HOW IS THE GAP BETWEEN THE CONCEPT AND PRACTICE OF INTEGRATED SEDIMENT MANAGEMENT BRIDGED?

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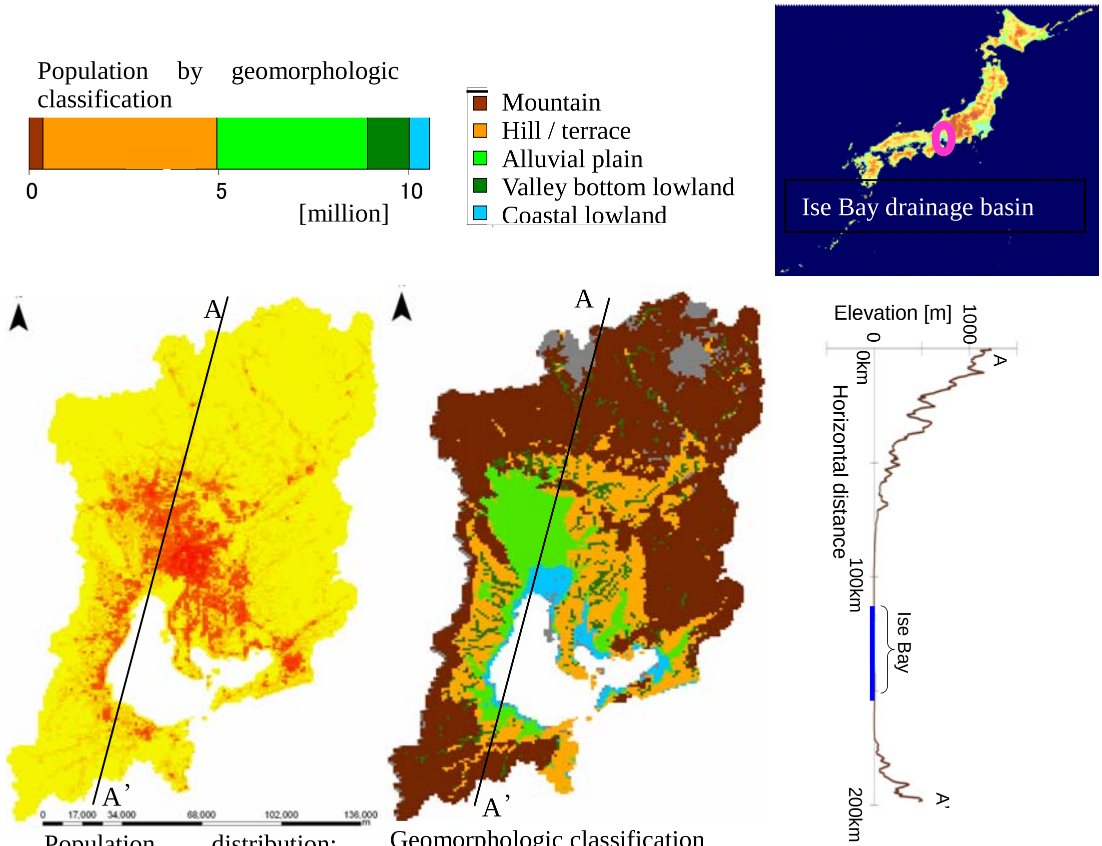
In Japan, various and intensive modifications to river systems through projects for sediment/flood control, water resources development, electric power supply, river improvement and so on have played extremely important roles in mitigating flood/sediment related disasters and improving our lives and society. At the same time, they have changed river-basin-scale sediment transport systems, bringing new problems with their system soundness in terms of continuity, sustainability and ecological functions. Perceiving that this shows limitations of a locally optimized approach by the area and purpose, which had been taken because of its efficiency, the government has already laid out the concept of "integrated management of a sediment transport system" as a new national policy direction. However, there still appears to be the gap between the concept and its practice, which may retard sweeping development of the new policy.

Instead of seeking for "magic technology" that alone can bridge the gap, this overview paper stresses three keys to firmly establishing integrated sediment management: (a) grasping and sharing an overall image of a sediment transport system by using a "common language" that macroscopically describes sediment transport phenomena, not being limited to excessively precise analysis; (b) appropriately performing a diagnosis to identify the structure of problems through a scenario-driven approach, not being preoccupied by stereotyped thoughts; (c) prioritizing the development of component technologies and linking them with policy setting & implementation processes. Specific methodologies essential to obtaining the keys are presented on the basis of characteristics of sediment transport systems in Japan. Finally, eleven issues on how to overcome obstacles in the implementation stage are discussed from perspective ranging from science and engineering to planning and social aspects, with the aim of suggesting strategy of research and development leading to the integrated sediment management.

Key Words : *integrated sediment management, river-basin-scale sediment transport system, river bed variation, reservoir sedimentation, coastal erosion, ecological function, habitat*

1. GEOGRAPHICAL CHARACTERISTICS OF RIVERS AND RIVER BASINS IN JAPAN – A COUNTRY WHICH MUST COEXIST WITH LIVELY MOVEMENT OF SEDIMENT

In Japan, which is an island nation with steep mountain ranges forming the backbone of its long, narrow national land, the topography of its river basins is complex and their scale smaller than those of continental rivers, and riverbed gradients are generally steep. Mountainous land, which yields most of the country's sediment, occupies 70% of Japan, and boundaries between mountainous zones and plains are clear (see **Fig.1 & 2**). There are many geologically fragile places in the mountains. In a warm humid climatic zone influenced by monsoon Asia, rainfall is frequent throughout the year (national average of about 1,700mm/year), it is often struck by typhoons, and torrential rain can, as shown



Population distribution: darker red indicates higher population density

Geomorphologic classification

Topographical section along A--A'

Fig.1 Typical geographical characteristics of Japan[1]. –Taking Ise Bay Drainage Basin as an example –

Mountains are steep and clearly demarcated from plains, and cover a large percentage of the land. But the population of the mountains is very low, with about a half of the total population living on the rest consisting of alluvial plains, valley bottom lowlands and coastal lowlands, and with the remainder distributed on hills and terraces. This means that many people live near or at places where flood inundations or the transport and deposition of sediment can occur.

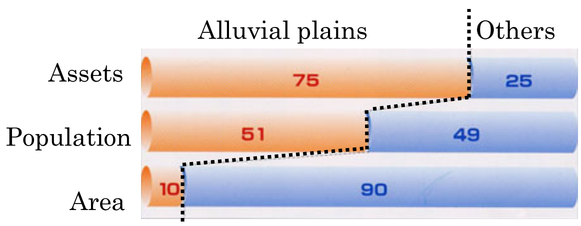


Fig.2 Distribution of assets, population and area in Japan[2] .

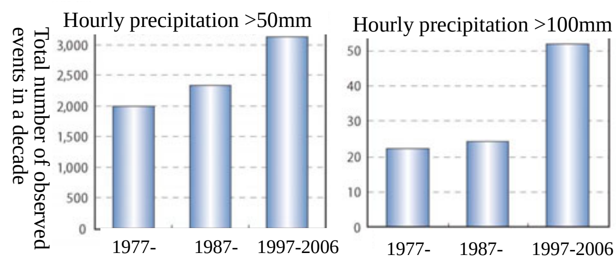


Fig.3 State of occurrence of torrential rainfalls in Japan[3] .

in **Fig.3,** fall from late spring to early autumn.

As a result, specific sediment yields are large compared with the world average, and in some river basins they exceed 2mm/year or even more, as is shown in **Fig.4**.

On the other hand, the mountainous land in Japan is mostly covered with relatively good quality forests which have the capacity to absorb heavy rainfall to a great extent. Therefore, it should be also noted that devastated streams and massive failures of mountainsides play significant roles in sediment yield (see **Fig.5**). Although the overall area of devastated streams is small, they persist in some mountainous regions, continuously forming important sediment production sources. Although massive failures induced by extremely torrential rains are rare, once they occur, they dramatically transform downstream river courses, supplying a huge amount of sediment in short periods of time.

The sediment produced has been transported down steep rivers to small areas of shallow sea water around the edges of the mountainous zones, forming alluvial plains. The alluvial plains occupy only about 10% of the national land, but during the period of modernization and urbanization, the small precious plains were occupied by half the population and about 3/4 of the nation’s assets were concentrated on their land as is shown in **Fig.2**, because the

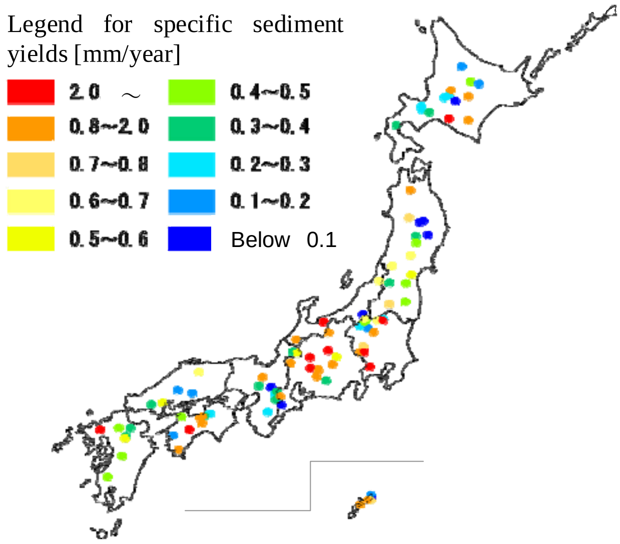


Fig.4 Specific sediment yields for dam catchment areas calculated from dam reservoir sedimentation data.[4)]

mountainous land covering 70% of the national land is too steep for land use.

Daily life and economic activities in Japan are conducted mainly on alluvial plains formed in only the past approximately 10,000 years and which are still under the influence of their formation process, along rivers which transport large quantities of sediment with spatial and temporal variety, and near sediment production sources occasionally activated by sudden phenomena. And these conditions will remain unchanged in the future as a result of the basic geographical conditions of Japan. This means that the people of Japan will continue to live along with lively movement of sediment.

2. DEVELOPMENT OF THE COUNTRY ACCOMPLISHED THROUGH VARIOUS MODIFICATIONS TO RIVER SYSTEMS

In Japan, artificial control of rivers has played extremely important roles in supporting economic growth and in preventing disasters and mitigating their effects so that people can live in comfort. Since the late nineteenth century when the end of the feudal period brought industrialization and urbanization, a variety of projects have been undertaken to control rivers and these were accelerated after World War II, transforming the state of Japan’s rivers. The following are typical examples.

In mountainous regions, sediment control projects, well-known as Sabo, have been

Fig.5 Examples of devastated streams and massive failures.
Devastated streams in the Tedori River basin (top left) and the Kurobe River basin (top right). The bottom photo shows a massive failure in the Naka River basin on Shikoku Island induced by the torrential rain in the excess of 1000 mm daily precipitation in 2004, inflicting a severe disaster including fatalities and destruction of homes, roads and bridges. The collapsed sediment flowed down into a tributary stream of the river, raising its bed by several meters.

energetically implemented to reduce disasters caused by sedimentation of narrow torrential river courses by excessive runoff of sediment, the collapse of slopes, landslides, and debris flows.

Dam reservoirs, which have played a key role in flood control (flood discharge regulation), water resource development (securing water for urban and irrigation use), and supplying power to support the reconstruction of the national land after World War II and high speed economic growth, have been designed appropriately and constructed in mountainous regions throughout Japan to achieve these multiple purposes (see **Fig.6**). Dam reservoirs in Japan are now capable of storing a total of 25.2 billion m^3: but, it is equivalent to only 6% of all theoretically available water resources.

