# CLASSIFICATION OF AQUATIC AREAS FOR NATURAL AND MODIFIED RIVERS

**Tae Sung Cheong** [1], **and Il Won Seo** [2]

[1] Post Doc. Research Associate, School of Civil, Urban, and Geosystem Engrg.,
Seoul National Univ., Seoul, Korea
[2] Assoc.Prof. School of Civil, Urban, and Geosystem Engrg., Seoul National Univ., Seoul, Korea

---

**Abstract**: For the design of suitable aquatic habitats and habitat management purposes, sensitive descriptors for aquatic areas were identified and analyzed. The classification system of the aquatic areas were developed for natural streams and modified streams in Korea. Relationships among the descriptors of an aquatic area such as channel width, meander wave length, and arc angle have been defined. The analysis indicates that the total mean sinuosity is 1.25 for the main channels of natural streams, whereas the mean value of the sinuosity of modified streams is 1.14. The mean values of the total area, the width, and the length for the sandbars of natural streams are larger than those of modified streams.

---

**Key Words**: riverine aquatic habitat, classification, geomorphic and hydraulic descriptors, hierarchical system

## 1. INTRODUCTION

Streams are an important source of water supply for public, industrial, and agricultural use. They also serve navigation, waste assimilation, and recreational purposes and are an integral part of the habitat structure (aquatic area) for fish and wildlife. In natural streams, the physical aquatic area includes the shape of the channel cross section, the configuration of the bed including the forms of bed roughness, and the channel pattern which includes the configuration of the planform of the river. The spatial complexity of the aquatic area and the temporal variability of the area conditions influence the diversity of fish communities, and other forms of riverine aquatic life. This geometry of the natural streams is the result of the interaction between the discharge of the water, the sediment, and the composition of the bed and bank materials (Simons, 1979).

Streams and rivers have been extensively modified to improve drainage for agriculture and to abate flooding in urban settings. The common practice in recent days has been to widen, deepen, and straighten watercourses to accelerate drainage and provide an increased capacity in channel storage during flood events. Channel-training structures, revetment and levees have imposed a regulated flow regime and a set of man-made aquatic area conditions. Various man-made changes on aquatic areas of stream and river systems are essentially irreversible. Consequently, it is necessary to identify and categorize sensitive descriptors for the aquatic area in both natural stream and modified stream reaches that are valuable for wildlife and for the design of suitable aquatic habitats and habitat management purposes. The classification system of aquatic areas is based on geomorphic and hydraulic descriptors of rivers and man-made features of the streams. Aquatic areas in natural streams are dynamic mosaics of many different aquatic area types and geomorphological units (Cobb and Clark, 1981). Geomorphic and hydraulic geometry parameters, such as the width, depth, radius of curvature, arc angle, and other related parameters, are extremely significant in the evaluation and development of any aquatic area classification system.

In this study, through the review of generally related literature of geomorphology, channel patterns, and river meandering, a comprehensive classification system of two-dimensional aquatic areas for natural and modified streams is developed. The classification system to be developed incorporates a hierarchical structure to facilitate the habitat mapping and an inventory at different levels of resolution, from macrohabitat areas to microhabitat. In this study, sensitive descriptors for aquatic areas are identified and measured for 10 natural streams and 10 modified streams in Korea.

## 2. RESEARCH BACKGROUNDS

### 2.1 Classification of Aquatic Areas

The study of the classification of the aquatic areas for river systems was initiated by the U.S. Fish and Wildlife Service to identify promising strategies for reserving instream flows. They developed analytic tools to evaluate the quantity and quality of stream habitats. They also refined a methodology which is a state-of-the-art tool relating aquatic habitat suitability to instream flow. Colbert et al. (1975) established a database for the physical, chemical, and biological components of the aquatic system. The four major habitats sampled were the main channel, the side channels, river border areas, and areas downstream of dikes. Brussock et al. (1985) proposed a system for classifying running water habitats based on their channel form, which could be of three different sedimentological types: cobble and boulder-bed channels, gravel-bed channels, or sand-bed channels. Three physical factors, relief, lithology, and runoff, were selected as factors that control all other interacting parameters associated with channel forms. Bhowmik et al. (1990) suggested that variable aquatic areas include backwaters, wetlands, channel borders, island-braided areas, confluence of the main river with its tributaries, and vegetated banks protecting bottomland forests. Main channel areas may be less valuable for aquatic organisms because it is subjected to high velocities and turbulence from channel vessels. In contrast to the main channel, however, channel border areas, the side channel, bottomlands, ponds, and sloughs with reduced flow and substrates composed of fine-grained sediments, are valuable habitats. They suggested that important descriptors in determining the value of aquatic habitats include sinuosity, curvature, and arc angle of the bends because these attributes can affect flow, secondary circulation, lateral distribution of velocity, suspended sediment characteristics, and water depth, all of which are related to habitat value.

Simons et al. (1974) and Simons et al. (1975) conducted a comprehensive study of the historical geomorphology of the Mississippi and Illinois Rivers to determine the physical impact of river contraction works on river morphology and behavior, and subsequent effects on the side channels. Based on studies of past geomorphic changes and with a mathematical simulation of future river responses, they concluded that the present day manner of operation imposes no serious detrimental effects on the geomorphology or hydraulics of the river system in the study area. Chen and Simons (1979) conducted a geomorphic study to assess the impacts of human navigation activities on the hydraulics and geomorphology of the upper Mississippi River. To predict feature river changes, they developed one dimensional water and sediment routing models of several reaches of the upper Mississippi River. Cobb and Clark (1981) postulated that large alluvial rivers, such as the upper Mississippi River, are dynamic mosaics of many different aquatic habitat types and geomorphologic units. They also commented that a large river system is formed and maintained in a dynamic equilibrium of fluvial processes. They found those wide annual fluctuations in river stage and discharge generally cause pronounced seasonal variations in aquatic habitat characteristics. The U.S. Army Corps of Engineers (1981) developed a river categorization scheme to evaluate the benefits and costs of disposing of dredged material in contained areas outside of floodplains. They categorized the types of valley forms that constitute the valley of the Mississippi and its navigable tributaries using U.S. Geological Survey (USGS) topographic maps. They recommended that special attention be paid to specific habitat types, such as backwaters, bottomlands, forests, shoots, spawning areas, etc., within the floodplain.

