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Sustainable Strategies for the Dynamic Equilibrium of the Urban Stream, Cheonggyecheon

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Abstract. Cheonggyecheon, which had been transformed into a 14-lane urban highway and a large underground sewer system, was finally converted back to an urban stream again. Its transformation has been praised as a successful example of urban downtown regeneration and beautification. It is, however, obvious that there have not been prudent ecological considerations since the project's principal goals were to provide public recreational use and achieve maximum flood control capacity via the use of embankments. For a healthier and sustainable stream environment, Cheonggyecheon should be ecologically re-restored again, based on a dynamic equilibrium model. It must primarily establish a corridor of vegetation, an aquatic transitional zone, and install constructed wetlands nearby which support the water source. The upper streams of Cheonggyecheon should be further restored and supply natural waters. Furthermore, there ultimately needs to be de-channelization for hydrological sustainability. This would vary from merely increasing the sinuosity to thoroughly reconstruct a naturalized stream. Complete dynamic equilibrium of Cheonggyecheon can be accomplished through more fundamental sustainable strategies.

1. Introduction

The Cheonggyecheon restoration project of downtown Seoul, South Korea, was completed in 2005. "Cheonggye" indicates a geographic name of the stream and "cheon 천 (川)" means a stream in Korean. Korean normally calls the stream Cheonggyecheon [1]. We will call the Cheonggyecheon restoration project "CRP" briefly in this paper. CRP has been spotlighted as an example of successful downtown redevelopment and beautification through the stream restoration. The stream, which was covered by a multilayer infrastructure for vehicles during the 1960s, was reborn through demolishing a 6 km long, 10-lane concrete highway and transforming it into an attractive stream corridor (figure 1). While the CRP, however, has been regarded as a successful outcome for the regeneration of downtown Seoul [2-5], ecological and hydrological conditions in the restored stream have been criticized as an unsustainable product [6]. The enormous project was done in too short a time period, twenty-seven months, without far-sighted consideration of natural systems such as a self-sustaining dynamic over time and space, in what is defined as a 'dynamic equilibrium'. Although natural or human interventions to the stream could change environmental conditions, it allows the biological community to establish a dynamic equilibrium over time.

The dynamic equilibrium model was suggested by Huston. He argued that community diversity can be maintained by growth rates, a frequency of population reduction, or a low rate of competitive displacement. These variables are dependent and interactive among them. Through a trade-off in the dynamics, community diversity reaches a level of dynamic equilibrium, a point that the diversity may remain relatively constant over time. The dynamic balance is determined differently in different environments since the major parameters – frequency of reduction and rate of displacement – are showed with a wide range of variability there [7]. In this understanding, the dynamic equilibrium is mainly determined by the influence of species interaction to the environment rather than the relative competitive capability among the competing species [8]. In spite of frequent stream changes, a dynamic form of stability is persisted within a range of condition due to the dynamic equilibrium. For instance, although a flood event by heavy rainfall greatly influences the stream's environment and its ecosystems, a series of self-correcting mechanisms allows the ecosystems to adapt to sudden disturbances within a certain level. Human intervention, however, weakens or destroys self-sustaining tendencies of an ecosystem. Water contaminants, concrete channelization, and damming are formidable disturbances to keep from the natural resilience of the ecosystem. Therefore, stream restoration projects should remove the cause of the external stresses and disturbances and then ultimately achieve to regain self-sustaining ability and re-establish the desired state of the dynamic equilibrium. The dynamic equilibrium model has a significant implication for CRP which is struggling with ecological and environmental issues today. This paper aims to overview the CRP and its environmental and hydrological issues, and then proposes new sustainable ways to regain self-sustaining ability for the dynamic equilibrium in Cheonggyecheon.

Figure 1. CRP location in Seoul

2. Cheonggyecheon Restoration Project (CRP)

2.1. Project background and procedure

The Cheonggyecheon was historically and literally a 'valley of clean water'. As a tributary of the Han River, it has been a clean source in Seoul for several hundred years. It was a community place for housewives and children (figure 2). However, Seoul has remarkably developed with rapid urbanization and industrialization as a capital city of South Korea since the Korean War (1950-1953) and thus, the stream has become a large sewer and its banks turn to a place lined with the shanties of the poor (figure 3)[1].

