Urban Stream Restoration & Daylighting — Is Boston Ready for Another Emerald Necklace?

Totally or partially restoring waterways in urban settings can offset their costs by bringing in economic, social and environmental benefits to the localized urban areas as well as to the city as a whole.

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For millennia urban streams and rivers have been the lifelines of many cities and an integral part of the urban landscape. Paris has its Seine, Rome has the Tiber, London is on the Thames, Milwaukee has the Milwaukee River and Boston has the Charles River. In all cases, these water bodies spurred city development in the past and often resulted in city core demise when these rivers became highly polluted a century ago. Boston is now enjoying a revival of its river bank and new residential developments are being built on the bank of the Charles River after the recent clean-up. This revival can be viewed as a major accomplishment considering that a couple of decades ago the Charles River was ranked as one of the most polluted rivers in the nation.[1]

Until the middle of the nineteenth century, the pollution problem of urban streams was mostly due to urban runoff and flooding. Some side streets were unpaved and partially permeable. Human excreta from outhouses and latrines were collected in tanks that were emptied periodically by private haulers. To alleviate the flooding and the nuisance problem due to runoff, many cities at the beginning of the industrial age built storm sewers. However, in the second half of the nineteenth century these storm sewers became combined sewers due to the invention of flush toilets, which were connected from individual buildings to existing storm sewer lines. Because of the continuing discharges of heavily polluted urban runoff contaminated with feces from animals (mostly horses) and from humans via building sewer outlets, the pollution of urban

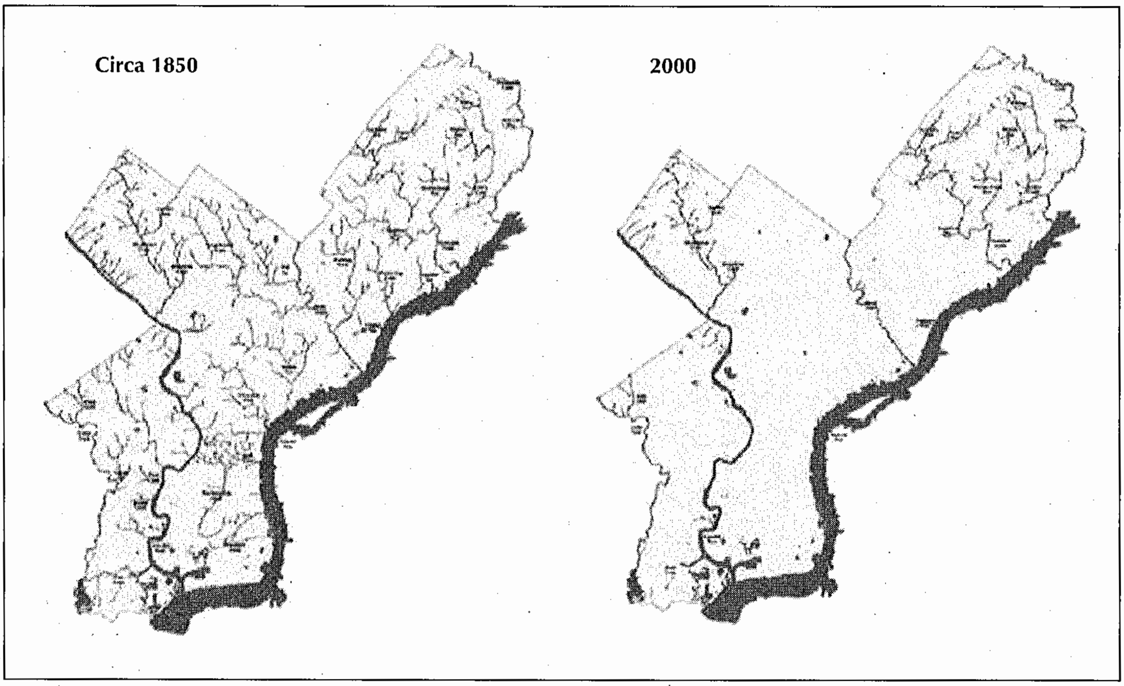

FIGURE 1. Urban surface streams in Philadelphia. To the left is a map of the city circa 1850; to the right is a map from 2000. ***(Courtesy of Howard Neukrung, City of Philadelphia.)***

rivers became unbearable and most smaller rivers became open sewers.

At the end of the nineteenth century, communities were building combined sewers and, later on, treatment plants as engineering methods to solve the problem of polluted surface waters. The goal of pollution control was fast conveyance of wastewater and urban runoff out of sight from the source to the nearest large water body. At the same time, impervious pavements were being placed on roadways throughout cities, thus preventing rainfall from infiltrating the ground. Concurrently, increased withdrawals of water from urban streams reduced the base flow needed for the dilution of pollutant loads between rain events. During dry weather, some streams carried a large amount of sewage, which made them effluent dominated. Effluent-dominated streams are those that during at least some time of the year carry mostly treated or even untreated sewage and wastewater.[2] The aim of these fast conveyance urban drainage systems (sewers, lined and buried streams) was to remove large volumes of polluted water as quickly as possible, protecting both public safety and property and discharging these flows without treatment into the nearest receiving water body.

A century ago horse-drawn wagons and coaches made up the majority of the street traffic. In the absence of effective treatment technologies to remove putrescible pollution from sewer outfalls and polluted urban runoff, city engineers and developers of that time resorted to grandiose projects in order to alleviate the pollution problems. In Boston, between 1857 and 1890, several square miles of tidal marsh of the Charles River estuary (what is now the Back Bay area) that were plagued by standing sewage pools were filled and converted to upscale urban development. This effort more than doubled the size of the city. At the same time, because of poor water quality — including bad odors and flooding — unsightly urban streams were buried into underground culverts and essentially converted to combined sewers. Such was the case with Stony Brook in Boston. The only visible reminders of this stream are place names such as Stony Brook Park or Stony Brook Subway Station. Many

Boston residents do not know that a medium-size historic river existed in the city one hundred fifty years ago.

The history of the disappearance of urban streams by burying them is not unique to Boston. The practice is ubiquitous to almost every large city in developed countries. Over a relatively short period of fifty to one hundred years, many urban streams that flowed freely from before the middle of the nineteenth century have disappeared from the surface and the urban landscape. Figure 1 shows the example of Philadelphia. Only the largest streams (for example, the Charles River in Boston) remained, mostly polluted, on the surface at the end of the nineteenth century.

The Emerging New Paradigm of Urban Drainage of Integrated Waste/Stormwater/Wastewater Management

Mitigating Urban Flooding. Building storm and combined sewers did not alleviate urban flooding problems and the increased use of impervious surfaces exacerbated flooding. Storm sewers were traditionally designed to carry flows resulting from storms having a recurrence interval of once in five to ten years. The capacity of combined sewers is generally six times the dry weather flow, which means that every rain with an intensity of approximately 3 millimeters (0.1 inches) per hour will result in an overflow. This overflow initiating flow rate is related to the generally accepted dimensioning of combined sewers to have design capacity at about six times the dry weather sewage flow.[3,4]

In parts of Tokyo, which is highly impervious, floods occur with a frequency of once in two years. Because the land in cities became highly valuable for development, cities expanded into floodplains. To minimize flooding, streams were straightened, diked and lined in order to increase the velocity and the streams' capacity to carry more flow. Figure 2 shows the Los Angeles River today, a concrete fast-flow flood conveyance channel that, during flooding, often has supercritical flow, especially under bridges. Increasing the velocity during high flows creates adverse safety problems, which are especially dangerous to children wanting to play or falling into the supercritical flow sections during floods. The answer to this problem was to fence off the streams. Streams lined with concrete or similar masonry materials cannot support aquatic life and the result is equivalent to putting them underground. The rivers converted into flood conveyance channels also received overflows from combined sewers and stormwater runoff (see Figure 3). Hence, lining streams and building sewers did not resolve neither the flooding nor pollution problems. At best, the problem was moved downstream and accentuated.