## 2.2 Channel Pattern

The channel patterns that have been recognized are meandering, braided, and straight. In natural streams, pool-riffle sequences appear in both straight and meandering channels that create a diversity of aquatic areas necessary to support fish and other riverine life forms in a viable aquatic ecosystem. A definition sketch of a regular meander path is shown in Fig. 1. The sinuosity, which is defined as the ratio of channel length to thalweg distance, varies in rivers from a value of unity to a value of 4 or more. Rivers having a sinuosity of 1.5 or greater are

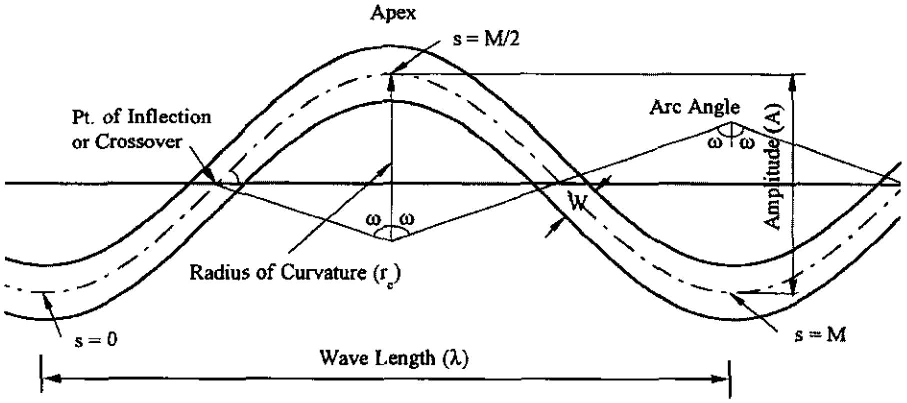

Fig. 1. Definition Sketch of Meander Geometry

meandering, and below 1.5 are classified as straight or sinuous. Assifi (1966) analyzed the radius of curvature and the arc angles of bends for 1529 km of the lower Mississippi River. His results show that distribution curves of bend radii and arc angles illustrate the variability of the characteristics of bends in the lower Mississippi River system. Chang and Toebes (1970) investigated the planforms of two naturally meandering rivers, the Wabash and the White Rivers in Indiana, U.S.A., using a variety of statistical descriptors of the planform. They postulated that two groups of factors, the geology and soil, and the flow rate and channel slope, are major factors that control the meander planform. Dury (1973) postulated that most channel characteristics, including channel width, meander wavelength, and sinuosity, can be expressed as power functions of the drainage area. Since discharge at a given recurrence interval can also be expressed as a power function of the drainage area, the channel characteristics can be expressed as power functions of discharge.

Brice (1974) analyzed meandering patterns of three reaches of the White River System in Indiana, U.S.A. Measurements were made on the meandering pattern as represented by the river centerline, which was traced from USGS 7.5-minute topographic maps and aerial photographs. He suggested that the radius of curvature is the fundamental property of a meander loop, even though some subjectivity is involved in the delineation of simple loops. He also concluded that a log normal size distribution of meander loops is probably characteristic of most natural streams. Hey (1976) presented the relationship between radius of curvature, width, and arc angle using data obtained from rivers in the United Kingdom. His result show that the meander arc length or riffle-riffle spacing, which is measured along the meander path, appeared to be well correlated with the channel width. Bhowmik and Stall (1979) and Bhowmik (1984) developed hydraulic geometry relationships for the floodplains of nine river basins in Illinois and four river basins outside of Illinois. Hydraulic geometry parameters, such as floodplain width, surface area, and sinuosity, were related to the drainage area of the individual stream segments.

## 3. AQUATIC AREAS AND DESCRIPTORS

The nomenclature and definitions of aquatic areas used in this study are adopted from Seo and Bhowmik (1991). Definitions of aquatic areas are given below and descriptors for each aquatic area are listed in Table 1. Examples of the typical aquatic areas are shown in Fig. 2.

The main channel, including the navigation channel, channel border, and sandbars, conveys the majority of the river discharge throughout the channel area. The boundaries of the main channel are apparent shorelines (the land/water boundaries visible from aerial photos taken at a reference level of river discharge), straight lines across the mouths of secondary and tertiary channels, and the line along the top of inundated portions of the natural bank line. The main channel aquatic area includes the gated sections of the navigation dams and the tail-water areas. The tail-water areas are included in the main channel category, although there are unique microhabitat conditions in the tail-water areas downstream of the navigation dams. The navigation channel is the designed corridor which pilots can navigate on. The navigation channel extends through the locks at each lock dam. The navigation channel is usually in the main channel, but in some reaches it is located in secondary channels.

**Table 1. Summary of Aquatic Areas and Descriptors of the Aquatic Habitat Classification**

| Areas | | | | | Descriptors |
|---|---|---|---|---|---|
| Aquatic Areas | Channel* | Main Channel, Secondary Channel | Navigation Channel | | Length of Straight Reach (m), Meander Wavelength (m), Length of Curved Reach (m) |
| | | | Channel Border | Wing Dike | Number per meter, Number of Polygon, Area of Polygon, Number per Each Polygon<br>Rivermeter of Polygon (m), Left/Right side of Thalweg Line, Inside/Outside of Bend |
| | | | | Closing Dam | Rivermeter (m), Left/Right side of Thalweg Line, Inside/Outside of Bend |
| | | | | Bank Revetment | Rivermeter (m), Left/Right side of Thalweg Line, Inside/Outside of Bend |
| | | | Sandbar | | Rivermeter (m), Distance from Thalweg Line (m), Orientation to Thalweg Line (m) |
| | | Tertiary Channel | | | Orientation to Secondary Channel [Rivermeter (m), Upstream Angle (degree), Downstream Angle (degree), Inside/Outside of Bend] |
| | | Tributary Channel | | | Orientation to Main Channel [Rivermeter (m), Upstream Angle (degree), Downstream Angle (degree), Inside/Outside of Bend] |
| | | Excavated Channel | | | Orientation to Main Channel [Rivermeter (m), Upstream Angle (degree), Downstream Angle (degree), Inside/Outside of Bend] |
| | Backwater | Contiguous | Abandoned, Channel Lake, Borrow Pit Lake, Man-made Channel Lake, Floodplain, Shallow Aquatic, Impounded | | Number (frequency), Area ($m^2$), Length (m), Width at the Mouth (m), Width at the Mouth to Main Channel Width Ratio, Orientation to Main Channel [Rivermeter (m), Angle of Mouth (degree)] |
| | | Isolated | | | Number (frequency), Area ($m^2$), Rivermeter (m), Length along the Main Axis (m), Width (m) |
| Non-Aquatic Area | Island | | | | Number (frequency), Area ($m^2$), Maximum Width (m), Maximum Length (m), Relative Position [Rivermeter (m), Head Angle (degree), Tail Angle (degree)] |