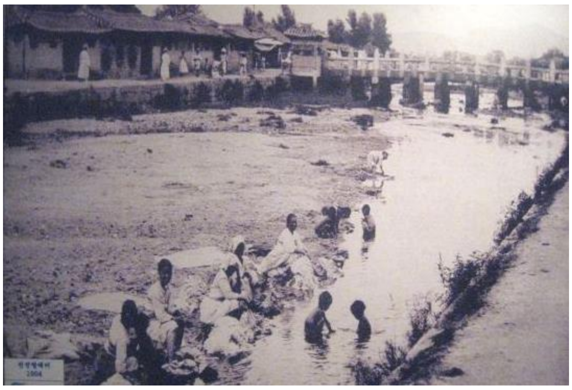

Figure 2. Cheonggyecheon in the 1900s [1]

Figure 3. Cheonggyecheon in the 1950s [1]

In the end of the 1960s, Seoul proposed a plan to cover the stream and build a 10 lane-highway system on it. The construction of the new roads stimulated economic growth in the area and substantially contributed to the establishment of an industrial and commercial center there (figure 4). In the mid-1970s, elevated inner city highways of four lanes were additionally constructed on the roads to meet increasing traffic demands (figure 5) [9]. These infrastructures have played a significant role in the dramatic economic development of Seoul for several decades later. They have been considered a symbol of modern urban growth in Korea and other Korean cities have tried to apply this approach to the redevelopment of their contaminated urban streams.

Figure 4. Road construction in the 1960s [1]

Figure 5. Urban highway in the 1970s [1]

Despite the initial success of the CRP, the downtown started to decline due to the relocation of heavy industries to the periphery of Seoul, and air quality around the highway became highly polluted in the 1980s. Moreover, a critical security issue was raised with concerns about the structural instability of the aging highway and harmfulness of detrimental gases under the covered road [9]. A proposal to restore the stream, CRP, came into the public spotlight and was a major issue in the election of a mayor of Seoul in 2003. The city of Seoul launched the CRP soon after the election. The initial stage was to remove the elevated highway of 5.4 km (figure 6).

The city and the participating construction companies tried to carry out the project as quickly as possible, in an effort to minimize the potential of severe flood events, which frequently accompany heavy rainfall in the area during the summer season, to disturb the construction [6]. Nearby merchants conducted a series of demonstrations protesting economic losses to their businesses. Traffic control was also a critical issue since the existing fourteen-lane roads into just a four-lane road was too radical changes in the downtown accompanying a high traffic demand. Critics argued that CRP should be a long-term project in consideration of a financial cost, traffic congestion and restoration of historic relics under the covered road. Despite these issues, the CRP procedure was completed in 27 months by a strong leadership of the city mayor (figure 7). In the five years since the project was implemented, there have been remarkable environmental and ecological changes in and around Cheonggyecheon.

The air quality has been improved and urban heat island has been diminished[10]. In addition, the number of fish, bird, and insects has increased every year in the restored stream. However, there occurred hydrological issues with water quality problems.

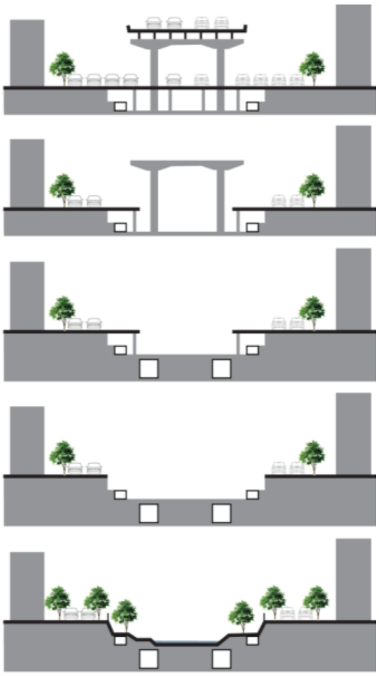

Figure 6. Road demolition and stream restoration procedure [11]

