Estimating the Air Temperature Cooling Effect of the Cheonggyechun Stream Restoration Project of Seoul, Korea

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ABSTRACT

Urban stream restoration projects can improve water quality, wildlife habitats, urban landscape, outdoor recreation spaces, and urban microclimate. The objectives of this research were to investigate temperature cooling effect of urban streams by using satellite imagery, to evaluate environmental variables related to stream cooling effect, and to estimate the cooling effect of the Cheonggye stream restoration project of Seoul, Korea. Findings of this research can be summarized as follows. First, a method of estimating temperature distribution around urban streams by using satellite imagery was developed. Scatter plots of distance from stream edges and average temperature obtained through multiple buffering were used for the estimation. Second, urban temperature cooling effect of streams was estimated by comparing background temperature and temperature of each buffer zone. Third, environmental factors affecting stream cooling effect were also identified. Fourth, the temperature cooling effect of the restoration project was estimated based on three scenarios. An estimated cooling effect based on the average cooling effect of existing tributaries showed the most significant effect; 2.0℃ lower than the present level at the edge of the renovated stream. It was estimated that the temperature of the same area would be 1.4℃ cooler than the present level if the cooling effect of the Yangjaechun was used as the bench mark. But the effect would be 1.2℃ lower than the present level if environmental variables related to the temperature cooling effect of urban streams were used as the bench mark.

Key Words : Urban Heat Island, Stream Restoration, Remote Sensing, Temperature Cooling Effect, Multiple Regression Analysis

I. BACKGROUND AND OBJECTIVES

Traditional river engineering projects for flood prevention and water resource development usually result in the deterioration of environmental quality. Much of the floodplains of the Han River and its tributaries in Seoul were reclaimed to build new residential areas and urban infrastructure during the rapid urbanization period since 1960s. The entire length of six tributaries and more than 60% of the length of the seven streams in Seoul were covered to build urban streets or simply to conceal the source of stench from severely polluted urban streams (SDI, 2000).

Stream restoration projects improve water quality, wildlife habitats, urban landscape, and outdoor recreation spaces (Allan, 1995). Additionally, restoration of the covered section of urban streams can also improve urban environment by the cooling effect of streams. The completion of the Cheonggyechun stream restoration project started in 2003 will drastically improve the urban environment of the CBD of Seoul. The project includes the demolition of a 5.86km long elevated urban expressway and the opening-up of a 5.4km long cover structure previously used as a major urban artery. The traffic volume of the project site was estimated to be approximately 168,000 vehicles per day. The project would create a stream channel that is 10~30 m wide and 40cm deep, and a daily stream flow of 93,700 tons. Linear urban water front parks would be created on river terraces of 3.7~12.8m wide. Expected benefits of the project such as water quality improvement, aquatic ecosystem restoration, urban outdoor activity spaces, and scenic beauty were included as items for the citizen survey by using WTP (willingness to pay) method (Seoul, 2003). But the cooling effect of the restoration project was excluded during the benefit/cost analysis of the project.

Researches on urban heat island based on the temperature data collected at weather stations could use only limited number of observations. The number of temperature measurement could be increased significantly by using mobile measurement with bicycle or automobile mounted thermometers. Both methods of ground measurement would result in inaccurate spatial distribution of urban temperature in large urban areas due to either insufficient number of data measurements or measurement errors caused by the change of temperature during the measurement or inappropriate distribution of data collection points (Stringer, 1972). The advent of satellite remote sensing technology has made it possible to study urban heat island problem both remotely and on continental or global scales (Streutker, 2002). The most often used sources of data have been AVHRR, MODIS, ASTER, Landsat TM, and Landsat ETM+ (Tsuyoshi 1986; Nichol 1994; Lino 1996; Lo, 1996).

