipitation in their leaves and branches. Also, tree canopy plays a role as a sunshade and decreases temperature. (Photo: City of Philadelphia)

(14) Land Conservation

The water quality and flooding impacts of urban stormwater also can be addressed by protecting and maintaining open spaces and sensitive natural areas within and adjacent to a city. (Photo: City of Seattle)

2. Development of rainwater retention & infiltration basin

J-Mix is a novel rainwater retention and infiltration base which enables Japanese-style green infrastructure. J-Mix is made of recycled concrete wastes (including other recycled aggregates) with a uniform particle size and coated its surface with humus. Void content ratio is 41% which can retain rainwater in the void sufficiently (**Photo 5-1**).

Humus buffers and keeps the pH of rainwater from alkalization occurred by recycled aggregates (as long as the retained rainwater is discharged from the base within 24 hours), as well as facilitates root growth through the voids. **Photo 5-2** shows a result of root growth 4 years and 4 months after installing recycled aggregates with (left) and without (right) humus coating under a camphor tree. The root growth was better in the recycled aggregates with humus coating (J-Mix) as the roots extended downward uniformly in the installed base, suggesting that the structure of J-Mix is suitable for plants.

Photo 5-1 Appearance of J-Mix (Void content ratio is 41%)

Photo 5-2 Root distribution of camphor tree 4 years and 4 months after planting. Root growth under recycled aggregates with humus coating (C: left section) was pretty good

3. From single to multiple functions

Conventionally built constructions made of concretes or plastics (grey infrastructure) for stormwater management work only during rainfall and is a single-purpose facility. In addition to the existing facilities, natural green infrastructure with multiple functions is expected in the future. Green infrastructure functions as rainwater retention infiltration and provides many benefits such as water treatment, pollutants removal, drought mitigation, groundwater recharge, microclimate improvement, and tree growth promotion (**Table 1-1**).

4. On-site infiltration of rainwater

In matured cities, tall buildings are built to stand in rows and road surface is covered by asphalt. Consequently, according to the data in Tokyo Prefecture, about 45% of rainfall has become discharged as surface runoff directly into sewers and rivers. Rainwater beyond cities' stormwater management capacity overflows and seriously damages the cities. In the United States, stormwater management has been advanced to capture on-site and infiltrate into the ground. For instance, downspouts were disconnected and natural rainwater infiltration systems such as rain gardens, planter boxes, bioswales, and pervious pavers were installed. **Figure 5-1** shows a conceptual diagram of green infrastructure in cities which infiltrates rainwater into the ground through rooftop gardens and rainwater retention and infiltration base built underground. It is important that stormwater is captured on-site in order not to be discharged directly into sewers.

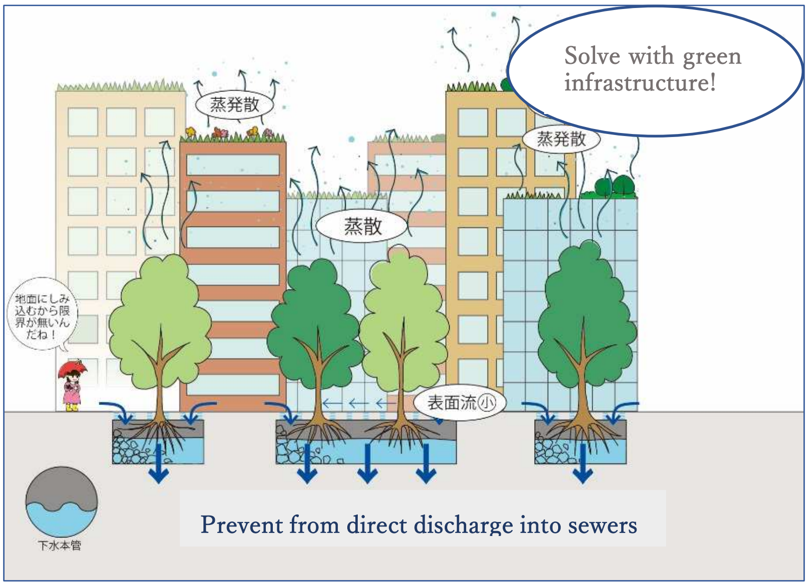


Figure 5-1 Cities need to elaborate stormwater management system to let rainwater infiltrate into the ground (Conceptual diagram)
The basic of green infrastructure is to reduce the amount of stormwater discharged into sewers by infiltrating rainwater into the ground

According to the City of Portland, more than 74% of rainwater was retained in rain gardens and peak flow was reduced by 81%, suggesting that on-site stormwater management can substantially reduce the burden of surface runoff flowing into sewers. In New York City, the infiltration amount of rainwater by rain gardens is huge (2,200 gallons (about 8.3 m^3) per garden), and the city plans to manage more than 1 inch (about 25 mm) of stormwater runoff from 10% impervious area using rain gardens.

