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Deformation Process of Sandbar and Interaction between Vegetation and Sandbar in Meandering Channel of Shibetsu River

DEFORMATION PROCESS OF SANDBAR AND INTERACTION BETWEEN VEGETATION AND SANDBAR IN MEANDERING CHANNEL OF SHIBETSU RIVER

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ABSTRACT

The Shibetsu River originally had a number of meanders, and a wetland extended at its lower reaches. Cut-off works to straighten the meandering river course began in 1953. As a result, safety against flooding was improved, the wetland disappeared and farmland development in the river basin progressed. In recent years, however, there have been increasing demands from local residents for the creation of a better river environment. Restoration of the natural river environment has therefore been promoted since 2000. Since it was considered to be difficult to ensure safety against flooding if only the old meandering river course was restored, it was ultimately decided that the old river would be restored while maintaining the present straightened river course. Water was reflowed into the restored meandering river course on March 18, 2002. The meandering river experienced several floods during which annual maximum daily discharge exceeded the average annual maximum daily discharge rate. Several field studies were conducted to visually observe changes in the channel and flow conditions. And to quantitatively understand changes in landform, cross-section surveys were performed. These investigations showed that bank erosion, other than the expected bank erosion at the bifurcations, occurred in many places because of meander bends and flow deviation due to sandbars. The erosion resistance of banks differed markedly between the pre-improved channel and the excavated channel. Therefore, it is essential to take this behavior into consideration when predicting channel migration. It is also important to gain a thorough understanding of the areas to be affected by the plan through the examination of relevant data, including the centerline of the channel, bed configuration and flow conditions.

Key Words : *Shibetsu river, re-meandering, restoration*

1. Introduction

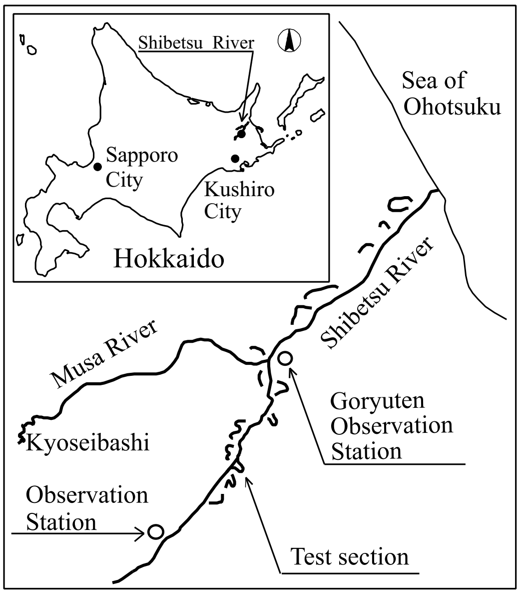
In recent years, numerous opportunities have arisen in Japan to discuss environments surrounding rivers, and since 1990, attention has begun to be directed to the natural habitats of living things. However, the point of view taken in the past toward conservation and reproduction of natural environments was limited solely to river channel environments, and the concept of a region formed by a river was weak. Moreover, the relationship between river dynamics (i.e., not only that the riverbed is moving, but the river itself is shifting) and river ecosystems was not sufficiently understood, creating a situation that was not conducive to promoting techniques for conservation or reproduction of sustainable river environments. It was under such conditions that Japan amended its River Law in 1997, adding "maintenance and conservation of river environments" as important river management objectives. The Shibetsu River meandering restoration project had been planned under this background.

The Shibetsu River had meandered through wetlands, but to prevent floods, the channel was straightened in 1932. Efforts to restore the river to its natural flow have been under way since 2000. Because studies on changes in channel flow and on habitats have focused mainly on the section from the estuary upstream to the Kyosei area, where there is an ecological restoration test ground, that section was chosen for the research. The project of the Shibetsu River is the Japan's first model case of nature restoration.

