# Post Workshop Summary,

# The Sino-U.S. Joint Workshop on Sediment Transport and Sediment Induced Disasters

**March 15-17, 1999**
**Beijing, China**

**Prepared for the National Science Foundation**

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**The First Sino – U.S. Joint Workshop on Sediment Transport and Sediment Induced Disasters**

## Abstract

The First Sino – U.S. Joint Workshop on Sediment was organized with strong support from both the United States and China, with the intention to strengthen information exchange and cooperation on research on emerging hydro-environmental problems. The Natural Science Foundation of China has established a national key research project, *Study on Mechanisms of River Sedimentation, Disasters, and Control Strategies* in China, and is interested in establishing a bilateral cooperation program with the United States on sediment transport and sediment-induced disasters. A joint workshop was considered to be an effective approach for scientists and engineers from both countries to exchange knowledge and experience, to explore research and educational needs, and to initiate future collaborations. In a three-day meeting in Beijing, China, following by a five-day field study in the Loess Plateau along the middle reach of the Yellow River, the participants exchanged their knowledge and experience on sediment-related topics and identified opportunities for future research and cooperation. A major emphasis of the workshop was to promote direct discussions. The workshop sessions were therefore structured to have all presentations at the beginning of each session and have more than half of the session time for discussions. The format worked very well and resulted in ample exchanges of experiences and needs for future studies. The purposes of this report are to report on the workshop and the discussions summarized from the meeting in Beijing.

## Acknowledgments

The Illinois State Water Survey and the University of Illinois at Urbana-Champaign supported the authors to coordinate this technical workshop. Financial support came partially from the National Science Foundation (NSF) of the United States and the Natural Science Foundation of China (NSFC). There were many men and women whose hard work contributed to the success of this workshop. The names are too numerous to be listed here. We sincerely appreciate Drs. William Y. Chang and L. Douglas James of NSF, whose endorsement and support were crucial; and Professor Shihui CHEN of NSFC, without whose initiation and endorsement this workshop would not have been realized. The most important element for a successful workshop is the participants. The high quality of the participants from China and the United States and their thorough immersion in the discussion sessions are gratefully acknowledged. Eva Kingston of the Illinois State Water Survey edited the camera-ready version of the report, and Linda Hascall provided expert advice on the illustration of photograph layout.

## OVERALL SUMMARIES

The three-day workshop meeting in Beijing on March 15 – 17 consisted of 9 sessions and presentations of 39 papers. A five-day site visit along the Middle Reach of the Yellow River in the Loess Plateau was also conducted on March 18 – 22 as part of this collaboration. Twelve U.S. and approximately 50 Chinese scientists/engineers/managers participated in the workshop, and 37 workshop members, including all U.S. participants, participated in the field study trip. The U.S. team from diverse disciplines had mixed degrees of experience and included five sediment hydrologists, five sediment hydraulicians, one sediment ecologist, and one geomophologist.

The workshop format was specifically designed to allow more time for discussion than for presentation. More than half of the time in each session was allotted for open discussion led by the Chinese and U.S. co-chairs of each session. Co-chairs of each session were also asked to summarize discussions for each session. The session summaries and session co-chairs are listed below. Through the extensive in-depth discussions among workshop participants, Chinese excellence was confirmed in reservoir operation in conjunction with sediment sluicing, in developing transport mechanics for hyper-concentrated flows, in extensive laboratory model testing skills, and in applying laboratory experiments to large-scale prototype problems in various environments. Through historical development, Chinese scientists and engineers have accumulated broad prospects on the effectiveness and weakness of man-made measures in countering sediment-related disasters. On the other hand, U.S. scientists and engineers are leading in laboratory instrumentation and in numerical model development including building process-oriented models or systems applications. The U.S. also pays more attention to environmental issues.

The field study was in the eastern part of the Loess Plateau through which the middle reach of the Yellow River flows. The Yellow River is known for sediment-related issues, and this region is the major sediment source for the Yellow River and the origin of Chinese civilization.

By traveling on mountainous roads on two buses the field team had an excellent opportunity to observe erosion patterns in the well-known Loess Plateau. It is hard to conceive that these vast, bare lands were covered by forests some 2,000 years ago. Human disturbances have significantly contributed to the current poverty-stricken consequences. Field trip participants observed astonishing land erosion forms, ultimate head cut, bank erosion and sedimentation, terraced fields, self-sustained agriculture, and local use of sediment.

The field team also visited the Hukou waterfalls, Sanmenxia Reservoir, and Xiaolongdi Dam. The Hukou waterfalls are located at a significant constriction of the Yellow River. Because of its geological formation, the waterfalls have withstood erosive forces of the river flow and formed a control section that has prevented the propagation of bed erosion downstream. At Sanmenxia Reservoir, the field team learned from reservoir director Mr. Lu that about 2/3 of the reservoir was lost due to siltation within the first year after initial ponding. A significant number of studies have been done at the dam, and information acquired has been adopted or applied to other reservoirs in China. Recently, the dam has been successfully modified for sediment sluicing. With its sluicing structures and designated operational modes, the Sanmenxia Reservoir can essentially maintain a balance between the annual incoming and outgoing sediment loads. Impacts of sediment-laden flows on turbine and powerhouse structures were discussed. The Xiaolangdi Reservoir is currently under construction. It is the most downstream dam and will control 93 percent of the drainage area of the Yellow River. Besides flood prevention, its sediment sluicing design has considered desirable morphological changes in the Lower Yellow River. The team was fortunate to have the opportunity to observe the entire site, visit a demonstration model, and discuss with site engineers the future joint operation model of the Sanmenxia and Xiaolangdi Reservoirs.

In addition to their practical field experience, Chinese scientists and engineers have collected a large amount of data for potential studies of the mechanisms of sediment movement. From the workshop, it was apparent that in sediment studies, the United States emphasizes issues and impacts, while China emphasizes problems and solutions. There is potential for future cooperation between both countries.

This First Workshop was organized by Dr. ZhaoYin Wang of the International Research and Training Center for Erosion and Sedimentation, China; Dr. David T. Soong of the Illinois State Water Survey; and Professor Ben C. Yen of the University of Illinois at Urbana-Champaign. At the concluding session, all participants considered the efforts were worthwhile and strongly recommended the formation of an organizing committee to prepare a second workshop to be held in the United States in 2001. Professor Panos Diplas of the Virginia Polytechnic Institute is the chair of that committee.

## List of Workshop Sessions and Schedules

***Workshop at Beijing***

*March 15, 1999 Monday*

Session 1: Physical and Numerical Modeling of Sedimentation
Session 2: Morphological Changes and Disasters
Session 3: River training and Strategies for Sediment Disaster Reduction

*March 16, 1999 Tuesday*

Session 4: Alluvial Sedimentation
Session 5: Sediment Movement in Rivers
Session 6: Fluvial Hydraulics and Sediment Transport
Session 7: Slope and Channel Erosion Control

*March 17, 1999 Wednesday*

Session 8: Human Activities Induced Sediment Problem
Session 9: Reservoir Sedimentation and Irrigation
Session 10: Concluding session.

***Field Study Trip***

*March 18, 1999*: Visit Xian and vicinity
*March 19, 1999*: Xian – Loess Plateau – HuKou Water Falls
*March 20, 1999*: HuKou Water Falls – Loess Plateau – TungGung – SanMenXia
*March 21, 1999*: SanMenXia – XiaoLangDi – ZhengZhou (take night train to Beijing)
*March 22, 1999*: Beijing: visit and sightseeing

## SESSION SUMMARIES

### Session 1: Physical and Numerical Modeling of Sedimentation
### Misganaw Demissie and Jenren Ni

**Keynote lecture by Ben C.Yen**: *From Modeling the Yellow River to River Modeling*

Professor Yen provided a historical perspective on modeling in general and application to the Yellow River in particular. Professor Yen traced the start of modern river hydraulic modeling to Louis Jerome Fargue of France, who built a 1:100 scale model of the Garonne in 1875. However, it was German hydraulic engineers who developed hydraulic models for the Yellow River starting with Herbert Engles (1854-1945), and then followed by his former student Otto Franzius (1878-1936). The studies in Germany resulted in opposing management opinions for the Yellow River: a narrow dike for the mean flow channel vs. dikes far apart. Leading Chinese hydraulic engineers were trained in Germany under Engels, who is considered the father of river hydraulic modeling.

Then Professor Yen presented important facts about the Yellow River and compared it to other rivers in the world. Even though the Yellow River does not have the highest discharge or largest drainage area, it produces the highest sediment discharge ($1610\times10^6$ tons/yr) of any other major river in the world.

Professor Yen pointed out that the Yellow River is sometimes referred as the "Sorrow of China" because of the destruction it has caused over the years. Efforts to manage the Yellow River have a long history, going back to 2278 B.C. when Emperor Yu started the Yellow works. Even though there have been some disastrous floods, the Yellow River has been managed successfully for many years. Recent trends in reduced flow and sediment load have created a new challenge.

Finally, Professor Yen discussed the limitations of both physical and numerical models. He pointed out that physical modeling has been neglected in recent years in favor of numerical modeling. He believes that both physical and numerical models should be applied carefully with correct understanding of the phenomenon that is being modeled.

**Xuejin Shao**: *Dynamic and Kinematic Wave Models of 1-D Rill Flow: A Comparison*

Professor Shao simulated hillslope overland flows due to rainfall excess by the two methods. Results showed that the Kinematic Wave could approximate the Dynamic Wave for broad sheet overland flows and moderate rainfall. However, for small rill width and high rainfall intensity, there is a significant difference between the two models. In general, the Kinematic Wave tends to underestimate flow depth and overestimate velocity.

**Wing Hong Wai**: *Three-dimensional Numerical Modeling of Cohesive Sediment Transport by Tidal Current in the Pearl River Estuary*

Initially, Professor Wai stressed the fact that they were dealing with fine cohesive sediments, and that the use of proper settling velocity, reference concentrations near the sea bed, and the critical shear stress were very important factors. They obtained values for the parameters from research conducted in China. The model solution scheme was the splitting method that partitions a time step into three fractional time steps according to physical phenomena. The model results were compared to observations from a number of tidal gauging stations in the estuary. Professor Wai and co-authors felt their results matched the observed data reasonably well for water elevation, but not as well for velocity.

**Yitian Li**: *Numerical Modeling of Flood Detention Basins Operation in Complex River Network System*

Professor Li investigated the detention basin operations in the multiply connected network of the Dongting Lake region of the Yangtze River. The results show that the model predicted the water level and discharge correctly.

**Discussions and Comments**

**Hall to Wai:** You showed the development of sediment concentration over time in the estuary. However, your initial concentration started at zero. That is not really the case in the estuary. What would the true initial concentration be? How you interpret your depositional rate?

**Reply:** The initial suspended sediment concentrations used in the morphological simulation are based on the equilibrium concentrations obtained after a certain spin-up period. The spin-up period for the concentration from initially zero to reach an equilibrium stage is about one month in this area.

**Ghidaoui to Wai**: Given the uncertainties in data, model, etc., what is the time scale beyond which the predictive capability of sedimentation numerical models becomes unreliable?

**Reply**: When we are applying seabed evolution modeling at a particular region, we may first try to get some ideas about the return period of some known seabed features such as a sand bar in that region. If the model can reproduce the seabed feature within the anticipated period of time, than the sediment simulation may be considered reliable or the results are trustworthy.

**Comment by Ghidaoui:** Climate modelers have accepted that long time simulations are simply impossible because of the nonlinear character of the model and the inaccuracies in both model and data. Yet, water resources and hydraulic engineers seem to run models over long time scales, i.e., well beyond the predictive capability of the model, and forget the fact that the results obtained by the model are, in this case, non-reliable and meaningless. To the mathematical modelers of sediment transport, what and how should we decide the reasonable modeling time?