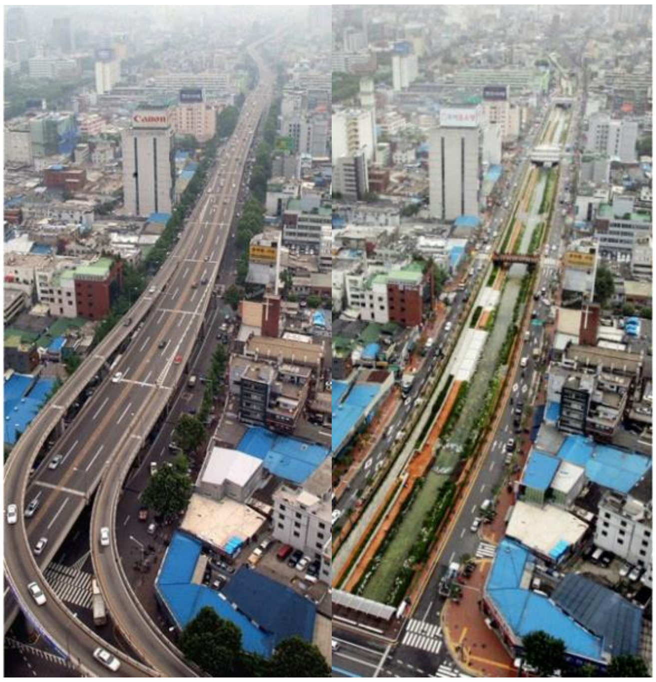

Figure 7. Transformation of the urban highway to the carnal[1]

2.2. Ecological and environmental issues

Historically, Cheonggyecheon was a seasonal stream with water flow in summer and mostly dry in the winter. However, the CRP planned year-round water flow to encourage human access to the stream and a variety of urban recreation activities. To keep consistent velocity with appropriate depth, a huge quantity of water was required. The primary water supply source of 98,000m3/day was conveyed through pipelines from the Han River, located 15 km away (figure 9). An additional 22,000 m3/day of groundwater, infiltrated into the existing subway tunnels, was collected and discharged into cheonggyecheon at several points through fountains and waterfalls. To minimize water losses from the restored channel by 3%, bentonite mats of fine clay layers were laid over the more permeable upstream riverbed and sheet pile walls were installed along each side (figure 8)[12]. In addition, combined sewer overflow (CSO) system was applied and it influenced the hydrological environment of the CRP. It results in high water levels and strong flows through the system after storms, creating flashy conditions that scour the bottom and affect habitat quality in the stream [13].

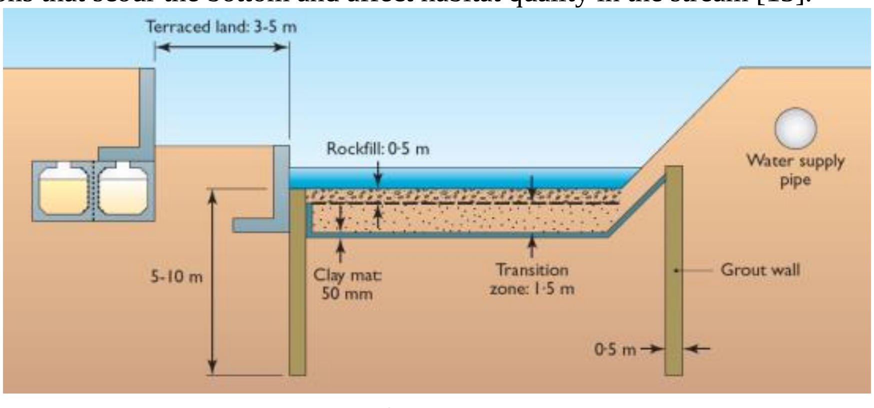

Figure 8. Section of the urban carnal in CPR [1]