Those who live in and use alluvial plains have faced on an urgent need to reduce the danger of floods inundating their land by increasing flood discharge capacity of river courses. Expanding river cross-section areas by excavation has been, along

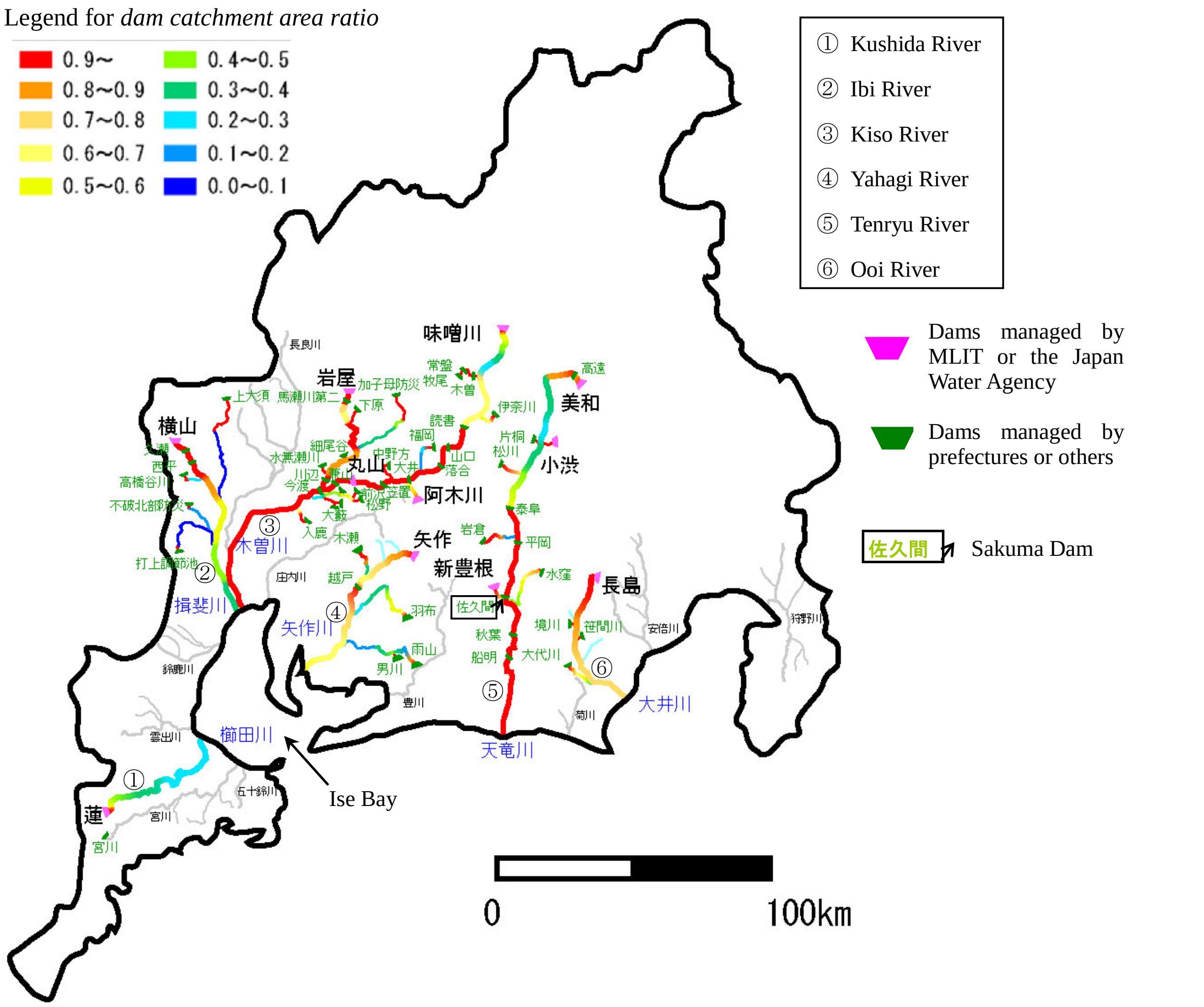


Fig.6 River system map of the Chubu Region for *dam catchment area ratio*[4]. The left half covers Ise Bay Drainage Basin, geographical characteristics of which are shown in **Fig.1**.

Dam catchment area ratio is defined as a percentage of area of dam catchment to the total catchment area with reference to a location on a river. Dam reservoirs have been constructed in mountainous regions throughout Japan, effectively controlling floods and supplying water. While there are river systems on which the ratio is large down to the river mouths, there are river systems where this value is high only in upstream areas. The degree of impact of dam reservoirs on downstream rivers can vary greatly, depending on the location of the dams on a river system.

with the construction of levees, an effective and practical countermeasure, as is shown in **Fig.7**.

3. EFFICIENCY AND LIMITATIONS OF OPTIMIZED APPROACHES BY THE PURPOSE AND THE AREA

Efforts to improve river systems as described above have, needless to say, made a great contribution to progress towards each of the goals: sediment-relate disaster countermeasures mainly in upstream and mountainous areas, flood-related disaster countermeasures mainly along alluvial river reaches, water resource development and electric power supply by dam reservoir construction, and so on. At the same time, these have resulted in great

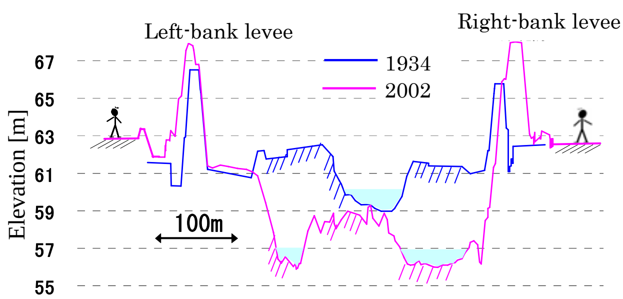


Fig.7 Cross-sectional change between 1934 and 2002 at the Tedori River 11km point from the river mouth located in its alluvial fan river reach.

This typically shows a great effect of channel excavation on flood disaster prevention by increasing a flood flow capacity and by lowering flood water stages. Unless a river responds quickly to excavation, channel excavation is a simple, but also a strong and highly reliable method.

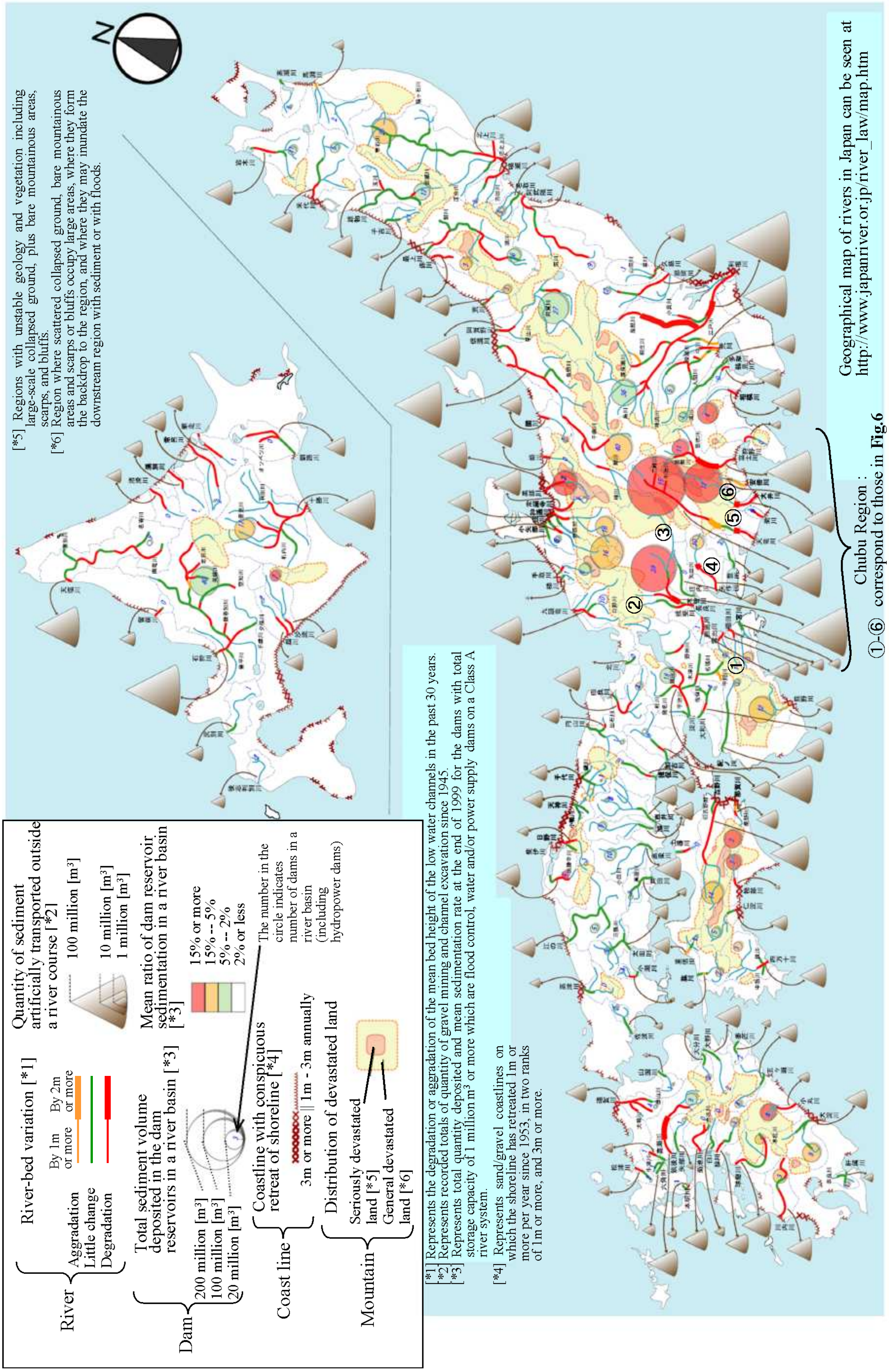


Fig.8 Sediment transport system census map 2002 by the River Bureau, MLIT.

changes to the basic characteristics of the movement of sediment in Japan's rivers.

Fig.8 is called a *sediment transport system census map* prepared by aggregating, combining and processing all measured data related to sediment transport and geomorphic change in the *sediment transport systems* of the Class A rivers. A *sediment transport system* is defined as, "a continuous range of sediment movement from the upstream source of a river basin to its coastline". From this figure, it is possible to know the total dam reservoir sedimentation volume and rate in a river basin. It shows the distribution of devastated mountain land, river course variation trends (riverbed aggradation or degradation), state of shorelines, total quantity of sediment transported artificially outside the river course (based on sand & gravel mining and channel excavation data recorded since 1945) and so on for each sediment transport system.

This map provides fundamental information that should be the starting point to gain a comprehensive overview of the overall state of sediment transport systems in Japan. And this figure shows that if the total quantity of sediment deposited in dam reservoirs is obtained, it is approximately 1.18 billion m^3. And the total quantity of sediment transported artificially outside the river course is obtained as 1.13 billion m^3. If this combined quantity of sediment was spread over the entire land of Japan, it would raise its surface by 6mm.