**Comment by Hotchkiss**: In multidimensional modeling, and physical modeling as well, very often we paid too much attention to simply reproducing observed data. In the process we neglected to think about large changes that have not been seen. For example, who would have expected the Yellow River to dry up? Who would anticipate such an event decades ago? But had we anticipated that event, then we probably could physically model the deposition and decreased conveyance in the main channel, and begin to answer questions about what happens if such occurrences would happen. That ability of models, to predict beyond what has been observed recently, is one we probably have not used to its best advantages. It seems that if we have predicted the latest difficulty, then we respond to that. It seems that for the numerical and physical models, we should be looking into changing watershed conditions, and changing climate conditions, and try to anticipate beyond short-term problems.

**Bhowmik to Yen**: What is your view on the future of physical and numerical modeling?
**Reply**: My sincere hope is that both physical modeling and numerical modeling will flourish. Both physical and numerical models are necessary, they are complementary, and they are equally important. It would give a distorted view if we look into one and neglect the other. As I tried to say earlier, we are not God, we don't know everything. The danger of trying to play God is more with numerical models than with physical models, and the results of physical models should be more real. As a very simple example, for the Navier-Stokes equation, without perturbation you will have laminar flow forever, and we all know that is not true. To Ghidaoui's challenge, the answer is very simple. If God developed the model, it could run forever. If we human develop the model, it would collapse before we die.

**Comment by ZhaoYin Wang**: Modeling of the Yellow River is particularly difficult from other rivers because of fine sediment. One cannot use general sediment transport formulas to calculate the sediment in the Yellow River. For example, a very common phenomenon, the more sediment comes from upstream, the more sediment can be transported downstream. Therefore there is almost no theoretical formula that can be used on the Yellow River. Also because the river is very shallow and the channel is very wide, it is difficult to scale in physical models. Therefore we have to use a distorted model. In the laboratory modeling the fine sediment is also a problem. There are no general rules that can apply to the Yellow River. But we have many data and experiences in adjusting or determining coefficients for model verifications.

**Reply by Yen**: The problem with the Yellow River is that we don't know the boundary for the models. The whole bed is moving rheologically during high flows. I would like to supplement two more points. The first one is sediment backwater profile computation for the Sanmenxia Reservoir. The sediment backwater profile has gradually migrated up to Xian. China is very unique in terms of data available, and I encourage the Chinese counterparts to look into the sediment backwater effect because any human interference with rivers would impose such backwater effects of different degrees. The second is the effect of time-varying flow on the channel and sediment, particularly, the residual effect of major floods. The channel configurations, particularly the bed forms, crafted by major floods are not compatible with smaller normal flows, and yet the much more frequent smaller flows are unable to make any significant modification on the major-flood features. Therefore, the normal and low flows in a channel are not necessarily the best representation for the flow. What are we doing now? Either we conduct a laboratory experiment with a steady flow over a long time to observe the changes in the channel, or we do the calculation, try to simulate the flow, and hope the prediction for the future is true. The problem is that we don't know enough on how to model very fine sediment because its settling property is affected by flow unsteadiness, On the opposite side, we don't know how to model very large sediment either. Rivers in Taiwan and many other places, sediment sizes can be the sizes of a house or bigger. These large rocks and boulders are moved only occasionally by extremely large floods and stay in place for a long time.

**To Wai**: It seemed that your grid size and time scale are fairly large. How are the vertical variations?
**Reply:** The vertical variation may not be as important as the horizontal variation in large-scale seabed morphological modeling, especially when we're comparing the residence time of a particle in a horizontal plane and within a modeled layer. The vertical variation may be averaged out.

**Garcia to Wai:** There are quite some discrepancies between what we measured in the laboratory or in the field and what we can simulate using the model. What is most important is the physics of the processes.
**Reply**: This is true. Very often we find many discrepancies between computed results from models and laboratory measurements or field observations. Every region may have its unique controlling physics that govern the local sediment transport processes. We still have a long way to go in the development of a comprehensive multidimensional sediment transport model. Just like Dr. Garcia mentioned vertical stratification in the bay, in the summer vertical stratification in some parts of the Pearl River estuary is very intense. The simulation I presented here is just based on one tidal cycle, only without stratification effects, and we refer this condition to a representative tidal cycle in a wet season. So the application of the computed results is still very limited, and we should not over generalize the model as well. I would like to follow up Professor Yen's comments. In numerical modeling, we (modelers) have incorporated a lot of results determined from laboratory experiments in parameterizing what we call the closure terms in numerical models. For example in my simulations the values of settling velocity, reference concentration, threshold shear stress, are all based on a large extent from physical and laboratory experiments. Actually we (modelers and experimenters) should work hand in hand in this area. The current trend right now is to use laboratory experiments to focus on the functions of important parameters, and use numerical models to simulate large-scale long-term seabed variations.

**Comment by Zhaoyin Wang**: The current trend right now is to use laboratory experiments to focus on determining the parameters of important functions, and use lab-determined parameters in numerical models to simulate large-scale long-term seabed variations.

## Session 2: Morphological Changes and Disasters
### Brad Hall and Guanqian Wang

**Keynote lecture by Nani Bhowmik**: *Morphological Variability of the Upper Mississippi River*

Dr. Bhowmik's presentation focused on the natural and human-induced geomorphological characteristics of the Mississippi River and its floodplain. Representative characteristics of the river's discharge, slope, sediment transport, and floodplain dimensions were provided. Highlighted in Dr. Bhowmik's presentation was the significant increase in loss of floodplain acreage due to levee construction with distance downstream from the river's source. Implications for flood hazards and opportunities for floodplain restoration were described. An interesting proposal from Dr. Bhowmik's experience and analysis of the Mississippi and Illinois River systems is that the Illinois River could potentially be used to assess floodplain restoration concepts prior to larger scale implementation on the Mississippi River.

**Desheng Jin**: *A Preliminary Experimental Study on Non-Lineal Relations of Sediment Yield to Drainage Network Development*

Dr. Jin's work was an extension of the classical experiments completed by Dr. Stan Schumm on drainage network development. Important conclusions of Dr. Jin's experiments indicate a marked reduction in sediment load as time progressed during each experiment, as well as the significant morphological variability of the drainage network reached after each experiment.

**Fazle Karim**: *Channel Erosion Damages and Protection Measures in Southeast Arizona*

Dr. Karim's position with the local flood control authority in Pima County, Arizona, provides him with a unique perspective on the flood control needs and performance of structures constructed in a geomorphological regime dominated by severe monsoons and thunderstorm events. Soil cement bank protection works very well in this environment, and has resulted in significant reductions of flood damages to properties and infrastructure in Pima County.

**Changxing Shi**: *Characteristics of Hazard-prone Environment and Types of Sedimentary Hazards on the Lower Yellow River*

Sedimentary hazards highlighted during Dr. Shi's presentation included flooding, desertification, bank erosion, and water logging and salinization of adjacent floodplain soils. The perched channel characteristics of the Yellow River only aggravate all of the above processes. Reducing sediment discharge to the Yellow River through watershed management and sediment trapping in reservoirs will help alleviate some of these problems, but as Dr. Shi noted in his discussion, reducing sediment inflow is "an arduous and time-consuming task."

**Ouyang Zhang**: *An Experimental Study on Temporal and Spatial Processes of Wandering Braided River Channel Evolution*

Mr. Zhang's measurements included an assessment of the "ergodic" nature of braided and meandering channel evolution – that space and time substitutions for measurements can be incorporated in the experimental design.

**Discussions and Comments**

Discussions after the presentations focused primarily on information brought forth during Dr. Bhowmik's presentation. "Restoration" of floodplains, aquatic habitat, and other features associated with rivers is becoming a major activity in several water management organizations. Flood control is still vitally important, however, society is demanding that environmental values be given higher priority in design. Dr. Marcelo Garcia indicated that society demands that expertise from a sociologist, Mr. Brad Hall recommended the expertise of an economist, and Dr. Panos Diplas indicated that fisheries ecologists are becoming much more sophisticated in their hydrodynamic and hydraulic data requirements. Dr. Bhowmik echoed these comments and indicated that multidiscipline study approaches are routinely used on the Upper Mississippi River. Dr. Karim indicated that "greening" of soil cement bank protection measures are now utilized as standard parts of their designs.

Mr. Hall attempted to elicit discussion on the morphological experiments completed by Ouyang Zhang and Desheng Jin. Mr. Hall's thoughts were that the ergodic nature of Ouyang's experiments could be brought to bear on Desheng's experiment. The authors replied that the physical scale of the experiments must be taken into consideration, so a direct mixing of the techniques must be well planned.

**Hall to Bhowmik**: We talk about the needs to bring in environmental issues, which I heartily agree with. But we also need to bring in the dollar or the aids for doing the projects and have economic views also.
**Reply**: You are right. The money will make a difference in what can be or cannot be done. The reason I emphasize bringing in environmental scientists is because the environmental concerns are very important issues now in many countries including the U.S., but we cannot put dollar values on a lot of environmental issues. That is the major problem. The other factor I want to address is that most current biological models use essentially two parameters, a velocity with a biological parameter or the substrate (bed material characteristics) with another biological parameter. The purposes of those models are addressing fish habitats or if certain types of fish will be sustained. So even hydraulicians have very good high-quality models, but the gap between the two areas is there. Biologists certainly want to know what is happening. The economics is certainly very important but I want to caution us, especially when still in school, do not forget to address the environmental issues.

**Comment by Garcia:** Dr. Bhowmik has a point, we engineers need to have broader views and work with other disciplines that we are not familiar with, so that we can be more successful. Currently, I am working on a project funded by the NSF/EPA watershed program that involves economists, geomorphologists, and sociologists. I don't think we would have the opportunity to get this project if we were not working together with other scientific disciplines.

**Comment by Diplas**: Today fish biologists become more sophisticated. They are looking beyond information like what is the substrate or beyond what can be provided by the models. One of the skills they are using is the fish tanks for studying fish activities and the interaction with other parameters. For example, I am collaborating with fish biologists to investigate why in two similar streams one has abundant fish and the other has very little. If we look into more details, we find the one with abundant fish has obstructions, and the fish are hiding behind these obstructions. Now in the two-dimensional modeling we are looking into hydraulic structures behind a single obstruction. What we are trying to do is follow general topography and study what net effects make sense to the fish biologists, and then we distribute the effect to the entire stream to study the overall effects. We need to learn from fish biologists about what we are missing. In this way we can learn a lot from scientists of different disciplines.

**Response by Bhowmik**: By working with biologists on research projects for the Upper Mississippi and Illinois Rivers I have learned new knowledge from the biologists about the rivers, which was known to them for many years. For example, the mussels orient themselves downstream to filter the flow for food, which certainly has reasons in hydraulics. Now we are studying navigation traffic effects on the river environment. Then it makes sense that the physical effects such as flow reversals or the return flows can disorient the mussels' intake habit. In the state of Illinois and many parts of the U.S., the managers are now biological scientists. We need to work together to produce good science. Without engineering science, many biological activities in the field won't work out either.

**Ghidaoui to Bhowmik**: There are a number of factors for a river to change its course such as change in land use, sedimentation problems, climate changes, the runoff finds a more stable course etc. What are the main factors behind the Mississippi River changing its course?
**Reply**: Geological and geomorphologic changes occur in a fairly long time. What hydraulic engineers try to do has to be done within a given time frame; we are making predictions within a timeframe. Therefore connection between these areas has to go through data. And that is one of the difficulties in prediction, which is true to all parts of the world. For the Mississippi and Illinois Rivers we are fortunate to have fairly long-term data, including rainfall, discharge, sediment, stage, etc. Some stream discharge records are more than a hundred years long now. However, for a major event like the 1993 Flood, we cannot say it is the record flood based on what we have now, and major floods can still happen. We can only predict what is going to happen within what we know. It is a postulation. However, what has happened in the past is generally a good indication for the future. So studies by geological and morphologic scientists are important because they can tell us what has happened in the past. All over the world, many things are changing such as the land uses, the climate, agricultural practices, engineering techniques, these can all affect the morphologic changes of the rivers.