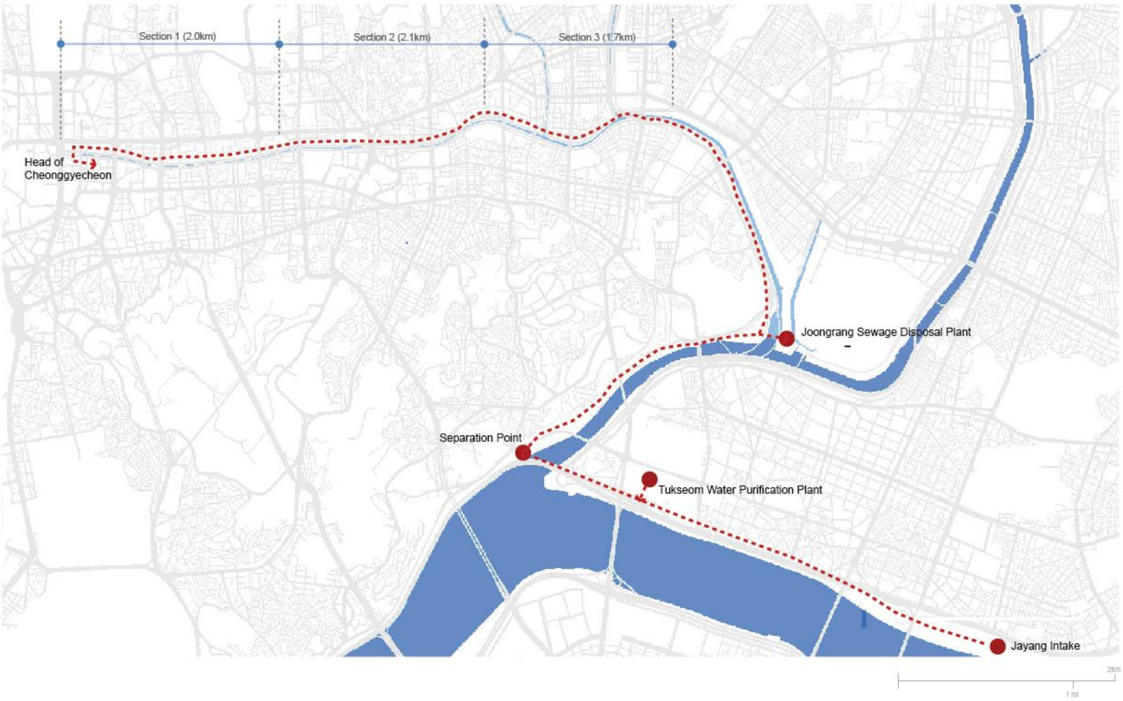

Figure 9. CRP water supply system [11]

Since CRP was completed in 2005, Cheonggyecheon has suffered from several problems with water quality[14]. Algae blooms have emerged over years (figure 10). The rapid accumulation of algae populations occurred in the whole water course in the spring and fall, March to May, and again October to November, and algae bloom were found in the upstream reaches in the summer and winter, from June to September and between December and February [15, 16]. This had negative impacts on the aquatic ecosystems. The algae blooms are closely associated with excess phosphorous and nitrogen levels in the water which are produced from sewage, wastewater treatment plants, and improperly functioning septic systems. Excess nutrients usually lead to eutrophication, resulting in ecological imbalances that cause the overgrowth of plants and animals and the discoloration of the water. It negatively impacts the aquatic environment, causing problems such as anoxia, water quality degradation, and reduction of fish and plant populations [17]. The main water source for Cheonggyecheon is not natural water from the mountains but rather chemically treated water that is piped from the Han River. And then the treated wastewater discharges into the upstream of the Cheonggyecheon intake point, and the water treatment process does not remove phosphorus and nitrogen. As a result, the algae blooms occur when they meet with sufficient sunlight into the stream. Furthermore, mass mortality of fish has occurred after heavy rainfall in the Cheonggyecheon area. According to the data from Seoul, it is estimated that the quantity of fish death reaches approximately 2,000 for last 10 years [18]. It has mostly resulted from the combined sewer overflows (CSOs) containing untreated wastewater discharges into the surface water. Combined discharges of untreated wastewater and storm water runoff overflowed into Cheonggyecheon whenever rainfall intensity exceeded approximately 0.02 mm/h. Dissolved oxygen is crucial for fish and other aquatic life. Dissolved oxygen concentrations are significantly impacted by CSOs in receiving water [19]. The mass death of Cheonggyecheon fish is closely associated with the reduction of dissolved oxygen level by CSOs [18].

The problems of fish kills and algal bloom create ecologically and aesthetically unpleasing conditions. There could be also public health concerns associated with continued fish kills and algae blooms. The problems with water quality and hydrology would prevent the stream community from continuing to recover to the extent that it could if those problems were not present. Improvements in both hydrological conditions and water quality could enhance the restored stream’s value both as habitat and a recreational and aesthetic resource for the city’s people.

Figure 10. Algae bloom in Cheonggyecheon [16]

3. Proposed strategies for sustainable Cheonggyecheon environment

Compared with the previous polluted and degraded environment of covered roads and elevated urban highways, the CRP has certainly had a significant positive effect, in that it has brought Cheonggyecheon back as a stream following the removal of highway infrastructure. In addition, it has been a successful example of urban regeneration with respect to air quality improvement and dramatic growth in real estate values around Cheonggyecheon. It is, thus, regarded as a successful urban regeneration by stream restoration. However, we argue that the CRP should be reconsidered with an understanding of ecological dynamics for sustainable nature. Confronting environmental and ecological issues such as algae blooms and mass mortality of fish, the CRP needs to reintegrate the lost natural dynamics of the stream and design with nature. It should ultimately pursue restoration of ecological function, which improves the Cheonggyecheon environment over time. We would propose two significant solutions to the current ecological problems of the CRP: the vegetation of the aquatic terrestrial transition zone (ATTZ) and the constructed wetlands for treatment of source water.