* in the channel column, not included descriptors are Number (frequency), Area ($m^2$), Width (m), Depth (m), Width-to-Depth Ratio, Sinuosity, Radius of Curvature (m), Deflection angle (degree), Wave Length to Radius of Curvature Ratio.

The channel border is the area between the navigation channel and the riverbank. The boundaries of the channel border are the apparent shorelines, the navigational buoy line, straight lines across the mouths of secondary and tertiary channels, and the lines along the inundated portions of the natural bank line. Wing dikes are stone and brush channel-training structures that extend laterally into the main and secondary channels to concentrate flow into the navigation channel. The boundaries of wing dike areas are defined by proximity to wing dike structures. The landward boundaries follow the apparent shorelines and inundated portions of the natural bank line. The riverward boundaries are perpendicular across the riverward end of the wing dike. Closing dams are stone and brush channel-training structures that are built across channels to concentrate flow into the navigation channel. Where closing dams are near the main channel border, the upstream boundary is across the mouth of the channel. The lateral boundaries are the apparent shorelines of the channel. Bank revetments are the armored shorelines of the

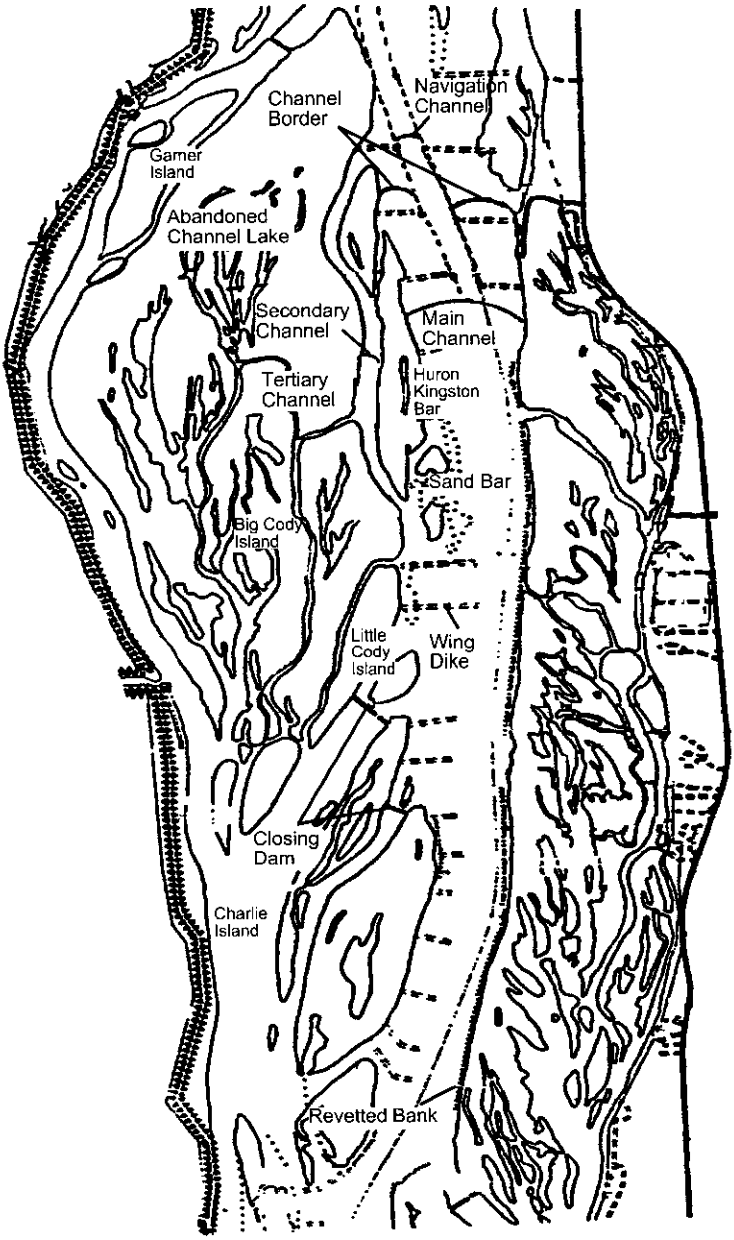

**Fig. 2 Example of Upper Mississippi River System Aquatic Areas (after Wilcox, 1990)**

main and secondary channels. Most revetments are articulated concrete mattresses or rock riprap. Limited lengths of shoreline with concrete or steel bulkheads or paved levees are included in this category.

Sandbars are flat-sloped areas within the main channel and major secondary channels that are characterized by sand substrates. Sandbars have side slopes of less than 1V:6.67H, they are completely submerged at the 5 year exceedence river frequency discharge, and they are not connected to shore at the reference river discharge level. Portions of emergent sandbars at the reference river discharge are unvegetated.

Secondary channels are large channels that carry less flow than the main channel. Their boundaries are the apparent shorelines, straight lines across the mouths of tertiary channels, and straight lines at the upstream and downstream limits of the apparent shorelines where secondary channels connect with the main channel. Tertiary channels are small channels. The lateral boundaries of tertiary channels are the apparent shorelines. The upstream and downstream limits of tertiary channels are straight lines between the upstream and downstream limits of the apparent shorelines. Tributary channels are channels of tributary streams and rivers. The landward boundary is the line where the tributary crosses. The lateral boundaries are the apparent shorelines. The riverward limit of tributary channels is a line drawn across the downstream limits of the apparent shorelines. Excavated channels are man-made channels with flowing water.