**Hsu to Bhowmik**: It will be interesting to compare the large rivers, like the Yellow River in China with the Upper Mississippi River in the U.S., especially on the effects of man-made changes.

**Reply**: This will be an interesting topic. However, I would like to emphasize that the Upper Mississippi, the Illinois, the Missouri, and the Ohio Rivers are regulated for navigation purposes. They are maintained to have at least 9 feet navigation depth. It will be unlikely to have flow drying up situations except for extreme conditions. Other than that fact, I believe we have many similar cases and it will be a very interesting subject.

## Session 3: River Training and Strategies for Sediment Disaster Reduction
## Grace Brush and Yitian Li

**Keynote lecture by Diankui Li**: *Sediment Carrying Capacity of Sea Current and the Training of the Yellow River Mouth*

Mr. Diankui Li emphasized that delta formation is a natural process, and that the river channel or the river mouth region will certainly change its course over time. Li proposed to construct a defined channel, possibly guided by submerged dikes or other means, at the mouth of the Lower Yellow River and to extend it into a deeper part of the sea. In this way, stronger sea currents could move sediment transported to the sea away and therefore a delta would not form so rapidly at the river's mouth. Sediment deposition at the river's mouth is a main reason for repeated flooding at nearby cities. The channel could be extended to repeat the process when needed.

Professor Marcelo Garcia compared the Yellow River to the human circulatory system. The Yellow River can be considered as bringing blood (water) and cholesterol (sediment) to the Bohai Sea (heart). When there is too much sediment, the river finds it easier to go in another direction (analogous to bypass surgery). However, bypass surgery works for a limited number of years. Similarly, the river can change course again depending on the flow and sediment loads.

Professor Shou-Shan Fan remarked that there is coastal erosion downstream in the north Yellow River, the Mississippi River, and the Nile River. Sedimentation in river mouths is an intensive problem throughout the world and many strategies are used to control sedimentation.

**Misganaw Demissie**: *Sediment Management Strategies for the Illinois River*

In response to a question on how much sediment must be moved by dredging in order to keep the navigational channels open, Dr. Demissie answered that most of the dredging by the U.S. Army Corps of Engineers is limited to where the tributaries enter the Illinois River. This varies from year to year depending on the particular situation. Flushing sediment out of the lower Illinois River has been considered. This would require constricting the area to increase the velocity. There are a lot of difficulties also because much of the sediment deposited since the 1930s and 1940s is contaminated. Rollin Hotchkiss commented that regulations regarding removing sediments from reservoirs differ from state to state in the U.S.

**Zhigang Shen**: *Influences of Nature-friendly River Training Works on Bed Load Transport*

Increasing or introducing roughness can reduce the flow velocity that may result in reduction of riverbed scouring. But increasing roughness can also increase turbulence, which can increase riverbed scouring, especially of fine sediment. The scale of the submerged dike also has to be reasonable or otherwise scouring may be increased and the flood level elevated. The importance of human activity as well as tidal currents on sediment transport was also discussed.

**Shixiong Hu**: *Shrinkage of the Estuarine Channels of the Haihe Drainage System and Its Influences on Flood Hazard.*

Dr. Hu reported that overusing water in the upper and middle reaches of the Haihe River has caused serious flood hazards for the lower reaches because the discharging capacity of estuarine channels are reduced. The lower reaches dry up in spring and early summer, and sediment deposited at the river's mouth is rarely scoured away. He analyzed the sources of the sediment and flooding damages if the current deposition rate remains unchanged. Several preventive and mitigation measures were suggested

**Discussions and Comments**

**To Demissie**: How much sediment is dredged annually? Could you describe the dredging techniques? It seems that dredging is applied to maintain the channel depth only, but the channel width is still narrow. This cannot solve the problems of deposition, and flood stage can become higher. Has sediment flushing been considered?

**Reply**: Dredging activities on the Illinois River occur mostly at locations where the mouth of the tributaries is and where there is coarse sediment. Dredging is not done regularly because the tributary inputs vary from year to year depending on different events that could have occurred in the watersheds. As for the sediment flushing, the average channel gradient of the lower Illinois River is very mild. Therefore the velocity is low, generally about 1 foot per second. That puts significant limitation on the flushing capacities of the river unless major engineering works like constricting the main channel are done. Another major problem with flushing and dredging is the fact that most of the sediment deposited in the 1930s through 1950s is contaminated. Flushing contaminated sediment downstream can cause more pollution problems for other locations.

**Comment**: Contaminated sediment and erosion downstream can be problems for the Three Gorges Dam.

**Response by Zhaoyin Wang*:*** Contaminated sediment is not a serious problem for the Three Gorges Project because there are not many pollutant industries in the upstream, and the state has begun to control the development of such industries. Downstream erosion is more challenging, and that can cause navigation and irrigation problems. The regulation capacity of the lakes downstream of the reservoir will be reduced because of the channel erosion. The main strategy is "store clear and release turbidity," which may mitigate the problems. Other strategies are still under study**.**

**Response**: In the U.S., if a reservoir starts to flush sediment now, it has to face environmental regulations stipulated by the U.S. Environmental Protection Agency because it becomes a point source. However, if in a reservoir design the regular flushing is included, then it is not a major problem. So any future design can consider flushing as one of its activities.

**Comment by Hotchkiss:** Regarding removing sediments from reservoirs in the U.S., the policies differ region by region. For example, in the Central part of the U.S. dams have retained sediments and make water clearer downstream. That has changed habitat for the fish. The EPA therefore stopped considering sediment as a point-source pollution. And they along with the Corps of Engineers will allow sediment to be reintroduced into the river. This has been done in the central part of the U.S. where sediment intercepted by the reservoirs and is allowed to by-pass the dam and enters the river downstream in maintaining some semblance of natural rivers. In this case, however, sediments have not been contaminated, and it is just a matter of preserving sediment continuity.

**Gary Li to Zhigang Shen**: Your experiments have demonstrated reductions in sediment transport with increasing channel roughness. Have you observed the cases of increasing sediment transport due to the introduction of roughness? Several studies done in Europe have shown that when flow depth is shallow, the introduction of roughness can actually increase sediment transport due to introduced vortices behind the roughness elements.
**Reply**: We did observe turbulence eddy behind roughness elements in our laboratory flume. But the activity is limited to that narrow zone, and this narrow zone diminished as the discharge of flow depth increases. The diameters of the roughness elements used in the flume range from 5 to 6 cm, and the water depths tested range from 5 to 13 cm. Increased sediment transport was observed when the water depth is lower than the roughness elements.

**To Hu:** There were a lot of structures constructed along the coast of the Bohai Sea by local governments. These structures have induced tremendous sediment deposition along the coast. The shrinkage of the river may be caused by human activities. Local governments should share the responsibilities for repairing the damages.
**Reply**: Some work has been done already, such as rebuilding the beach dikes, but the results are not very promising. The impacts are not limited to human societies but also on the water environment, and that part is very difficult to evaluate. We also need to be cautious about what approaches we take to repair the damages so that we can minimize secondary impacts.

**Fan to Hu**: Your presentation showed that water and sediment from the Yellow River are moving northward into the sea, but the sea current is moving southward. Is this a permanent situation? Also how will reduction in sediment loads in the Yellow River from reservoir operations upstream affect your study? The estuaries of the Mississippi River and the Nile River illustrate the problems you may face in the future.
**Reply**: Sedimentation at the rivers' mouth is a major problem to many countries around the world. We have done experimental studies using tidal gates like those used in Europe but the results were not very good. The sea currents change with season, for example, the sea current is moving southward in the fall, but northward in the summer. Sediment transport is influenced by factors including sea current, residual flow, and tidal current. As a consequence, most of the sediment from the Yellow River is moving northward and eastward into the sea, which has been observed from satellite images. Reduction in sediment loads of the Yellow River due to reservoir operations upstream will have little influences to my study. Sedimentation at the river mouth is a major problem to many countries around the world. We have done experimental studies on tidal gates to stop tidal water, like those used in Europe, but the results were not very good. We will learn more from river mouth training in other countries.

**Comment by Fan**: Sedimentation at coastal regions is a very important and difficult issue. There are two different problems that have to be addressed by engineers: littoral drift along the coast and sediment supply in the river. When waves hit the shore with an angle, they divide into two components, one normal to the shore and another parallel to the shore. Their directions and magnitudes depend on many factors including the direction of the wind, depth of the water, and magnitudes of the waves. When flows and sediment from the river meet with the tide at the river's mouth, the sediment becomes unbalanced. So depending on the sediment loads from the river and the littoral drift along the coast, the sediment movements in an estuary could go in either direction. Such problems occur at the mouth of the Yangtze River, the Mississippi River, the Nile River, and many other rivers. One good example is the 1942 diversion of the Santee River into the Cooper River to help lessen the required sediment dredging from the Charleston Harbor downstream. After the diversion, however, the annual dredging required at the harbor was increased from 80,000 to 10,000,000 cubic yards. One explanation found by the study at the Massachusetts Institute of Technology was that the flow regime at the harbor had been changed from completely mixed to stratified after the diversion.

## Session 4: Alluvial Sedimentation
### Shou Shan Fan and Shuyou Cao

**Keynote lecture by Jinren Ni**: *Particle Suspension in Sediment-laden Flow*

This paper is composed of five major sections: comparison of existing theories, integration of existing formulas, interpretation of various vertical profiles, applications of the kinetic theory, and conclusions.

First, the authors examined and compared the six most popular theories of suspended sediment distribution in sediment-laden flow: diffusion theory, mixing theory, two-phase flow theory, stochastic theory, energy theory, and similarity theory. They found that each theory has its advantages and disadvantages, and each produces a corresponding formula for vertical sediment distribution. However, the theories examined by the authors gave nearly the same form as the diffusion equation even though they have undergone different mathematical treatment. In Table #1, 13 representative formulas deduced from different theories for vertical sediment distribution are listed.

Secondly, the authors developed a general formula from which most formulas in Table #1 can be reproduced. At present, the data used for the calibration of the general formula are limited. More precisely measured data are needed for the accurate determination of key parameters in the general formula. Dr. Ni concluded with the following points.

1. The continuum concept, which has been proved very successful for describing liquid fluid motion, seems inadequate for describing motions of discrete solid particles in two-phase flow. Although stochastic models can be used to describe the motion of a singular particle in the fluid, it cannot be applied to the interactions among the solid particles.
2. The authors propose to apply the kinetic theory to the hyper-concentrated flows where collision interactions become major mechanisms.
3. There exist two major types of sediment vertical profile distribution: Pattern I and II. The Pattern I distribution can be explained by the ordinary theory, whereas the Pattern II cannot. A proper description of the Pattern II distribution requires full understanding of the motion of individual particles, interactions among particles, and the near-wall dynamics of turbulent flow.
4. Many theories, including diffusion theory, mixture theory, two-phase flow theory, energy theory, and similarity theory were all originated from the continuum concept. The final equations that were deduced from these theories are all similar as the diffusion equations except for slight differences in appearance in expressing the sediment diffusion coefficients.
5. Many formulas for Pattern I vertical sediment distributions can be integrated into a generalized formula in which each of the previous formulas is simply a special case of the integrated formula.

**TaWei Soong**: *Fine Sediment of the Upper Mississippi and Illinois Rivers and Its Disastrous Consequences*

This paper was written to address: (1) the increasing sediment deposition in streams and lakes of the Upper Mississippi River (UMR) and Illinois River (ILR) watersheds; (2)

the severe environmental impacts of the sediment deposition; and (3) optimal methods required for removing the sediments and mitigating the associate impacts.