The objectives of this research were as follows. First, to develop a method to estimate the urban temperature cooling effect of the streams in Seoul. A method to analyze temperature distribution of Seoul based on remote sensing of satellite data and spatial analytical capability of GIS was employed. Second, to investigate environmental factors such as the scale of streams and the pattern of landcover types related to the cooling effect. Third, to estimate the cooling effect of the Cheonggyechun stream restoration project. The transformation of huge sewage box type stream into a clean stream with rapids and pools will surely enhance the environmental quality of the CBD of Seoul.

II. RESEARCH METHODS

1. Test Streams

Data collection for the selection of test streams included landcover map, aerial photographs, and field trips to test sites. Two factors were taken into account during the selection of test streams. First, stream segments with less than 60m wide were screened out so as to exclude mixed pixel errors of Landsat ETM+ sensor (Jensen, 2000). There are 36 streams with the total length of 229.07km in Seoul. The total length of streams classified as the national level stream, municipal level 1 stream, and municipal level 2 streams are 66.4km, 3.8km, and 158.87km, respectively. Therefore, upper sections of many tributaries were excluded. Second, stream segments unsuitable for the estimation of cooling effect of the Cheonggyechun restoration project were also excluded. Stream segments with major artifacts such as urban expressways and parking lots on river terraces and banks were excluded. Stream segments adjacent to major forest covers were also removed since the

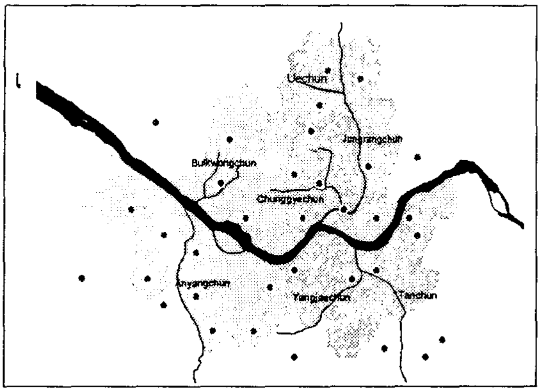

Figure 1. Location map of test streams and AWS (Automatic Weather Stations)

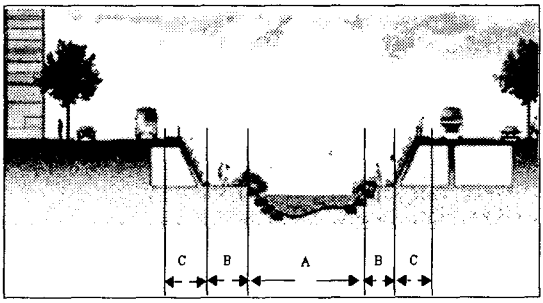

Figure 2. A typical section of the Cheonggyechun renovation
A: Lower channel width, B: Stream terraces, C: Stream banks

restoration site passes through highly developed CBD with limited vegetation covers. Test streams can be seen in Figure 1, and the Cheonggyechun is located in the center of the city. The size of watershed, the length and width of the stream are 50.96km^2, 13.7km, and 12~84m, respectively. A typical section of the restoration project is shown in Figure 2 .

2. Transformation and Calibration of the Temperature Distribution of Seoul

An image of Landsat ETM+ (path/row: 116/34) obtained on a clear, hot day was selected. The selected image was obtained on the 7th of Sept, 2001. The temperature of Seoul Weather Station at the time of satellite image acquisition was 24.4℃, and the highest temperature of the day was 29.6℃. High temperatures of the previous six days were also higher than 26℃ (Meteorological Office, 2002). There were no significant rainfall during the previous six days, thus it can be safely assumed that the stream flow condition and temperature cooling effect of the image acquisition day were close to that of a typical summer day.

Satellite image preprocessing and classification were carried out. The preprocessing stage includes image registration and image fusion. Since the streams under investigation have relatively small width, it is necessary to improve the spatial resolution of the Landsat ETM+ imagery. Spatial resolution of 15m of panchromatic band was used to improve the spatial resolution of multispectral bands of Landsat ETM+. The HIS[1] transformation was employed for the fusion process (Lillesand, 2000). The produced image showed much better contrast compared to the original imagery. The image was also registered to 1:25,000 scale digital map of the test site.