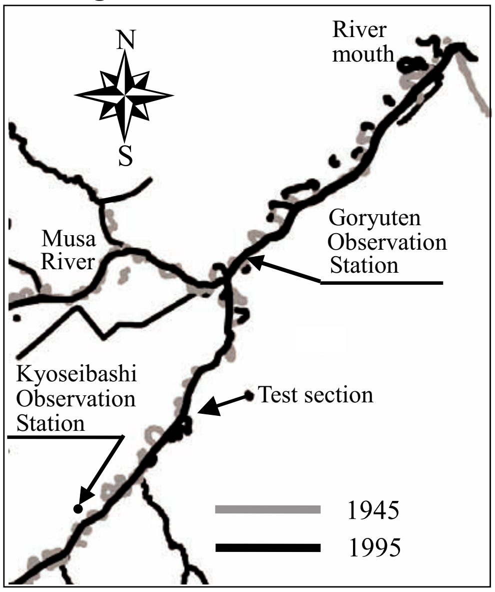
In this paper, we report on a study we conducted concerning river channel changes in the experimental section of the Shibetsu River after commencement of water flow, for the purpose of clarifying actual conditions and the main causes of changes in the river channel of a watercourse where an extremely hydraulically complex two-way river channel phenomenon exists, and investigating the possibility of projecting river channel shape in the future. The Shibetsu River was selected as the first case of re-meandering project because of the comparatively large number of land features remaining in the vicinity in Shibetsu River, such as oxbow lakes, which can be used immediately for meander restoration. Various river environment restoration methods have been studied, and there are even advanced examples of such works in Europe and other regions [Watanabe 2002)]. In Japan, however, there were no precedents of meander restoration for purposes of nature restoration, and the phenomena such restorations may cause from the standpoint of both river engineering and ecology were unclear. In addition, the river channel that had been straightened to ensure discharge capacity remained, and meander restoration using oxbow lakes was considered as one method for true meander restoration. Because this would mean addressing the extremely complex phenomenon of undertaking meander restoration while retaining the straight channel, to understand and solve the technical issues involved the decision was made to first create an experimental section to increase understanding of the phenomenon. Test flows using part of the former river channel (oxbow lake) had already been conducted on the experimental section since March 18, 2002.

2. Outline of the Shibetsu river restoration project

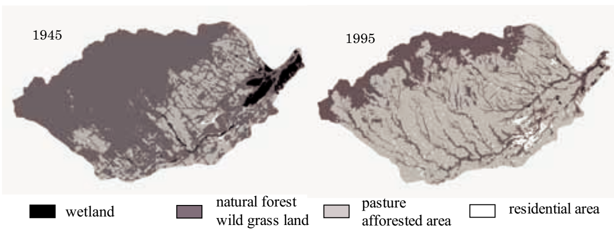
The Shibetsu River has a river channel 78 km in length and a river basin measuring 671 km^2. The river flows into the Sea of Okhotsk (see **Figure-1**). Until around 1945, the appearance of the Shibetsu River consisted of numerous repeated meanders, with the mountainous region along the upper reaches of the river covered by natural forest and the lower reaches flowing through a vast helocrene extending over a broad, undeveloped area. After 1953, full-scale cutoff works were completed to straighten the meandering river channel lower the levels of groundwater and the river, with the goal of increasing land use in the river basin and improving flood safety. As a result, most of the helocrene along the lower reaches of the river was converted into farmland during the latter half of the 1980s, and flood safety improved rapidly. The change in the river channel and landuse of the basin during these years is shown in **Figure-2** and **Figure-3**. As times changed, however, the situation surrounding the Shibetsu River also changed greatly, and local demands calling for an attempt to restore the river's past natural ecosystem increased. Towards this end, "nature restoration-type river development" is being promoted as a means to carry out meander restoration and accomplish nature restoration along the Shibetsu River.