*Physical Impacts of Sedimentation*

Due to rapid changes in land-use patterns in the UMR and ILR watersheds since the completion of the lock and dam system in 1930, the upland erosion and sediment delivery to tributaries and main streams have been accelerated. The 1993 U.S. Geological Survey's analysis of 14 hydrological regions has shown that the annual sediment yields of the UMR was 102 tons per square miles, which ranked second only to the 110 tons per square miles of the Lower Mississippi River. It was predicted that at the current sedimentation rate, many channel border areas of navigation pools of the UMR would soon be filled.

*Environmental Impacts of Sedimentation*

It was also found that sediments deposited in channel border and backwater lakes were mostly fine sediment. In addition, sediment particle size is one of the most important physical controls affecting the fraction of heavy metals found in sediment. High metal concentrations are usually associated with finer particle sizes.

At the ILR, the overall sedimentation rate was about 3 to 7 centimeters per year. In general, fine sediments of the UMR contain traces of PCBs and high concentrations of metals, nitrate, and total phosphorus for which disposal is difficult.

Suspended sediments increase water turbidity that could impair reproduction and reduce growth of mature aquatic plants and affect the survival and growth of buds and seeds. Also, turbidity could reduce light transmission that is needed for photosynthesis.

*Case Study: Peoria Lake on the Illinois River*

Peoria Lake is the largest flow-through lake of the ILR. It covers 14,000 acres and is subdivided into Upper and Lower portions by a natural constriction with a narrow constricted outlet at the lower part. In 1985, the lake volume was only 39,000 acre-feet as compared to 120,000 acre-feet in 1903.

The river was deep and wide following the completion of Peoria Lock & Dam in 1930. Presently, the main channel is a narrow, deep navigation channel between flat submerged plains, with channel border areas on both sides filled with fine sediments.

Removing sediment to improve the aquatic environment and downstream water quality and aquatic community has been considered for Peoria Lake. Due to concerns regarding contamination in the sediment, conventional dredging techniques are considered to be inadequate. At present, different dry dredge methods have been examined. However, they are limited by factors such as the excavation depth, dredging capacity, delivery length, disposal sites, and more importantly, the overall cost. Understanding bed sediment characteristics, hydrodynamic forces, inter-relations of sediment with pollutant transport, and biologic responses is necessary for providing proper management solutions to such problems.

**Zhao-Yin Wang**: *Effects of Shape on Incipient Motion of Sediment Particles*

This paper discussed an experimental study of the effects of particle shape on the initiation of motion. The study was conducted in a tilting flume 10 meters long, 0.3

meters wide, and 0.5 meters high. In the middle of the flume, the bed of a test section 2 meters long was made up with movable gravel particles 0.1 meters deep. The remaining portion of the flume bed was covered with plastic plates on which grains were glued to obtain the same roughness as the test section. Immediately downstream from the test section, a holed box was installed to collect the particles entrained from the test section. Flat, elliptical, and round grains were used in the experiments.

Forty-eight experiments were conducted. During the tests, water depth and surface slope were measured with three stage gauges. Velocity distributions were measured with a 1-D LDA in the middle, upstream, and downstream of the test section. Movement of the grains was observed through the glass sidewalls of the flume. The rate of bed load transport was measured by the sediments trapped in the collection box. There were two concluding remarks.

1. Experiments demonstrated that before an imbricate cluster structure is developed, the particle shape has insignificant influence on the initiation of motion of individual particle. After the imbricate cluster structure has developed, however, the critical Shields parameter for initiation of flat particle motion is 65 percent higher than for round particles.
2. The effect of the length of the test section was also studied. It was concluded that the influence of the test section length is negligible when the test section is longer than 1.4 meters. This suggests that the results of particle motion initiation found from a 2 meter long section were compatible to those from river flows.

**Panayiotis Diplas**: *Regime Morphology of Equilibrium Alluvial Channels*

This paper employed a concept of turbulent diffusion of downstream momentum in the lateral direction to develop a model for obtaining shear stress applied by the flow upon the boundary of channels. Such a model can reconcile the coexistence of stable banks with active beds, which represents the typical scenario encountered in natural streams during floods.

This model represents a refinement of Dr. Gary Parker's singular perturbation stable channel model that was limited to the flat bed region, while the bank was assumed to follow a cosine profile. The model determines the bank profile by solving the coupled equations of fluid momentum diffusion and particle force balance with a Runge-Kutta-Merson Scheme. For channels transporting bed load, the width of the flat bed region can be determined by numerically solving the momentum diffusion equation over the central region of the channel and matching the flat bed and bank solutions at the junction point.

The present application of the model is limited to threshold channels, and to channels with static banks and dynamic beds. The channel dimensions predicted by the model for such cases are in good agreement with available field and laboratory data.

In a typical design problem, the inputs needed are: (1) either the flow rate or the channel bed slope, (2) the properties of channel material (size, coefficient of static friction, etc.), (3) lift-to-drag ratio, and (4) the value of the critical bed stress. The model can determine the remaining design parameters: top channel width, center channel depth, either channel slope or flow rate, or the shape of the channel perimeter. The model was developed based on the assumptions that the channel is straight, secondary currents are ignored, bank material is non-cohesive, the contribution of bed forms to the overall channel resistance during floods is small, and that bed material is coarse enough to preclude suspension.

## Discussions and Comments

**To Ni:** Could you characterize to what conditions does the Type II Distribution apply?
**Reply:** I believe that at present it is very difficult to derive a solution to judge the applicability of Type I distribution. Type II distribution extends into the boundary and depends on particle motions especially near the wall. From our research and laboratory results, we think Type II distribution has more opportunity to apply to light particles, or for light particles near launch.

**Ghidaoui to Ni:** Your findings included that different theories led to the diffusion equation. This is not surprising! From a macroscopic point of view, there are two physical mechanisms for the transport of matters: advection and diffusion. In fact, I think what you have proved is the different approaches and formulations to the same theory.
**Reply**: (*Cannot be retrieved due to background noise*.)

**Garcia to Ni**: For the diffusion and re-suspension part, you seemed to have diluted concentration by volume so your suspended sediment concentration was less than 1 percent. It seems that one can't get such answer using the diffusion-dispersion theory. Have you used any theory or data to explain the Type II distribution? The Type II distribution seemed to be applicable to pipe flows or hyper-concentrated flows! The reason why concentration decreases away from the bed is because there is a fluidized bed where sediment concentration is very large. Then none of the theory you showed will work for Type II distribution. I believe Type I is applicable to diluted suspension and Type II is applicable to very large sediment concentrations. It will be helpful to find where the bed is! If you move into the bed region, the concentration may be diluted again.
**Reply**: These two types of distribution are derived after we studied many theories and functions. At first we also thought they depended on sediment concentrations. But after analyzing data from both laboratory and field, we found even in very low sediment concentrations Type II distribution was still applicable. The sediment concentration is not the only factor.

**Ghidaoui to Ni**: I want to follow up Dr. Garcia's question. For small concentrations, you've investigated the concentration at the bed. Can you describe what your findings are? Do you know if other researchers found the concentration near the bed? Have Chinese scientists found similar results?
**Reply**: I know Professor Sumer and also Professor Wang Guangqian have done some work. I have some vertical data of very low concentrations for light particles that can be used for this problem. I think it should be very clear for the low concentration profile, and into distributions.

**ShaoHua Hsu to Ni**: What is the limitation of your generalized formula?

**Reply**: Because the generalized formula depends on several parameters, we have to know in advance the values for those parameters. Initially the generalized formula was in a very simple form that we derived directly from the theory. Later on we have made many modifications and come up to its present form. For future work I think the function of generalized formula can be concentrated on studying how parameter "*a*" will vary with particles' properties. At present we are encountering the difficulties of available data. Experimental data are limited, and we can only use data from the field and some data from Russia. Maybe in the future studies we shall investigate how the parameters will change with fluid and sediment properties.

**Hall to Wang**: It is great to look into particle incipient motion using particle shape factor as a criterion. The instrumentation and measurement criteria, according to my past experience, seemingly can make differences on the incipient motion. In one of your slides you showed the relationship between shear stresses and transport rate is a step function for the flat particles. I wonder if there are some initial inflow conditions, bed sorting, and time development of both the flow field and the bed characteristics to help the interpretation of the transport rates?
**Reply**: The development chart is not showing the relationship for a long time. However when the flow rate is lower, the development of imbrication will need a long time or not developed at all. In our experiments we tested each discharge as long as 4 hours, or at least 1 hour. So we need a very long time to complete the experiments. However, when the flow rate or the shear stresses are larger, the imbrication can be developed.

**Comment by Diplas:** Dr. Wang's experiment brings up a very interesting point that I think may have been overly violated. The notion is that many experiments used hand-placed materials and tested against different discharges until they got the incipient motion, and derived criteria for incipient motions. The fact that these were hand-placed materials was forgotten. It is very important to run the experiments for hours, and be able to simulate natural conditions by either recycling the materials or introducing similar materials into the flume to simulate naturally based construction of the bed. Then start measurements to precede the incipient motion experiment.
**Reply**: Very good point. In our experiments we did run each test for a long time before taking measurements.

**Comment by Fan**: There are several items that may be useful to the audience. The American Society of Civil Engineers has a task group looking for methods to verify computer models. Dr. Sam Wang currently chairs this group. There is also a new book that addresses this particular issue. In addition, there is an inter-agency study on bank erosion, and I believe a report is under preparation now.

**Gray Li to Zhaoyin Wang**: My question is on armoring processes. For flat particles, you reported a significant increase in critical shear stress, about 65 percent. In order for others to use your results, you may want to define that armament quantitatively.
**Reply**: To quantitatively describe the armament may be difficult. Our results do fit our current set-up, but more work is necessary.

**Hu to Soong**: We have fine sediment problems in the Haihe River and Bohai Bay. At present, some sediment is dredged, and the dredged sediments have been placed on the land, especially the farmland to make use of the materials. The sediment is difficult to de-water, however. In any case, sediment does not cause only troubles; sediment is also an important resource. In the U.S., do you try the fine sediment for land use? Are there any ways to use the sediment?

**Reply**: Thanks for pointing out the issue on beneficial use of sediment. It is an important concept, and I believe it is well looked into in China especially for the Yellow River. The beneficial use of sediment is a major subject in the Illinois River Task Forces. However, the sediment we are facing in the Upper Mississippi and Illinois Rivers may contain contaminants at some locations. These sediments are mostly deposited in backwater lakes and side channels. If there are pollutants, reusing the sediments will be difficult. On the other hand, sediments from the main channel are mostly larger particles and mostly are clean and can be reused for road construction or other purposes. Currently, an idea has been looked into seriously is dredging sediment to improve local habitats, such as building artificial islands and deeper areas, for fish and aquatic plants and animals.

**Comment by Demissie:** There are chemical analyses done for sediment cores from the Illinois River by another agency. In the analyses they analyzed water content, organic carbon, and concentrations of various contaminants in various layers. These sediments were also dated by Cesium 137 procedure. The results showed that sediments in the top layers are cleaner than those in the lower layers, which were deposited in the 1930s to 1950s.

**Hall to Diplas**: I am very interested in the stable channel design procedure that you presented. Your formula looks into cross-sectional characteristics. Do you have any recommendations for longitudinal variations in cross-sectional characteristics for curvatures or alternate bar formations?

**Reply**: Obviously, I started with a simple case, and then we can handle from there on. The theory and methodology presented here are suitable for gravel streams. In such streams under bankful, or formative discharges, bedforms tend to be poorly formed and therefore do not contribute significantly to the overall channel resistance. However, I believe that the same formulation could be extended to the case of sandy streams, and provision could be made for the bedform resistance. In this case though, the problem might become a bit more complicated because the large amounts of suspended load need to be accounted for, and the present theory allows only for bed load movement. Efforts to generalize the model to include sediment transport are currently under way.