The degree of cooling effect is affected by landcover types on riparian areas. Water surface and vegetation cover have much higher evapotranspiration compared to than that of dry soil or hard paved areas. And heat storage and convection capacity can also be significantly affected by intensive human trampling and the construction of various artifacts (Gregory, 1987). Land cover classification of Landsat ETM+ imagery was executed to improve the accuracy of cooling effect estimation of urban streams. The Maximum likelihood[2] ruler among Parametric Ruler

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1) A system of producing color imagery that is adapted to human vision. Intensity is the color brightness, hue is the actual colour and saturation defines the purity or "greyness" of the colour.

2) With the basis on the probability of ratio of classifying the pixel to the appropriate band, the input band follows the regular distribution and such ratio remains constant through the whole classifications and classes.

from ERDAS Imagine 8.5 was used for the image classification. The land cover classification with the satellite imagery produced four categories: water body, vegetation, bare soil, and artifacts.

The temperature map of Seoul was created using thermal band of Landsat ETM+ imagery. The following equation was used to convert DN's in an image back to radiance units:

$$L_{\lambda} = \text{"gain"} \times QCAL + \text{"offset"}$$

Where:

"gain" = Rescaled gain (the data product "gain" contained in the Level 1 product header or ancillary data record) in watts/(meter squared × ster × μm)

"offset" = Rescaled gain (the data product "gain" contained in the Level 1 product header or ancillary data record) in watts/(meter squared × ster × μm)

QCAL = the quantized calibrated pixel value in DN

ETM+ Band 6 image can also be converted from spectral radiance to a more physically useful variable. This is the effective at-satellite temperatures of the viewed Earth-atmosphere system under an assumption of unity emmissivity and using pre-launch calibration constants (Landsat7 Science Data Users Handbook). The conversion formula is:

$$T = \frac{K2}{\ln\left(\frac{K1}{L\lambda} + 1\right)}$$

Where:

T = Effective at-satellite temperature in Kelvin

K2 = Calibration constant: 1282.71 Kelvin

K1 = Calibration constant: 666.09 watts/ (meter squared × ster × μm)

L = Spectral radiance in watts/ (meter squared × ster × μm)

Since the temperature obtained from the thermal band of the satellite imagery would be affected greatly by the scattering and absorption of atmospheric path radiance, a temperature regression equation between the satellite measurement and air temperature of corresponding pixels should be developed. Air temperature measured by using the networks of AWS (Automatic Weather Station) mainly installed for the measurement of urban air pollution was used for the regression equation. Temperature measurements of 27 AWSs in Seoul and seven AWSs in surrounding jurisdictions were used to develop following temperature transformation equation:

3. Temperature Cooling Effect of Streams

The temperature cooling effect of a stream would decrease gradually according to the distance from a stream, and the air temperature beyond a certain threshold distance would be that of the background temperature of the area. Such gradual trend affected by a stream can be identified by using the multiple buffering of GIS (Chou, 1997). The band width of the buffering was set to be 30m based on the spatial resolution of the image fusion of the Band 6 of the satellite imagery (Quattrochi, 1997). The average temperature of all pixels located in each buffer, or a zone of 30 meters wide, from both edges of a stream is plotted on a graph of air temperature (Y axis) and the distance from a stream (X axis). The number of pixels in a buffer is determined by the length of a stream and the environmental characteristics related to the stream cooling effect. The temperature cooling effect of a stream buffer can be shown as follows:

$$C_{Buffer}(m, n) = B_m - T_{Buffer}(m, n)$$

where, $C_{Buffer}(m, n)$ = Cooling effect (℃) at the n th buffer of stream m

B_m = Background temperature of stream m
$T_{Buffer}(m, n)$ = Temperature (℃) at the n th buffer of stream m

The temperature after the completion of the Cheonggyechun stream restoration project can be estimated by two methods. The first one was to estimate the temperature by comparing the present temperature of each buffer of the Cheonggyechun and the cooling effect of control streams. Data collected for the selection of control streams included image fusion data, aerial photographs, and field trip. Two types of control were used for this study: the cooling effect of the Yangjaechun and that of the four tributaries of the Han River. Yangjaechun was selected for two reasons. The hydrological characteristics of the stream are similar to those of the Cheonggyechun and it has become a very successful stream restoration project in Korea. This is an easy method, but the accuracy can be significantly affected due to the difference of hydrological characteristics and land use patterns between the Cheonggyechun and control streams.