Backwater areas included all aquatic areas other than channels. Contiguous backwater areas are hydraulically connected by surface gravity flow at reference river discharges. For mapping purposes, "contiguous" indicates having apparent surface water connection with the rest of the river. Isolated backwater areas are those having no hydraulic connection by surface gravity flow at reference river discharges. For mapping purposes, "isolated" indicates no apparent surface water connection with the rest of the river. There are several different types of backwater areas, i.e., floodplain shallow aquatic areas, floodplain lakes, abandoned channel lakes, tributary delta lakes, lateral levee lakes, scour channel lakes, floodplain depression lakes, barrow pits, man-made lakes, and impounded areas.

## 4. APPLICATIONS

### 4.1 Selection of Streams

In order to determine the various parameters necessary for the development of a classification system for the aquatic areas of 10 natural streams and 10 modified streams, a series of identification codes has been developed with necessary descriptors for each category of aquatic area. The 10 natural streams are Chungmi-Cheon, Daewkandae-Cheon, Gye-Cheon, Keumgye-Cheon, Maeji-Cheon, Samsan-Cheon, Seom River, Ung-Cheon, Youngduk-Cheon, and Yudong-Cheon. The planform descriptors of these natural streams are measured using Korea Geological Survey topographic maps (scale 1:5,000). Ten study reaches were selected to provide representative aquatic areas of natural stream conditions throughout a river basin. In this study, all descriptors for aquatic areas are measured along the Seom River for the low flow condition, whereas width, sinuosity, radius of curvature, arc angle, and wave length are measured along the other 9 natural streams. The other hydraulic and geometric features of each stream are collected from the published reports. This information was used to investigate the distribution of the aquatic areas, and to develop a fundamental structure of the classification system.

For the comparison of aquatic areas of modified streams with natural streams and definition of man-made features, the planform descriptors for each category of aquatic areas are measured in 10 modified streams, which are Ansung-Cheon, Bokha-Cheon, Cheongan-Cheon, Daegyo-Cheon, Kyongan-Cheon, Taehwa River, Tan-Cheon, Wangsuk-Cheon, Yangjae-Cheon, and Yanghwa-Cheon. For measuring each category of aquatic areas of these streams, Korea Geological Survey topographic maps (scale 1:25,000) are used. Within the floodplain of these modified streams, aquatic areas can be defined that correspond to both geomorphic and man-made features.

### 4.2 Delineation and Measurement of Aquatic Areas

In the delineation of the aquatic areas, Korea Geological Survey topographic maps were used as base maps. All aquatic areas are delineated and marked on the base map in different colors. Identification codes and numbers for each category are also marked on the base map. A manual on the classification procedure is being written in order to clearly outline the procedures necessary to delineate and measure the aquatic areas and to input the data for the analysis. Measurement of the descriptors of each aquatic area is done on the base map. All necessary measurement lines, marks, and descriptors for all aquatic areas are also drawn on the base maps. An engineering ruler with different scales is used to measure channel width and lengths. Curved distances and area of each aquatic area are measured by using the KP-90 planimeter. The radius of curvature and the arc angle are measured using a compass and a 360-degree protractor. Measured data for planform descriptors of each category of aquatic areas are inputted and organized in the computer database for further analysis. Electronic spreadsheet programs are used to compute statistical parameters for all descriptor data. Different types of graphs and diagrams, including frequency histograms and polar plots, are used to investigate the statistical characteristics of data for each descriptor.

## 5. ANALYSIS OF RESULTS

### 5.1 Seom River

The Seom river basin in Hwengseong-Gun of Kangwon-Do is a tributary to the South Han River. The Seom River at its confluence with the South Han River has a drainage area of 2471.6 $m^2$ and a channel length of 32 km, and has alluvial channels. Bed materials found in the study reaches ranged from silt to medium-sized pebbles, and aquatic habitats were also found in study reaches. 102 measurement positions were measured with an equal spacing of 300 m along the Seom River basin. Statistical characteristics of each channel, the backwater, the channel curvature, and the meander of the Seom River are given in Table 2. The total sinuosity computed based on the definition of Leopold et al. (1964) in which sinuosity is defined as the ratio of channel length to the thalweg line distance, becomes 1.17 for main channel. This sinuosity is low according to the classification criteria proposed by Leopold et al. (1964). Meander wavelengths measured according to the definition of Leopold et al. (1964) are also given in Table 2. The mean wavelength is 485.9 m. The mean area of the sandbar is 101.2 $m^2$; the mean width and the mean length of the sandbar are 94.5 m and 660.9 m, respectively. In this study, the sandbar is divided into the alternating bar and the point bar, and two sandbars were measured along the main channel in this study.

Seo and Bhowmik (1991) measured the planform descriptors in Pool 13 of the upper Mississippi River in 51.2 km channel lengths. Statistical characteristics of the main channel, the channel border, and the navigation channel for Pool 13 and the channel curvature and the meander of Pool 13 are given in Table 3. The meander characteristics for the Seom and Mississippi