Rediscovering Urban Rivers. Many cities have viewed sewer separation as a solution to the pollution caused by combined sewer overflows (CSOs) — thus, creating a dual system, one for sewage and other wastewater, and the second for cleaner yet still sometimes unacceptably polluted urban stormwater runoff, snowmelt and clean upstream flow (such as in the watershed of Stony Brook). Separating flows was deemed beneficial by many wastewater utilities since it eliminated the need to treat stormwater (which is costly). However, pollution problems were not fully solved by separating combined sewers. Current and future regulations require discharge permits and further removal of pollutants from storm sewers, which may require the installation of costly and inefficient end-of-pipe stormwater treatment systems. It does not provide any social benefit to put cleaner stormwater back underground into a storm sewer. Even in dense areas, best management practices (BMPs) for surface water management are available for incorporation into the landscape in order to prevent and/or control storm runoff and snowmelt pollution and to recharge groundwater resources, which in Boston would be needed to prevent the subsidence of historic buildings (especially in the Back Bay area, which is built on the old tidal marsh area).[4,5]

For the past decade, urban planners, landscape architects and environmental visionaries have been promoting an approach to maximizing surface water in urban areas. Cities that make use of this approach have been termed *water-centric, sustainable, ecocities* or *cities of the future*. Some fundamental concepts

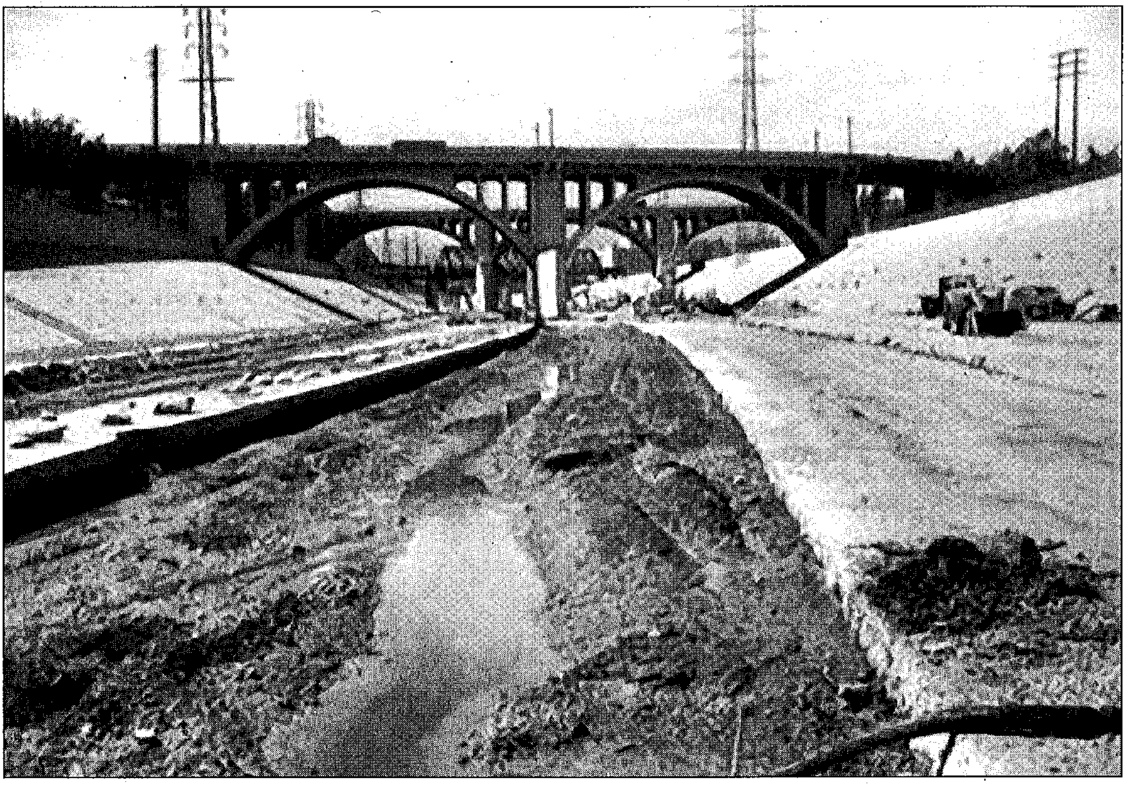

FIGURE 2. A view of the Los Angeles River. This river was once a natural river but it was converted into a lifeless flood conveyance channel with no connection to the population living nearby. The river in some sections is a perrenial effluent-dominated channel; in other sections, it has no dry weather flow. *(Courtesy of the U.S. Army Corps of Engineers, National Archives.)*

have emerged and what seemed to be an utopian vision ten years ago is becoming a reality.[6-8] Developing concepts of "Cities of the Future" is now a major effort of the International Water Association (IWA) and the Water Environment Federation (WEF), as well as of visionary urban planners and architects. One of the major goals of water-centric eco-cities is to significantly reduce water use by reclaming used water (in this approach, using the term *wastewater* is not appropriate because the intent is not to waste water), rain water harvesting and capture, and the use of runoff. Ecocity concepts build on the concepts of low impact development (LID) but differentiate from LID by more stringent performance criteria that also include net zero carbon footprint.[9] In both approaches, storm drainage is on the surface, combined and storm sewers become obsolete, and surface water bodies are integral and dominant features of the landscape. Cities such as Malmö and Göteborg in Sweden and Zurich in Switzerland have most of their storm and clean water drainage on the surface. By cleaning up both sewage using advanced treatment and urban runoff by settling, biofilters and other BMPs, restored and daylighted streams become a resource from which clean water and energy can be reclaimed.

Ideally, the fundamental goal of restoration is to return the ecosystem to a condition that approximates its condition prior to disturbance.[10-13] This approach does not mean that a densely built urban environment would be returned to a pristine state or, more likely, to agricultural land that preceded its development. The goal is to have ecologically and hydrologically functioning urban system in which rain water would recharge aquifers and natural sys-

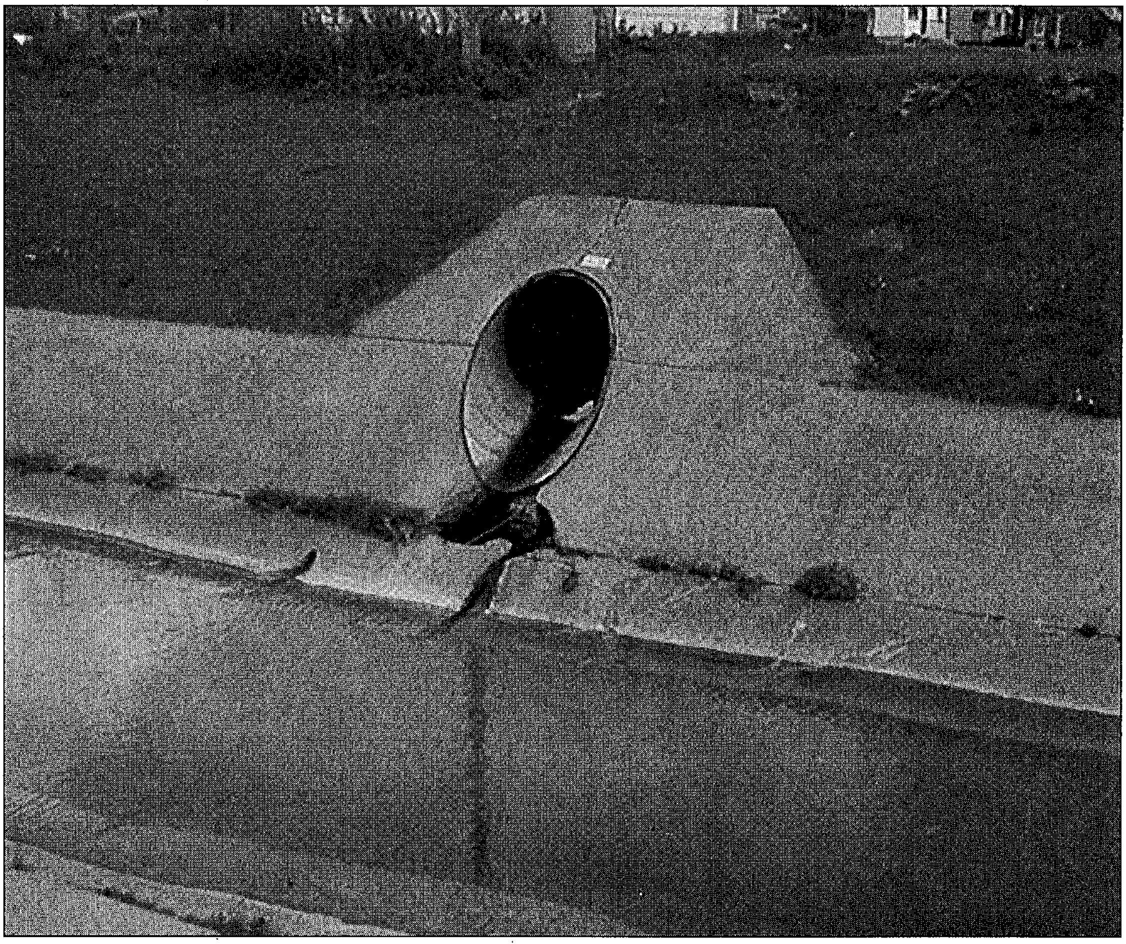

FIGURE 3. A view of Lincoln Creek in Milwaukee before restoration in the 1990s. The stream was a concrete-lined channel that received CSOs.

tems would be interconnected, expanded and protected. Currently, a compromise between the ecological goals and economic reality may be necessary in some places and LID professionals are sometimes focusing on the most feasible solution, recognizing that pre-disturbance conditions are not immediately achievable given the money, time and politics involved.

Daylighting is a more recent term used to describe uncovering buried and highly modified underground culverted streams by restoring the surface water body ecological functions and conducting landscape enhancement. Current preserved or restored, as well as daylighted, water bodies are generally an integral part of an ecological green urban corridor.