The second method was to estimate the cooling effect based on the environmental factors related to the effect. Environmental variables were grouped into two categories. The first category was related to the physical scale of streams, and included variables were stream width, lower channel width or width of water surface, stream length, and the size of water surface of each stream. The second category was related to vegetation cover on stream terraces and banks, and land cover types of adjacent areas were classified into vegetation, artifacts, and bare soil. The temperature cooling effect of environmental variables was estimated by using multivariate regression analyses. Environmental characteristics responsible for the stream cooling effect were used as independent variables and mean air temperature of each buffer was used for dependent variable. A stepwise selection method was used to evaluate the coefficient of environmental variables.

III. RESULTS AND DISCUSSION

1. Air Temperature Map of Seoul

The land cover map is shown in Figure 3. Classification error matrix constructed with ground truth of 73 reference points resulted in overall accuracy of 87.7%. The cover type with the highest classification accuracy was vegetation (94.1%). The accuracy of water (83.3%) was the lowest, and it could be caused by mixed pixel effect of narrow streams. Since most land except steep slopes and high elevations was developed into high density urban areas, large patches of vegetation and water bodies are located far from most built-up areas. Thus the cooling effect of open spaces could provide little comfort to residents and visitors of Seoul during summer season.

The surface temperature extracted from the Landsat thermal band by using the NASA formula should be transformed to air temperature. The atmospheric scattering and absorption of reflected and emitted electromagnetic energy could deteriorate the quality of remotely sensed data. As mentioned before, the surface temperature was transformed into air temperature by using the temperature measurements of 34 AWS as independent variables of following temperature transformation equation. Two methods of resampling, nearest neighbor and 3×3 windows, were applied so as to test the reliability of the AWS measurement (Lillesand, 2000). The Pearson correlation coefficient between the AWS data and the satellite thermal data of nearest pixel was 0.720, but that of the AWS data and 3×3 window of the satellite data was 0.831. Thus the 3×3 moving window was used for the transformation and calibration process of the surface temperature of all pixels of satellite data (Sep. 7, 2001) into air temperature. The regression equation was as follows.

$$Y = 0.63 \times X + 14.867$$

Where, Y = Transformed temperature (℃)
X = Surface temperature from Landsat thermal band

Since the equation has R^2 of 0.809, the accuracy of air temperature of pixels was satisfactory for the estimation of stream cooling effect. The temperature distribution map of Figure 4 shows that the temperature of the Han River and forest covers is much lower than that of built-up areas. The highest and lowest temperatures of pixels in the map were 37.53C and 7.28℃, respectively.