**Table 2. Summary of Aquatic Areas and Descriptors of the Seom River**

| Aquatic Areas | Descriptors | No. | Mean | Std. Dev. | Min. | Max. |
|---|---|---|---|---|---|---|
| Main Channel | Area ($m^2$) | 104 | 23.990 | 11.47 | 1.3500 | 55.800 |
| | Width (m) | 104 | 83.550 | 51.11 | 375.00 | 27.500 |
| | Sinuosity | 21 | 1.1700 | 0.190 | 1.4800 | 1.0100 |
| | Radius of Curvature (m) | 35 | 259.80 | 326.7 | 1675.0 | 155.00 |
| | Deflection angle (degree) | 35 | 61.690 | 57.90 | 166.00 | 45.000 |
| | Wave Length (m) | 8 | 1434.2 | 519.1 | 979.00 | 2580.7 |
| Sandbar | Area ($m^2$) | 64 | 101.2 | 154.8 | 1.30 | 860.00 |
| | Width (m) | 64 | 94.50 | 89.09 | 10.0 | 370.00 |
| | Length (m) | 64 | 660.9 | 370.8 | 16.0 | 4432.5 |
| | Distance from Thalweg Line (m) | 64 | 69.16 | 134.7 | 10.0 | 922.50 |
| Secondary Channel | Area ($m^2$) | 22 | 14.46 | 19.82 | 1.25 | 36.500 |
| | Width (m) | 22 | 27.73 | 16.22 | 5.00 | 0.1400 |
| | Length (m) | 22 | 503.0 | 523.2 | 85.0 | 2283.5 |
| | Width to Main Channel Width Ratio | 22 | 0.510 | 0.330 | 0.14 | 1.4300 |
| | Upstream Angle (degree) | 22 | 109.1 | 48.58 | 18.0 | 176.00 |
| | Downstream Angle (degree) | 22 | 54.43 | 42.01 | 18.0 | 154.00 |
| | Radius of Curvature (m) | 22 | 208.6 | 354.0 | 0.00 | 1250.0 |
| | Deflection Angle (degree) | 22 | 49.14 | 43.30 | 0.00 | 122.00 |
| Tertiary Channel | Area ($m^2$) | 6 | 5.000 | 4.940 | 0.200 | 13.250 |
| | Width (m) | 6 | 18.33 | 13.30 | 10.00 | 45.000 |
| | Length (m) | 6 | 377.8 | 531.3 | 118.0 | 1459.0 |
| | Width to Main Channel Width Ratio | 6 | 0.240 | 0.090 | 0.200 | 0.4100 |
| | Upstream Angle (degree) | 6 | 202.9 | 93.50 | 56.00 | 306.00 |
| | Downstream Angle (degree) | 6 | 173.8 | 158.9 | 14.30 | 343.00 |
| Tributary Channel | Width at the Mouth (m) | 21 | 17.02 | 16.61 | 0.01 | 50.00 |
| | Width at the Mouth / Main Channel Width | 21 | 0.290 | 0.310 | 0.00 | 1.000 |
| | Downstream Angle (degree) | 21 | 139.6 | 117.9 | 5.00 | 335.0 |
| Backwater | Area ($m^2$) | 14 | 4.450 | 2.980 | 1.25 | 9.500 |
| | Width at the Mouth (m) | 14 | 32.92 | 32.22 | 10.0 | 110.0 |
| | Width at the Mouth / Main Channel Width | 14 | 0.500 | 0.300 | 0.20 | 1.200 |
| | Angle of Mouth (degree) | 14 | 238.6 | 121.5 | 28.6 | 350.0 |

sippi Rivers are compared in Fig. 3. In Fig. 3, ratio of wavelength to main channel width, ratio of wavelength to arc angle, and ratio of arc angle to wavelength for the Seom River are larger than those for the Mississippi River. A polar plot of the radii of curvature and arc angles is shown in Fig. 4. As shown in this figure, the mean value of the radius of curvature for the Seom River is essentially larger than that of the Mississippi River, and the arc angle for the Seom River is also bigger than that of the Mississippi River. This indicates that the upper Mississippi River is more sinuous than the Seom River.

### 5.2 Comparisons between natural streams and modified streams

Statistical characteristics of the main channel, the channel curvature, and the meander characteristics of natural streams are given in Table 3. The total mean width of the 11 natural streams is 72.03 m, and the mean widths of the 11 natural stream range from 12.10 m to 521.5 m. The total sinuosity becomes 1.23 for the main channels of the 11 natural streams, and the mean sinuosity of

**Table 3. Summary of Descriptors of the Main Channel of the 11 Natural Streams**

| Streams | Width (m) | Arc Angle (deg.) | Radius of Curvature (m) | Sinuosity | Wave Length (m) | Wave Length /Width | Wave Length /Radius of Cuv. |
|---|---|---|---|---|---|---|---|
| Chungmi-Cheon | 57.33 | 97.06 | 349.44 | 1.28 | 793.21 | 13.84 | 2.27 |
| Daekwandae-Cheon | 14.76 | 96.31 | 164.84 | 1.38 | 312.20 | 21.14 | 1.89 |
| Gye-Cheon | 15.05 | 86.19 | 323.15 | 1.78 | 342.21 | 22.74 | 1.06 |
| Keumgye-Cheon | 12.10 | 89.18 | 214.71 | 1.28 | 337.43 | 27.60 | 1.57 |
| Maeji-Cheon | 17.50 | 73.14 | 357.14 | 1.03 | 414.03 | 23.66 | 1.16 |
| Samsan-Cheon | 24.50 | 108.1 | 231.00 | 1.18 | 365.08 | 14.90 | 1.58 |
| Seom River | 83.55 | 102.8 | 432.95 | 1.15 | 1485.2 | 17.78 | 3.43 |
| Ung-Cheon | 14.38 | 71.10 | 241.00 | 1.04 | 205.38 | 14.29 | 0.85 |
| Youngduk-Cheon | 18.56 | 89.12 | 182.35 | 1.06 | 360.97 | 19.45 | 1.98 |
| Yudong-Cheon | 13.13 | 90.44 | 196.88 | 1.32 | 243.34 | 18.54 | 1.24 |
| Mississippi River | 521.5 | 39.40 | 2389.4 | 1.07 | 5068.5 | 9.720 | 2.12 |
| Mean | 72.03 | 85.71 | 462.08 | 1.23 | 902.51 | 18.52 | 1.74 |
| Std. Dev. | 150.8 | 18.97 | 644.89 | 0.22 | 1429.3 | 5.150 | 0.73 |
| Minimum | 12.10 | 39.40 | 164.84 | 1.03 | 205.38 | 9.720 | 0.85 |
| Maximum | 521.5 | 108.1 | 2389.4 | 1.78 | 5068.5 | 27.60 | 3.43 |