For more than one hundred and fifty years landscape/urban development architects, beginning with Frederick Law Olmstead, recognized the value of water bodies for recreation, enjoyment and health of urban populations. Cleaning up urban streams can be a force to attract people back to the cities from the suburbs, thus increasing real estate values near these water resources. Today, cities are also beginning to rediscover the increased economic and social value of water bodies, large and small, transecting their urban areas. Citizens and city governments now realize that streams buried by unrestricted development have intrinsic no social and economic value. As a matter of fact, the areas above and around buried streams in most cases deteriorated and left disadvantaged populations in dilapidated neighborhoods.

FIGURE 4. Cheonggye overpass built a 10-lane road over the Cheonggyecheon River in Seoul in the 1980s. Alternate public transportation by electric buses and subway replaced the traffic capacity lost by removing the overpass. ***(Courtesy Seoul City.)***

Realizing only economic and social gains without addressing the environment and pollution may not be sustainable but the economic and social revitalization success of daylighting of urban rivers and their restoration have shown the attractiveness of these projects. For example, after some clean-up, cities such as San Antonio in Texas and Ghent in Belgium have modified and beautified their abandoned streams and Ghent is now opening (daylighting) its buried water bodies — in each instance the economic benefits far surpass the restoration costs. The most dramatic case of discovery and metamorphosis of a lost water body occurred in the early 2000s in Seoul (see Figures 4 and 5). Examples of other stream restoration projects are listed in Table 1. Pinkham[14] and France[15] list additional case studies.

The Cheonggyecheon River in Seoul (Republic of Korea) is an artificial river without an upstream flow, which was lost by the urbanization of the watershed.[16] Flow is provided during dry periods by pumping 1.4 cubic meters (1.8 cubic yards) per second of water from the large Han River located about 15 kilometers (9.3 miles) downstream. This pumping requires a lot of energy, which makes the project carbon negative. Also, almost no BMPs (such as pervious pavements and other infiltration that could restore base flow) have been implemented in the watershed, resulting in frequent CSOs. A warning system has been installed along the river asking people to leave the paths along the river because of the CSOs and high flow danger occurring at times when rainfall intensity exceeds 5 millimeters (0.2 inches) per hour.

However, the above three examples, no matter how architecturally attractive they might be, are not sustainable based on the triple bottom line (economic, social and environmental) assessment. All three examples provide substantial economic benefits, including increased tourism, higher values of real estate and businesses surrounding

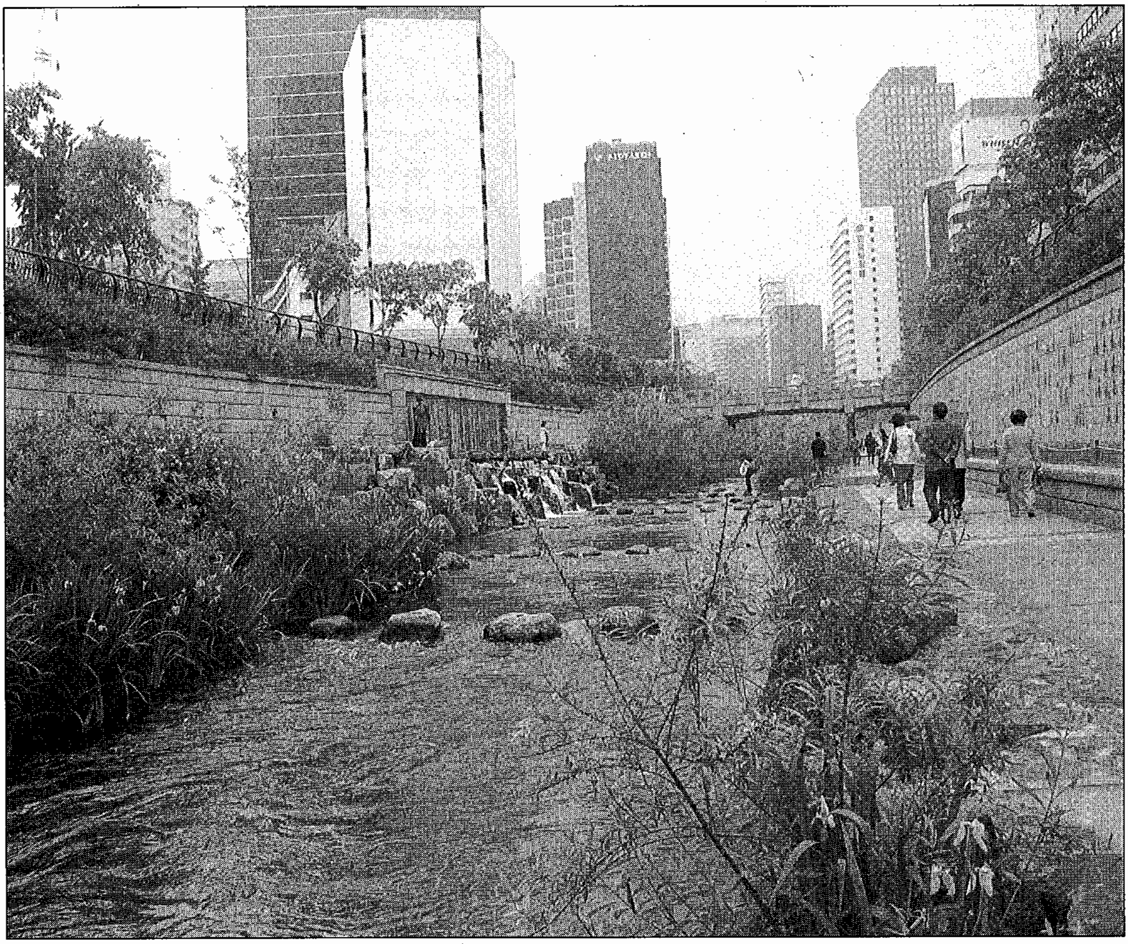

FIGURE 5. A view of the recreated Cheonggyecheon River in 2008. The river forms a 6-kilometer (3.7-mile) -long urban oasis and cultural center in Seoul. This photo shows the stepping stones that allow people close contact with the river and provide water cascade for aeration.

the river and social benefits to people for enjoyment, pleasant environment and employment. However, the San Antonio River is not ecologically and also not hydrologically functional (it is essentially an impounded concrete-lined channel that in some places suffers from hypoxia or even anoxia and cannot support a sustainable and healthy fish population). Canals in Ghent also provide poor habitat and in 2008 still suffered from pollution by CSOs that had not been fully abated.

The Cheonggyencheon River in Seoul is a highly sophisticated hydraulic system with engineered CSO discharges, parallel sewer lines and pipelines bringing flow to the river. Nevertheless, this type of river restoration project ultimately may not be fully replicated elsewhere on the same scale. On the other hand, water quality in the river is relatively good, habitat has been established and the river supports fish population.

New Developments & Retrofitting — Renaturalizing the Urban Landscape. The goal of stream restoration is not simply to bring buried streams to the surface as an architectural decoration. Daylighting and restoration revitalizes urban areas and neighborhoods by restoring, as much as possible, the ecological corridor adjacent to the stream. This effort is similar to what Frederick Law Olmsted achieved one hundred forty years ago in the

TABLE 1.
Examples of Stream Restoration & Daylighting

River	Location	Type of Modification	Main Benefits
Providence River	Providence, Rhode Island	Daylighting the river in the downtown area, urban landscaping	River festivals, riverside restaurants, cafes, pedestrian paths, fishing, boating
Lincoln Creek	Milwaukee, Wisconsin	Renaturalization of 15 kilometers (9.2 miles) of the creek by removing concrete lining, wetland & habitat restoration, flood storage, control of CSOs	Elimination of flooding for 2,000 homes, restoration of flora & fauna, water quality improvement, recreational fishing, parks, neighborhood revitalization
Emscher River	Ruhr District, Germany	Formerly a raw effluent dominated surface sewer; raw sewage inputs & concrete lining were removed; renaturalization, brownfield remediation; connecting river with monuments of old heavy industrialization	Recreational & educational benefits; significant water quality improvement; the river is located in the formerly most industrialized part of Germany, the entire watershed is being converted to a memorial of old industrialization
San Antonio River	San Antonio, Texas	Engineered concrete-lined impounded channel, in places aerated with cascades, very poor habitat & relatively poor water quality	Economic benefits from tourism, conventions, downtown revitalization, social benefits of employment & aesthetics
Cheonggyecheon River	Seoul, South Korea	Engineered recreation of a manmade river in the historic downtown Seoul fed by pumping flow from another larger river, good habitat with functioning flora & fauna, receives CSOs	Large economic benefits of downtown commerce & business revitalization, tourism, & a cultural center, controlled flood & CSO conveyance, aesthetics
Strawberry Creek	Berkeley, California	Daylighted & restored creek from subsurface culvert; water quality improvements by control of illicit connections, recreating habitat & introduction of flora & fauna	University of California campus beautification, education, water quality, the daylighting project continues to downtown Berkeley
Arcadia Creek	Kalamazoo, Michigan	Daylighted three blocks of concrete lined channel (no renaturalization) & two blocks of open pond in densely populated downtown district, poor habitat	Flood control benefits & downtown beautification
Streams in Zurich	Zurich, Switzerland	20 kilometers (12.4 miles) of streams buried in the city have been daylighted and renaturalized, additional 15 kilometers (9.2 miles) revitalized, base flow & habitat recreated	Daylighting highly desired by the population, brooks & creeks have been recreated even in dense parts of the city, drainage for clean water