Throughout Japan, anxiety spread that various river improvements and sediment control projects undertaken energetically on river courses in this way to achieve each of these goals would result in significant disruption of sediment transport systems which span entire river systems, and that this would undoubtedly cause the following new problems. **Fig. 8** certainly shows a dominant trend for riverbed degradation throughout Japan and for retreating shorelines along many coasts, providing fundamental support for such concerns. In fact, as explained later, it is essential to take a more cautious scientific attitude to the issue of the causal relationships between phenomena on each river system. However, at least, on the assumption that the above concerns are generally justified, a common awareness of the need to create appropriate technological countermeasures has been established. We are also aware that at the same time as approaches by the purpose and by the area have been extremely effective, they are accompanied by specific side-effects and that integrated management is definitely required to overcome these side-effects.

4. NATIONAL POLICY DIRECTION: INTEGRATED SEDIMENT MANAGEMENT OF A SEDIMENT TRANSPORT SYSTEM

The basic directions of sediment management in line with such basic awareness have already been formulated at the government level. First, a clear awareness of the challenges was presented in the policy proposal "Basic directions of future river improvement policy looking ahead to the society of the twenty-first century", presented by the River Council to the Ministry of Construction (MOC), predecessor of the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) in 1996.

"Problems concerning sediment occur in various ways in each area: mountains, plains, river mouths, coastlines, and so on. Problems seen in the mountains include the occurrence of disasters caused by sedimentation of torrent streams by sediment run- off from devastated mountain land, massive failures of mountainsides, landslides, and debris flows, plus problems such as the reduction of dam functions by dam reservoir sedimentation in high sediment yield regions. Problems on alluvial plains, at river mouths, and along coastlines include riverbed degradation, plugged river mouths, and retreating coastlines. Past countermeasures were planned individually according to the purpose in each area, but such individual responses cannot achieve sweeping resolution of these problems."

Basic policy directions to resolve such problems were laid out as follows in a report by the Sub-committee of the River Council on Integrated Sediment Management under the title "Towards integrated sediment management of a sediment transport system" in 1998.

1) As a new perspective to the overall resolution of sediment-related problems, the concept of "sediment transport system" defined as a continuous range of sediment movement from the upstream source of a river basin to its coastline must be introduced. And integrated sediment management should be performed under this concept. To do so, "spatial continuity", "temporal continuity", "quantity and quality of sediment (grain size and habitat formation)" and "relationship with river flow" need to be considered.
2) The goal of sediment management is the creation of a rich and vigorous society by preventing disasters caused by sediment movement, conserving the ecosystems, landscape, etc. in river and coastline environments and appropriately using rivers and coastlines based on the

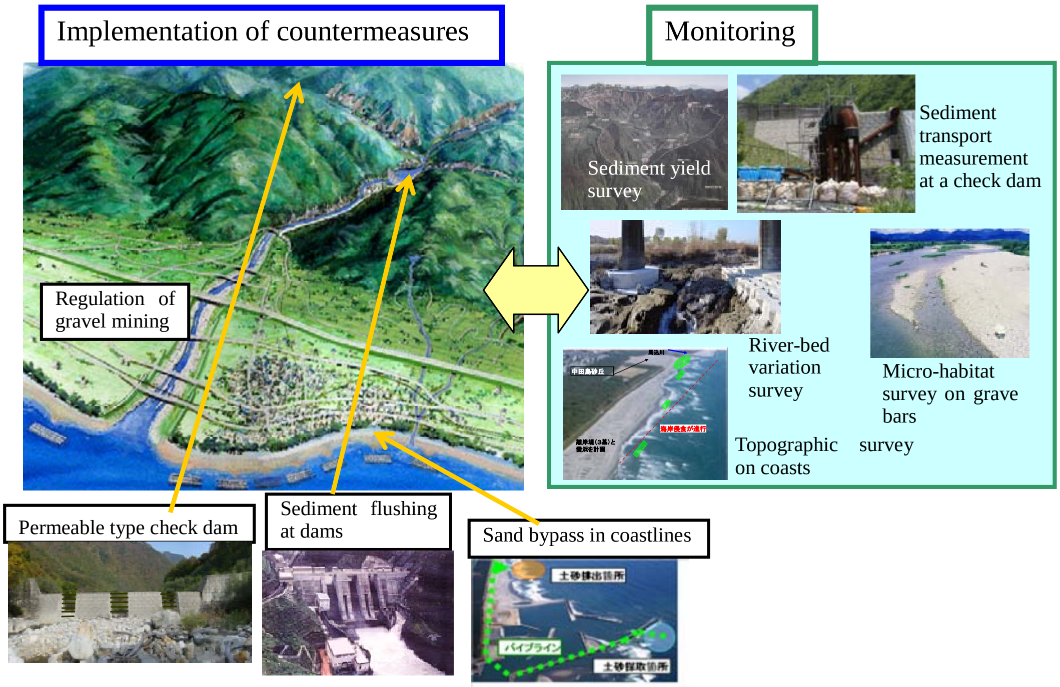


Fig.9 Various initiatives conscious of integrated sediment management of a sediment transport system.

characteristics of each river and coastline.

3) Choosing some sediment transport systems as pioneer cases, river managers should conduct monitoring of the state of sediment, test countermeasures such as supplying sediment, and observe their effectiveness and impacts. Quantities and the quality of sediments should be monitored and research conducted to improve prediction methods, in order to prepare plans to undertake integrated sediment management and to take countermeasures. Specifically, the following are important.

<u>Monitoring of sediment movement</u>: On sediment transport systems where problems with sediment management have occurred, the quantity and quality of sediment should be systematically and consistently monitored throughout the system.

<u>Wise control of sediment runoff in mountains and foothills</u>: Disasters caused by unexpected and excessive runoff of sediment should be prevented while sediment supply should be maintained as appropriate for downstream rivers and along coastlines.

<u>Establishment of new sediment management systems at dams</u>: Effective and safe sediment management systems around dam reservoirs such as sediment bypass, pass-through and removal should be established.

<u>Achievement of appropriate and consistent sediment management throughout sediment transport systems</u>: Integrated sediment management including sediment supply should be implemented while maximizing the use of the above approaches.

The above appears to show that the basic policy direction has been placed on a firm foundation and the process is steadily reaching the implementation stage. In fact, in some sediment transport systems, activities have been undertaken energetically in recent years, as is shown in **Fig.9**. Examples of these include large-scale measurements of sediment transport using weirs, measurements of riverbed variation during floods, the construction of sediment check dams designed with slits or openings so that harmless sediment flows downstream and of dam reservoirs with sediment bypass or removal functions, the resupply of sediment deposited in dams to rivers downstream, the restoration of bare gravel riverbeds by reactivating gravel transport, and artificial beach nourishment or sand bypasses on coastlines.

These have been undertaken with greater consciousness of integrated sediment management throughout a sediment transport system than in the past. But it cannot be stated that a unified implementation system has been introduced with clear common targets and under integrated sediment management plans for the said sediment transport system, so sediment management is still partly dependent on enthusiastic efforts to undertake individual projects, which are not always well-coordinated. So here, a gap remains between the concept and practice of integrated sediment management in a sediment transport system.

5. THREE IMPORTANT POINTS TO FIRMLY ESTABLISH INTEGRATED SEDIMENT MANAGEMENT

To bridge this gap in order to bring integrated sediment management closer to the stage of full-scale application, I wish to stress the following three points, which were presented by Tsujimoto and I[5).

[A] *Grasping an overall image of the sediment transport system or not being limited to precise analysis of details*

The state of a sediment transport system is, of course, clarified by surveying, observations, and monitoring, phenomena analysis, and by modeling, but it is vital that these activities be matched to the purpose: understanding of overall phenomena in a sediment transport system.

It is not easy to grasp an overall image of a sediment transport system extending from the drainage basin to the seacoast. There is an inevitable tendency for phenomena analysis and precise modeling of separate areas to take precedence. When scientific analysis advances, there is a tendency for technologies that express more details with greater precision to follow. If such methodologies become too familiar, people probably adapt too much to using different “languages” for each area concerned. In order to avoid becoming preoccupied with phenomena in each area, it is essential to establish a “common language” as a way of gaining a common understanding of a sediment transport system targeted. This is so because even if detailed phenomena have been minutely collected, overall phenomena are not necessarily obvious, and this means that it is vital to discover resolution which is appropriate to viewing overall phenomena.

[B] *Appropriately performing a diagnosis to identify problems and how the sediment transport system are linked to them*

Managing a sediment transport system is a method of achieving goals, and its heart is “management for what purpose?”. In other words a consciousness of the goal of resolving problems is essential. Without it, a strange conversation could occur as follows. “Yes, integrated sediment management is very important. Let’s begin! By the way, what are we going to do to implement it?” This means it is essential to understand the structure of problems in the sediment transport system and then find how to link handling of the sediment transport system to resolving problems. And phenomena related to the structure of problems are not limited to the sediment transport system. Cases where phenomena related to a sediment transport system constitute only a part of a problem can occur. It is important that, instead of thinking that dealing appropriately with a sediment transport system will resolve all problems, you specify what kinds of phenomena other than sediment transport are related to the occurrence and resolution of problems.

[C] *Prioritizing the development of component technologies and linking them with policy setting & implementation processes*

At the stage where necessary knowledge related to A and B above is obtained to study integrated countermeasures used to manage a sediment transport system, it is essential to first prepare applicable component technologies. It is important to hold discussions to decide what component technologies are necessary and under what priority they should be developed, and it is also necessary to clarify how the application of each component technology will contribute to the total management of the sediment transport system.

Sediment transport system management handles a temporally and spatially wide range of phenomena deeply linked to society, so it is important to hold discussions to determine the best methods of proposing, coordinating, and deciding countermeasures. Specifically, topics to be discussed include management planning, the concept of setting goals, ways to achieve a consensus, balancing a variety of goals, and implementation strategies. Another important point is the scientific and technological information which should be provided for this purpose.

Items A, B, and C defined above do not exist independently, but they are strongly interdependent, so it is vital that all three be discussed in parallel.

6. HOW TO OBTAIN A COMMON LANGUAGE: VITAL FOR OVERCOMING POINT [A]

(1) Grain size distribution supplied from mountains to alluvial plains in Japan

Sediment supplied by production sources in the mountains includes a wide range of material ranging from clay to boulders. Although it cannot be generalized that the importance of the abrasion and crushing in the production of fine-grain sediment is ignored, when discussing a sediment transport

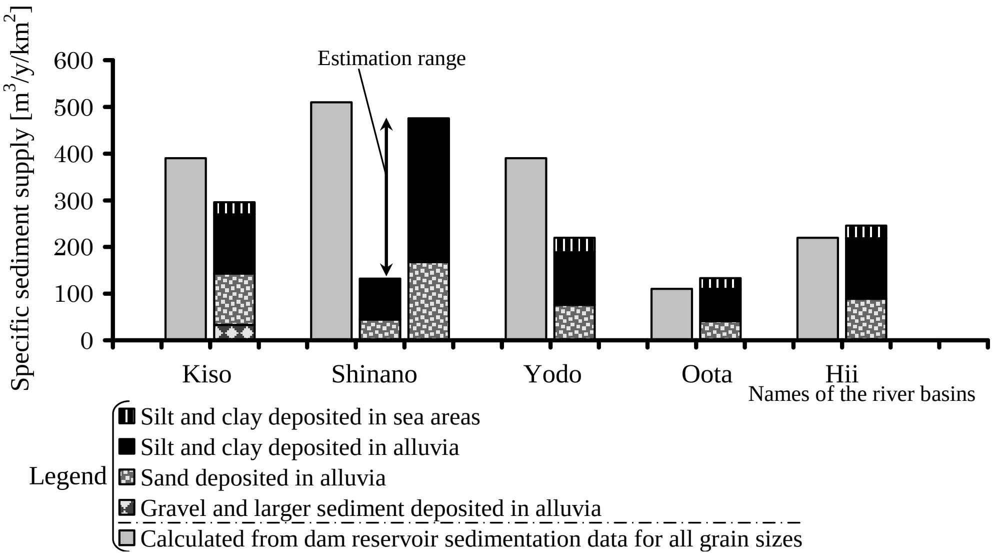


Fig.10 Long-term mean quantity of sediment supplied to the alluvial rivers for each grain size range investigated based on the volume and grain size distribution of their alluvia[6]: the quantities for all grain sizes can be compared with dam reservoir sedimentation data indicated by the adjoining grey bars.