Fig–1 Outline of the Shibetsu River



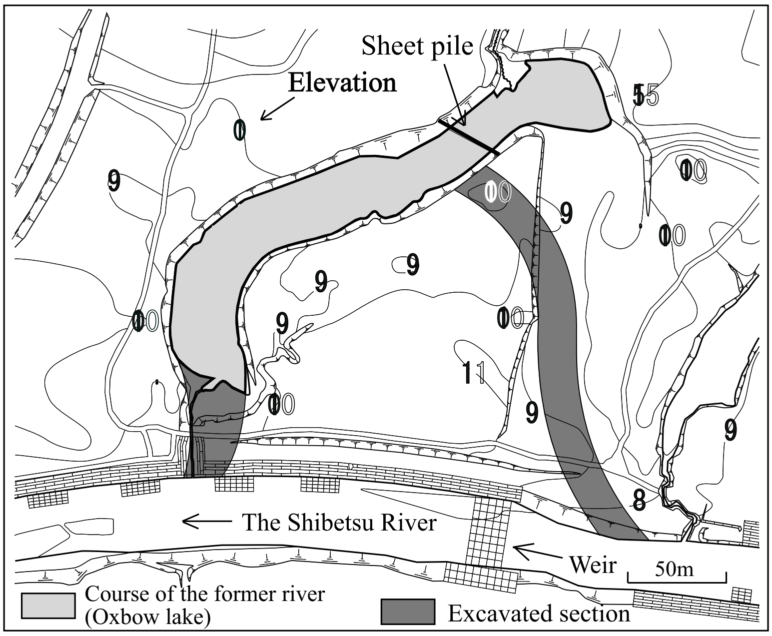
Fig–2 Changes of the river course



Fig–3 Changes of the landuse in the basin

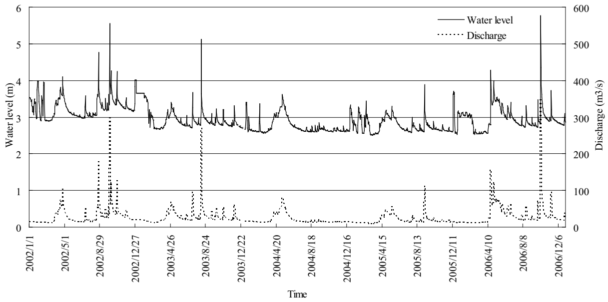
3. OUTLINE OF THE EXPERIMENTAL SECTION

An experimental section was established along the right bank of the river, from a point



Fig–4 Landform of experimental section and condition of connection channel

8.4 km upstream to a point 8.6 km from the river mouth. This section is in a location where the elevation of the hinterland is comparatively high and there are no levees or dams, and there are no concerns about flood control even if unanticipated phenomena should occur. An overview of the experimental section is shown in **Figure-4**. In the experimental section, making a design-scale flood flow safely for flood control purposes was assumed to be impossible along only the meandering former river channel (oxbow lake). Therefore, a method to ensure discharge capacity by widening the former river channel (oxbow lake) was devised. However, because this would completely alter the natural environment along the river banks on a large scale, a decision was made to leave the present river channel (straight channel) unaltered and connect it with the former river channel (oxbow lake). This created a two-way river channel along this stretch of the river. In the experimental section, the meandering former river channel (meander channel) has a riverbed gradient that is shallower than that of the present river channel (straight channel) (2002). This raised a concern the former river channel (meander channel) would be buried by silting. Therefore, a semi-permeable weir (created by packing gravel into net bags) with a 1m head was set up in the present river channel (straight channel) at a point approximately 30m downstream from the former river channel (meander channel) and present river channel (straight channel) bifurcation point, so that most of the Shibetsu River flow under normal circumstances will flow into the former river channel (meander channel). Because the downstream side and upstream side of the former river channel (meander channel) area had been filled during the river cutoff works, a riverbed with a 20m width and a single section with a 1/2 river bank gradient were excavated for connecting to the present river channel. Although this exposed sandy soil on the excavation surface, the vegetation cover was expected to recover naturally and the bank was left bare. Following the cutoff works in 1967, the former river channel (oxbow lake) had become a closed water zone after being separated from the present river channel (straight channel). Over the years, a unique ecosystem had formed here. Therefore, as control data on ecosystem changes wrought by the water flow, a part of the former river channel (oxbow lake) was left as a closed water zone. To accomplish this, a sheet pile was erected on the former river channel (oxbow lake) at the location shown in **Figure-4**. At commencement of the test flow, the former river channel (meander channel) had a length of approximately 470m and a riverbed longitudinal slope of roughly 1/2,500. The average particle size of riverbed material sampled prior to the water flow was 2.8mm. On the other hand, the present river channel (straight channel) length is



Fig–5 Discharge and water level at the Goryuten Observation Station

approximately 220m, with a riverbed longitudinal slope of about 1/1,200 and an average particle size of 11mm.