TABLE 2.
Natural Systems & Their Equivalent BMPs

Natural Systems	Nature-Mimicking BMPs
Watershed With Infiltration	Pervious pavements, green roofs with French drains, rain garden infiltration of roof downspout excess water, bioretention, other infiltration practices.
Ephemeral Pre-Stream Channels	Rain gardens, vegetated buffers or sand filters connected to landscaped swales or dry storage ponds for flood water.
1st Order Perennial Streams With Base Water Flow From: ■ Springs ■ Headwater Wetlands ■ Headwater Lakes	Daylighted, restored or created streams with base flow from: ■ Groundwater infiltration ■ Clean water inputs from dewatering basements or condensation from air conditioners ■ Decentralized high efficiency treatment plant effluents ■ Restored or created wetlands ■ Wet ponds with stored stormwater
2nd Order Streams	Restored original streams with reclaimed floodplains & riparian wetlands; floodplain converted to recreational park & buffer zones; storage in lakes & ponds in the reclaimed floodplains.
3rd & Higher Order Streams	Removal of channelization & impoundments wherever possible, providing passage to migrating fish & flood storage. Significant portion of flow may originate from upstream non-urbanized areas.

Note: From Ref. 2

Muddy River Watershed in Boston, which was originally muddy undeveloped land. Therefore, restoration should restore the hydrology of the watershed to a more natural status and create ecological functioning ecotones between the restored water body and the built surroundings. These goals can be accomplished by implementing various BMPs, including rain gardens, pervious pavements, biofilters, infiltration, swales, etc. Table 2 presents a comparison of natural and equivalent BMP systems and restored streams. It shows that each natural hydrological and ecological feature can be replicated by BMPs and stream restoration. Furthermore, landscape architects realized the hydrological and ecological functionality of BMPs and, as a result, BMPs are not aimed only at treatment but also on the prevention of pollution.

The proposed drainage concept for Stony Brook contains BMPs featured in many urban stormwater management manuals.[4] The novelty is only in using them in an integrated context of the urban landscape and the total hydrologic cycle as an alternative to the traditional fast-conveyance subsurface drainage. The concepts were introduced in Novotny and Hill[17] and also covered in Novotny.[2] Stream restoration and management technologies are extensively covered in the Interagency Task Force manual.[13]

Establishing base (dry weather) flow in daylighted/restored urban streams is a challenge because groundwater regime has been greatly altered by imperviousness and sewering and cannot be restored solely by landscape BMPs. New sources of base flow, in addition to increasing groundwater recharge by infil-

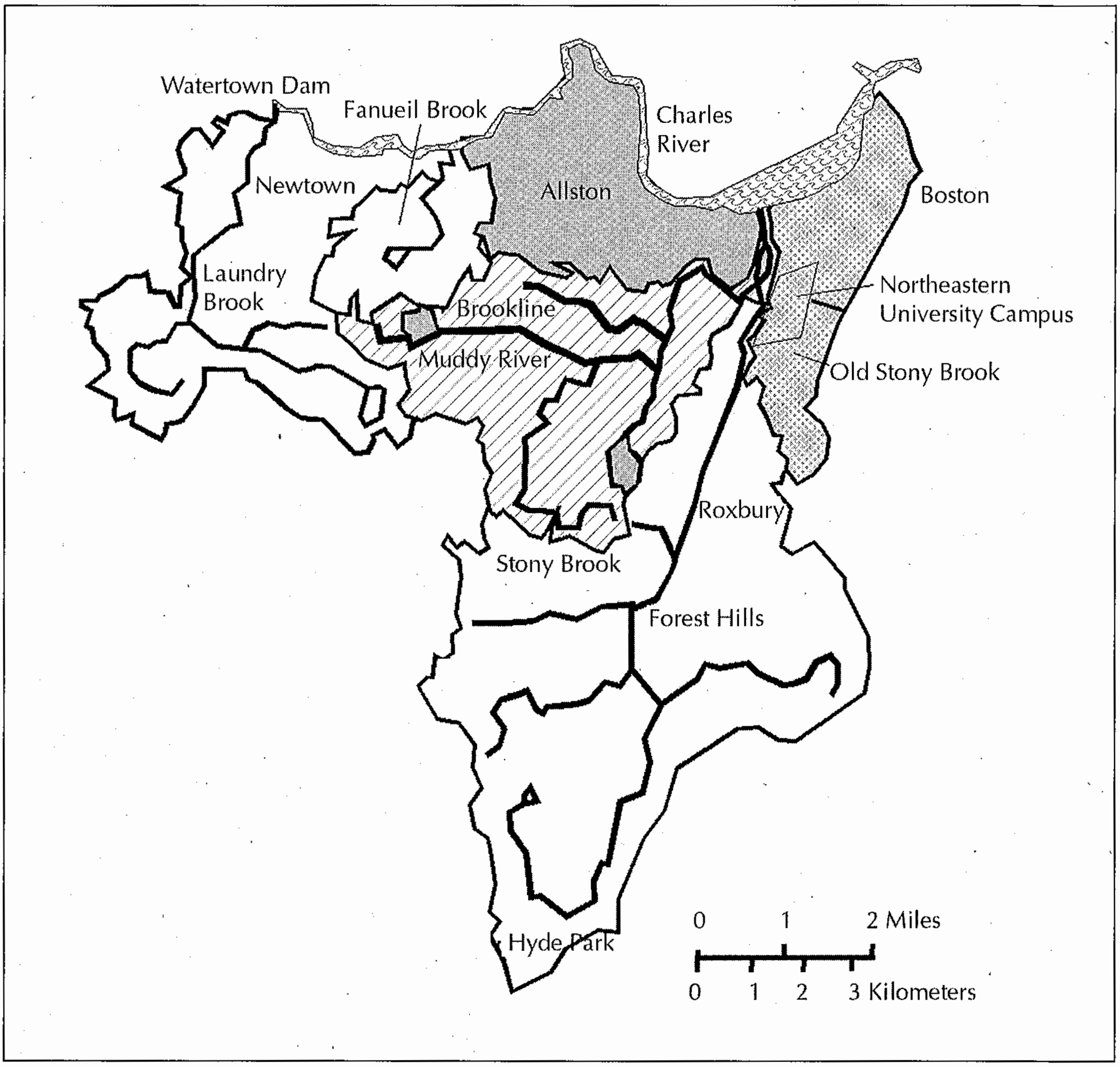

FIGURE 6. Map of the Stony Brook and surrounding watersheds.

tration BMPs, may also include clean water from dewatering basements, underground garages and tunnels, as well as from highly treated effluent discharges. These efforts may require a small satellite water reclamation (treatment) plant that would retrieve a portion of sewer flow, treat it to a high degree and reuse the water locally for various purposes such as toilet flushing, irrigation, cooling and providing ecological flow to restored streams.[18]

Daylighting Stony Brook

The Stony Brook watershed is located south of the Muddy River and has an area of 35.8 square kilometers (13.84 square miles), larger than that of the Muddy River (see Figure 6). The headwaters are in the Stony Brook Reservation in Hyde Park. Before the early 1800s, the brook's flow was unusually clean and clear. It became a vital and an important water resource due to the development of the area between Forest Hills, Roxbury and the present Northeastern University campus.[17] The area surrounding the brook attracted many breweries and other industries that eventually disappeared in the second half of the twentieth century. Because of flooding, the brook was sequentially "tamed" since the 1830s by channelization and later by culverts.[19]