An overwhelming percentage of all sediment supplied from mountains is sediment with a grain size of sand and finer. The transport of gravel and larger sediment causes vigorous sediment transport and great riverbed variation which cause sediment disasters, mainly on mountain river courses. However, in terms of overall quantity, most of that supplied is fine grain size material.

Interestingly, long-term (about 10,000 years) mean specific sediment supplies estimated correspond to those based on dam reservoir sedimentation data which indicate far short-term (a couple of decades) values.

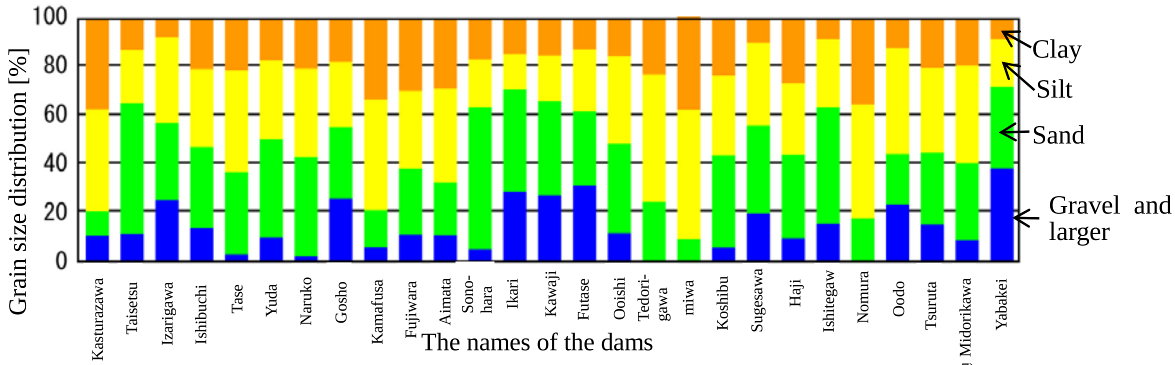


Fig.11 Grain size composition of sediment deposited in the dam reservoirs[7].

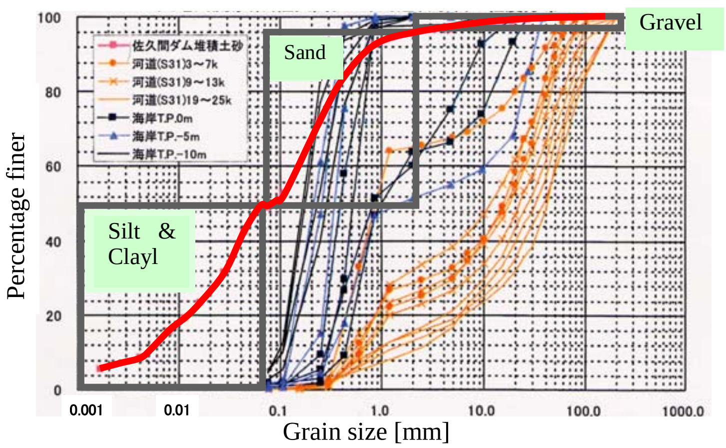


Fig.12 Grain size distribution of sediment deposited at the Sakuma Dam on the Tenryu River (thick red line) and the grain size distribution in the downstream river (orange) and on the seacoast near the river mouth (blue, black)[8] : the location of the dam is shown in **Fig.6**.

Although the main river-bed material is gravel, sand that will be beach material is already supplied to the dam in large quantities.

system in Japan, overall, it should be assumed that at the stage where it has flowed through the mountains a certain distance, the percentage of sediment flux between gravel & larger sediment, sand, and silt & clay have become generally constant.

A lot of borings for various construction works have been made on alluvial plains in Japan, which has made it possible to more precisely draw 3-D strata structure of alluvia, which have been deposited for years. By calculating the volume of alluvia for each grain size group from strata structure obtained in this way, we can estimate long-term mean sediment supply from mountainous land (about 10,000 years for major alluvial plains in Japan) if we choose the case where sediment transported away to the bottom of the deep sea can be neglected.

Based on the volume and grain size of alluvia for example, the grain size distribution of sediment supplied to alluvial plains from mountains during the past 10,000 years has been estimated to be 50 to 60% silt & clay, 30 to 40% sand, and less than 10% gravel and larger, as is shown in **Fig.10**. Grain-size distribution of sediment deposited in a dam reservoir generally corresponds well to these percentages, as is shown in **Fig.11**. Sediment with a grain size of sand and finer which account for most of the sediment transport in downstream rivers already exists at positions in dam reservoirs in the mountains (see **Fig.12**).

For such reasons, as a primary approximation, it is possible to grasp sediment transport systems within the framework: How does sediment with the above grain size distribution supplied from mountains to alluvial plains behave in rivers and on coastlines?

(2) Effectiveness of the approach: grasping sediment movement for each grain size group

The behavior of sediment with such a wide range of grain sizes can be grasped effectively by tracking movement for each of the grain size *groups* as shown below.

1) The manner in which sediment in a sediment transport system is transported, is exchanged with riverbed material and influences river topography all vary greatly according to the grain size group. Consequently, treating sediment as a uniform mass is meaningless. On the other hand, separating grain sizes into too many fractions from the beginning, as is often the case with sediment transport modeling, is too complex and even hinders essential study of overall trends.
2) In many cases, it is better to begin by considering sediment movement for each of the three grain size groups: fine-grain sediment (silt, clay and in some cases finer sand), sand, and gravel & larger.
3) To control the phenomenon which is the focus of attention, it is necessary to track movement of the grain size group that governs this phenomenon. Inversely, it is not necessarily reasonable to track all grain size groups.

A good example for explaining the movement of each of the above grain size groups is a river course that is seen typically for large alluvial rivers in Japan: a steep slope gravel-bed reach (segment G) connecting with a mild slope sand-bed reach (segment S) (see **Fig.13**). Grain size groups which are gravel & larger, sand, and silt & clay, in the above percentages, are supplied from mountains to alluvial rivers.

From upstream to downstream, gravel is transported mixed with riverbed material (gravel) in segment G, then stops at the downstream end of segment G. Sand almost entirely passes through segment G without its transport flux varying very much, and after it reaches segment S, it is transported mixed with riverbed material (sand) until it reaches the river mouth where it is finally discharged into the sea. Accordingly, in segment S, sand that is riverbed material is actually supplied directly from the sediment production source. Some silt & clay can be deposited on floodplains (natural levees), on gravel beds as top fine sediment layers in alluvial fan rivers, and on river-beds near the river mouth as temporary riverbed material. But most passes through both segments G and S to flow into the sea.

It is possible to explain the basics of the bed profile evolution with sharp longitudinal sorting as is shown in **Fig.13**, by macroscopically grasping the movement of each grain size group.

In the above, the movement of gravel governs riverbed variation in the gravel bed reach, and the movement of sand governs riverbed variation in the sand bed reach. The movement of fine-grain sediment governs the formation of top fine sediment layers attributable to the rapid expansion of stable vegetation areas on gravel bars (see **Fig.14**), floodplain accretion forming natural levees (see **Fig.15**), its deposition in super low velocity areas near river mouths, and the material transport of nutrient salts or pollutants etc. (including supply to the sea).

It is highly likely that main bed materials in the furthest downstream river course segment play a primary role in supplying material forming coastline topography, but there are cases where, according to the grain size of the material which governs the formation of coastline topography, even finer

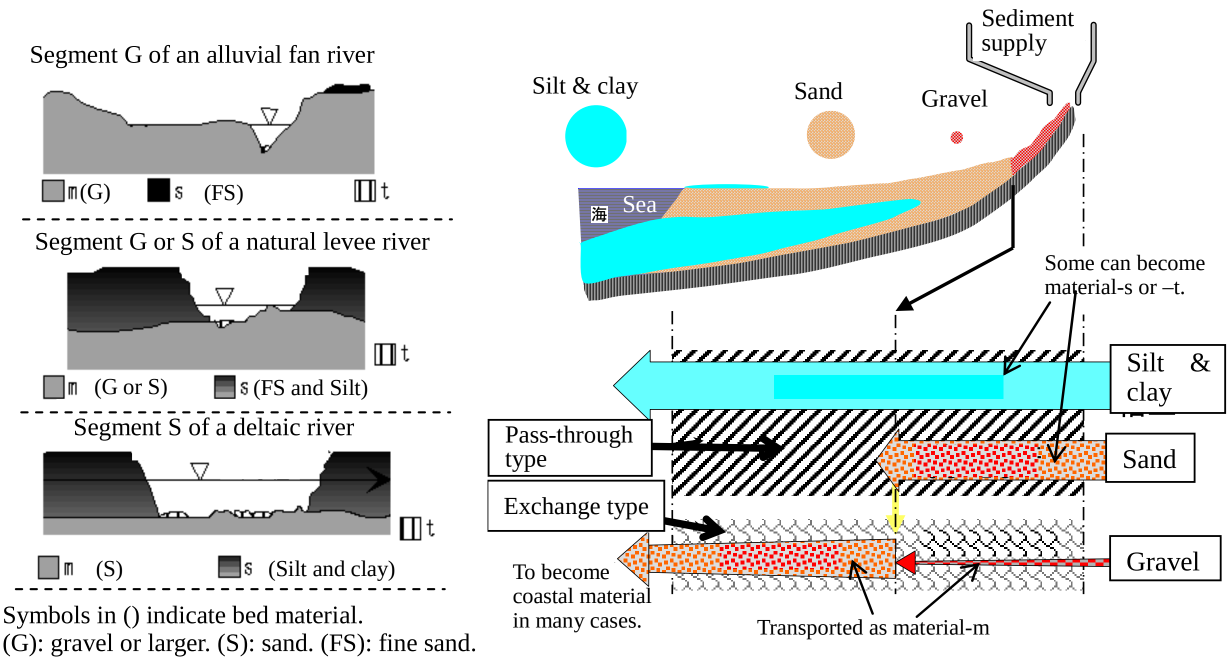
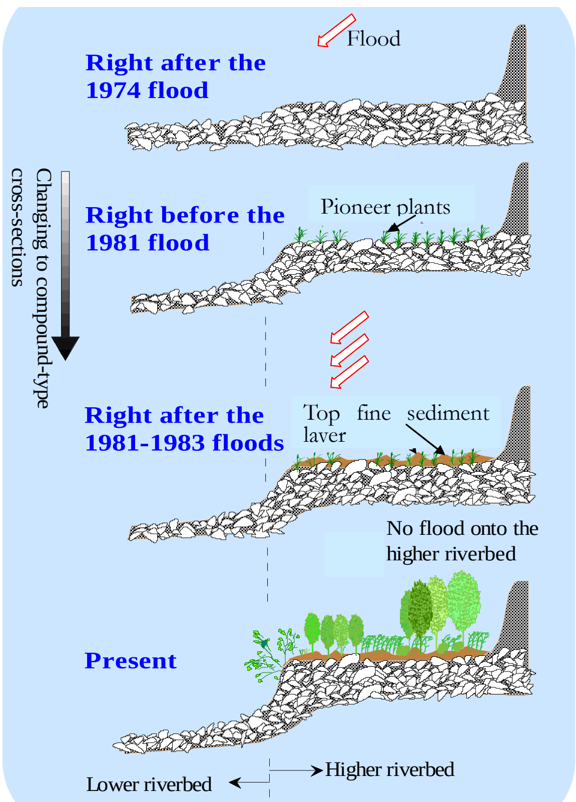


Fig.13 Explanation of macroscopic movement of grain size groups (silt/clay, sand, and gravel/larger) and their roles in longitudinal river-bed profile evolution for a river course composed of a steep slope gravel-bed reach (segment G) connecting with a mild slope sand-bed reach (segment S)[6].