**Comment by Yen**: An important purpose of this workshop is discussion. Through the discussions, hopefully we can bring out the assumptions and views. Actually the problems we look into are the same problems from different prospectives. Dr. Wang, you could have answered Dr. Li's question by saying that this is a probabilistic problem. Although there has been much work done before on sediment behavior, we did not look enough into the fundamentals. Dr. Wang and Dr. Ni, I congratulate you for looking into the fundamentals again. What needs to be looked into more is the science. This is something very important because our basis of knowledge on sediment motion starts from a single sphere. Beyond the single sphere we need to look into, for example, what are the effects of the particle shape, its orientation relative to the flow, etc., and then take the probability into consideration by looking into the stochastic nature of flow and sedimentation. Armed with the basic understanding of single particle behavior, we will be ready to look into the effects of nearby particles and boundaries. If we can make good efforts and able to formulate something very simple for applications, then we will be in good shape. So you both have taken a very good beginning step; but that may not be fast enough for others who are looking for results for applications now.

Likewise, in Dr. Ni's work, you try to look into the problem along the line of energy; perhaps the momentum idea is also supplementary. Right now we still lack full understanding when particle interactions are important. We need such understanding from the scientific side. If we are looking from the engineering side, then we try to lump things into a coefficient or a constant or an index. In your presentation, you applied the terminal fall velocity to determine the dispersion coefficient $\beta$, which is then treated as a constant. In reality, due to the velocity gradient and turbulence fluctuation, the true sediment fall velocity is different from its idealized terminal fall velocity. If you use the true fall velocity, you may get different results and may get closer to reality. The terminal fall velocity that is determined from the graph based on Rouse's experiment applies to still water and assumes infinite water body, and is generally larger than the true fall velocity. This fall velocity difference is also a problem in the design of settling basins for which we usually use the terminal fall velocity. As a result, most of the sediment generally won't settle within the length of the basin and therefore the tank efficiency is not very good.

## Session 5: Sediment Movement in Rivers
**Marcelo Garcia and Onyx Wing Hong Wai**

**Keynote lecture by Donald W. Knight**: *Flow Mechanisms and Sediment Transport in Compound Channels*

Professor Knight presented an overview and some published results of a collaborative project in the United Kingdom on flow mechanisms and sediment transport in natural channels.

**Shiqi Zhang**: *A 1-D and 2-D Combined Sediment Model for the Estuary of the Yellow River*

Prof. Zhang demonstrated the coupling between a one-dimensional (1-D) tributary model and a two-dimensional (2-D) open-sea model for the study of siltation patterns.

**Brad Hall**: *Quantifying and Mitigating Flood Risk in Rapidly Aggrading Fluvial Systems*

Mr. Hall, a principal of a consulting company in the State of California, reviewed their findings of an extensive flood risk investigation in southern California, USA.

### Discussions and Comments

Professor Ben Yen raised a question to Professor Zhang on the numerical coupling tactics employed to link between (i) the flow field and the sediment field and (ii) the 1-D tributary model and the 2-D open-sea model. The remaining questions and comments in this session were mainly on Professor Knight's channel hydraulics project. Because the project covers various aspects of fluid mechanics and sediment transport in natural channels, the questions and comments were also fairly diverse from inquiring about bottom shear stress measurements, bedload and suspended load transport between floodplains and main channels, Froude number in compound channels, similarity scales in modeling meanders, to suggesting publication of a compilation of the project reports. In view of the accomplishment of Professor Knight's project, the Chinese delegates believed that the experience learned from this project was valuable. With this experience, similar in-depth and systematical investigations of rivers in China can be organized such that effort will not be overlapped and data can be shared for the benefit of any future research advancements in this area.

**Yen to Knight**: The boundary shears stress measurements you have shown in the graph, were they the truly direct shear measurements? Or they were deduced from velocity distribution, such as the velocity impact type Preston gage measurement?
**Reply**: The shear stresses were direct measurement based on Preston tube, and they were integrated up to check with energy. We always tried to check with Reynolds' shear stress to assure quality. We also checked with vertical Reynolds' stress measurement that we measured within a rigid boundary.

**Yen to Zhang**: You have essentially two sets of equations, one set for the channel portion and another set for the sea portion. In each set you have the flow momentum/continuity equations and the sediment equation, and you try to couple them.

To couple these equations numerically you face several levels. One portion is the channel part and sea part, and another portion is the flow part and the sediment part.

There are several levels of coupling techniques one can use:
1. Solve the differential equations altogether. This is physically sound but numerically difficult. I call this true coupling, but I have not seen anybody use such an approach yet.
2. Alternatively, one can solve for the flow part and then, at the same time step, for the sediment part in the channel and then to the ocean part. Then use an ADI (or ADE) technique to couple the 1-D solution to 2-D. One goes back and forth between the 1-D and 2-D until the solution is reached. And then move on to the next time step. This is the alternative coupling.
3. The third one is external coupling in which case one solves the flow for the whole domain and then solves for sediment in the river and sea for that time step. Use the modified geometry to re-compute the flow until one reaches a solution.
4. The non-coupled model is the one where flow is computed for all space and time steps and then solves for the sediment and no feedback.

So my questions to you are: #1) For the 1-D part or the 2-D part, were the coupling of the momentum/continuity equations with sediment equation the true coupling or the alternate coupling? and #2) Were the coupling of your 1-D and 2-D domain the alternative coupling or external coupling?

**Reply**: -----. The flow field was separately calculated and the hydrodynamic results were used as driving force for the transport of sediments. The junctions between tributaries and the open sea were numerically connected in the model by an alternating direction implicit scheme.

**To Knight**: My questions are related to sediment transport between the main channel and floodplains. The sediment transport you discussed was the bed load mode or the suspended load mode? Did you feed the sediment both in the main channel and floodplains or just in the main channel? Was there any longitudinal sorting or the sediment became equilibrium between the main channel and floodplains?

**Reply**: First of all, sediment was injected upstream and was very fine sediment. The interests were lateral dispersion and longitudinal dispersion measurement and simultaneous turbulence measurements with fluorescent dye and also very fine sediment. In slides I showed there was very fine sediment induced on top of a fluorescent sand bed where the bed roughness was known. They have kept the lateral eddy diffusitivity of the dye with the fine sediment. A paper published by Dr. Garrener showed the topic to be very interesting.

**Comment by Knight**: We are dealing with fully developed shear layers so there is no continued lateral spreading in the longitudinal direction. It is purely uniform up to the initial length. The flow is laminar so the stability we are sure the shear layers were fixed. As for the Froude number of the experiments, with large channel facility the Froude numbers if I remembered correctly, typically are in the range of 0.4-0.7. I have done compound channel work with the Froude number up to 3.5 looking at detailed boundary shear and the definition of critical flow. I am aware that you can get simultaneous subcritical and super-critical flows in the same cross section. It is indeed a problem with the practice. I have a paper published on the subject few years ago and I can show you too later.

**Diplas to Knight**: My question is about the interactions between main channel and floodplain in the case of meandering channels. You have shown there is secondary circulation developing. I imagine that on the other part of the bed value you are enhancing the strength of secondary currents. In one part of the bank we may have agriculture, but on the other part of the bank we may have increased strength. I was wondering if that has any significance in the generation of cutoffs that we have during such floods.

**Reply**: The reason for very little enhancement of second currents further downstream. What tends to happen is the very large injection of fluids from the main channel to the floodplains. That interaction introduced quite large shear stress, which correlated with vegetation nearby. But the changes in secondary circulation are very dependent, especially dependent on the floodplain roughness. We have looked at different vegetation on sediment transport and geomorphology. It is a very complicated process just surfacing, the major mechanisms. Clearly more work needs to be done.

**ShaoHua Hsu to Knight**: Have you compared the river bed profiles for the meandering channel in the model and in the real rivers? What is the similarity so that your results can be used in engineering applications?

**Reply**: The experiments we have done were purely scientifically based without reference to natural rivers. We have looked the similarity laws by virtually looking into the mechanisms, which I think is quite right to start with the physics. If the physics is right, then we understand what is going on. We have been involved with lots of other studies including Japanese Rivers with very low sinuosity. They are very concerned about bank protection, vegetation, and flood protections. They have contented, as we have, with some of the laboratory results without terrific data. As all physical experiments do, there are some discrepancies, but the general picture is very good.

## Session 6: Fluvial Hydraulics and Sediment Transport
**Rollin Hotchkiss and Gary Li**

The five speakers in this session discussed sediment behavior and modeling in rivers varying from the fine-sediment-dominated Yellow River to very coarse-sediment-dominated mountain streams.

**Keynote lecture by Jongxin Xu**: *Complicated Behavior of Erosion and Siltation of the Yellow River and the Fluvial Processes*

Professor Xu described how the behavior of hyper-concentrations of fine sediment differs from our intuitive hypotheses. Hyper-concentrated flow can occur with less stream energy than non-hyper-concentrations. Applications to scour, meandering, and braiding were illustrated with the Yellow River as an example.

**Jinme Liu**: *Effect of Coarsening of Surface Bed Material on Non-equilibrium Sediment Transport in Process of River Degradation*

Jinme Liu discussed the effects of sediment gradation on the non-equilibrium sediment transport lag. Using equations and computer analyses, Ms. Liu showed that the distance for equilibrium sediment transport rate increases with the heterogeneity of the sediment mixture. The key to the analysis is the concept of a sediment mixing layer in the bed.

**Shuyou Cao**: *Stability of the Nianchu River after Regulation by Straightening*

Dr. Shuyou Cao discussed what happened when 200 km of the Nianchu River in Tibet were straightened and constrained to flow between relatively narrow levees. Within four years of construction, there were two breaks in the levees due to the river re-establishing a meandering pattern within the channel. Computer simulations of the river indicated that the placement of groins could induce a deep, meandering, stable channel within the levees. Installation of the groins has so far been successful.

**Ellen Wohl**: *Boulders on the Move: Geomorphic Hazards from Floods and Debris Flows along Mountain Rivers*

Dr. Ellen Wohl discussed the positive contribution that geomorphologists can make to engineering studies. Field training and experience allows a geomorphologist to recognize paleoflood evidence that engineers would likely not recognize and take into consideration when estimating hazards. Dr. Wohl explained a method that can be used to differentiate between hazard levels in the field due to, for example, debris flows. The method was illustrated using a case study from a community in Glen Canyon, located at a confluence with the Colorado River.

**Hongwu Zhang**: *Two-dimensional Sediment Mathematical Model for Unsteady Flow in the Lower Yellow River*

Dr. Yuxin Xu, speaking on behalf of Dr. Hongwu Zhang, explained a two-dimensional model for unsteady flow for water and sediment. The basis of the model was explained and applied to the Yellow River in China. The agreement between the measured and computed erosion/deposition was good across the cross section.

The session is an example of how we need to collaborate more closely in our work. For example, the pioneering work on hyper-concentrated flow on the Yellow River was not included in the two-dimensional model of the same river. And the work and non-equilibrium sediment transport in mixtures was not included in the computer model applied to the Nianchu River. The session, therefore, is a beginning point for future collaboration.

**Discussions and Comments**

**Bhowmik to Wohl:** In 1976 there was a severe flood in Big Thompson Canyon of Colorado. The flood also had hyper-concentrated flow similar to the conditions at the Yellow River. What is your thought?