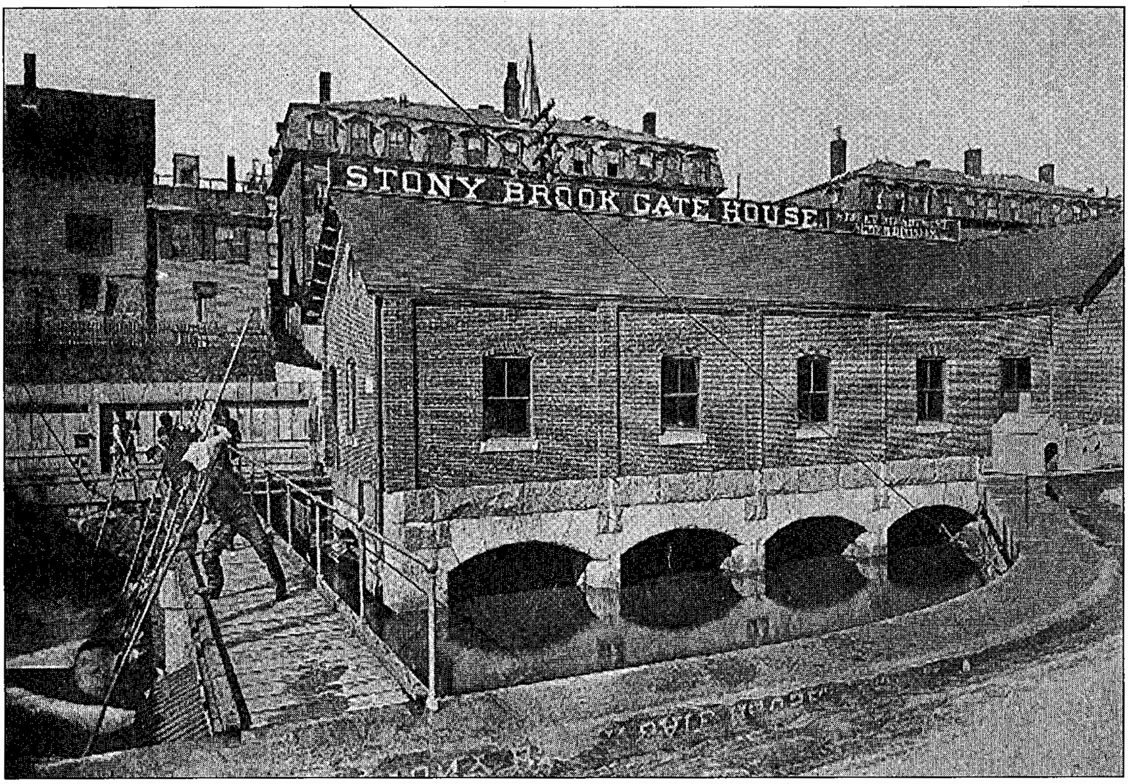

FIGURE 7. A picture of the gate house of Stony Brook (with screens) before the stream entered underground. ***(Published in the City Records and Boston News-Letter. Courtesy of BostonHistory.TypePad.com.)***

In the second half of the 1800s, lowlands in the neighborhoods into which the brook was discharging became terminal sewage pools. Periodic epidemics swept through the adjacent neighborhoods regularly. Raw sewage from Stony Brook flowed directly into the tidal Back Bay, with environmentally destructive results. Historian Cynthia Zaitzevsky describes the effect of sewage on the Back Bay:[20]

> "[T]he residue lay on the mud flats, baking odiferously in the sun. Eventually it became incorporated into the mud. Under these conditions, the last vestiges of the salt marsh could not remain healthy for long. When the park commissioned surveyed the area in 1877, animal life was no longer able to survive in the waters of the Back Bay."

The gate house shown in Figure 7 is gone today but the river still flows underground, paralleling the Orange Line mass transit corridor and discharging its flow into the Charles River. To control flooding, Stony Brook was converted from an open-walled channel in 1873 to a large culvert (4.7 by 5.2 meters [15.67 by 17.33 feet]) and in some sections into a double conduit (2.5 by 2.7 meters [8.25 by 9.5 feet]) combined sewer in 1934 (see Figure 8). The location of the original channel was changed for the culvert, separating the watershed of the brook into a "New" Stony Brook that carries most of the flow from the watershed and an "Old" Stony Brook, which carries today combined flows from the Northeastern University (NEU) campus and the area of Roxbury south between Columbus, Tremont and Washington streets. The New Stony Brook borders the Northeastern University campus and flows under Parker Street. It now carries all of the natural flow of Stony Brook, urban runoff flows from areas of Jamaica Plains between Forest Hills and the Museum of Fine

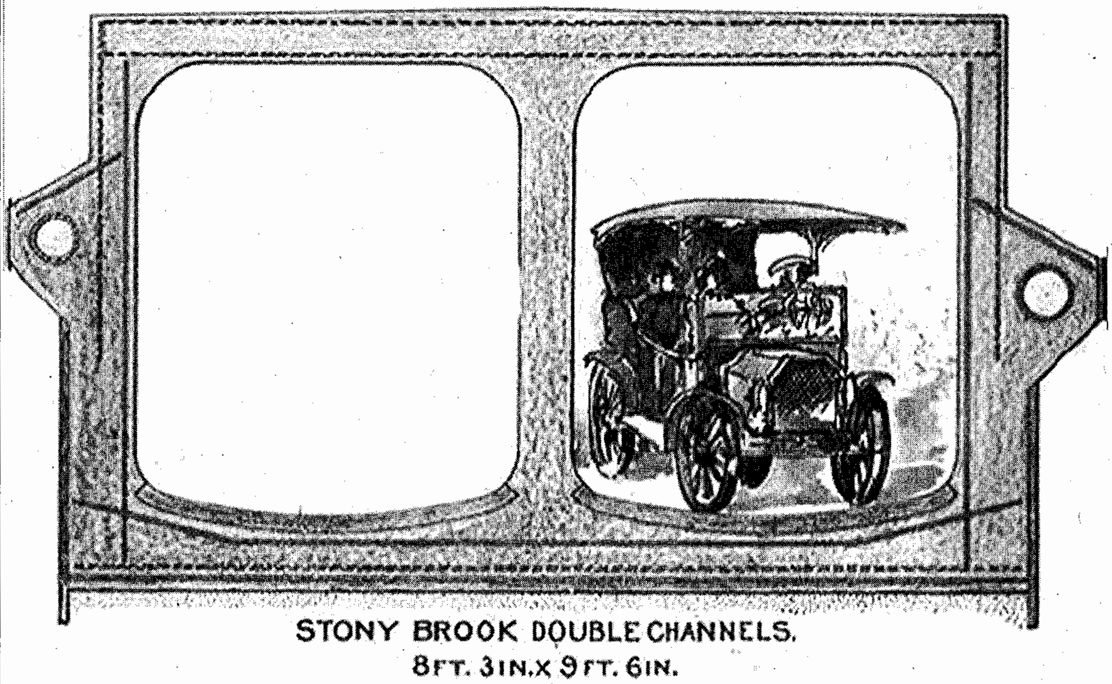

FIGURE 8. A double culvert of the underground Stony Brook.

Arts, and clean water infiltration into the culverts (see Figure 9). The New Stony Brook discharges into the Charles River via the Boston Gatehouse #1 and the Charles Gatehouse behind the Museum of Science. Currently, the bottom of the culvert is about 6.5 meters (21 feet) below Parker Street.

The Old Stony Brook is contained in two large culverts under Forsyth Street transecting the campus of NEU between the Ruggles T Station and the Muddy River (see Figure 9). The Old Stony Brook is essentially a combined sewer, cut off from its headwater flow, with infiltration between rain events. At the bank of the Muddy River it is diverted to the Prison Point CSO Facility via Boston Gatehouse #2.

In the new millennium, between 2002 and 2007, the entire New Stony Brook between Forest Hills and Muddy River was separated and a new sewer was built for collecting sewage. The relatively clean water originating in the Stony Brook headwater nature conservancy area upstream is now flowing mostly in oversized underground single and double culvert storm sewers. The Old Stony Brook remains a combined sewer.

Meanwhile, since Stony Brook was buried in the 1930s a large portion of a once very lively and important part of the city that used to surround the brook has deteriorated. Daylighting Stony Brook could bring significant city revitalization benefits that would enhance the quality of life for people living in the areas of Roslindale, Forest Hills, Roxbury and Jamaica Plain where Stony Brook is buried.

Daylighting Proposal. Three teams of NEU senior students, in their capstone design projects under the guidance of the engineers/mentors from the Charles River Watershed Association, and one team of graduate students analyzed the potential of daylighting Stony Brook on the NEU campus as well as on neighboring areas. The NEU campus suffers from frequent flooding of basements, the latest in 2008. The last disastrous flood of NEU and surrounding areas occurred in 1996. Since not much has been done in the watersheds of

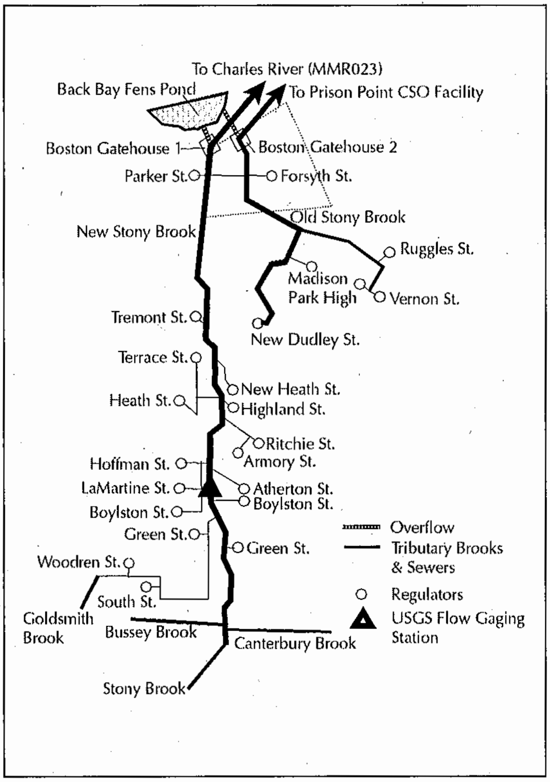

FIGURE 9. A map of the culverted Stony Brook, with locations of the Old and New Stony Brook culverts. ***(Replotted from the U.S. Geological Survey.)***

Stony Brook and more campus development with impervious area was added, it is safe to conclude that the area is still in the one hundred year flood zone, with more frequent basement flooding to come. Basements at NEU have laboratories, university stores, classrooms, shops and underground passages (tunnels).