On the left, the classification of river bed material into m, s and t is presented. Material-m plays a primary role in governing the formation of longitudinal bed profiles and river-bed configuration, roughness coefficients of a low water channel, scouring depth essential for design of structures, the habitat structure composed of riffles and pools, and so on. When the words, "riverbed material" are said, the speaker is often referring automatically to material-m.

A riverbed made of material-s is formed by the deposition of formerly suspended fine-grain size sediment beside the main flow. Material-s even forms floodplains themselves in natural levee zones. The deposition of material-s in alluvial fan is generally thin wherever it occurs. However, vegetation flourishes far more readily than at a location where gravel (material-m) is exposed.

The existence of material-t is often temporary and unstable, as it is flushed out or sharply reduced by even the smallest floods. The covering of material-m by material-t, even partially or temporarily, is important as a change in micro-habitat structure, and it could also impact the material cycle when low flow condition is prolonged. CPOM can be included in this category.



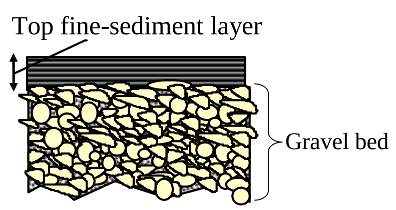


Fig.14 Role of the top fine sediment layer in the riparian woodland expansion observed in the Nagata reach of the Tama River[9].

The top fine sediment layer which was carried on gravel beds by the floods of 1981 to 1983 triggered the wood land and dense herbaceous plant area. The top fine sediment layer formed on top of the gravel bed of an alluvial fan river is only a few tens of centimeters thick at the most, and does not raise the riverbed very much, but it has an important impact on the prevalence of vegetation.

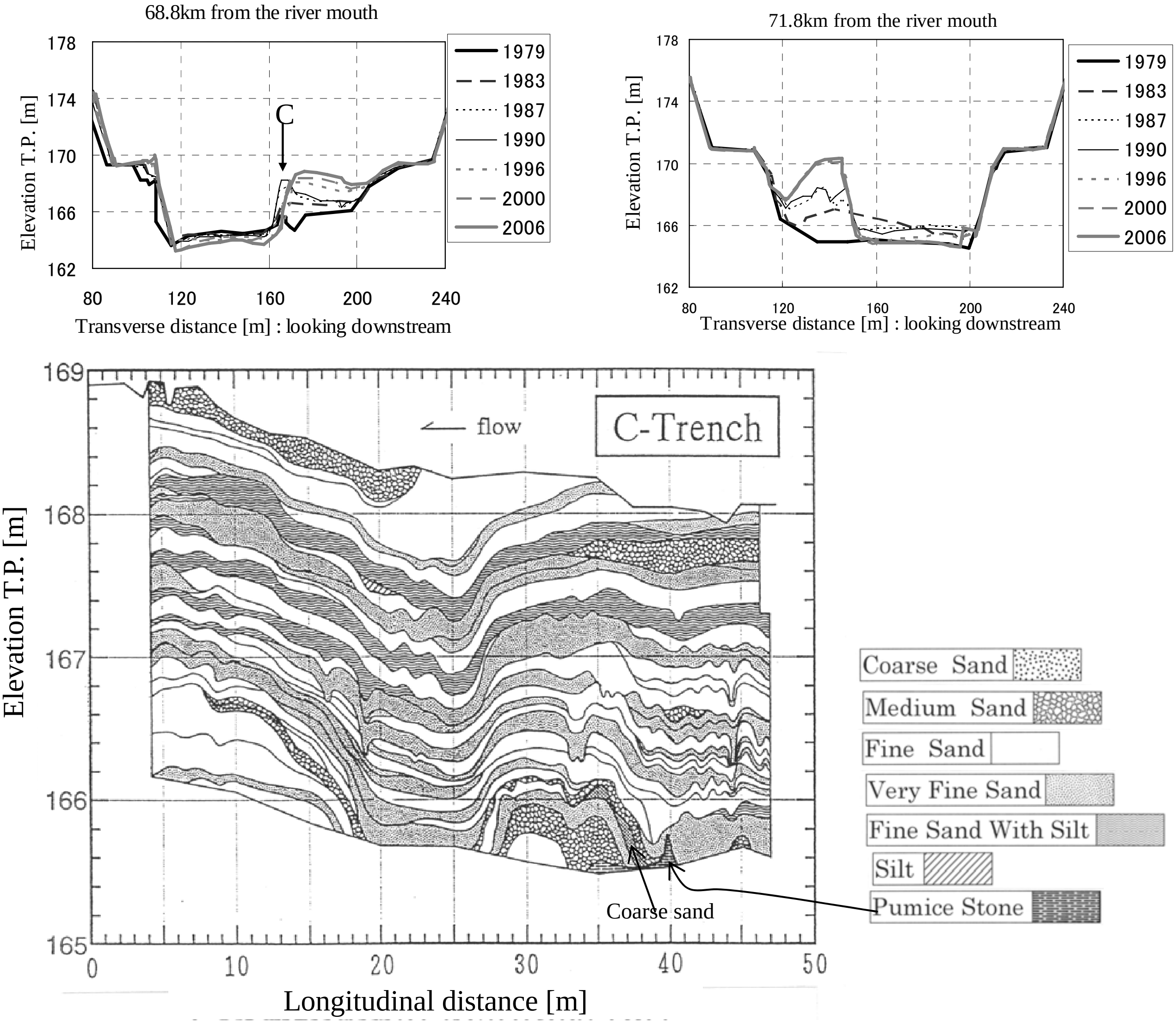


Fig.15 Channel narrowing caused by the floodplain accretion observed in the Sendai River[10]: an example of contribution of fine sediment.

Tops: Cross-sectional changes. Bottom: Soil stratification observed on the face of the trench excavated longitudinally with about 2m deep and about 40m long, lateral location of which is point C shown in the top left figure. The excavation and observation was made in 1993-1994. Most of the newly deposited sediment is fine sand or finer, while material-m is gravel.

Normally, since fine grain-size sediment is of the pass-through type, it does not cause deposition of such scale, but if external impacts force the channel shape to deviate from quasi-equilibrium, significant deposition of fine grain-size sediment (otherwise pass-through type) can occur.

sediment is effective.

If we extend the concept of grasping sediment movement for each grain size group, it is not difficult to reach another concept —that of the "*effective* grain size group", which is defined as a grain size group that affects certain specified river geomorphic change and phenomena concerned.

(3) Exchange type and pass-through type: a key to understanding macroscopic sediment movement

In addition to the approach of grasping sediment movement for each grain size group, it is also very important to categorize macroscopic movement of such series of grain size groups as either *exchange type* or *pass-through type*[6]. "Throughput load"[11] and "over-passing load"[12] are similar to the concept of *pass-through type*. Please refer to **Fig.13** again to grasp the following explanation on these two types.

Exchange type is defined as a macroscopic transport manner of a grain size group in which the group is transported with significant exchange with the main bed materials. The flux of sediment transport belonging to this type varies longitudinally, and the transport of main riverbed materials is of the exchange type, which is explained by its definition. Sand transport in Segment S and gravel & larger sediment transport in Segment G in **Fig.13** are categorized into exchange type.

Pass-through type is defined as the other macroscopic transport manner in which a grain size group concerned exchanges little with the main bed materials (at the most, to a degree which fills gaps in the main riverbed material on the surface). Sediment transport of this type can not contribute to riverbed variation unlike exchange type. Sand transport in segment G and silt & clay transport in segment G and S in **Fig.13** are categorized into pass-through type. The flux of sediment transport of this type varies longitudinally only a little. As was mentioned above, some silt & clay becomes floodplain material (natural levee) and top fine sediment layer, but its quantity is much smaller than the total flux, or its deposition is temporary. That is why the categorization of silt & clay transport into pass-through type in **Fig.13** is justified.

(4) Efforts to prepare river-basin-wide sediment movement maps as a practical tool for obtaining a common language

A *river-basin-wide sediment movement map* presents the movement of sediment in a river system based on unified guidelines and the method shown below, in line with the approaches described in the previous sections.

1) The thickness of a river course usually drawn schematically in the map is indicated by the flux of a grain size group of sediment.
2) The sediment production sources are displayed by dividing the river basin into sub-river basins as river basin management units with scale appropriate to the clarification of the river basin characteristics.
3) It displays sediment movement for each grain size group.
4) It displays sediment movement classified into exchange type or pass-through type.
5) Based on measurements, it is supplemented by calculation as necessary, and parts not understood should be clearly indicated, for instance by labeling them "unknown".

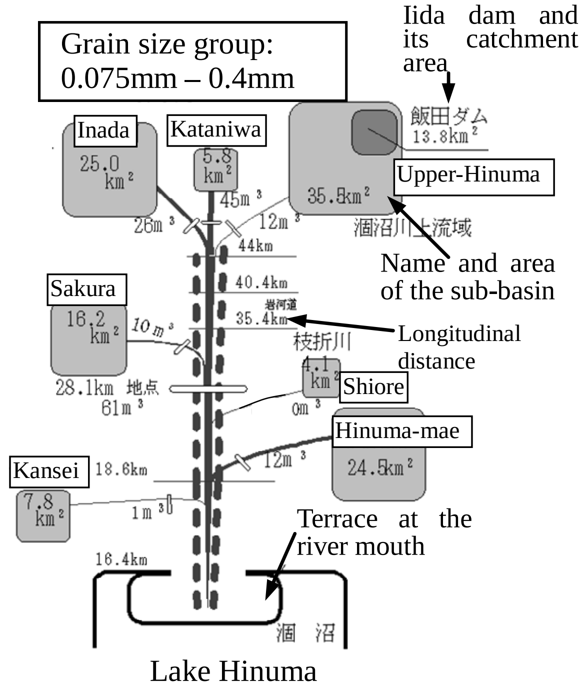
MLIT (MOC before 2001) carried out a project of systematically observing sediment in 21 river systems throughout Japan from 1999 to 2002 and summarized the results as river-basin-wide sediment movement maps[14)]. In addition, maps were prepared separately for other river systems as an advanced initiative. For some river systems, maps for a number of periods from the past to the present or maps of the situation before and after dam reservoir construction were created. These are being used as powerful tools to macroscopically clarify the change of sediment movement over time, and to assess the possible effects of river modifications on sediment movement. Typical maps are shown in **Fig.16-18**.