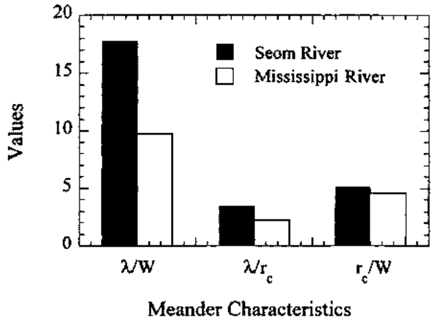

**Fig. 3 Comparisons of Meander Characteristics for Seom and Mississippi river**

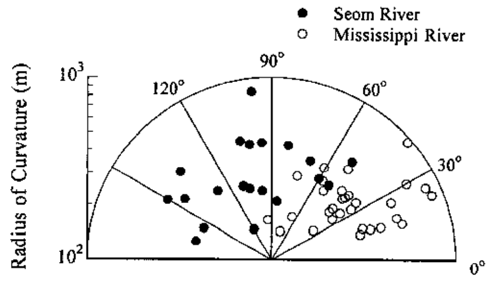

**Fig. 4. Polar Plot of Radii of Curvature and Arc Angle for the Seom and Mississippi Rivers**

the 11 natural streams range from 1.03 to 1.78. The meander wavelengths measured are also given in Table 3. The mean wavelength of the 11 natural streams is 902.51 m. The mean ratio of the wavelength to the radius of curvature is 1.74. This value is much smaller than those reported by Chang and Toebes (1970) and Brice (1974). They reported that the ratio of wavelength to the radius of curvature of the White River in Indiana, U.S.A. ranges from 3.8 to 6.0. The characteristics of the sandbars measured in the natural streams are listed in Table 4. The total means of the area, the width, and the length for the 10 natural streams are 26.53 m$^2$, 55.50 m, and 337.07 m, respectively. The distance from the thalweg line ranges from 7.237 m to 69.156 m.

**Table 4. Summary of Descriptors of the Sandbar of the 10 Natural Streams**

| Streams | Area ($m^2$) | Width (m) | Length (m) | Distance from Thalweg Line (m) |
|---|---|---|---|---|
| Chungmi-Cheon | 44.38 | 153.1 | 630.08 | 31.15 |
| Daekwandae-Cheon | 15.85 | 32.32 | 259.29 | 9.732 |
| Gye-Cheon | 24.64 | 36.01 | 207.74 | 9.702 |
| Keumgye-Cheon | 18.91 | 32.57 | 216.45 | 7.237 |
| Maeji-Cheon | 6.287 | 34.75 | 250.50 | 15.50 |
| Samsan-Cheon | 11.29 | 48.29 | 362.71 | 12.93 |
| Seom River | 101.2 | 94.51 | 660.91 | 69.16 |
| Ung-Cheon | 7.712 | 42.00 | 220.00 | 10.93 |
| Youngduk-Cheon | 11.37 | 52.34 | 348.42 | 10.26 |
| Yudong-Cheon | 23.65 | 29.17 | 214.58 | 8.333 |
| Mean | 26.53 | 55.50 | 337.07 | 18.49 |
| Std. Dev. | 28.49 | 39.23 | 171.61 | 19.08 |
| Minimum | 6.287 | 29.17 | 207.74 | 7.237 |
| Maximum | 101.2 | 153.1 | 660.91 | 69.16 |

**Table 5. Summary of Descriptors of the Main Channel of the 10 Modified Streams**

| Streams | Width (m) | Arc Angle (deg.) | Radius of Curvature (m) | Sinuosity | Wave Length (m) | Wave Length /Width | Wave Length /Radius of Cuv. |
|---|---|---|---|---|---|---|---|
| Ansung-Cheon | 23.52 | 84.89 | 352.86 | 1.15 | 352.42 | 14.98 | 0.10 |
| Bokha-Cheon | 21.32 | 102.4 | 189.06 | 1.08 | 323.92 | 15.19 | 1.71 |
| Cheongan-Cheon | 15.80 | 75.18 | 463.64 | 1.18 | 206.01 | 13.04 | 0.44 |
| Daegyo-Cheon | 19.15 | 105.4 | 257.81 | 1.16 | 400.94 | 20.93 | 1.56 |
| Kyongan-Cheon | 61.09 | 81.11 | 546.05 | 1.25 | 857.03 | 14.03 | 1.57 |
| Taehwa River | 98.75 | 94.17 | 1479.2 | 1.07 | 1274.9 | 12.91 | 0.86 |
| Tan-Cheon | 25.54 | 83.43 | 308.93 | 1.14 | 771.03 | 30.19 | 2.50 |
| Wangsuk-Cheon | 35.27 | 87.69 | 463.94 | 1.18 | 762.26 | 21.61 | 1.64 |
| Yangjae-Cheon | 10.83 | 83.29 | 312.68 | 1.12 | 456.35 | 42.13 | 1.46 |
| Yanghwa-Cheon | 21.11 | 106.9 | 242.19 | 1.12 | 217.28 | 10.30 | 0.90 |
| Mean | 33.24 | 90.45 | 461.63 | 1.14 | 562.21 | 19.53 | 1.27 |
| Std. Dev. | 26.91 | 11.12 | 374.74 | 0.05 | 343.56 | 9.84 | 0.70 |
| Minimum | 10.83 | 75.18 | 189.06 | 1.07 | 206.01 | 10.30 | 0.10 |
| Maximum | 98.75 | 106.9 | 1479.2 | 1.25 | 1274.9 | 42.13 | 2.50 |

Statistical characteristics of the main channel, the channel curvature, and the meander of the modified streams are given in Table 5. The total mean width of the 10 modified streams is 33.24 m, and the mean widths of the 10 natural stream range from 10.83 m to 98.75 m. The total sinuosity is 1.14 for the main channels of 10 modified streams, and the mean sinuosity of the 10 modified stream ranges from 1.07 to 1.22. This mean value of the sinuosity is smaller than that of natural streams. This means that a common practice for modifying streams is to straighten

**Table 6. Summary of Descriptors of the Sandbar of the 10 Modified Streams**

| Streams | Area ($m^2$) | Width (m) | Length (m) | Distance from Thalweg Line (m) |
|---|---|---|---|---|
| Ansung-Cheon | 19.96 | 43.75 | 159.92 | 472.7 |
| Bokha-Cheon | 28.19 | 41.98 | 296.98 | 11.39 |
| Cheongan-Cheon | 30.52 | 41.20 | 257.07 | 7.337 |
| Daegyo-Cheon | 23.91 | 28.13 | 253.13 | 7.813 |
| Kyongan-Cheon | 37.68 | 45.57 | 292.74 | 20.36 |
| Taehwa River | 68.22 | 69.20 | 366.96 | 35.71 |
| Tan-Cheon | 26.00 | 37.25 | 294.75 | 12.00 |
| Wangsuk-Cheon | 20.63 | 34.17 | 189.69 | 13.33 |
| Yangjae-Cheon | 1.560 | 10.00 | 65.625 | 6.250 |
| Yanghwa-Cheon | 26.87 | 32.75 | 295.00 | 1.250 |
| Mean | 28.35 | 38.40 | 247.19 | 58.82 |
| Std. Dev. | 16.85 | 14.95 | 86.582 | 145.7 |
| Minimum | 1.560 | 10.00 | 65.625 | 1.250 |
| Maximum | 68.22 | 69.20 | 366.96 | 472.7 |

watercourses in channel storage. The mean wavelength of the 10 modified streams is 562.21 m. The mean ratio of wavelength to the radius of curvature is 1.27. This value is smaller than that of natural streams. The characteristics of the sandbars measured in the natural streams are listed in Table 6. The total means of the area, the width, and the length for the 10 natural streams are 28.35 $m^2$, 38.39 m, and 247.186 m, respectively. The distance from the thalweg line ranges from 1.25 m to 472.73 m. The mean value of the distance from the thalweg line is smaller than that of natural streams.