The objectives and tasks given to the students by their instructor were to:

- Rediscover Stony Brook and consider daylighting to revitalize the NEU campus and surrounding neighborhoods by connecting the campus and areas in Roxbury, to Olmsted's Emerald Necklace of Muddy River;
- Make the daylighted stream an asset to the campus — as a place where students could relax and study the hydrology and ecology of urban streams;
- Consider revitalizing the surrounding neighborhoods;
- Develop viable hydrology of the daylighted stream with a permanent natural base flow and address the flooding problem of the campus; and,
- Consider in the design also "greening" of the campus to reduce flows and pollution by urban runoff from the campus and surrounding contributing watershed by implementing BMPs such as green roofs, pervious pavements and rain gardens.

It should be pointed out that most of the undergraduate students on the teams were a part of the junior "Hydrologic Engineering" class that entered the 2007 GE-MTV Ecomagination national student contest in which they were runner-up [out of more than one hundred entries] with their design of the "Green Campus" hydrology. This student project proposed and evaluated BMPs on the campus such as green roofs (to retain rainfall and provide insulation to the mostly flat roof buildings on the campus in order to reduce their carbon footprint), infiltration in raingardens and treatment of surface runoff in swales and biofilters. The project found that by modeling with the Hydraflow model based on National Resources Conservation Service (NRCS, formerly the Soil Conservation Service) Runoff Curve Number that the hundred year flood flow from the campus can be reduced by 15 to 25 percent.

Daylighting the New Stony Brook under the Parker Street was rejected by the teams because this street and Ruggles Street are important traffic arteries. Parker Street is also in a densely built environment. Furthermore, it would not alleviate the flooding problem because most stormwater from the campus discharges into Old Stony Brook (see Figures 6 and 10). Daylighting New Stony Brook under Parker Street would be very difficult, disruptive and would bring little or no benefits to the community. The teams focused on Forsyth Street, which currently does not carry traffic and is an unsightly dead end street that connects Huntington Street with the Ruggles T Station. This street with the daylighted stream could become a pedestrian mall in the middle

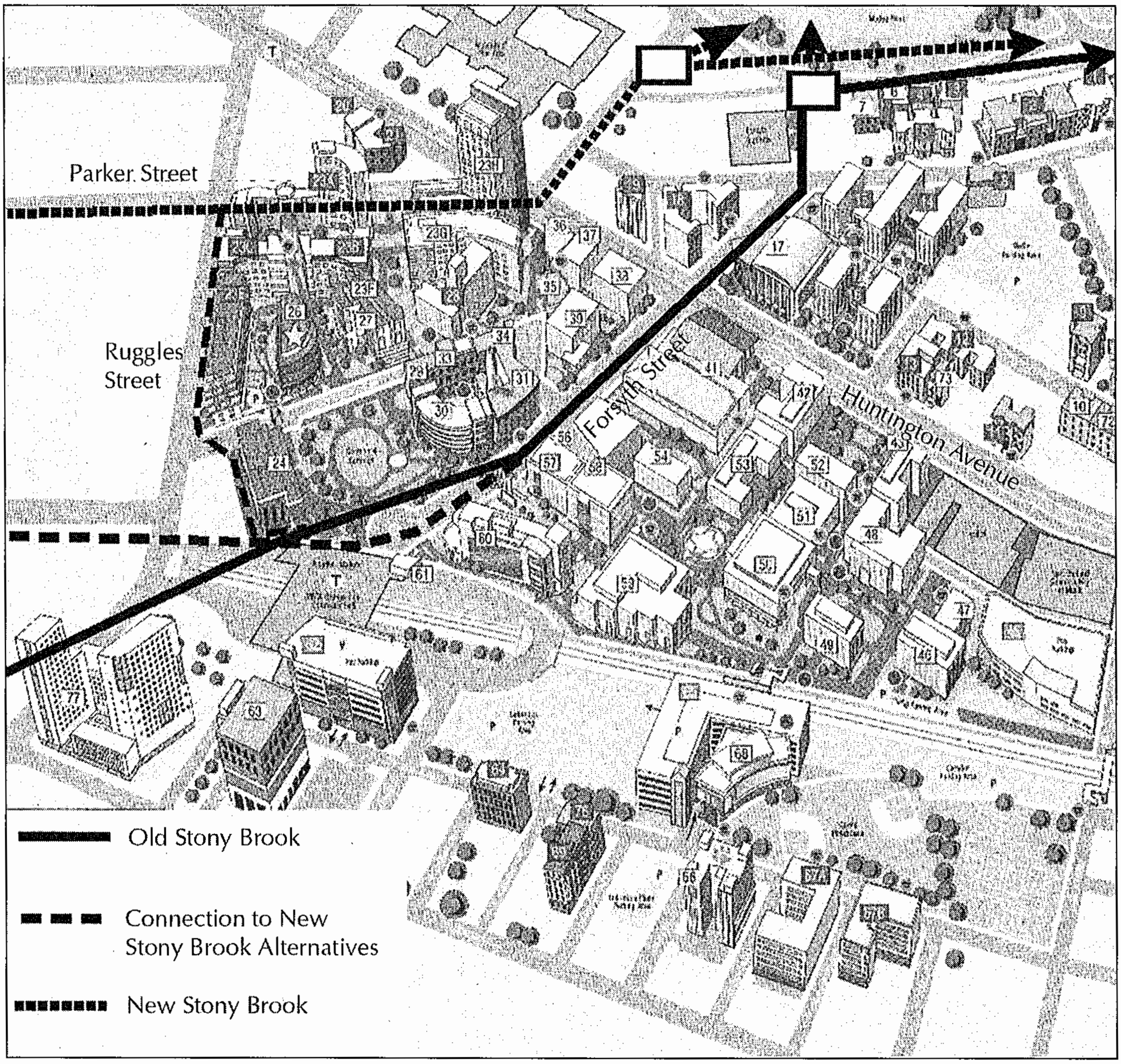

FIGURE 10. NEU campus map with Stony Brook alternatives.

of the campus, connecting the campus with the Fens and opening the university to those who arrive by train or subway. The stream would also provide educational opportunities to study the ecology of urban streams and also would provide opportunities for students to relax. The teams developed three alternative designs as shown in Figures 10 and 11.

Alternative 1. This alternative was a new near-surface channel over the existing culverts under Forsyth Street that would receive base flow (0.15 cubic meters [5 cubic feet] per second) from New Stony Brook by a pumping station located at the intersection of Parker and Ruggles streets, connecting with the Old Stony Brook location north of the Ruggles T Station. The low flow of New Stony Brook is about twice the flow to be withdrawn. It would also receive treated stormwater and clean water discharges (basement sump pump flows and condensate from air conditioning systems) from the surrounding campus. Forsyth Street would become a pedestrian mall allowing emergency vehicular access (fire trucks and ambulances). The rendering of this channel is shown in Figure 12. The channel connected with the "greener" campus surface drainage could be designed to carry one hundred year runoff as calculated by the Hydraflow software based in the NRCS Runoff Curve