4. SURVEY METHOD ALONG THE EXPERIMENTAL SECTION

To understand the change in the river channel, a course of traverse was set in the upstream and downstream directions of the river channel at a 20m pitch and cross sectioning was completed before and after flooding. In addition, because of the possibility the shape of riverbed sandbars or river bank erosion would not be measured at a course of traverse with a 20m pitch, and because cross sectioning would not be implemented immediately following flooding of the experimental section, cross sectioning was supplemented with site reconnaissance by conducting a visual examination. Furthermore, when conducting the reconnaissance, photographs were taken to provide objective data of the observations concerning the changes to the river channel. Observations of the flow condition were also made, which will enable an investigation of the flow changes, albeit quantitatively. On the other hand, because discharge is normally not being observed in the experimental section, we decided to use the rate from the discharge at the observation station at the confluence with the Musa River about 3 km downstream. The time change of the discharge and water level at the Goryuten Observation Station (5.4 km from the river mouth; see **Figure-1**) on the dates when cross-section surveys and site reconnaissance were implemented are shown in **Figure-5**.

Table–1 Relationship between discharge in the experimental section and discharge at the Goryuten Observation Station

Date of Observation	2002		2003
	19 Mar	19 Apr	9 May
Before diverging (A)	7.3	44.2	32.3
Meandering channel (B)	6.9	26.1	20.4
Goryuten Observation Station (C)	10.8	64.4	50.2
(A)/(C)	0.68	0.69	0.64
(B)/(A)	0.95	0.59	0.63

5. SURVEY RESULTS

5.1 Flow regime after test flow

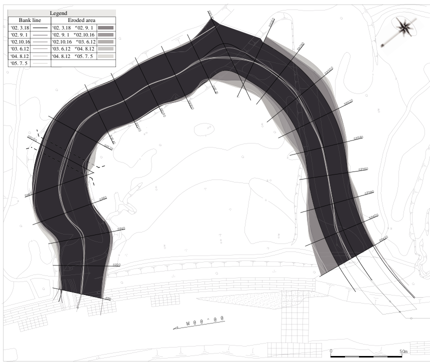
In the flow regime at the Goryuten Observation Station shown in **Figure-5**, the floods during April and May of each year were caused by snowmelt. Other floods were floods accompanying heavy rainfall. The mean value for maximum annual daily discharge from 1970 through 2001 at the Goryuten Observation Station was approximately 160m^3/s, and on four occasions the river channel in the experimental section experienced floods in excess of the mean value for maximum annual daily discharge. On October 8, 2006 particularly, a flood occurred that generated a maximum daily discharge of 348m^3/s. All four of these floods flowed only in the low water channel section of the experimental section. Two of four floods were occurred in 2002 and there is no large flood from September 2003 to September 2006 (about three years).

As shown in **Table-1**, from the discharge observation results since commencement of the test flow, the discharge in the experimental section ranges from 60 percent to 70 percent of the discharge at the Goryuten Observation Station. From this, we estimated the mean value of the maximum annual daily discharge in the experimental section to be approximately 100m^3/s.

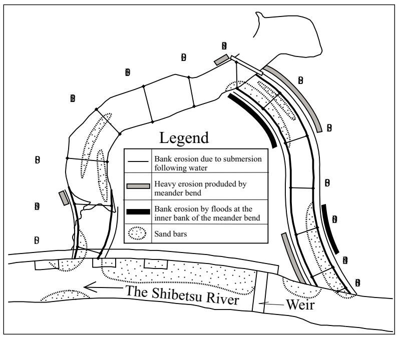
5.2 Condition of changes in the river channel

Vertical aerial photographs at the experimental section had been taken five times. The first is in June 2002, three months after water flow commenced. The second is in May, 2003, 14 months after water flow commenced. The third is in November, 2005 and the fourth is in May 2006. The newest is November 2006, after the largest flood in the observed period. These photographs show in **Figure-6**. From the photograph of June 2002 in **Figure-6**, the formation of sandbars can be seen on the inner bank side of the former