However, large rain gardens in foreign countries with a space of one driveway lane cannot be accommodated in the narrow land area of Japan. Therefore, one of the feasible methods is to retain and infiltrate rainwater underground such as under the walkway (**Figure 5-2**). If the rainwater retention and infiltration base is installed on permeable ground (coefficient of permeability is more than 0.14 m/hour) with a dimension of 100 m long, 4 m wide and 0.6 m deep, about 157 m^3 of rainwater is captured and infiltrated. It is economically and simply installed with effective stormwater capture in permeable land area, and also an additional benefit of cooling down the streets by capillary action of rainwater occurred in the base is generated by this method.

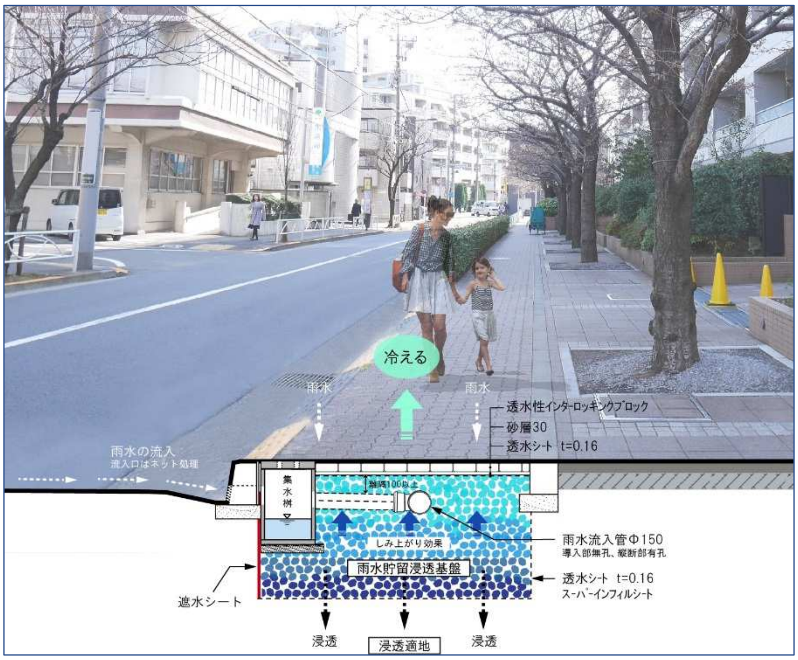


Figure 5-2 On-site method to capture rainwater fallen on road and walkway (Conceptual diagram)
Rainwater is captured and infiltrated with rainwater retention and infiltration base, as well as streets being cooled down by capillary action of rainwater occurred in the base. Also, the rainwater retention and infiltration base are good for planting. (Please contact us for further details of the road base system)

5. Utilization of rainwater

In the Architectural Institute of Japan Environmental Standards (AIJES) issued in 2011, the word "Amamizu-Katsuyou (rainwater utilization)" was defined. Utilized rainwater was named "Amamizu" which differentiates from stormwater or polluted water which is of no use and should be discharged away immediately. The word "Amamizu" was also used in the Act on the Advancement of Utilization Rainwater enacted in 2014. In March 2016, "Technical standards for rainwater harvesting" were issued by the Architectural Institute of Japan and a new term "Chiku-U (rain stock)" was defined[13)]. The term consists of 4 categories: disaster prevention, stormwater management, environmental resilience, and rainwater utilization. Coefficient of rain stock was also defined, and a rain stock height of 100 mm was targeted as a new approach. Also, a nonprofit organization, Rain City Support was established. Thus, a new era of "Amamizu" has kicked off in Japan.