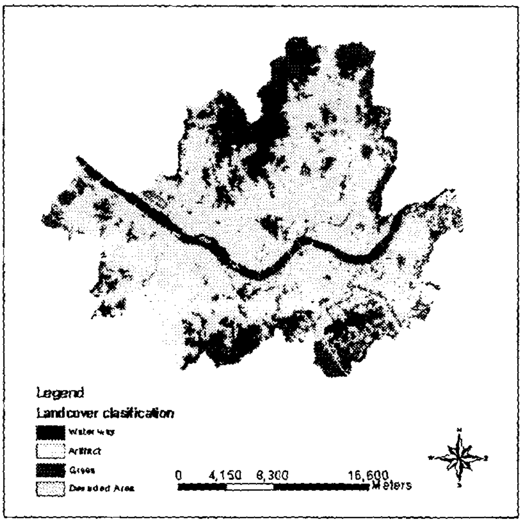

Figure 3. Landoover classification map of Seoul

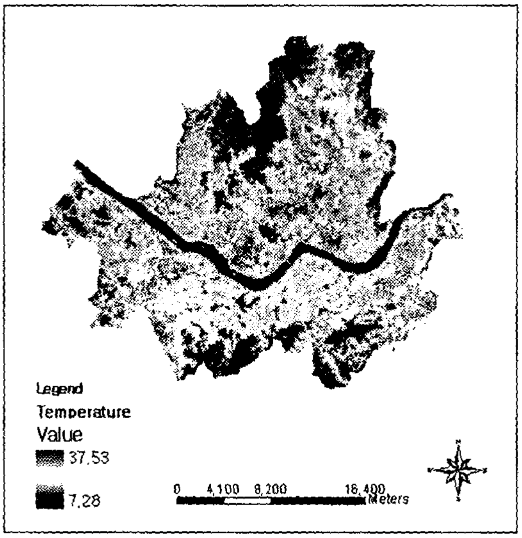

Figure 4. Air temperature map of Seoul (Sep. 7, 2001)

Environmental variables determined to have auto-correlation were excluded during the multivariate regression. As shown in Table 1, four independent environmental variables related to stream cooling effect were selected: lower channel width, size of vegetation covers on river terraces and banks, size of surface water, and the percentage (%) of vegetation cover in adjacent areas.

Table 1. Selected environmental variables related to the cooling effect of test streams

Categories	Lower channel width (m)	Width of Vegetation cover on river terraces (m)	Size of stream zone (km^2)	Vegetation cover in adjacent areas (%)
Jungrangchun 1	60	30	1.02	4.4
Jungrangchun 2	50	10	0.34	4.1
Anyangchun	70	100	1.59	4.2
Tanchun	50	130	1.08	27.5
Yangjaechun	25	80	0.24	24.6
Bulkwangchun	10	30	0.13	2.0
Uechun	15	20	0.20	5.2

2. Measurement of Stream Cooling Effect

The trend of air temperature cooling effect of a stream can be seen on the scatter plots of air temperature (Y axis) and the distance from a stream (X axis) in Figure 5. The average temperature (25.05℃) of all pixels located within 30 meters, or the average temperature of the first buffer, from the both edges of the Anyangchun can be identified in the graph. The pattern of temperature distribution of areas adjacent to the stream can be seen by connecting scatter plots of a stream. Findings can be summarized as follows.

First, background temperature of areas close to test streams was identified. Temperature curves of streams passing through highly developed areas are merging at the range of 27.3~27.5℃. But the background temperature of the Yangjaechun passing through less developed areas reaches the maximum point at 26.8℃ at 210m from the water edges. Temperature decrease beyond the threshold point of the stream reflects significant cooling effect of open spaces in the watershed. Second, stream cooling effect for each distance zone was estimated by computing the temperature difference between the background temperature and that of each distance zone. For example, the temperature difference of 1.2℃, between the background temperature at 210m distance zone of the Yangjaechun (26.8℃) and than that of areas within the 30m buffer of the stream (25.6℃) represents the cooling effect at the buffer zone. Third, stream cooling effect was identified by comparing cooling effects of test streams. For example, the temperature of 26.24℃ at 30m buffer of the upper segment of the Jungrangchun is 0.98℃ higher than that of the corresponding buffer of the lower segment of the Jungrangchun (25.26℃). This means that the lower segment of the stream have greater cooling effect due to wide water body and better vegetation cover. Fourth, the relationship between distance from a stream and the cooling effect was identified by examining the shape of each temperature curve. For example, the zone of stream cooling of the Jungrangchun 2 shows that excellent cooling effect at the 30m buffer, but the effect decreases significantly at the point beyond 120m buffer. On the other hand, the cooling effect of the Tanchun is much wider than that of the other test streams because of relatively better and wide open spaces along the stream.