**Reply**: There were actually two different events along the Big Thompson River: there was a rainfall-generated flood in 1976 in which 141 people were killed, and a dam-burst flood in 1982 during which 3 people were killed. The passage of these flood waves was analogous to glacier-lake outburst floods that I have studied in Nepal. During the Nepalese floods, downstream changes in channel and valley geometry and sediment supply caused the flow to alternate between hyper-concentrated flow, debris flow, and water flood along the length of the channel. These types of changes make the flow very difficult to hydraulically model. The geomorphic effects associated with the Big Thompson River floods were similar to those described Nepal; steep, narrow channel reaches were dominated by erosion, whereas wider, lower gradient reaches were primarily depositional. An interesting point was that the US Geological Survey conducted a study immediately after the 1976 Big Thompson flood and estimated a recurrence interval on the order of 10,000 years. This estimate was based on a misinterpretation of radiocarbon-dated materials. They recurrence interval has subsequently been revised to more on the order of 300 years. This type of changes in recurrence interval estimate has significant implications for hazard engineering.

**ZhaoYin Wang to Wohl**: Your study involves the movement of boulders. Have you applied techniques such as using radio tracking of rocks or using color tracking? There were some studies done in Germany applying those techniques.

**Reply**: The experiments you described mostly dealt with supercritical flows associated with storm hydrographs or snowmelt events, as in the work of Peter Ergenzinger and others, who examined a snowmelt-dominated channel in Montana. These studies have examined what might be considered "normal" peak annual flows, as opposed to extreme events. It will be more difficult to estimate the degree of coarse clast or boulder movement that occurs during extreme flows which occur only rarely. In the case of infrequent flows, you may have to wait many years before a marked clast move. To my knowledge, no one has yet tried to do this type of work with really coarse particles. It would certainly be worthwhile, but would require a very long-term study.

Regarding the movement of very large boulders, another approach is to reconstruct the flood profiles and hydraulics using appropriate flow-routing models, map the locations of very coarse sediment deposition, and relate flood hydraulics to boulder deposition. The implication is that this approach works only if the channel and valley geometry do not change substantially during the flood (as for example via scour and fill), and one can reconstruct the geometry present during the flood. People have used this approach to develop depositional regimes for coarse sediment for various channels. What they cannot do is examine entrainment conditions.

**ShaoHua Hsu to Wohl**: You have created the hazard map for debris flow especially linearized for some relationship using the weighting function. The first question is that the debris flow will move and deposit on some places which may be hazardous to people. So does your map show those places or just show where the debris flow occurs?
**Reply**: That's a good question, and my map is actually simplified for presentation. There are two parts to be considered. The first part is where debris flow initiates; the second part is where the deposition occurs. In case one doesn't want people to live on debris-flow fans or at the base of the flow zone, we can examine past depositional patterns and estimate where deposition will be occurring in the future. That is of the most concern, because people don't generally live on the very steep slopes where debris flow initiates. The map that I showed focused on zone of deposition.
**To Wohl**: My second question is how do you decide the weighing factors for each parameter? And why do you use the linearized form?
**Reply**: We thought that the best approximation of the relationship between debris flow controls and occurrence was linear, but this is a first, subjective approximation. We subdivide the dataset so that we assign the weighing factors from one portion of the set and test them against another portion of the set, and thus determine the accuracy of the weightings against actual field data.

**Soong to Xu**: There are different methods for determining the suspended sediment concentration in the laboratory. Like the filtration method set by the U.S. Geological Survey using 1.5 μm filter paper. That means particles with size less than 1.5 μm are not considered in the final results. Could you tell me how suspended sediment concentration for the Yellow River is measured? Is the method standard for other rivers in China?
**Reply by Z.Y. Wang**: We take the samples from the river, dry and weigh them in the laboratory. So we use the whole sediment to determine the weight of suspended sediment, and then calculate the concentration for the Yellow River.

**Diplas to Wohl**: Do you have the opportunity to collect samples to see if there is any size stratification in the deposit? During debris flows would one see stratification, or armoring or others?
**Reply**: We did not collect samples of the debris flows at Glenwood Springs. We mostly used historical records for debris flow occurrence because the study site was an urban area from which debris-flow deposits had been cleared. For the work at Nepal, we spent a lot of time looking at clast fabric and clast orientation. We examined two channels in Napel. In both cases there was evidence that as flow went downstream, it alternated between hyper-concentrated flow, debris flow, and water flow, so characteristics such as stratification wold vary depending on locations. I have observed size stratification, but this varies as a function of the location along the channel because it relates to where flow transitions are occurring. Debris flow deposits generally are not stratified, sorted, or armored.

**Diplas**: I have seen from several rivers that fine materials appear on top of coarse materials. It seems contradictory to what we have seen previously.
**Reply**: The dominant feature we saw in Nepal was extensive deposition across the floodplain. Superimposed on this were longitudinal boulder bars or boulder berms, in which the clast was much coarser than clast moving across the floodplain as a whole. We don't know too much about the hydrograph characteristics in relation to sediment supply, but the sediment deposition present after flow probably occurs primarily during recessional flows. So, yes, we do see "coarsening upward" sequences on the floodplain associated with these boulder bars.

**Gary Li to Wohl**: Your model for predicting possible debris flow involves several variables, and you used value weight for each variable. My question is how confident you are about those value weights and your predicting equation?
**Reply**: We actually feel quite comfortable about the equation because basically the weighting factors were derived from one subset of data and tested against a different set of data and historical data. The equation did pretty well in predicting where would occur but at a coarse spatial resolution. If one wants to use the equation somewhere else, then it would be necessary to adjust the weighing factors. The limitation then is that the model needs more data for further calibration and verification.

**Hotchkiss to Xu and Zhang**: In this session, the first paper mentioned the differences between flow modeling and concentration, and talked about hyper-concentrations. Our last speaker then talked about the application of a two-dimensional sediment transport model for the same river. So the question is: Dr. Xu. Did you incorporate Dr. Zhang's work on hyper-concentration in the computer model?
**Reply:** We study the same issue from different directions. We studied from a geomorphologic approach, whereas Dr. Zhang was using the hydraulic approach. It seems like a perfect opportunity to work closely.

**ShaoHua Hsu to Xu:** You mentioned that there are two possibilities to route the channel. One is the regular routing and the other is the hyper-concentrated flow routing. But we know that in creating the hyper-concentrated flow, the channel will be eroded. How are you going to create the man-made hyper-concentrated flow?
**Reply**: Our suggestion is provided by Professor Qi Pu of the Yellow River Commission. In my opinion, it is a very good idea. But before putting it into practice we still have a long way to go. I think it is very difficult to make hyper-concentrated flow on large scales in the field, like the Xiaolangdi Reservoir, in such a short time. But we can try to find out the technology.

**Comment by Yuelan Liu**: When sediment comes to the reservoir, there is a stratified reservoir formed because of the turbidity. If the reservoir operation is designed properly, then the hyper-concentrated flow can be released. That is one method to create hyper-concentrated flow. Another method is to use dredges to artificially erode riverbanks and bed during flood periods. But it is still a suggestion, not yet really applied. I did experiments on this subject and also observed from reservoirs in Shannxi Province. When they released the water and draw down the reservoir, the drawdown-induced rapid flows and flow caught sediment, hence developed into hyper-concentrated flows.

## Session 7: Slope and Channel Erosion Control
## Panayiotis Diplas and Shaohua Marko Hsu

**Keynote lecture by Marcelo Garcia**: *Navigation-Induced Flow Forces and Sediment Erosion in the Upper Mississippi River Basin*

Professor Garcia presented a model for computing sediment entrainment in unsteady flows, which are similar to those induced by inland navigation traffic. The model was obtained on the basis of a series of flume tests that examined the differences in shear stresses observed between steady and unsteady flows. Temporal and spatial distributions of bed shear stress beneath a 1:25 scale inland barge-tow model were measured for a variety of flow and maneuvering conditions. A large number of data were also gathered for a set of flow and maneuvering conditions (PDF test) so that statistical properties of the bed shear stress below the propeller axis could be observed. It was concluded that although the presented stochastic model does not offer a large improvement over existing deterministic models, fluctuations in bed shear stress play an important role in the suspension of sediment. Furthermore, the timing of sediment entrainment in unsteady flows is more closely related to shear stress fluctuations than it is to the ensemble average stresses.

**Zhanbin Li**: *Modeling on the Inter-rill Erosion Processes on Field Plot in the Loess Plateau of China*

Professor Li presented a method to calculate the kinetic energy of rainfall, which was developed on a theoretical model derived for evaluating the kinetic energy of a single raindrop. Both methods are presented, and the overall conclusions are:

- The peak rate of inter-rill erosions related to rainfall intensity, rainfall kinetic energy, and slope.
- The average rate of inter-rill erosion during individual time period for variable rainfall intensity varies with the rainfall intensity and rainfall duration or runoff production area.

**Gary Li**: *Initiation of sediment motion in laminar overland flow*

Professor Li investigated the initiation of sediment motion in laminar overland flow. He examined closely the effect of the following three factors: surface roughness, raindrop impact, and fluid viscosity. Analyzing sediment data from a 2 degree slope, he found the critical dimensionless shear stress in laminar overland flow is much smaller when surface roughness and rainfall are present than when they are not. Disturbances generated by surface roughness or rainfall entrain otherwise immobile sediment. Thus the threshold of sediment motion in laminar flow on a rough surface in the presence of rainfall is similar to that in turbulent flow. He also discussed the finding that critical flow power in laminar flow on rough surfaces is positively correlated to fluid viscosity and negatively correlated to rainfall intensity and surface roughness.

**Jinfa Lu**: *Effect of River Basin Scale on Sediment Yield in the Middle Yellow River Basin*

Professor Lu organized the bioclimatic and morphologic features of the Middle Yellow River according to downstream variation of specific sediment yield. Through this process, he found that the bio-climatic and morphological features are important control factors on the relationship between sediment yield and drainage basin area.

**Zhongli Zhu**: *Rivers' Features on Alluvial Fans in Northwest China*

Professor Zhu analyzed and correlated morphologic characteristics from more than 10 rivers in northwestern China and found that the straight channel is the main river pattern of this region. Braided rivers only develop on the middle segment of the rivers.

**Rollin Hotchkiss**: *Reservoir Sedimentation: Research Needs and Re-focusing Perspectives*

Professor Hotchkiss delivered his research findings and view on reservoir sedimentation and reservoir management. The shortcomings of traditional cost-benefit analyses were illustrated. Traditionally short design life is assigned to dams and reservoirs. A short design life is incompatible with sustainability. Sustainability is not only desirable but also necessary when dealing with non-renewable resources. He described recent advances in cost-benefit analyses for long-term sustainability development. He also gave a very detailed list of suggested areas for future research.

**Discussions and Comments**

**Karim to Hotchkiss**: What methods are available for predicting sedimentation in reservoirs?

**Reply**: At the present time, we do a rather poor job in predicting sediment inflows to reservoirs. For example, in India 21 out of 24 reservoirs have been under designed for sediment; some by an order of magnitude. What we need to do is to look into the assumptions in our soil yield equations that we use. If the present watershed is well forested, we must assume that the forest at least at some place will disappear, and then increase the sediment yields based on uncertainty in the watershed land uses. It is not a failure of the equations; it's a failure in our ability to change input values on uncertainty.

**Karim to Hotchkiss:** In reservoir sedimentation, it is important to predict total volume of deposited sediments as well as distribution of deposited sediments at different locations. I would like you to comment on the available computer-based sediment deposition models. What is the status of their development?

**Reply**: We can predict the distribution of sediment within the reservoir rather accurately. Tools like hydrodynamic models are available. But the issues are simpler than that. Basically there are coarse sediment loads and fine sediment loads. The coarse loads will settle and form deltas in the stream, and the fine loads will be carried by turbidity currents to the dam. So there are two conditions in a simplified manner; the sediment will be in either one place or the other. With models, we can predict the sedimentation more accurately. But so far we have used neither in building a dam. That is where the problem is.

**Comment by Fan**: There are a number of reasons for some of the confusion regarding sedimentation problems in many of the non-Federal reservoirs in the U.S. (1) We do not understand the reservoir sedimentation problems that involve a great deal of uncertainties; (2) the models available are heavily data-dependent; and (3) most importantly, we lack adequate data to calibrate, verify, and implement the models.