6. Economical stormwater capture with lawn fields

Given that a countermeasure for surface runoff mitigation is applied throughout buildings or regions, a more economical and reasonable solution is found compared to a countermeasure applied to individual building.

In case of Tokyo's permeability assessment[14)] made in each land use, permeability in green fields is assessed to be 20 mm/hour in grass field and 50 mm/hour in lawn field as well as planted field. Therefore, reduction amount of surface runoff in a cubic meter of green field is estimated to be only 20 L or 50 L, respectively. This amount can be increased by installing rainwater retention and infiltration base under the green fields (**Figure 5-3**).

When a 200 mm deep rainwater retention and infiltration base is installed under green fields, quantity of infiltration Qf = influence coefficient C (0.81) × relative infiltration rate (calculated based on infiltration occurred only into the bottom layer) × saturated hydraulic conductivity f (0.14 m/hour) = 0.146 (m^3/hour), and then void retention amount 0.2 m × 41% = 0.81 (m^3/ m^2) is added to the value, which becomes 228 L of reduction amount of surface runoff in a cubic meter of green field. Given 600 m^3 of countermeasure for surface runoff mitigation required in one hectare of land development, it is fulfilled by allocating 27% of land for green field with water retention and infiltration base. Furthermore, it has been reported that the rainwater infiltration under green fields ended up becoming a good maintenance for them with a lower amount of irrigation.

Thus, the quality of green fields is enhanced and the cost for surface runoff reduction is decreased by installing shallow and wide rainwater retention and infiltration base.

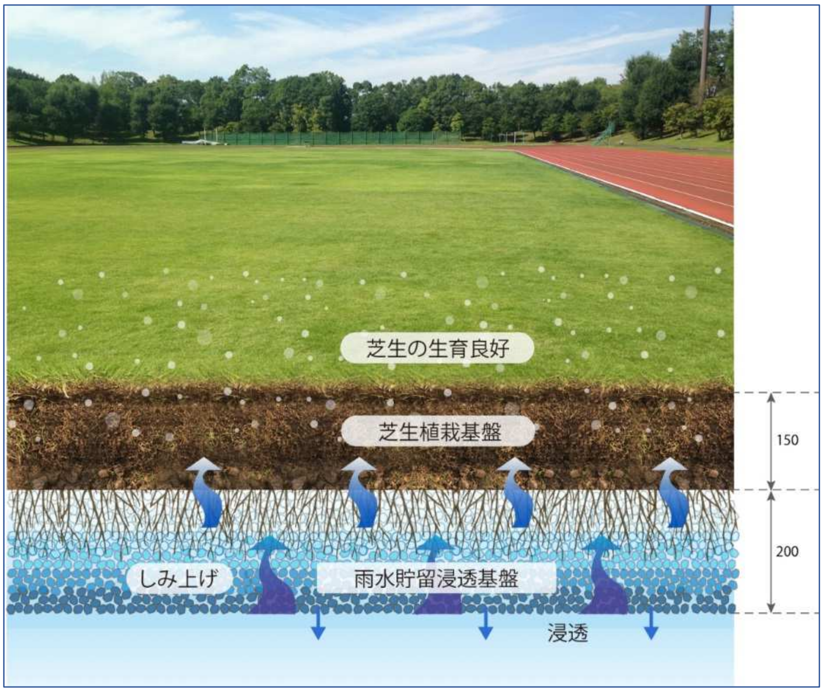


Figure 5-3 Stormwater management using lawn fields (Conceptual diagram)
Regional target amount of stormwater capture can be complemented by using lawn fields as a rainwater retention and infiltration tank. The figure shows an example of rainwater retention and infiltration base installed under a lawn field (100 mm deep) to enhance its quality.

Afterword

Green infrastructure is expanding all over the world. In Japan, it is becoming gradually recognized as a new concept that merges various fields such as environment, urban development, and disaster prevention/mitigation. However, we heard many voices starting that they do not know the method for exactly realizing this. Therefore, we made this brochure as a handbook that explains simply the green infrastructure method (draft) and its benefits. As mentioned at the first section in Chapter 01, this brochure was more focused on the installation of green infrastructure for rainwater countermeasures, but we hope that people, especially living in cities, will feel the attraction of green infrastructure as something that is relevant to their lives, through this brochure. We hope that green infrastructure will be adopted and take root in Japan as early as possible.

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