In Fig. 5, the measured mean values of the radius of curvature for both natural streams and modified streams are plotted against the measured mean values of width. All of the measured mean values used in this study can be considered as fully developed meanders because there exist so many sinuous rivers for which the relative curvature $r_c / W$ is considerably greater than 2.4 or 3 (Hay, 1976). In Fig. 6, measured mean values of wavelength for both natural streams and modified streams are plotted against measured mean values of width. A feature of the measured data is that the mean values of wavelength for both streams do increase appreciably as the mean values of width increase. However, the wavelength of the natural streams increases more rapidly than the modified streams with the width. In this study, empirical equations for the wavelength were computed by a nonlinear least square technique similar to that employed by Leopold and Wolman (1964) for the mean width

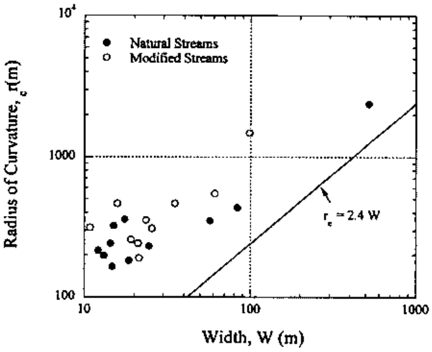

Fig. 5. Relation of Radius of Curvature with Channel Width

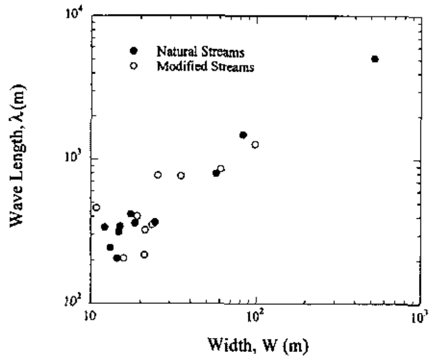

**Fig. 6. Relation of Wave Length with Channel Width**

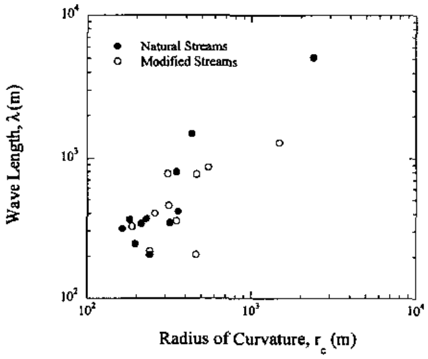

**Fig. 7. Relation of Wave Length with Radius of Curvature**

of the channel. The equations for natural and modified streams are given as;

$\lambda = 34.73W^{0.8}$, natural streams (1a)

$\lambda = 44.87W^{0.72}$, modified streams (1b)

In Fig. 7, measured mean values of wavelength for both natural streams and modified streams are plotted against measured mean val ues of the radius of curvature. A feature of the measured data is that the mean values of wavelength for both streams do increase appreciably as the mean values of the radius of curvature increase. In this study, empirical equations for the wavelength were computed by a nonlinear least square technique similar to that employed by Leopold and Wolman (1964) for the mean radius of curvature of the channel. The relations for the natural and the modified streams are given as;

$\lambda = 0.65\,\gamma_c^{1.16}$, natural streams (2a)

$\lambda = 7.24\,\gamma_c^{0.70}$, modified streams (2b)

The wavelength of the natural streams does increase more rapidly than the modified streams with the radius of curvature.

In Fig. 8, the width of the sandbar, $W_s$, for both natural and modified streams are plotted against the main channel width, in which $W_s$ of both streams increase as the channel width increases. The sandbar width of the natural streams does increase more rapidly than that of the modified streams with width. In this study, empirical equations for the width of sandbar were computed by a nonlinear least square technique for the main channel width. The result for the natural and the modified streams are given as;

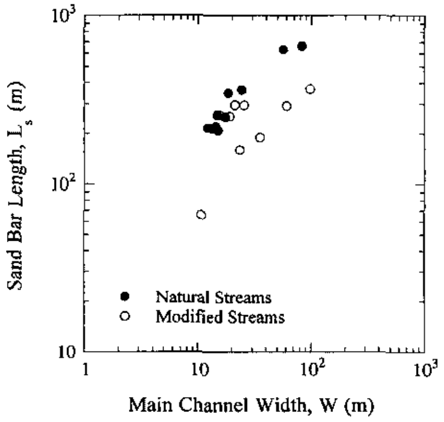

**Fig. 8. Relation of Sand Bar Width with Main channel Width**

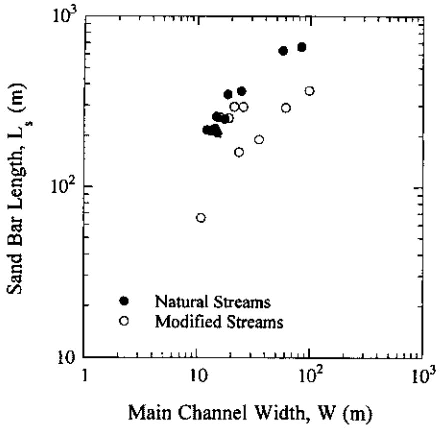

**Fig. 9. Relation of Sand Bar Length with Main Channel Width**

$$W_s = 4.92\,W^{0.74}, \quad \text{natural streams} \qquad (3a)$$

$$W_s = 5.38\,W^{0.57}, \quad \text{modified streams} \qquad (3b)$$

In Fig. 9, the longitudinal length of the sandbar, $L_s$, for both natural and modified streams are plotted against the channel width, in which $L_s$ of both streams increase as the channel width increases. However, $L_s$ of the natural streams does increase more rapidly than that of the modified streams with width. The empirical equations for the longitudinal length of the sandbar were computed by a nonlinear least square technique for the main channel width. The results for the natural and modified streams are given as;