**Zhaoyin Wang to Gary Li**: Shallow or film flows over slope are usually unstable and often develop into a series of roll waves. Such a phenomenon is affected mainly by the Froude number. Did you observe such roll waves in the experiments? How did the roll waves affect the initiation of sediment, and how do you take the wave disturbances into account in your model?

**Comment by Garcia (in response to Zhaoyin Wang's question)**: The timeline concept is very interesting. What is most interesting is that the timeline works opposite to what we thought. In sediment transport, usually coarse material has more energy than fine material. In sediment suspension, we find finer materials easily sheltered in the viscous sub-layer. That makes it more difficult for turbulence to pick them up. We know there is much research on turbulence picking up individual particles, but not much on mass particles. Your experiment is eye-opening, particularly for naturally occurring flows because you are accounting for those, but we do very little. I also have a comment on Gary Li's explanation regarding viscous effects. With viscosity you assumed laminar flow in the viscous sub-layer, but I don't think it is laminar in there. It is a flow with viscous effects. We still have turbulence there. Your experimental flume showed a lot of scouring; that is why you have calculated a higher shear stress value. But there is a lot of drag from the obstacles in the flume. They cause skin friction as well as form drag thus increasing your calculated shear stresses. Those are not viscous effects.

**Reply by Gary Li**: In the study we used the Reynolds' number to define laminar flow. We also noticed during the experiments that the flow was really disturbed by raindrops or stones. We cannot say the flow is turbulent because flows between stones are still laminar. To be more precise, the sub-title could be laminar flows disturbed surface stones and raindrops. As for Dr. Wang's question on rolling waves, we did not observe rolling waves forming in very shallow flows. But we did observe rolling waves when the flow is deep, in several centimeters, and in another experiment for simulating gully or rill erosion.

**Comment by Yen:** There are several developments in dam and reservoir design worth noting. The U.S. Army Corps of Engineers are contemplating of looking into dams or reservoirs for a 30-50 year life span – shorter than the old days – on a risk analysis base. They are also contemplating, in view of today's difficulty to get approval and get the project going, the sediment-sluicing plan, which I learned recently that private companies and countries around the world in dam design are starting to consider. This is an excellent thing. In this way we just give the rivers a little more room to operate, less environmental impact.

My first comment to Gary's work is that, if we just work with a single, small sphere in the laminar flow range, we can get solutions. With the simplified conditions in laminar flows, we can get analytical solutions for certain cases, but in most cases it's no problem to get solutions numerically. In your case of a homogeneous small sphere, its incipient motion is a function of the depth to size ratio, and also a function of embedment (buried depth) ratio. If you want to consider more than one sphere, it can still be done numerically as long as the flow is laminar. However, if we look beyond the particles we should understand that:

- Laminar flow resistance factor does not apply with rainfall – when raindrops are present it modifies flow resistance.
- If one uses the momentum approach in his study, the difference in the values of the resistance coefficient under different rain intensities is not much. However, if the energy approach is used the differences will be obvious.
- The Kinematic wave is a momentum equation.
- Gary talked about energy level of raindrops, but in fact it is momentum. Because it is the impact force acting on particles. If Gary could work out raindrop as a momentum input, that would be more appropriate.
- Particle incipient motion is totally probabilistic. Local shear stress is quite different during and after the raindrop falls.

As to the question whether the flow is laminar or not? Under the impact from raindrops, the flow is actually instantaneously and continuously unsteady. Although the flow may be laminar, your critical Reynolds number of 500 or 2000 (with R or 4R) is really not applicable. Instantaneously the flow field is more like a cross flow around an impinging jet. You should look at the raindrop distribution as a probabilistic issue. So you have a continuous probabilistic eddy flow. Professor Hans Einstein learned the probabilistic aspect about the raindrops when he was a child, way before he worked on deterministic solution of hydraulic problems.

**Reply**: Yes, if the flow is laminar without disturbance, equations are available and for some there exist analytical solutions or numerical solutions. We actually have some equations derived. For instance, for laminar flow the friction factor and Froude number can be related together. If you plot friction factor against Froude numbers on the log-log scale, it is a straight line for the very simple case of truly laminar flow.

For the probabilistic issue of sediment initiation, one may ask: Does initiation condition really exist? Some discussions are saying that the initiation condition of sediment movement does not exist because we can't deterministically define that condition at all. It is a probabilistic situation, not a deterministic situation. But my study is simply trying to look at the initiation condition defined in my way to the surface conditions.

In the equation I used the flow power to relate sediment movement to flow power that is actually an energy term. The reason to use flow power, which was defined by Bagnold in 1966, is because flow power is more compatible to two aspects of the sediment movement. In sediment movement both the volume and the speed of moving sediment are important. When we try to model the sediment movement, one should, on one side of the equation, have sediment transport capacity or rate, on the other side of the equation, both force, which is shear stress, and some sort of variable to represent the speed, which is velocity, in the simplistic term. Flow power actually combines both shear stress and flow velocity in just one term. So Bagnold introduced this term years ago. In my study, I simply adopted his term. We think initiation of sediment motion is a special case of sediment movement where sediment transport was equal to zero. So in that way, we justify the use of flow power instead of shear stress or other force terms.

## Session 8. Human Activities Induced Sediment Problem
## Nani Bhowmik and X. Shao

**Keynote lecture by Grace Brush**: *A 300 year History of Land Use and Sedimentation in the Chesapeake Bay Watershed and Estuary*

Dr. Brush's talk concentrated on the depositional characteristics of pollen grains and the use of pollen grains as indicators of the time frames within which sediments are deposited. The Chesapeake Bay in the USA was used as an illustration of the effects of increased sedimentation due to deforestation and agriculture on the ecology of an estuary.

**Lianyuan You**: *Effect of Coal Mining on River Sedimentation – A Case Study from the Shenfu-Dongsheng Coal Field in the Loess Plateau, North China*

Professor You discussed the sedimentation patterns and magnitudes of sediment deposition in rivers due to coal mining activities in the Shenfu-Dongsheng coalfield.

**Huapeng Qin**: *A Case Study of Sediment Impact on the Ecosystem*

The impacts of sediment deposition to the ecosystem on the Shenzheu Bay in Shenzheu Economic Special Zone were presented by Dr. Huapeng et al.

**Shaohua Marko Hsu**: *Phenomena and Controlling Factors in Drawdown Flushing Processes*

The last paper in the session was by Dr. Hsu. It was discussed that a volume erosion factor could be quite useful to define the percent of erosion from the deposited sediments due to flushing activities.

**Discussions and Comments**

There were several questions from the participants to the presenters. Questions and answers are as follows:

Several participants asked questions of Professor Hsu on the sediment flushing research. Questions related to the downstream impacts of flushed sediments, fate of the flushed sediments, scales used for the experimental work, and whether or not the stream/river can carry the flushed silt were asked. Prof. Hsu answered as follows: slope needs to be increased to assist the flushing, flushed sediment will be washed away to the downstream channel, and the river should be able to transport the sediment and sediment should not block the channel. There were also some discussions on an experimental set up in Taiwan where naturally available sands were used in the laboratory experiment.

A question was also asked of Professor You related to the conceptual difference in opinion between the Yellow River commission and the Coal Mine Authority on the impacts of human activity on the potential increase in erosion and its relationship to coal mining activities. Professor You responded that even though he and others are fully aware of these different opinions, they do not have sufficient information to settle these differences.

It was a lively discussion, and probably more questions would have been directed to the speakers if more time were available.

**Wohl to ShaoHua Hsu**: One of the issues we faced in the U.S. is, because of the reservoirs there is not enough sediment downstream and hence generally there are channel incision and bank erosion. On the other hand, sediment is released in a large volume so we have pool volume losses or fish habitat losses. With the scheme you have shown, could you mimic actual sediment flow in natural rivers by timing the flushing of sediment? Is the timing important?
**Reply**: I believe there is a possibility to do that. But there is a balance between how much and when we can do the sediment flushing. Your point is correct, the timing is very important.

**Gary Li to ShaoHua Hsu**: Two questions to Dr. Hsu. The first one is: Do you consider sediment flushing an impact to downstream? The second one is: What is the sediment size distribution in the experiment?
**Reply**: To your first question, since the sediment is coming from the upstream, I don't consider it constitutes any impacts to downstream. In our experiment, the sediment did not clog the downstream channel either. Of course, if the sediment is polluted, it is another issue. To your second question, I used uniform-sized sediment in my experiment. In the real world, it is not the case. But what I showed is only for sediment basins, not reservoirs. The water will bypass, then go to the reservoirs. The channelized section is only used in sediment basins.

**Gary Li to Brush**: Do you have data for the Chesapeake Bay for the last 30 years in terms of fishery productivity and sediment load?
**Reply**: We have sedimentation rates and have the fishery harvest records, which is not really the fishery population. So we know what the fishery production is in tons. There is over fishing occurring too. In the 1970's, fishery harvest began declining and has not recovered.

**Hall to Brush:** What is the specific gravity of pollen grains? Do pollen grains exhibit hydrophobic characteristics?
**Reply**: Most pollen grains are more or less buoyant, but upon entering an aquatic system, they are quickly immersed into the water column and then settle into the bottom of the system.

**Hall to Brush**: I have another question regarding the applicability of your techniques to other areas. In the western U.S., most large storms over large basin areas (thunderstorm events excluded) occur in winter months. Is the runoff season not in phase with the pollen generation season?
**Reply**: My argument is that the pollen is not coming in with runoff; it comes in atmospherically. Some of the pollen may come in with runoff but the majority of the pollen is coming in atmospherically.

**Demissie to Brush:** One of the problems we face in using sediment cores to determine sedimentation rate is the variability among different locations. Another problem when using sediment dating is the disturbances in the sediment layers resulting in mixed sediment samples. How did you distinguish between disturbed sediment cores in the analyses?

**Reply**: Those are the real problems anywhere. For your first question, the technique we have worked out is to take multiple cores at a location. I could not take one sediment core and expect to have the representative sedimentation rate. The second question with respect to sediment disturbance is also important. What I generally do is estimate the probability of getting intact sediment core or continuous cores at a location. In a fresh water location we have to take up to six sediment cores to get one that is intact; in more saline areas we take 10 or more cores to get one that is intact because there is so much biological activity from burrowing warms, etc. So we do have to take multiple cores from one location.

**Demissie to Brush**: Have you seen reduction in sedimentation rate in the recent years due to conservation practices in the watershed?

**Reply**: We have observed reductions related to conservation. But we also find it difficult to separate conservation practices from farmers' abandonment since 1930s. But there is certainly a reduction. In some places the reduction is down to where it was in the pre-European time.

**Zhaoyin Wang to Brush**: The most disastrous red tide occurred last year along the coast of the China seas, especially in Hong Kong and the Bohai Bay. People believed that the red tide is caused by increasing human activities and releasing too much pollutant and nutrient into the sea. Two species of algae, like diatom, produce sticky liquid and so kill other animals, and therefore caused great loss of fish. Do you know how to identify these species and how to mitigate red tide impact?

**Reply**: Diatoms are identifiable to species because of their silica shell. They are very useful indicators of many water quality properties.

**Jinchi Huang to ShaoHua Hsu**: I have done some experiments on sediment flushing from reservoirs. From our experiments, we found the effect of flushing is directly related to the flushing time. This is because in the reservoir flushing processes, with the water level lowering, intensity of the flow will decrease, and the slope will also be changed. Can you comment on this process?

**Reply**: Yes, in the flushing process, you get more flushing in the beginning and then you get less and less. So if you have longer flushing time, then you get less efficiency, and waste a lot of water. In our sediment basin design, we will have to have a base slope, which will make it easier to flush anything away faster. If you have a flat bed, then you will have several tons of deposition, which will take more time to flush away. So you can't have control on the geometry. Then you need take more time, like in the navigation channel in the Three-Gorges Project. But if you have a choice, you better have some base slope that will save you a lot of time.