3.1. Vegetation of aquatic terrestrial transition zone (ATTZ)

The practice of vegetation in the ATTZ is one way to re-establish the dynamic equilibrium in the environment. Cheonggyecheon was channelized with a concrete material and enclosed with the purpose of intensive management for public recreation and flood control. Much of the ecological stream corridor was not considered and was simply confined to a narrow linear space [6]. Vegetation buffers are few between the upstream and midstream. The proposed vegetated corridor along the ATTZ can ecologically and environmentally benefit to communities. The vegetated ATTZ can serve as a meeting point for land and water, and terrestrial and freshwater organisms over time and space and it contributes to the richness of aquatic and terrestrial habitats [20]. Thus, the diversity and abundance of the species play a significant role to achieve an ecologically valuable self-recovering and self-sustaining system [21, 22]. While the population of wildlife species has been gradually augmented at Cheonggyecheon every year, its diversity is pretty limited and a majority has been discovered at downstream, located a short distance away from Han River [23]. Thus, networked vegetation of ATTZ should be created in the whole stream area in order to facilitate species movement and access leading to the dynamic equilibrium.

The vegetation corridor also functions as flooding control [22]. The CRP has been striving to control flooding events and their water flow in the summer season. The vegetated buffers in the floodplain have an effect to reduce the velocity of floodwaters. The roughness of their surfaces leads floodwaters to be temporarily detained and gradually released with infiltration to the bottom for groundwater recharge. As result, it diminishes the swiftness of the water flow and flood peaks. Water quality and temperature can be also protected by the vegetated ATTZ [24]. Current critical Cheonggyecheon issues, which are the algae blooms and the massive losses of fish by combined sewer overflows (CSOs) in the rainy season, have occurred due to the degraded water quality. As the vegetation buffer corridor can temporarily retain water and assimilate pollutants of surface water and CSOs, such as sediments, nutrients and pathogens, it helps to keep from contaminating the stream water. Moreover, shades of trees and shrubs lead consistent temperature of the water, which affects the algae bloom event and dissolved oxygen concentrations of Cheonggyecheon. When heated water meets excessive nutrients in a stream, it provides adequate conditions to multiply blue-green algae into a bloom, which usually displace aquatic food source. Meanwhile, the solubility of dissolved oxygen, which is necessary for fish, declines in a high temperature of the water since the oxygen level is inversely proportional to the temperature in the water. In this perspective, shading of the vegetation can play a significant role to deal with the critical issues of Cheonggyecheon by stabilizing the water temperature. The vegetated ATTZ will obviously strengthen the resilience of the ecosystem and make a healthy aquatic habitat in Cheonggyecheon.

There are many strategies and repair practices to ecologically enrich the ATTZ: vegetation establishment, root wad revetments, live crib walls, live stakes, and so forth [25]. Especially, Cheonggyecheon requires an effective vegetation type selection to consider the environmental solutions. The Table 1 indicates effectiveness of different vegetation types for specific buffer benefits. The trees have remarkable benefits to water quality, aquatic habitat, flood control, and visual effects. The groups of grasses particularly work effectively for filtering to improve water quality. The ATTZ of upstream and midstream in Cheonggyecheon, where is located nearby downtown and frequently produce algae blooms, should be vegetated with more trees and grass than shrubs in order to maximize filtering effects, aquatic habitat and visual interest.