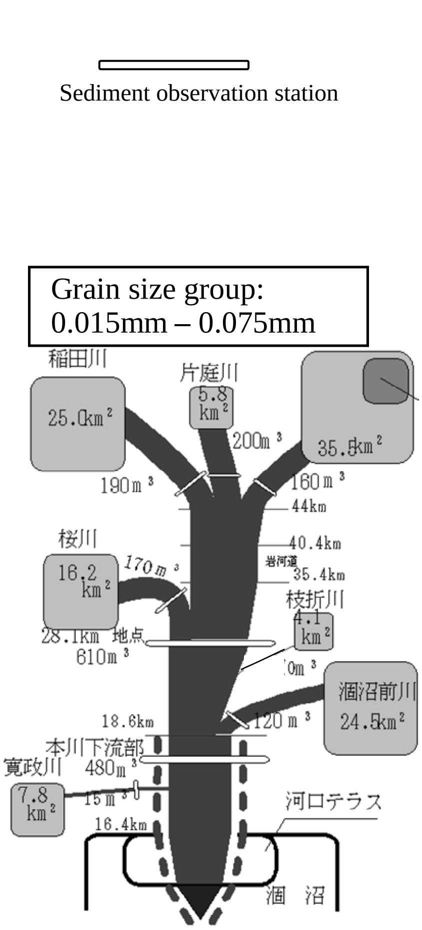
These maps, for instance, clarify which grain-size groups are supplied primarily by which sub-drainage basins, and specify the grain-size groups that compose the river mouth terrace and the grain-size groups that compose the bottom sediment of lakes beyond the terrace. As for the impacts of constructing a dam reservoir on each grain-size group, it is possible to give appropriate primary diagnoses that answer questions like: Does this or does it not appear in the form of riverbed variation or in coastline erosion?

(5) More strategic observation and improvement of sediment transport modeling

Initiatives such as the above are counted on to play a role in refining surveying, observation, and also monitoring strategies that not only contribute to point [A], but also clarify the weak points of present sediment movement observations for our understanding of both phenomena at individual locations and overall sediment transport systems. For example, map preparation initiatives have created awareness of problems that include the following.

1) A practical and reliable method which can be used to stably observe bed load as quantitative data has not been established.
2) Wash load can be observed relatively easily by combining bucket sampling, automatic samplers and turbidity meters: however suspended load (specifically, for sand) must be assessed by clarifying its vertical distribution. Existing methods still need to be improved.
3) Using dam sedimentation data is an extremely useful way to supplement the weak points of sediment flux observations. It is emphasized to promote the clarification of dam sedimentation by grain size, as well.
4) It is necessary to perform mutually supplementary observations and calculations to clarify the movement of sediment in a sediment transport system, because sediment transport measurement during floods, in particular, requires considerable effort. An important point of debate is the ideal way to divide the roles of observation and calculation.





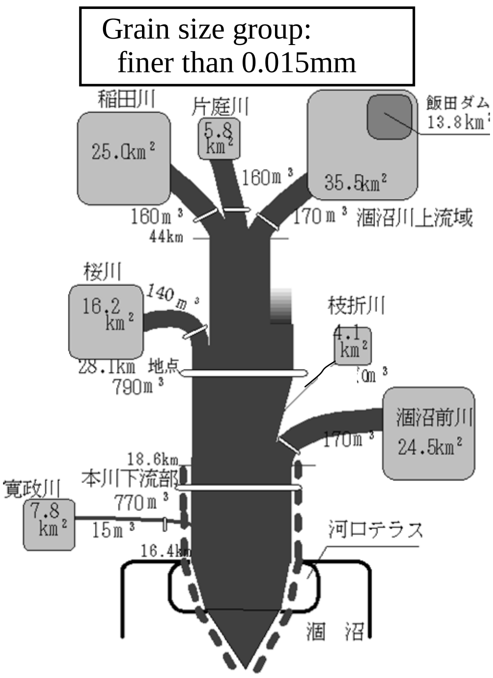


Fig.16 River-basin-scale sediment movement map for the Hinuma River sediment transport system (total movement by a flood on September 16, 1998) [13]

The river reach sandwiched by broken lines indicates exchange type. The reach without them indicates pass-through type. The numbers with m^3, with km^2 and with km indicate sediment volume transported, catchment area and longitudinal distance from the rive mouth respectively.

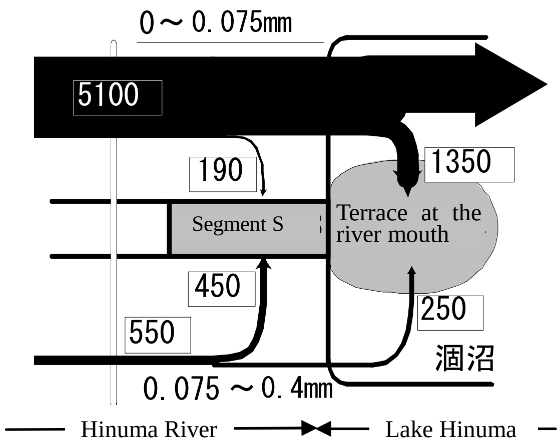


Fig.17 River-basin-scale sediment movement map for the Hinuma River sediment transport system: Detailed map focusing on its river mouth area [13].

The numbers inside the rectangles indicate 1990-1998 mean annual quantity of transported sediment to be deposited or to pass through [m^3]

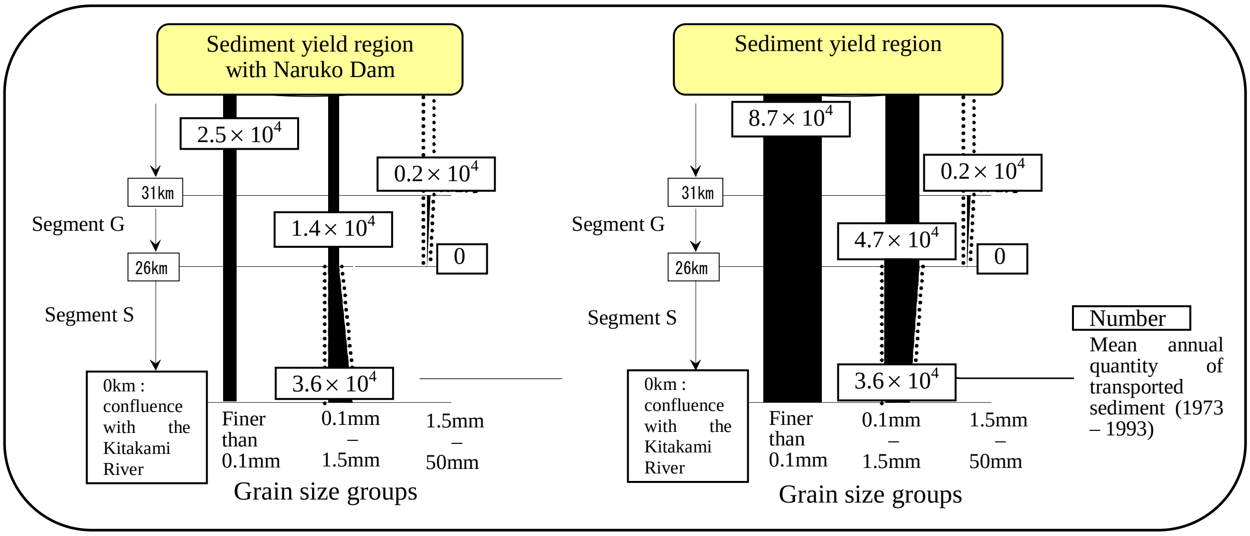


Fig.18 River-basin-scale sediment movement map for the Eai River sediment transport system [13)]
Left: Mean annual quantity of sediment transported under the present situation (with the dam).
Right: Mean annual quantity of sediment transported when the condition of no sediment deposited at the Naruko Dam is given.
The river reach sandwiched by broken lines indicates exchange type. The reach without them indicates pass-through type.

By comparing the two maps, we can make a primary examination on possible patterns of channel response to sediment supply reduction. For example, it can be judged from the comparison that while the supply reduction of the 0.1-1.5mm group causes little degradation in the reach of Segment G where it is transported as pass-through type, degradation is likely to occur in the reach of Segment S where the group is transported as exchange type and the supply reduction can bring longitudinal decrease in sediment transport flux. Although precise prediction of the degradation should be made by river-bed variation calculation, such a primary examination enables us to identify the way precise calculation can work to diagnose and resolve problems.

5) When an attempt is made to reproduce the transport of a pass-through-type grain-size group by conventional methods of riverbed variation calculation, it may be calculated that sand that is supplied in larger quantity than gravel is gradually mixed with the so-called exchange layer of a gravel bed surface, and that the main riverbed material contains a large quantity of sand. Such calculation results in a balance of sand in the sediment transport system that differs from the actual situation. It is necessary to conduct further studies of conditions under which this awareness is appropriate, along with more rational handling methods[5)12)15)16)].

7. PROBLEM RESOLUTION-ORIENTED MANAGEMENT: FOR OVERCOMING POINT [B]

(1) Importance of setting hypotheses to diagnose the problem

The key approach applied in order to clarify the structural outline of problems is to first establish a hypothesis (scenario for occurrence of phenomena that cause and foster problems), then select and apply a method needed to judge whether or not the hypothesis is correct. Inversely, adopting a set of methods related generally to sediment transport phenomena to reproduce phenomena may become a round-about approach, simply because the sediment transport system is governed by wide-ranging, complex and varied phenomena. Which combination of such methods is good depends on the scenario, so it is more important to collect good examples that have clarified the structural outline of problems than it is to rush to generalize the method.

(2) Importance of abandoning stereotyped diagnoses

One more key to clarifying the structural outline of a problem through an appropriate diagnosis is to avoid preconceptions. For example, there have been reports suggesting the conspicuous degradation of downstream riverbeds attributable to a dam reservoir. **Fig.8** can definitely be interpreted to show that a clear tendency for riverbeds to fall is dominant throughout Japan, and as stated above, if the total sediment deposited in dams is aggregated, an amount of 1.18 billion m^3 is obtained. For these two reasons, there is a tendency to argue for a simple link between blocking of sediment by dams and the resulting riverbed degradation. But this is not correct.

That is because to consider the causes of riverbed degradation, at the least, channel excavation and gravel/sand mining must be added to candidate factors. The total quantity of both amounts to 1.13 billion m^3. Needless to say, a direct effect of channel excavation and gravel/sand mining is the degradation of riverbeds, through which channel excavation for river improvement achieves the increase of flood flow capacity.

It is, therefore, necessary to, at the least, consider the degree of effectiveness of phenomena occurring at the location of dams and the direct action of excavating river courses and mining gravel/sand on rivers in order to analyze the causes of riverbed degradation. As shown by **Fig.10, 11 and 12**, much of the sediment accumulated in dams is of a grain size of sand and finer. Therefore, the quantity of riverbed degradation in gravel bed reaches (segment G) is completely out of balance with the quantity of gravel trapped by dams, and the excavation and mining of in-stream sediment is clearly a major cause of the degradation. The quantity of sand stopped by dams, on the other hand, is in the same order as the quantity removed, on the assumption that about half of the sediment removed from the river course is sand. For this reason, regarding sand, it can be pointed out that the direct action of the removal of sediment from the river course and the halting of sand by dams may both impact on the lowering of riverbeds (plus, land subsidence has been another major factor for some rivers in Japan).

It should be possible to avoid the kind of elementary interpretational errors mentioned above simply by performing analysis according to the actual state of the sediment transport system, by studying the balance of each grain-size group (in the above case, sand group and gravel group) instead of only comparing entire quantities of sediment, by separating phenomena occurring at dam locations and direct actions on the river course, and by remaining aware of the basic characteristics of the movement of the grain-size groups as shown in **Fig.13**.