Fig–6 Conditions of the experimental section



Fig–7 Changes in bank shoreline



Fig–8 Channel changes observed visually in the experimental section

river channel (meander channel) section and the present river channel (straight channel) section at a point in time three months after water flow commenced. Moreover, although the shape of the sandbars cannot be confirmed clearly in May 2003, because the water level when the photograph was taken was about 30 cm higher than in June 2002, the sandbars were confirmed by survey to have nearly the same shape as those in June 2002. When comparing the pictures in June 2002 and in May 2003, there are no large differences in the shape of the sandbars, but in May 2003 it is possible to discern that the right and left river banks in the area upstream of the sheet pile and the river bank on the left bank of the inflow area near the present river channel (straight channel) have been eroded substantially. This shows the sandbars were almost entirely formed by the first snowmelt floods, and that river bank erosion caused by the accompanying deviation of the flow is advancing with successive floods. Furthermore, because the river bank on the left bank side of the inflow area had been eroded by as much as nearly 12m by October 2002, there was a danger the weir built in the present river channel (straight channel) might be destroyed if the erosion progressed further. Therefore, to maintain the test flow, from December 2002 to March 2003 a revetment (cobblestones packed in netlike nylon bags) was constructed extending 70m from the tip of the inflow area. The changes in the river bank line of the former river channel (meander channel) section from March 18, 2002 immediately prior to the test flow as determined from cross sectioning are shown in **Figure-7**. After May 2003, the heavy bank erosion had not been occured. The remarkable river bank erosion of the river channel section that was newly excavated to connect the former river channel (meander channel) section and the present river channel (straight channel) section is clearly shown in **Figure-7**. The results of the site reconnaissance are summarized and shown in **Figure-8**. In addition to the river bank erosion on the left bank side of the inflow area that Sato et al (2002). pointed out based on indoor hydraulics experiments, river bank erosion believed to result from the water flow occurredin multiple locations along the newly excavated river channel section. The river bank erosion that occurred in the vicinity of SP280 on the left bank side, which is the inner bank side of the curve section, and at SP400 on the right side, were noted after snowmelt periods or the comparatively large-scale flood period that occurred in October 2002. Such erosion of the inner bank side is believed to have occurred because the main current line of the flow forms a free vortex flow near the inner bank side. On the other hand, the river bank erosion in the vicinity of SP40, SP240, and SP280 on the right bank side and SP420 on the left bank side is on the outer bank side of the curve section. This is because the riverbed on the outer side of the bank in the curve section is subject to scouring by secondary currents and the main current line forms a forced vortex flow toward the outer bank side. But some influence from the sandbars formed on the inner bank side of the opposite bank side is also assumed. On the other hand, because the river banks along the former river channel (oxbow lake) are covered with vegetation and cobblestones are exposed in some sections, no remarkable river bank erosion has occurred at the present time. The positions of sandbar formation are nearly identical to the condition that could be deduced from the results of the indoor hydraulics experiments conducted by Sato et al (2002).

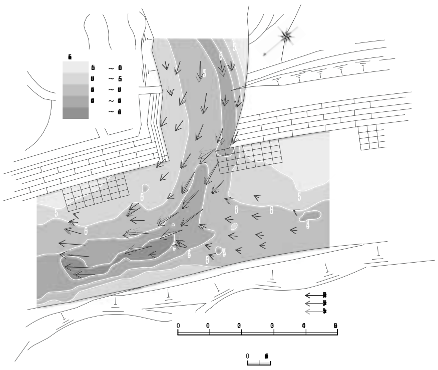
5.3 Change in flow direction and flow velocity in the vicinity of the inflow area and outflow area

On May 26 and 27, 2003, we conducted a survey of the flow direction and flow velocity in the vicinity of the inflow area and the outflow area of the former river channel (meander channel). We placed a course of traverse in both the downstream and upstream directions, at an average interval of 10m, set up seven cross sectioning direction survey stations on the present river channel (straight channel) section and five survey stations on the former river channel (meander channel) for each course of traverse, and performed the survey. The survey station interval in the direction of depth was measured at 5-30cm. The results of the measured flow velocity and flow direction are shown in **Figure-9** and **Figure-10**. For the measurements of the flow direction and flow velocity, we used an electromagnetic flow meter and an ADCP (Acoustic Doppler Current Profiler). The water level at the Goryuten Observation Station was about 3.2m, roughly identical to the low water flow regime on the survey days because the snowmelt flood had ended.