Table 1. Effectiveness of different vegetation types for specific buffer benefits [26]

Benefits	Grass	Shrub	Tree
Stabilize streambank			
Filter sediments, nutrients, pesticides, and pathogens			
Filter nutrients, pesticides, and microbes from surface water			
Protect groundwater and drinking water supplies			
Improve aquatic habitat			
Improve wildlife habitat for field animals			
Improve wildlife habitat for forest animals			
Provide economically valued products			
Provide visual interest			
Protect against flooding			

3.2. Constructed wetland

As to the algae bloom issue, the critical problem is the water supply system which dominantly conveys Han River water to the head of Cheonggyecheon upstream and discharges into the stream after a chemical treatment in a sewage disposal plant. Within the current water circulation, there is no process to filter large amounts of phosphorous and nitrogen. High levels of phosphorus and nitrogen cause eutrophication and algae bloom in Cheonggyecheon [15, 16, 18, 27]. We propose installing constructed wetlands at discharging points of upstream water source in Cheonggyecheon, since the wetlands can play a remarkable role in removing BOD, TSS, organic nitrogen, and phosphorous from the source water, and can also provide a habitat and public recreational benefits. There is a substantial body of literature about the construction and use of treatment wetlands for the improvement of water quality, and many well-implemented examples can be found [28-30].

Constructed treatment wetlands can be defined as engineered or constructed wetlands that enhance water quality through transforming or removing contaminants with physical, chemical, and biological mechanisms. It takes advantage of natural processes with a combination of wetland vegetation, soils, and their related microbial assemblages. A key role of the wetland is to improve water quality. The most significant concern for Cheonggyecheon's algae bloom is the treatment of nitrogen and phosphorous. While septic and primary tank effluents would include organic nitrogen and ammonia, the treatment pond is able to change reduced or oxidized forms of nitrogen, and phosphorous in a system of the constructed wetland. Nitrogen is removed by flocculation, sedimentation, filtration, and interception processes in the system (figure 11). The sustainable phosphate removal process is achieved by the accretion and burial of phosphate within the wetland sediments (figure 12) [28]. Treatment wetlands can be engineered to take care of a range of concentrations of contaminants, from removing relatively high levels of nutrients from the municipal wastewater to cleanse the storm water of sediments, metal, nutrients, and other contaminants.

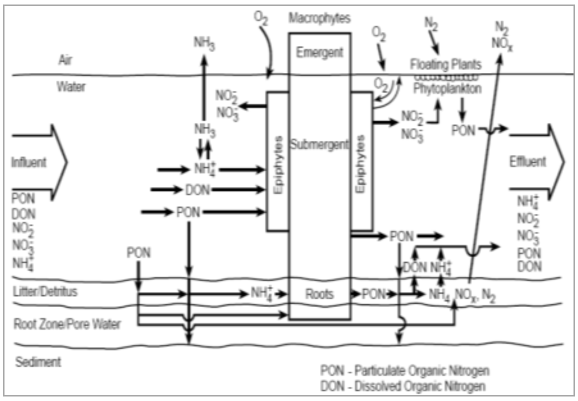

Figure 11. Nitrogen Transformation (FWS wetland)[28]

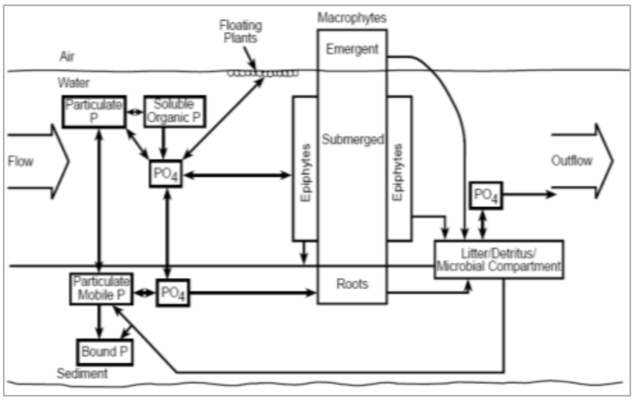

Figure 12. Phosphorus cycling (FWS wetland)[28]

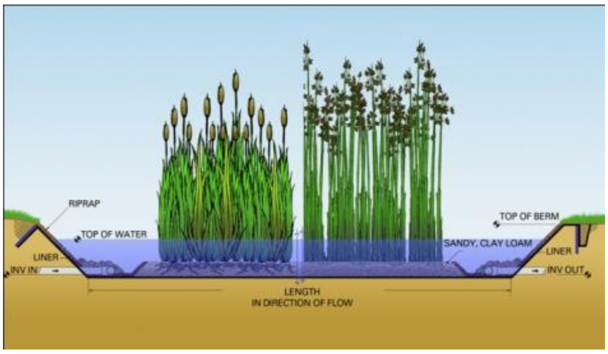

Figure 13. Free water surface wetland(FWS) [31]