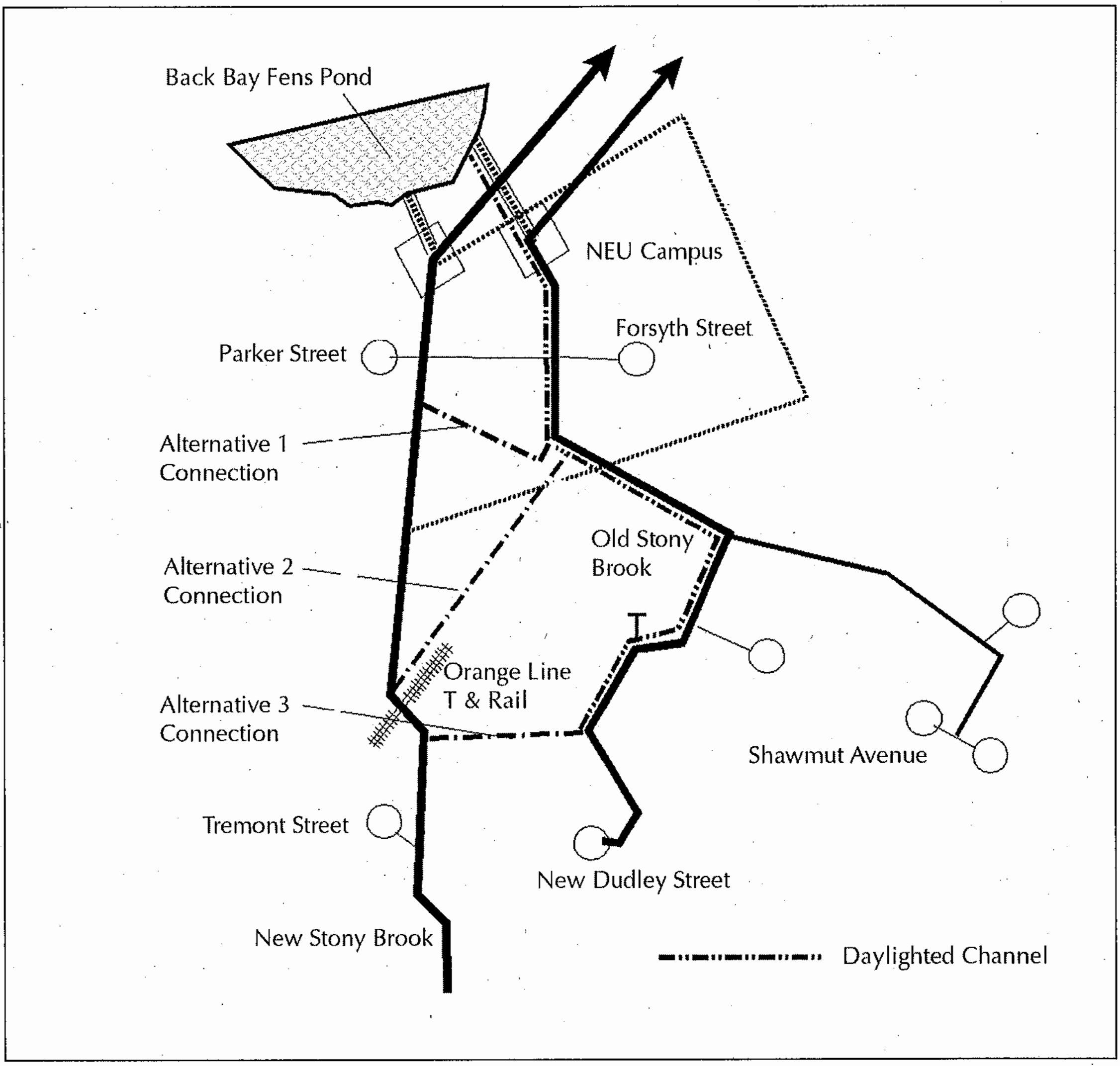

FIGURE 11. Map of the alternative path of the daylighted channel to Forsyth Street on the NEU campus.

Hydrological model. This flow would be subtracted from the one hundred year flow in the culverts below and could eliminate the problem of campus flooding. The design team also proposed BMPs in the watershed south of the campus, including a storage pond, to reduce flooding. The channel would be 1.2 to 1.5 meters (4 to 5 feet) below the present grade between the Ruggles T Station and Huntington Avenue (see Figure 12) and would slide before the Huntington Avenue crossing by a "waterfall" or cascade to the grade of the right culvert of the Old Stony Brook. This scheme would eliminate the need to build an underpass under the Huntington Avenue. Before the slide and crossing the avenue, the CSO in the right culvert would be diverted into the left barrel, which would have enough capacity as proven by calculation. Figure 13 depicts the channel north of Huntington Avenue, showing that the daylighting would have beneficial effect on the flooding situation of the campus. This alternative would benefit mainly the university community and would provide a connection to the Fens.

One problem with Alternative 1 was the energy requirement for pumping, which would have a negative effect on greenhouse

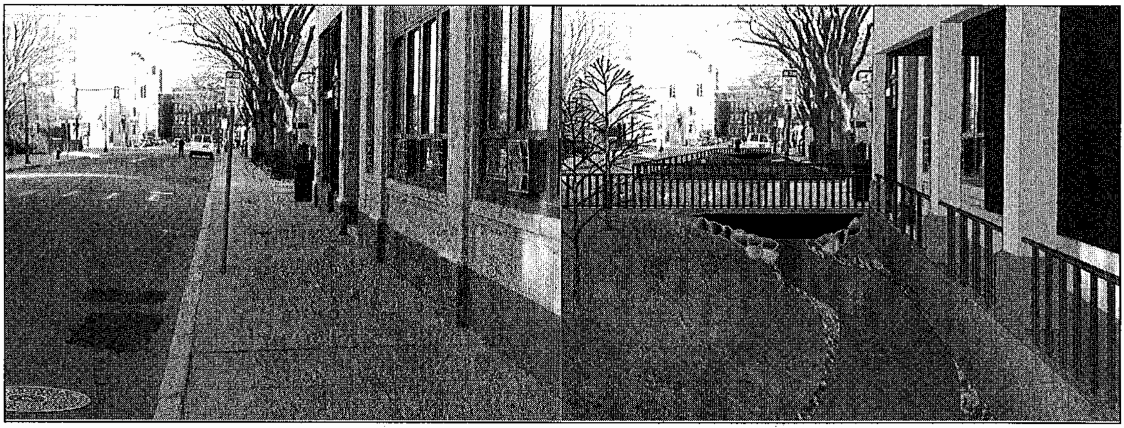

FIGURE 12. Alternative 1 — Monument to Stony Brook on the campus of NEU. The natural base flow would be delivered from New Stony Brook under Parker Street by a pumping station and a similar surface channel along Ruggles Street. On the left is Forsyth Street near Ruggles Station looking towards Huntington Avenue today. On the right is a rendering of the same site by the students in the 2007 capstone class.

carbon emissions because the pumping energy would be provided by a fossil fuel electric power plant. The creek through the campus would be a "monument" to the buried water body that would have a limited function to collect surface runoff and clean flows from the campus to eliminate campus flooding.

Alternative 2. As shown in Figures 10 and 11, this alternative would connect Old Stony Brook by a naturalized channel similar to that shown on Figure 5 paralleling the Orange Line mass transit corridor either on the southeast or northwest sides of the corridor. In either case, the recreated connecting stream would benefit the Roxbury community. Base flow would be withdrawn from the Stony Brook culvert east of the cross-section of Tremont and Gurney streets and the channel would also receive treated (by BMPs) stormwater runoff. Pumping may not be required. The area between Gurney and Albert streets is now unsightly empty paved lots (see Figure 14). Between the T station and Ruggles Street is a low-income housing development. The channel would continue under Ruggles Street through a new underpass and connect with either the right or left culvert of Old Stony Brook on the NEU side of the Ruggles T Station. This culvert would be converted into an aesthetic channel. One culvert would remain a combined sewer carrying combined sewage from the watershed upstream (southeast) of the Ruggles T Station; the other culvert would be converted to the daylighted stream. The connecting channel would bring the natural flow from New Stony Brook to the daylighted Old Stony Brook by gravity; hence the water surface elevation of the daylighted Old Stony Brook on the campus would be about 5 meters (16.4 feet) below the current grade of Forsyth Street. This scheme would create a river oasis for the entire campus. The students' rendering of the channel is shown in Figure 13 but it could be more similar to Figure 5. The location of the urban river corridor/oasis below the elevation of the surrounding built urban environment is very common and almost every major city has them. Creating the connection channel southeast of the Orange Line would put it into a current park setting.

Alternative 3. As shown in Figures 10 and 11, this alternative would connect Old Stony Brook with New Stony Brook at the point where New Stony Brook was diverted to Gurney and Parker streets many years ago. This alternative would follow approximately the old pre-development channel of the brook that was culverted in the nineteenth century. It would daylight one barrel of the two-culvert Old Stony Brook sections in the Linden Park neighborhood (see Figure 15)