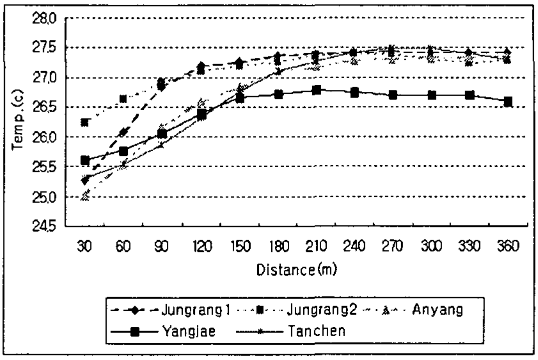

Figure 5. Graphs of air temperature cooling effect of test streams

As can be seen from Table 2, regression equations using logarithmic formula were developed based on the shape of the scatter plot that merges to the background temperature level at a certain distance from the edges of a stream. The equations can be summarized as follows. First, the values of R^2 (0.8642 to 0.9822) are very high. This means that the data and cooling effect estimation method used in this research are suitable to achieve study objectives. Second, stream cooling effect at any distance from a stream and total cooling effect of a stream can easily be computed by using the equations. Third, stream cooling effect varies according to environmental characteristics of test streams. For example, the range of cooling effect is limited to only 120m from the Uechun, but that of the main stream of Han River extends to 600m.

Table 2. Temperature cooling effects of test streams

Streams	Water front temp. (°C)	Background temp. (°C)	Cooling effect (°C)	Range of cooling effect (m)
Han river	22.1	27.043	4.943	600
	$y^{*} = 1.4496\mathrm{Ln}(x) + 18.023,\ R^2 = 0.8929$			
Jungrang 1	25.26	27.438	2.178	270
	$y^{*} = 0.8436\mathrm{Ln}(x) + 22.774,\ R^2 = 0.8642$			
Anyang	25.023	27.319	2.296	300
	$y^{*} = 0.9752\mathrm{Ln}(x) + 21.788,\ R^2 = 0.9461$			
Tan	25.311	27.487	2.176	270
	$y^{*} = 1.0266\mathrm{Ln}(x) + 21.574,\ R^2 = 0.927$			
Jungrang 2	26.229	27.406	1.177	240
	$y^{*} = 0.5164\mathrm{Ln}(x) + 24.548,\ R^2 = 0.9535$			
Yangjae	25.605	26.704	1.099	240
	$y^{*} = 0.4958\mathrm{Ln}(x) + 23.955,\ R^2 = 0.8778$			
Ue	27.28	27.847	0.567	120
	$y^{*} = 0.4286\mathrm{Ln}(x) + 25.831,\ R^2 = 0.9822$			
Bulkwang	27.608	27.963	0.355	150

*: regression equation

3. Statistical Analysis of Stream Cooling Effect

1) Environmental variables affecting stream cooling effect

Types and magnitude of environmental factors responsible for the cooling effect of environmental variables were also evaluated. Multivariate regression equations were developed by using four selected environmental variables as independent variables. The following equation was derived by the multivariate regression and the value for R^2 is 0.973.

$$y_1 = 0.294 + 0.0161 \cdot X_1 + 1.259 \cdot X_2$$

where, y_1 : Temperature cooling effect (℃)
X_1 : Width of stream channel (m)
X_2 : Size of stream zone (㎢)

Among the independent variables of the multiple regression models, only the width of the channel and the size of stream zone, that includes lower channel and river terraces, were evaluated as meaningful independent variables. In other words, greater channel width and river terraces increase the cooling effect. It can also be concluded that the poor status of riparian vegetation of test streams play insignificant roles compared to the water body itself.

2) The range of stream cooling effect

The range of stream cooling effect was set as dependent variable of the regression model. The width of the channel turned out to be the only environmental variable with statistical significance, as can be seen in Table 4. The value for R square is 0.815, and the significance level was at 0.01.