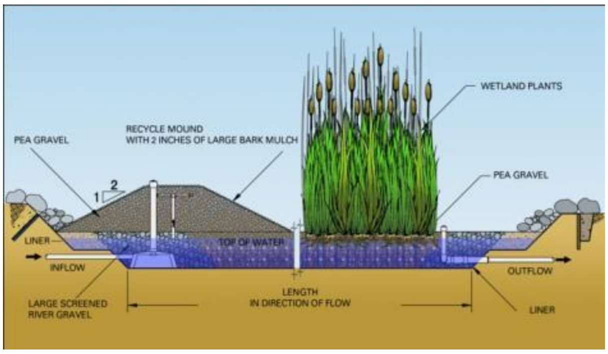

Figure 14. Vegetated submerged bed wetland(VSB) [31]

There are two sorts of constructed wetland: free water surface system (FWS) and vegetated submerged bed (VSB) system. A FWS system is typically similar to a natural wetland in terms of physical structure and performance. It consists of various combinations of open-water areas and fully vegetated surface areas, and outlet structures. To prevent water loss, subsurface is made by fine clay or impervious geotechnical materials and sufficient soils in order to support the growing vegetation. The FWS system is characterized with shallow water depth, low flow velocity, and linear channels for plug-flow conditions. The berms and inlet and outlet structures serve as a regulation and distribution of wastewater flow (figure 13). The VSB system, on the other hand, consists of gravel beds, which allow wetland vegetation to grow, with an impermeable clay layer of subsurface. Water flow is controlled by, not only the inlet and outlet structure like the FWS, but also gravel size and shape in a transverse channel (figure 14). The VSB has more diversity to create physical aesthetics of the wetland with the optional choice of gravel and vegetation. However, FWS has performed better in the water treatment process [28, 31].

Figure 15. Water source from upstream of Cheonggyecheon

Figure 16. Upstream of Cheonggyecheon

For the Cheonggyecheon issues, the constructed wetlands can be installed with a combination of FWS and VSB systems. The FWS system can be dominantly installed at a discharge point of the stream head since algae blooms have frequently occurred at upstream and midstream areas. More than half of the supplying water, which contains excess phosphorous and nitrogen, discharges into the stream head and requires high performance of a constructed wetland. The stream head area of Cheonggyecheon consists of an urban plaza with a hard floor and an underground reservoir for discharge (figure 15, 16). Although the plaza can offer a space for the cultural events of a downtown, more environmental benefits and visual interests can be provided by installing a constructed wetland in the plaza. In other words, it can accomplish as not only a water quality improvement through a natural filtering process, but plaza beautification with natural settings. Furthermore, the constructed wetlands can be established in connection with several CSOs discharge points along Cheonggyecheon. They can serve as detention ponds there and filter pollutants of CSOs. Seoul City has been struggling to physically remove increasing algae by cleaners and sprinkler trucks. It leads to a huge cost of the clean-up. Unless natural resilience can be restored, economic and ecological sustainability is hardly achieved in Cheonggyecheon. We assert that high performance of the constructed wetland helps to lead progressive advances of ecological function and dynamic equilibrium.

4. Conclusion

Cheonggyecheon, which had been transformed into a 14-lane urban highway, and then into a large sewer, was finally converted back to an urban stream again. Its transformation has been praised as a successful example of urban downtown regeneration and beautification. It is, however, obvious that there have not been prudent ecological considerations since the project's principal goals were to provide public recreational use and achieve maximum flood control capacity via the use of embankments. For a healthier and sustainable stream environment, Cheonggyecheon should be ecologically re-restored again, based on a dynamic equilibrium model. By confronting the current water quality issue, which causes algae bloom and does not allow a suitable environment for fish, Cheonggyecheon must primarily establish a corridor of vegetation, an aquatic transitional zone, and install constructed wetlands nearby which support the water source.

Furthermore, when pondering a long-term Cheonggyecheon restoration plan, more fundamental sustainable strategies must be applied. For instance, the upper streams of Cheonggyecheon should be further restored and supply natural waters. A combined sewer system should become a separate system equipped to handle both excess rainwater and sewage. In addition to these hydrological ideas, there needs to be de-channelization to create favourable conditions for riparian vegetation recruitment. This will help to encourage the biodiversity of riparian ecosystems, enhancing water quality, and sustaining the health of the stream environment. This would vary from merely increasing the sinuosity to reconstruct a naturalized stream thoroughly. The complete dynamic equilibrium of Cheonggyecheon can be accomplished through these strategies.

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