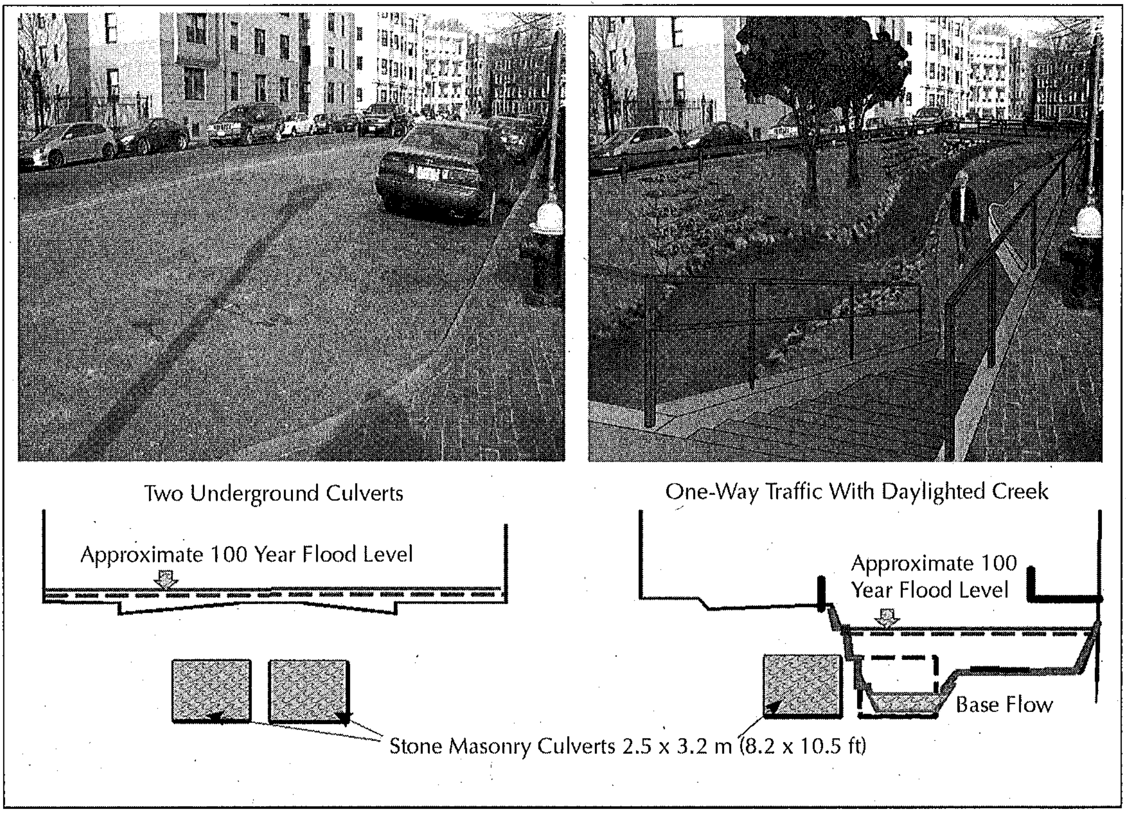

FIGURE 13. Forsyth Street on the NEU campus north of Huntington Avenue today (left) and after daylighting (right). A daylighted stream with hydrologically functioning landscape can reduce flooding and increase resilience against extreme events. ***(Rendering by students in the 2007 class.)***

and continue towards Ruggles and Forsyth streets. The Old Stony Brook also transects Roxbury Community College. The location of the Old Stony Brook culvert is well documented on restored maps from 1895, although some street names have changed and area was transformed from semi-industrial to residential and education.[21] The underpass under the Ruggles T Station also has two culverts; consequently, a new underpass may not be needed. Both Alternatives 2 and 3 would be more beneficial to the Roxbury neighborhoods and the college campus; Alternative 2 would be far less disruptive and most likely more economical. However, connecting the NEU and Roxbury College campuses by a surface water body with bike and pedestrian paths appears to be socially very attractive. A socio-economic study should establish the preference.

The social benefits of the Alternatives 2 and 3 include new parks with foot and bike paths, playgrounds, places for riverside restaurants, etc., thus making the neighborhoods highly desirable places to live.

Pros & Cons of Daylighting Stony Brook. The daylighting of former streams turned into storm sewers and underground culverts is relatively straightforward and creates increased economic and social revitalization benefits. Numerous case studies of daylighting and stream restoration (see Table 1) have improved neighborhoods and attracted new development. Architecturally, urban streams are attractive for urban dwellers — providing places for relaxation and for enjoying urban nature. These new stream corridors could become ecotones between nature and the built urban zones. However, these daylighted and restored urban streams are not the same as the

FIGURE 14. Alternative 2 — The area between Station and Albert streets where the connecting channel between New Stony Brook and Old Stony Brook could be located and landscaped. The Orange Line is behind the trees in the background.

pre-development natural water bodies and may need maintenance. The restoration project must also include watershed restoration by implementing BMPs that would reduce imperviousness that could cause flash floods, loss of base flow and pollution as well as necessitate treatment of surface runoff.

Daylighting Stony Brook would be socially, environmentally and economically beneficial. Social benefits would include improving the quality of life and creating more attractive neighborhoods. The students of NEU, Roxbury Community College and area high and middle schools would get opportunities for education and research on the ecology of urban streams. The corridor would also be a place for relaxation and entertainment.

Environmental benefits would include significant reduction of flooding, which is especially troublesome on the NEU campus. Many on the campus are not aware that the flooding of basements is most likely caused by the backing up of combined sewage/stormwater flows in the Old Stony Brook conduits under Forsyth Street. Basements on the NEU campus are vibrant places of work and also include underground passages between the buildings. After daylighting, the channel under Alternatives 2 and 3 will carry clean base flow (about 0.3 cubic meters [10 cubic feet] per second)

FIGURE 15. Alternative 3 — Whittier Street (former Culvert Street) in the Linden Park neighborhood south of Tremont Street and southwest of the Ruggles T Station. The Old Stony Brook culvert is located under the street based on the 1895 map and also indicated by the large manhole cover.

from New Stony Brook, clean infiltration and inflow (for example, from sump pumps of basements), and clean urban runoff treated by BMPs such as surface grassed swales, biofilters and rain gardens. Current low flow of Stony Brook at Parker Street is 0.3 cubic meters (10 cubic feet) per second.

Technologically, daylighting is less costly than sewer separation and inherently includes landscape aesthetical and ecological improvements that also serve as runoff BMPs (rain gardens with biofilters, infiltration ponds and decorative swales). In contrast, sewer separation has no social and only marginal environmental benefits. Storm sewer flow still has to be treated. By leaving one culvert of Old Stony Brook buried as a (temporal) combined sewer, part of the urban runoff can be diverted into the daylighted channel by surface conduits (swales), treated by biofilters — and not by catch basins — into the combined sewer culvert. One would also expect that, as part of daylighting, implementing storm water infiltration by pervious pavements and infiltration areas would also alleviate the groundwater problem of the city. No new street underpasses may be needed; they are already in place in a form of large masonry culverts. Decorative small foot bridges will be built on the campus and in the adjacent neighborhoods. However, if Alternative 2 is chosen with the connection channel northwest of the Orange Line corridor (current Albert Street), then an underpass under Ruggles Street will be needed.

In built environments daylighting has many challenges that are social (resistance of local public works and sewerage utilities due to a lack of funds to maintain additional open spaces, objections of nearby residents, access to riparian properties); institutional (new waterway ownership and maintenance, open channel liability, potential new restrictive regulations to future riparian homeowners, lack of leadership); and technical (underground utilities will be affected, soil suitability, groundwater table and contamination, and location of streamside paths, picnic areas, green vegetation, etc.).[14] Reasonable resident concerns include also include litter control, vandalism and loitering.

Conclusions

The proposal for daylighting the historic Stony Brook presented herein covers less than 25 percent of the total length of the buried historic river. Other proposals for monument-type daylighting of Stony Brook have emerged upstream for Jamaica Plain and elsewhere. There are several web sites showing the history on, and nostalgia for, this long-lost important water body.[22] However, most people living nearby, even in places bearing the name of the buried water body, and the students and staff of NEU and Roxbury Community College do not know about this lost resource.

It was a great mistake of the last century to embark on large-scale sewer separation instead of considering daylighting. Current experiences of Berkeley, Zurich, Malmö, Portland, Seoul, Beijing and many other cities are proving the great benefits of daylighting.[23-25] Daylighting of urban streams and canals in Ghent is on a much larger scale than would be the case of Stony Brook. The people of Ghent and their city government, once they realized the tremendous social and economic benefits, have become enthusiastic about and proud of their project. They also realized that the cleaning up of CSOs must be contained in the project for it to become truly sustainable. The same is true for Malmö, Seoul and other cities.

The civil engineering students of NEU have done a great service to the city and the profession by working on the project which, at the beginning, looked impossible. They have proven and concluded that daylighting Stony Brook is feasible and would bring great benefits to the campus and the community. In a sense, daylighting Stony Brook is less challenging than the task Frederick Law Olmsted was facing one hundred fifty years ago when he embarked on converting waste mudflats and the relatively unattractive Muddy River (note the name) into what is now a jewel of the ecological urbanism known throughout the world — the Emerald Necklace. The daylighted Stony Brook will not be the same as the historic Stony Brook. The design will be threading the channel into a built environment and will have to be connected to urban renewal and revitalization efforts. But the current urban environment needs renewal and daylighting should be a major part of it. It may also bring jobs and, with the economic and social benefits, it might be economically viable as has been proven in the other already implemented daylighting sites. Furthermore, government grants may be available. The feasibility analysis should be done by the triple bottom line assessment because strictly economic analysis of cost and benefits may not provide a true picture. If the daylighting of the entire buried section of Stony Brook is done in this century, Boston would get its second Emerald Necklace. The conclusion of the student teams was: "It is doable. Let us do it."

NOTES — *This article summarizes the work of NEU senior civil engineering students in classes 2007 and 2008, as part of their capstone senior design class. Three teams with five members each worked on the project. Additional analytical work was done by the graduate students in the Hydrology class in 2008. Their work was professional and praised by their peers, mentors and civil engineering professionals who evaluated their work as a part of the senior design class. Legally, the students cannot take any responsibility for their findings and opinions nor can the author of this article. The worth of the student work and of this article is solely educational but it could be an impetus for further analyses and proposals by professionals, foundations and citizens interested in bringing the historic Stony Brook back to life. In March 2010, hundreds of professionals from all over the world*

will be gathering in Boston at an international conference to discuss and exchange knowledge and experience on developing the Cities of the Future and on stream restoration and daylighting. The conference is organized by the Water Environment Federation and the International Water Association. Daylighting of Stony Brook should be a discussion topic at the conference.

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