Other stereotyped and hackneyed diagnoses concerning dams are "armoring by dams" and "reduction of the supply of coastline materials by dams". Of course, according to conditions, there are cause-and-effect relationships between these, but inversely, there are many cases where other factors have greater effects, or where such phenomena do not occur. Placing simple and naive faith in a hypothesis or a preconception is not a good way to handle this matter. So what is a good way to grasp the downstream effect of a dam in terms of sediment movement, geomorphic change, habitat formation and so on?

(3) Framework for interpreting geomorphic effects of a dam reservoir on downstream reaches without falling into stereotyped diagnoses

a) Case focused on a sand group

A sand group is generally transported faster than a gravel/larger group along a river system, and as shown by **Fig.10** to **Fig.12**, the quantity supplied is far higher. If a dam cuts off or greatly lowers its supply, therefore, its impact reaches the downstream river relatively rapidly, and there is a high possibility that the physical environment of the river downstream from the dam will be in a state governed by the sand supply from rest of the river basin where no dams stop sand supply to the location. At the location reached by the sand supply reduction, there is a high possibility of the following occurring qualitatively.

<u>Gravel bed reach (segment G)</u>

In this section, the sand group is the pass-through type, so the presumed pattern is little change in the riverbed form, only with a reduction of sand temporarily deposited in gaps between the surface of main bed materials, in areas behind obstacles such as boulders, and on the bottom of a pool formed by scouring.

<u>Sand bed reach (segment S)</u>

In this reach, the sand group is the exchange type, so the riverbed may be lowered and the longitudinal slope may decline. When such a change occurs, the change leaps over the gravel reach and begins from the upstream end of the sand bed reach. This means that change of the river course does not always occur sequentially from upstream. The reason for this has been already explained by the movement of each grain-size group described in **Fig.13**.

In a case where the gravel segment is stretched to the river mouth (no sand bed segment exists), it can be hypothesized that the flux reduction of the sand group transported through the gravel section as pass-through type rapidly propagates downstream and easily causes reduction of sand supply to the seacoast. Inversely, on a river with a sand bed segment such as that shown in **Fig.13**, the impact of the halting of the sand group by the dam will, first, appear near the upstream end of the sand bed segment; then, after a little while, the impact of the reduction of the sand supply will be absorbed by the riverbed degradation from that point. Thus, it is presumed that the construction of a dam does not immediately reduce the sand supply to the seacoast.

A variety of processes related to the transport of the sand group can occur according to river characteristics. Among them, cases where the blocking of sediment by a dam does not lower the sand supplied to the seacoast are not rare. Therefore, Instead of attempting to analyze such a situation as it is, trying to directly link the total quantity of sediment deposited in a dam reservoir to the reduction of the sand supplied from the river to the seacoast, for example, is far from scientifically rational.

b) Case focused on a gravel group

This case deals exclusively with a gravel bed segment (segment G). A gravel group moves far more slowly than a sand group. Therefore, even if a dam etc. located upstream blocks gravel supply, it is not likely that effects of the blockage will quickly propagate far downstream (several tens of kilometers for example).

Within a certain range directly downstream from the dam, various changes may appear to be caused by blockage of the gravel supply. The ways these changes appear, however, are not limited to armoring or riverbed degradation. Instead, a variety of changes can occur caused by factors such as river discharges, a convergence pattern with tributaries, characteristics of the original river course, and so on. For example, in some cases, a dam is constructed on a river course where the mobility of gravel & larger sediment as the main bed material has already been low (such river courses are not unusual in mountainous regions). In this case, the slight decline of flood discharges due to dam operation sharply lowers the mobility further, which does not coarsen the gravel or lower the riverbed.

It must be assumed that downstream effects of dams on gravel beds have a variety of patterns in this way. It is possible to broadly categorize the response patterns by combining the degree of the decline of gravel-carrying capacity downstream from a dam accompanying flood control [large or small decline] with the degree of gravel supplied from tributaries downstream from the dam [large or small supply]. It can be hypothesized that, of these, armoring of the main bed material or degradation is likely to occur in cases of the [small vs. small] combination; while in the [large vs. small] combination, the river bed is likely to lose mobility (the above example); and in the [large vs. large] combination, even sedimentation can occur downstream of tributary convergence.

At a certain distance from the point where the gravel supply is blocked, the blockage of the gravel itself may have only a small impact on the riverbed. At such locations, rather than the blockage of gravel supply by the dam etc., the direct action on the river course, and in particular its past history, is likely to be more attributable to experienced change in the riverbed. Examples of direct action include riverbed excavation in a gravel bed river reach (including gravel mining), installation of a transverse structure (in particular, a fixed structure), or combinations of these. In the case of large rivers in Japan in particular, gravel mining, which had been actively done in the past, lowered the overall longitudinal river bed profile, as is discussed in (2). Its consequences still significantly remain in present river courses.

c) Does armoring always occur downstream from a dam? Discussion based on field survey results

Two dams were surveyed[17)]: Dam A, which had been in service for more than 30 years, and Dam B, which had been in service less than 10 years at the time of the survey (February to April 2006). Hydraulic and river course conditions and riverbed materials upstream and downstream from each dam were investigated, and results common to both dams are summarized as follows in 1)-4) below. **Fig.19** shows longitudinal changes of each river in mean riverbed elevation, water surface width, velocity, mean grain size of material-m, bed surface covering rate of material-t in the aquatic area and material-s on the terrestrial area on both sides. Please refer to both rivers in the figure. Spatial distribution of materials-m, -s and -t in the surveyed sections are schematically shown in **Fig.19**, as well. The definition of material-m, -s, -t is explained in **Fig.13**.

1) The grain size of material-m (gravel and larger) is almost identical upstream and downstream from the dam.
2) The bed surface covering rate of material-t (sand) in the aquatic areas is clearly smaller directly downstream from the dam: these reaches are identified by the thick arrows in **Fig.19**.
3) The fall of the bed surface covering rate of material-t (sand) directly downstream from the dam is rapidly restored between 4 and 10 km downstream from the dam.
4) The bed surface covering rate of material-s (sand) on the terrestrial areas is almost identical upstream and downstream from the dam. And these areas are covered with herbaceous vegetation.

It can be seen that material-m is unchanged by the dam or changed only slightly, while material-t in the aquatic areas is significantly reduced by the dam in specific sections. And based on these results, it can be stated that downstream effects of dams on river bed materials can be described appropriately only when material type (m or s or t?) and areas (aquatic or terrestrial?) are clearly explained.

Only two examples have been introduced here, so it is, of course, impossible to say the results represent

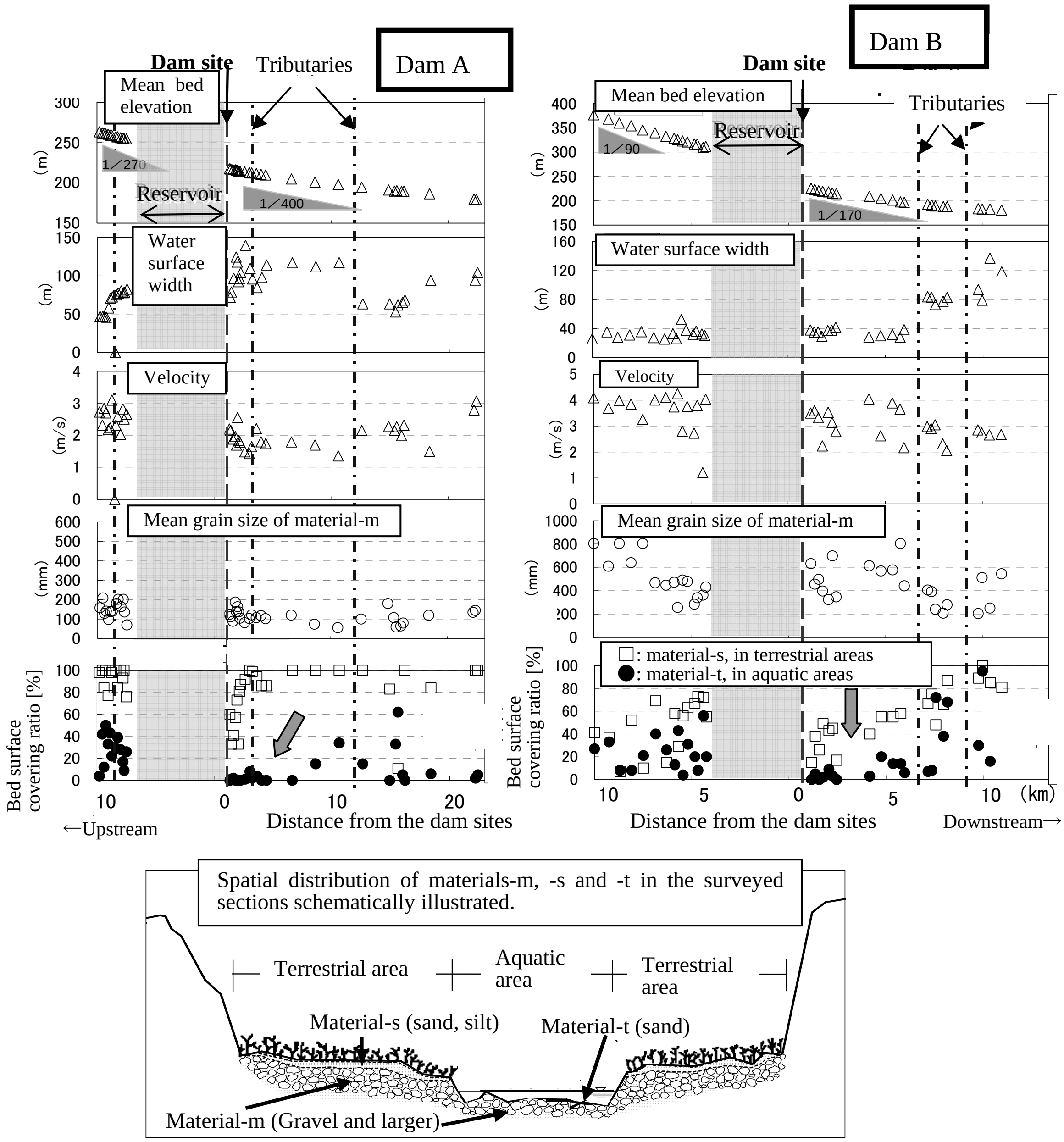


Fig.19.Example of an upstream vs. downstream comparison of riverbed material around a dam reservoir for river reaches whose hydraulic conditions are similar upstream and downstream[17].

Downstream is oriented to the right. Velocity and water surface width are those at the time of mean annual peak discharge. Material-m is expressed by its mean grain size. Material-s and –t are expressed by the bed surface covering ration; i.e. the percentage of area where material-s or –t covers the bed surface of material-m. In these surveys, the grain size of material-s and –t is 2mm or less.

a normal response. There are also examples of analysis showing that material-m is significantly changed; coarsened or washed away, for example. What is important is not to adopt the premise that if it is downstream from a dam, the same kinds of phenomena will occur. Instead, it is important to clarify whether or not the river course is changed by the dam on a factual basis and, if so, how this change occurs, and to analyze the overall relationship of the dam with the downstream river course.

In order to make such analyses, it is vital to plan a survey which will permit the application of scientific rationality that is suited to the level of sediment-hydraulic knowledge. Examples include "Before and After (BA) Design", which involves tracking change of a river course along with hydraulic forces in the same reaches downstream from a dam from before it was constructed until after it began operating; "Control and Impact (CI) Design (example introduced above), which involves comparing the upstream and downstream state of a river course where sections with identical hydraulic and river course conditions exist directly upstream and downstream from the said dam; and a combination of the two (BACI design).