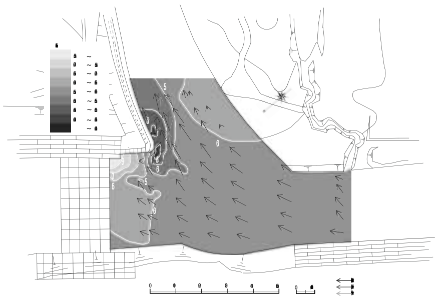
In the outflow area shown in **Figure-9**, the main current line of the flow appears as if drawn in a semicircle nearly following the deepest part of the riverbed, and because the discharge from the present river channel (straight channel) that overflowed the weir is also small, a stable flow regime from the former river channel (meander channel) to the present river channel (straight channel) is shown. This tendency of flow is the same from the vicinity of the water surface to the vicinity of the riverbed. In the inflow area shown in **Figure-10**, the flow from the present river channel (straight channel) flows smoothly into the former river channel (meander channel). When the flow along the river bank in the vicinity of the leading edge of the left bank side of the former river channel (meander channel) is examined in detail, the flow along the river bank moves toward the center of the river channel. The degree of this movement of the flow direction toward the center of the river channel grows stronger as water depth increases, and the influence of a secondary flow appears. Riverbed scouring is caused by the effect of this secondary flow in the vicinity of the leading edge of the left bank side. From the results of cross sectioning before the revetment was constructed, the occurrence of riverbed scouring was not confirmed and the river bank has been eroded to the hinterland side. However, from this survey after the revetment had been constructed, the influence of the revetment on strengthening the secondary flow and promoting riverbed scouring while protecting the river bank was confirmed. Moreover, a condition in which the river flows backward can be perceived in the vicinity of the divergence point (right shore side) of the present river channel (straight channel). From **Figure-9** and **Figure-10**, the condition of the flow is a main current line with a forced vortex flow toward the outer bank side. Furthermore, in addition to the influence on the inner bank caused by the sandbars, a watercourse that flows smoothly from the present river channel (straight channel) into the former river channel (meander channel) in the vicinity of the inflow area, and from the former river channel (meander channel) into the present river channel (straight channel) in the vicinity of the outflow area, is being maintained. The generation of sandbars that would close the flow into the former river channel (meander channel), which was a concern prior to the test flow, has not occurred at the present time.

6. Invasion of vegetation on sandbars

There is no large flood from September 2003 to September 2006 for about three years at the experimental section (see **Figure-5**) . Sandbars in this section were stabilized and emerged. The willow invaded on sandbars. The changing situations of invaded willows on the bar which generated at the inner bank of meandering part of the channel are shown in **Figure-11** Although the greatest flood in an observation period occurred in October 2006, destruction of the willow trees accompanying deformations of a sandbar was not generated. When growth of a willow continues,



Fig–9 Vector of flow directions and velocities at the outflow area



Fig–10 Vector of flow directions and velocities at the inflow area

Fig–11 Changing situations of invaded willows on the bar

the flow capasity at this section will be decrease and become a problem on river improvement and river environment. It is necessary to clarify the relation between growth of willows and formation of sandbars.

7. Conclusions

We implemented a follow-up survey of conditions of river channel migration during five years following commencement of water flow in the experimental section of the Shibetsu River Meander Restoration Project. Based on the study, we confirmed river bank erosion had occurred at various locations, including the inner bank side, as the result of flow deviation caused by river channel curves or sandbars, in addition to river bank erosion in the vicinity of the inflow area and the outer bank side that were anticipated based on indoor hydraulics model tests conducted beforehand. We confirmed it would be necessary to reflect these findings in future meander restoration plans. We also confirmed the ability to withstand erosion will differ greatly between the former river channel (oxbow lake) areas where the river bank is covered with vegetation and the newly excavated locations where the river bank was left bare, and ascertained that sandbars formed in the riverbed will greatly influence. If the period, when large flood does not occur, will continue for a some years, vegetation invades on sandbars and the problems on river improvement and river environment will be generated. Finally, we clarified it will be necessary to take these findings into account when predicting future river channel shape.

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