$$L_s = 42.68\,W^{0.64}, \quad \text{natural streams} \qquad (4a)$$

$$L_s = 51.27\,W^{0.45}, \quad \text{modified streams} \qquad (4b)$$

## 6. CONCLUSIONS

For the development of relationships among descriptors of aquatic areas and the classification system of aquatic areas, descriptors of 10 natural streams and 10 modified streams in Korea were measured. The empirical equations for the wavelength of the main channel from both natural streams and modified streams were developed by a nonlinear least square technique for the main channel width and radius of curvature. The empirical equations for the sandbar characteristics such as sandbar width and longitudinal length of sandbar from both natural streams and modified streams were also developed. In this study, the total mean sinuosity is 1.25 for the main channels of natural streams, and this mean value of the sinuosity is larger than 1.14 of modified streams. The mean values of wavelength for both natural and modified streams do increase appreciably as the mean values of width and radius of curvature increase. However, the wavelength of the natural streams does increase more rapidly than that of modified streams with width. The width and the longitudinal length of the sandbar for both natural and modified streams increase as the channel width increases. However, the sandbar width and longitudinal length of the natural streams do increase more rapidly than the modified streams with width.

## ACKNOWLEDGMENTS

This research work was partially supported by the Korea Institute of Construction Technology and the 1999~2000 Brain Korea 21 Project of the Ministry of Education, Korea. The support given by the Research Institute of Engineering Science at Seoul National University, Seoul, Korea is greatly appreciated.

## REFERENCE

Assifi, A. T. (1966). "Hydraulics and Geometry of rivers." Master of Science Theses, Civil engineering Dept., Fort Collins, Colorado, Colorado State University.

Bhowmik, N. G., Stall, J. B. (1979). "Hydraulic Geometry and Carrying Capacity of Floodplains." Research Report 145, Water Resources Center, University of Illinois at Urbana-Champaign, Urbana, Il.

Bhowmik, N. G. (1984). "Hydraulic Geometry of Floodplains." Journal of Hydrology, 68, 369-401, pp. 369-401.

Bhowmic, N. G., Miller, A. C., and Payne, B. S. (1990). "Techniques for Studying the Physical Effects of Commercial Navigation Traffic on Aquatic Habitats." NTIS, Technical Report EL-90-10. U.S. Army Corps of Engineers Waterways Experimental Station.

Brice, J. (1973). Meandering Pattern of the White River in Indiana-An analysis. In Fluvial Geomorphology. Edited by M. Morisawa. Binghamton, N. Y. State University of New York.

Brussock, P. P., Brown, A. V., and Dixon, J. C. (1985). "Channel Form and Stream Ecosystem models." Water Resources Bulletin. 21(5). pp. 859-866.

Chang, T. P., Toebes, G. H. (1970) "A Statistical Comparison of Meander Planforms in the Wabash Basin." Water Resources Research, 6(2), pp. 557-578.

Chen, Y. H., and Simons, D. B. (1979). "Geomorphic Study of Upper Mississippi River." J. of Waterway, Port, Coastal and Ocean Division. 105(WW3), pp.313-328.

Cobb, S. P., and Clark, J. R. (1981). "Aquatic Habitat Studies on the Lower Mississippi River, River Mile 480 to 530, Aquatic Habitat Mapping." Vicksburg, Mississippi: Environmental Laboratory, U.S. Army Corps of Engineers Waterways Experiment Station.

Colbert, B. K., Johnson, J. H, Scott, J. E., and Solomon, R. C. (1975) "Environmental Inventory and Assessment of Navigation Pools 24, 25, and 26, Upper Mississippi and Lower Illinois Rivers: An Aquatic Analysis. NTIS, Technical Report Y-75-2. Environmental Effects Laboratory U.S. Army Corps of Engineers Waterways Experiment Station.

Dury, G. H. (1973). "Magnitude-Frequency Analysis and Channel Morphometry." In Fluvial Geomorphology. Edited by M. Morisawa. Binghamton, N.Y.: State University of New York.

Hey, R. D. (1976). "Geometry of River Meanders." Nature, No. 262, pp. 482-484.

Leopold, L. B., and Wolman, M. G., Miller, J. P. (1964). Fluvial Processes in Geomorphology. San Francisco and London: W.H. Freeman and Company.

Seo, I. W., and Bhowmik, N. G. (1991). "Classification of Aquatic Areas of Three Pools in the Upper Mississippi River System. " Interim Report Illinois State Water Survey.

Simons, D. B., Schumm, S. A., and Stevens, M. A. (1974). "Geomorphology of the Middle Mississippi River." NTIS, Contract Report Y-74-2. Fort Collins, Colorado, Colorado State University Engineering Research Center.

Simons, D. B., Lagasse, P. E., Chen, Y. H., and Schumm, S. A. (1975). "The River Environment." Fort Collins, Colorado, Colorado State University Engineering Research Center.

Simons, D. B. (1979). River and Canal Morphology. In modeling of Rivers. Edited by Shen, H. W. New York, John Wiley &

Sons.

U.S. Army Corps of Engineers. (1981). "Geomorphic and Land Use Classification of the Floodplains of the Mississippi River and Its Navigable Tributaries above Cairo, Illinois." Chicago, Illinois.

---

Tae Sung Cheong, Post Doc. Research Associate, School of Civil, Urban, and Geosystem Engrg., Seoul Natl. Univ. Kwanak-Gu, Seoul 151-742, Korea
(E-mail: bicstar@plaza.snu.ac.kr)

Il Won Seo, Assoc.Prof. School of Civil, Urban, and Geosystem Engrg., Seoul National Univ. Kwanak-Gu, Seoul 151-742, Korea
(E-mail: seoilwon@plaza.snu.ac.kr)

(Received October 30, 2000; accepted January 4, 2001)