(4) How to handle cases where the problem is not limited to the sediment transport system

For example, if cases where reduction of sediment supply from a river or the construction of port and harbor facilities causes coastline erosion are concerned, the problem is entirely limited to a matter of a sediment transport system. But in cases where a problem includes both phenomena in a sediment transport system and phenomena unrelated to the sediment transport system, it is impossible to examine the structural outline of problems and ways to manage the sediment transport system unless their relationships are clarified. A typical case is one where the target is conserving or restoring the natural environment of a river.

There is no question that the sediment transport system is one fundamental condition which determines the river natural environment. Therefore, to discuss sediment transport system management that is intended to conserve and restore the natural environment, it is essential to answer the question, "What kind of sediment transport system can conserve or restore the natural environment of the river?" or more directly, "What kinds of sediment should be supplied (and what discharge should carry them) and how should they be supplied to benefit the natural environment of the river?"

Recently, extensive research has been carried out guided by an awareness of the importance of collaborative efforts between river engineering and ecology in order to conserve ecosystems in Japan. For example, collaborative research intended to improve the environments of river courses downstream from dams has been conducted, accumulating knowledge which appears to be related to the above questions[18]. The relationship between dynamic systems which form the physical environments of rivers with living organisms is being clarified through research on cases in individual fields and experimental streams[19)20]. But research has not begun full systematization to clarify the overall relationships between sediment transport systems and natural environments or study on the most effective way to manage a sediment transport system to conserve or restore its natural environment.

It is, therefore, necessary to expand the capacity of methods for describing phenomena in sediment transport systems. For example, above it was stated that in a steep slope gravel bed reach, the transport of sand can be viewed as pass-through type that does not contribute very much to riverbed variation. The sand is quite likely to be only deposited in the interstices of the gravel bed surface without reaching the stage where it completely covers the gravel bed (see **Fig.20**). Therefore, the perception that pass-through type of sediment transport brings little to river beds is correct as long as river course management to control flooding is concerned.

Fig.20 State of the river bed surface observed by hydraulic experiments designed to simulate a steep slope river with gravel or cobble as material-m.

The left photo shows the state when little sand is transported, and the right photo shows the state when an extremely large quantity is transported, while the rest of the hydraulic conditions are set the same. In normal mountain river courses, the usual situation is like the left photo. The quantity or height of sand between the gravel varies according to the quantity of sand transported. Even when the quantity of sand supply increases greatly, gravel can hardly be completely covered by sand, as the right photo shows.

However, when the objects of control are expanded to include micro-habitats on the riverbed surface, it is impossible to ignore possible changes caused by differences in the transport of pass-through-type grain-size groups. As for the example above, the environmental conditions for benthic fauna, periphyton and so on can be significantly different between when there is almost no sand in the interstices of the gravel bed surface and when sand partially or fully fills it. Therefore, once it is necessary to examine the state of a river course from the perspective of living organisms or ecosystems, it is also necessary to employ a new appropriate descriptive method or calculation method for sediment transport phenomena. In this context, for instance, how to specify "sediment maintenance flow" for gravel-bed river reaches downstream of a dam reservoir[21] has been one of the important research targets.

On a number of sediment transport systems in Japan, sedimentation of dam reservoirs has advanced to the degree that there is an urgent need for countermeasures. As keys to tackling this challenge, the study and implementation of flushing and bypass of sediment from dam reservoirs have already been launched[22] in addition to mechanical removal, where target grain size groups are usually sand, silt and clay. This is because a large amount of sedimentation is occupied by those grain size groups as is shown **Fig.10-12**. In this case, the targets are the additional quantities of sand, silt, or clay with high mobility accompanying the implementation. Significant

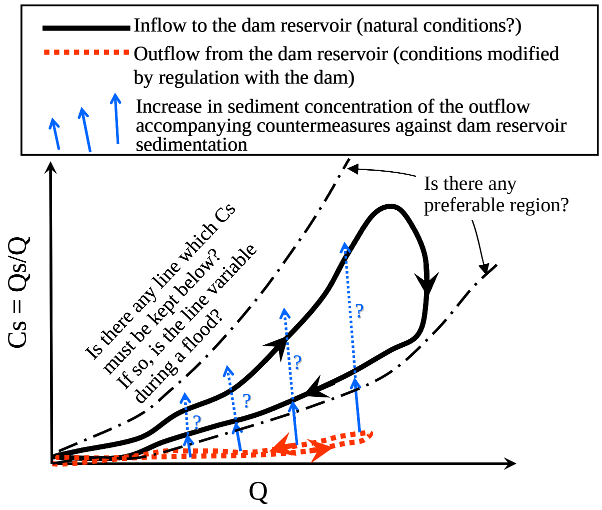


Fig.21 Idea on the control of the Q vs. Cs (= Qs/Q) relationship for sand or finer sediment to maintain or restore the soundness of instream micro-habitat.

On the assumption that the black thick line has been changed to the red broken line by flow regulation with the dam upstream, countermeasures against dam reservoir sedimentation are supposed to raise the red line toward the black line, as is shown by the blue arrows. However, according to methods adopted for flushing, bypass and so on, increased Cs may exceed the black line. For conserving instream micro-habitat, should we set a cap for the Q vs. Cs (= Qs/Q) relationship? Or should we control the relationship so that it will be kept within a "preferable region"?

riverbed variation is not likely to occur in steep slope gravel bed reaches, including mountainous streams, even if large-scale sediment flushing is done. Moreover, since sediment flux from dam reservoirs has been reduced, it can be said that the additional quantities play a role in restoring sediment transport as it used to be. However, as stated above, when the goal is to precisely control the state of micro-habitats on riverbeds to a specified range, more advanced sediment flushing (bypass, pass-through) technologies are needed.

Specifically, the key is to find a way to control the relationship of the flux Qs of sand or finer grain-size sediment with the discharge Q [the Q vs. Qs relation] or the relationship of Cs (= Qs/Q) with Q, where Cs corresponds to sediment concentration [the Q vs. Cs relation] (see **Fig.21**). And, it is necessary to clarify the degree of deviation from the band width of the Q-Qs or the Q-Cs relationship of natural (or present?) conditions that can be allowed from the perspective of its impact on living organisms in the riverbed. Discussion and clarification on this "allowable deviation" will lead to the "specifications for natural environment conservation" required for sediment flushing and so on. When such discussion is advanced, it will be inevitable to consider that the allowable deviation may change in time during a flood.

In the Kurobe River, after a flushing process is completed, clean water is released for a certain amount of time as "cleansing" to wash fine sediment on gravel bed surfaces which is deposited possibly during the flushing. This is the important germ of "environmental specifications" for the Q vs. Qs relation, where its time sequence is considered as well.

In cases where the problem cannot be limited to the category of a sediment transport system as explained above, it is necessary to further expand the way of defining a sediment transport system to consider its relationships with other phenomena (above, living organisms and ecosystems). This presents an opportunity to expand the horizon of sediment transport system technologies.

8. ISSUES ON THE IMPLEMENTATION STAGE OF INTEGRATED SEDIMENT MANAGEMENT POLICIES: FOR OVERCOMING POINT [C]

Based on the previous discussions, points of contention concerning integrated sediment management policies that consider the impact that modifications to sediment movement have had on river basin environments, including coastlines, are listed below.

1) Is "making comprehensive and integrated efforts" a tool for advancing matters or an ultimate "golden" goal?
2) What should be a desirable balance between survey research and practice? How do we reach a consensus concerning ways of obtaining this balance? How long will the problems wait for us?
3) Is it absolutely good for rivers and sea coasts that the sediment which had been stopped begins to move again? And, is such situation positioned as environmental restoration? If so, can the resolution to achieve the restoration of natural environment be the driving force for implementing an integrated sediment management policy? Or, rather, is reviving sediment movement a target of environmental impact assessment for avoiding environmental deterioration possibly caused by newly brought conditions of sediment movement? Or is the direction forward found somewhere between these attitudes? And, if so, how are they balanced?
4) Is "returning to the past" a banner? Is it always right? How influential has the accumulation of several decades since modifications to a river system started been? In circumstances where surroundings (social or natural) have been

transformed, if only part of the system is assumed to have returned to the past, can challenges appear elsewhere? If so, what sort of challenges?

It is probably certain that the sediment transport system has changed sharply from its past state due to the modifications; on the other hand, however, it is also true that many people may believe “the present situation is normal” after a certain amount of time has passed. In such a situation, there may be cases where the concept “return the sediment transport system to its past state” alone will not be adequate as a means for promoting policy implementation.

This leads to another important challenge; that is, how to find the best implementation process where gaining a consensus is crucial. In order to do so, it is necessary to explain the structural outline of the problem described under point [B]: how the sediment transport system management that is being attempted will change (or will not change) the river system extending to the coastline, and how this will be beneficial to the residents of the river basin.

5) How specifically and definitely can we indicate the quantity and grain size of sediment which must flow downstream in a river? Is such indication pin-point or is it presented as a range? Are there only conditions to avoid? Or will quantity and grain size be examined adaptively while setting hypotheses?
6) In order to advance integrated management, should we find a primary conductor who has strong incentives and motives to practice it, who is ready to dictate it, and whom the rest can count on? Possibilities include a dam reservoir manager who has been urged to cope with severe sedimentation, or a manager who administrates coasts and has had great difficulties in handling severe erosion. Or is it preferable for everyone concerned to evenly participate in promoting integrated management cooperatively toward shared goals on the state of sediment transport system to be achieved.

   Probably, the latter is more ideals, but that approach may have a tendency to let the discussion wander. The former may weaken the concept of “integrated”, but it can be more practical and realistic.
7) Two situations may emerge simultaneously in a sediment transport system; one is where management methods are readily and definitely determined; the other is where a lot of discussion is needed to determine them. When this is the case, how can we coordinate such a mixed situation?
8) The technological level of prediction of sediment transport-related phenomena can be organized into three groups: A: phenomena are largely understood and methods for predicting them are firmly established, B: scenarios and prediction methods have been proposed but not verified scientifically, and C: only rough scenarios have been discussed. When we examine integrated sediment management for a sediment transport system, it is likely that A, B and C are all concerned. In this situation, do we have strategies to coordinate them to reach the constructive conclusion? And are we rational enough not to retard overall decision making just because not all handled phenomena are supported by level-A prediction?
9) For policies which will take an extremely long time to become clearly effective, how will the effectiveness of the policies be positioned or explained? How will it be possible for people to savor a feeling of achievement?
10) Is “adaptive management” effective and attractive as the core of such policies? On the assumption that it is so, when solidly constructed structures are necessary to perform trial efforts and monitoring, how will they be matched with the framework of “adaptive management”?
11) Have we already obtained techniques and foundations whereby we can build social consensus regarding the creation of a new sediment movement order and the adoption of various ways to do so?

9. CONCLUDING REMARKS

Needless to say, it is valuable and important as a core concept for sediment management policy to restore sound sediment transport systems that have been deteriorated due to various modifications to river systems, while maintaining the benefits these modifications bring to our lives and society, and to achieve restoration through integrated sediment management.

At the same time, as was discussed in the previous section, it can probably be said that it is excessively naïve to implement this by relying on the virtue of the basic policy concept alone, without being prepared to carefully examine complexly interrelated phenomena, including social and historical aspects as well as scientific and engineering aspects. I would like to emphasize that it is necessary to tackle this challenge by adopting a strategy of wisely selecting and combining varied ways to deal with complex realities and by making steady improvements— not jumping to a beautiful outcome— while keeping naivety as a fundamental driving force to nurse our resolution to improve the sediment transport system.

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