**Youshu Chao to ShaoHua Hsu**: My question is on your scale model. First, what kind of material do you use in the laboratory simulation, natural sediment or processed materials? Next I would like to know how do you consider the similarity between the scour and the deposition? I mean the deposition scale and scour scale in the same model. It is difficult in getting the same number.

**Reply**: The experiments were done at the Hydraulic Laboratory in the Water Bureau. I think they used the real sediment from that area. The next question is an important one. I think the scale or the phenomenon for deposition is very different from erosion. So for the deposition, maybe the model scale you need to consider is flow velocity, etc., for erosion may be concentrated on the incipient motion. That is a different thing. So if you want to use the model, you should consider what you want to simulate. For this presentation, I only deal with erosion.

## Session 9: Reservoir Sedimentation and Irrigation
### Ellen Whol and Yeou-Koung Tung

**Keynote lecture by Shou-Shan Fan**: *Sediment Management in Hydropower Reservoirs*

Professor Fan gave a comprehensive view on major sedimentation issues at some hydropower reservoirs and the manner in which problems were cost-effectively mitigated and managed. In the U.S., most of the non-Federal hydropower (NFHP) reservoirs licensed by the Federal Energy Regulatory Commission (FERC) was constructed only within the past 100 years. However, many of them have already become unusable due to sedimentation or lack of maintenance. This paper is prepared on the basis of Dr. Fan's many years of experience with the NFHP at FERC. Advances in appropriate design or management practices can mitigate many, if not all, of the adverse impacts of sedimentation.

**Jinchi Huang**: *A Study on the Warping near Irrigation Headwork of the Lower Reach of the Yellow River*

Professor Huang, an expert in water quality, views the sediment in the Yellow River as a valuable natural resource for the extensive area along both sides of the Lower Yellow River. Through proper retention and settlement design, a large amount of sediment-laden flow can be diverted out for warping. In his presentation, warping for ameliorating saline-alkalinized soils is discussed, a general description on the warping for soil improvement has been provided, and a practical design example on silt filling at headwork of an irrigation project is examined.

**Summary of Discussions by Session Chairs**

Dr. Fan pointed out that, in general, we lack the means to calibrate/verify numerical models and physical models; so one-dimensional models may be more appropriate for use by regulatory agencies.

Dr. Wang Zhaoyin talked about the practice of removing reservoir sediment in China. In particular, there are some downstream advantages due to flushing, such as the fine materials could seal the leakage in canals.

Dr. Fan, however, pointed out the potential ill effect of fine materials in reservoir sediments on fish habitat or ecological systems.

Dr. Mohamed Ghidaoui addressed the general issues of sediment modeling and pointed out that the model and data should be compatible with respect to their quality and accuracy.

Dr. Fan followed the comments stating that, at the present stage, the quality of available sediment data from the field may not be compatible with the level of sophistication of many sedimentation models. He believed that a simpler model would be more suitable for the type of investigations done by regulatory agencies.

Along the sediment data, Dr. Rollin Hotchkiss raised the issue on the difficulties in data acquisition and distribution. Namely, the data are not free of charge and sometimes very expensive. On top of that, there is a wrong perception in general that there is sufficient amount of data available. Hence, requests for funds to collect data are very difficult.

Dr. Grace Brush pointed out that the U.S. NSF has a long-term collection of ecological data, which is centrally archived and should be available to the public. Mr. Brad Hall made the comment that the selection of a proper model should be made in the context of nature of the problem, experience of the modeler, and data availability.

## Discussions and Comments

**Ghidaoui to Fan**: From your experience as both a practicing engineer and a researcher, what is the time lag between research and practice in sediment transport, and how can this time lag be reduced?

**Reply**: This is a very good question, and unfortunately there is no answer. Our big problems are that we don't have good ways to select models, and we don't have good data to calibrate, to verify, and to implement the model that we select. In the sediment field, one of the biggest problems is the lack of adequate data. The problems associated with data are two-fold. One is we don't have the data that we need. Another is we don't have accurate ways to measure some data (roughness, etc). Also, we do not have guidelines to select models. My suggestion is that at research agencies, we can promote very sophisticated models, from 1-D to 3-D models. But for regulatory agencies, I think the simpler, the better. This is because a simpler model would be less confusing, and the regulatory agency would have an easier time of determining which one is better.

**Comment by Bhowmik:** With respect to Dr. Fan's comment, I believe that he made an extremely important point on data -- the availability or non-availability of standard sediment transport data. This is one area the U.S. is extremely lacking right now. Without actual data, how can one justify if the model is working correctly? So I think for any future activities, I would like to put an emphasis on real data collection. Somewhere, somehow, the monitoring program should benefit from it.

**Comment by Fan**: Thank you for the comment. Several years ago, I did talk with UNESCO regarding the possibility of developing a common international sedimentation database. In the U.S., most data used by the universities are often not readily available to regulatory agencies. As previously discussed, results will be significantly different when different data are used.

**Comment by Zhaoyin Wang**: For controlling sedimentation in reservoirs there are about five strategies in China. These approaches are to:

- *Store clear water and release turbidity.* This method is used for major, large reservoirs including the Three Gorges Project.

- *Draw down the reservoir during flood periods*. This method allows flow to carry sediment downstream and has been used in Shanxi and Shanxxi Provinces, especially in small reservoirs only.
- *Dredge the reservoir*. Mechanical dredging is feasible but is rarely used in China because of cost. At approximate 20 yuan per cubic meter, the cost is too high for most of the reservoir. Thanks to economic development, dredging becomes more and more feasible in China
- *Release hyper-concentrated current*. This method has been applied at many reservoirs along the Yellow River. Sediment-laden flow carries mainly fine sediment, so it is not directly deposited on the bottom of reservoirs. A turbidity sub-reservoir forms with high sediment concentration but maintains fluidity. One opens the bottom outlets and the high sediment concentration is released from the reservoir.
- *Use pipes*. Sweden is using flow flushing pipes on the bed of reservoirs. The pipe has many small holes on its wall so clear water and fine sediment can flow through. The pipe flow can have higher carrying capacity. That'll be a new challenge, but not used in China.

**Comment by Fan**: In the U.S. we've not really carried out flushing, but there was a flushing project in California some years ago. The project was to carry out flushing for different purpose. It used flushing to discharge fine material such as silt for stopping seepage in irrigation canals. On the other hand, people are against flushing because of environmental concerns. On the streambed, voids allow fish to lay eggs and pray. The fine sediment deposits would often plug the holes and kill the fish. Therefore, most concerns on reservoir flushing are actually the fine material carried by the flow. They are less worried about coarser deposits.

**Ghidaoui to Fan**: Most of the discussion on data has been focusing on the needs for data. Sometimes one needs to be careful about not taking lots of data but simple models. Because, I think, then one is running into the case of doing a lot of data fitting. A simple model tends to neglect lots of physics but detailed data contain a lot of physics. Then we are either lucky or unlucky to have lots of parameters in the model. You can always calibrate them by using the data. Of course, sometimes we run into the situation that we have only a couple of points, but too optimistic to go to complex models. In fact, we can make up many different parameters by using limited data. My point is that the complexity of the model needs to go hand in hand with the quality of the data. But sometimes we also forget we collect data to understand the processes. We should be careful doing extrapolation with the data. We don't believe them quantitatively, but we should look at them qualitatively.

**Reply**: I am not really promoting simple models. Let me explain why I said that. Often a scientific approach is to decompose a complex system into a number of linear systems. Why linear? Because one can superimpose its component linear solutions one over the other. If you have several systems that are not linear, then you cannot superimpose them together. After you integrate the sub-systems by some approach you need to verify the approach. For scientific research, complex models are often better. But at regulatory agencies, we don't know how to select model or how to compare the results derived from different models if the models are too sophisticated.

**Comment by Hotchkiss:** I wish I had better news about data collection. We have three problems, maybe four problems that reduce our incoming data. The first is high cost of data. In the United States, budget reduction for data collection agencies renders less and less data collected each year. Secondly in developing countries data is now for sale. It is not free, just like here in China. And that makes distribution of data difficult. The third problem is increased concerns about different processes in the environment (for example, air pollution, acid rain, and distribution of aerosols) divert money to measure those quantities from measuring basic water quantity. The fourth problem is the false faith about the computer models, that now we no longer need data and that our computers are able to simulate everything. So perhaps anything we can do is emphasizing to our students, undergraduate students and graduate students. Our real needs for the real world are data. Because we keep them running the computer models, and ultimately believe what the models say without ever seeing the data. On a large scale, I am not sure what we can do because I don't know one research agency that will pay money to collect data.

**Comment by Brush**: I don't know how applicable this is to engineering problems, but the National Science Foundation Mountain Ecological Research Center did collect data over a long-term period. That data has been put into a database and is available to everybody, and data has been put in the database after a year of collection.

**Comment by Hall**: With respect to the question on models and what is the best model, the big question is what are the physical processes you are trying to address, and not for what "model" should be used. I think that possibly the worst question to ask is what is the best "model" to use or apply. The correct question to be asked is what is the process you are trying to simulate? Then one can properly say which code adequately simulates the processes under consideration. I think another aspect we are neglecting is not just the "model" but is the "modeler" too. Speaking for myself and my personal experience, I am very confident in application of HEC6. However, I lack experience in the use of other models, such as FLUVIAL12, and I would have less confidence in the correctness of my results. So again it is not just the model, it is the modeler too.

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# Selected Photographs


Discussion between audience and speaker, Professor B.C. Yen


Presentation by Dr. N.G. Bhowmik

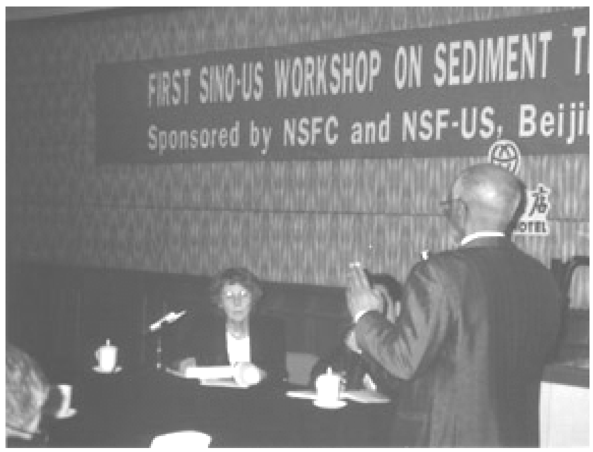
Discussion by Professor Panos Diplas

Discussion by Professor P. Diplas


Discussion between Professor Dr. Zhaoyin Wang
and Professor Ellen Wohl

Discussion between Dr. F. Karim (left) and Dr. S.Y. Cao

Presentation by Professor B. C. Yen



Discussion between Professor B. Brush (seated)
and Dr. M. Demissie


Discussion by Professor M. Garcia


Discussion by B. Hall and Dr. G.X. Wang


Workshop audience

Gully erosion in the Loess Plateau

Agricultural development on the Loess Plateau

A local village on the Loess Plateau

Terraced fields on the Loess Plateau

Gully erosion on the Loess Plateau

Ultimate head-cut formed by gully erosion
on the Loess Plateau

Terraced fields and farms in the gully

Hukou Waterfalls

A group photo at Hukou Waterfalls

Hukou Waterfalls

Another group photo at Hukou Waterfalls

Sanmenxia Reservoir looking from downstream

A group photo at Sanmenxia Reservoir

Construction at Xialongdi Reservoir

The field group visited the model demonstration

A group photo at the Xialongdi Reservoir Dam site

Dr. M. Garcia and Dr. R. Hotchkiss

A view of the Great Wall