Table 3. Coefficients of stream cooling effect estimation equation

Model		Unstandarized coefficients		Standarized coefficients	*t*	P-Value
		B	Std. Error	Beta		
1	Constant	0.256	0.049		5.258	.003
	Size of water surface	1.903	0.067	0.997	28.292	.000
2	Constant	0.294	0.030		9.566	.001
	Size of water surface	1.259	0.105	1.163	21.211	.000
	Width of channel	1.611E-03	0.003	1.995	2.782	.009

Table 4. Coefficients of the range of temperature cooling estimation model

Model		Unstandarized coefficients		Standarized coefficients	*t*	P-Value
		B	Std. Error	Beta		
1	Constant	123.000	29.516		4.167	.009
	Width of stream channel	2.300	0.680	0.871	3.972	.001

$$y_2 = 123.0 + 2.3 \cdot X_1$$

where, y_2 : Range of temperature cooling effect (℃)
X_1 : Width of stream channel (m)

4. Cooling Effect of the Cheonggyechun Restoration Project

The cooling effect of the Cheonggyechun restoration was estimated by comparing existing temperature profile of the site and the expected temperature profile produced by using afore- mentioned multivariate regression equation. Temperature profile at every 30-meter interval from the center of the existing Cheonggyechun was measured by using temperature map of Seoul derived from Landsat ETM+ imagery and digital map of Seoul. The same buffering method used for the estimation of cooling effects of other streams was utilized again. It can be seen from Figure 6 that the temperature at the top of the covered stream is 26.8℃. Huge traffic volume on the elevated expressway might be responsible for the high temperature. The temperature at 90m from the stream decreased to 26.6℃, but temperature beyond the buffer increased again. High traffic volumes of adjacent parallel east-west arteries in the CBD would be responsible for such temperature distribution.

The typical section of the stream restoration project had average stream width of 70m and average channel width of 20m (Seoul, 2003). By substituting design parameters to existing conditions, the following equation can be derived.

$$y = 0.39 \times \ln(x) + 24.44$$

where, y: Estimated temperature (℃)
x: distance from the renovated stream (m)

The estimated temperature pattern of corresponding distance from the stream after the restoration project is also plotted in Figure 6. It was estimated that the cooling effect of the 30m buffer of the restored stream was 1.0℃ and the range of cooling effect extended to 150m from the restored stream.

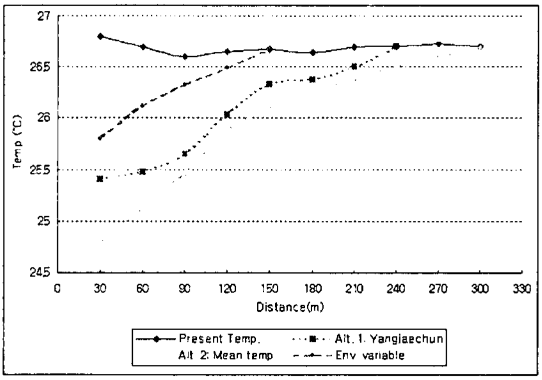

Figure 6. Temperature cooling effect of the Cheonggyechun restoration project

The cooling effect at 60m, 90m, and 120m buffer were estimated to be 0.58℃, 0.27℃, and 0.16℃, respectively. Such cooling effect during summer days will be appreciated by residents and visitors to the area.

Ⅳ. CONCLUSIONS

The objectives of this research were to develop a method to estimate temperature cooling effect of urban streams, to evaluate environmental variables of urban streams for the stream cooling effect, and to estimate the cooling effect of the Seoul Cheonggyechun restoration project. Findings of this research can be summarized as follows. First, temperature distribution curves around urban streams were produced by employing scatter plots obtained through multiple buffering of temperature around urban streams. Second, temperature cooling effect of urban streams was estimated by comparing background temperature and temperature of buffer zones around urban streams. Third, environmental factors affecting stream cooling effect were also identified. Fourth, the temperature cooling effect of the Cheoggyechun restoration project was estimated. The temperature at both edges of the restored stream would be 1℃ lower than the present level, and the cooling effect zone would extend to 150m from the stream.

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