The Erosion vs. Sedimentation Cirle - Or "The Chicken and the Egg!"

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#1 Title slide: Having the assignment of making the opening presentation at a conference with the central theme of erosion and sedimentation offers a significant opportunity and a somewhat intimidating challenge. The opportunity is one of introducing a very well-planned program with some excellent speakers, educational topics, and cutting-edge research updates. During the next couple days you'll have an opportunity to listen to and learn from presentations addressing erosion and sedimentation on irrigated land and upland; in-channel sources; measurement and associated impacts of erosion and sediment; sediment in relation to Montana's water quality standards; erosion and sediment modeling; and case studies from sediment monitoring and remediation projects in Wyoming and Montana.

#2 Outline slide: What I hope to accomplish at the start of this conference is to first introduce the topics of erosion and sedimentation, including some definitions, descriptions and examples. I hope to provide some insights into the processes of erosion and sedimentation; then provide some examples of the sources and sinks role that these two processes play in concert. Next, present a few pictures of the implications. I'm sure you'll hear much more from other speakers about methods of quantification of both erosion and sedimentation, but I thought I'd introduce the subject. And finally, I'd like to talk for just a few minutes about BMP and BEPs - how we deal with sedimentation and erosion.

#3 First the earth's surface is lifted: An introduction to the processes of erosion and sedimentation on the landscape necessitates posing the obvious question: 'how are these two processes related?' Additionally, 'which process leads and which follows?' There is a sequence of events - as this picture illustrates - first there is movement - the earth's surface or materials of **the earth's surface are lifted up.**

#4 Then gravity goes to work. Study of erosion quickly reveals a corresponding sedimentation process - and most likely - with the exception of lake or ocean bottoms - sedimentation eventually leads to further erosion. In fact, the erosion and sedimentation processes are a conflict of naturally occurring forces and geologic events: forces of gravity, physical and chemical weathering, fluid transport and mechanics; geologic uplift countered by peneplane development.

#5 California storm runoff: Erosion and sedimentation are two naturally and simultaneously occurring geologic processes, generally harmoniously progressing across the landscape. Together these two competing circumstances are responsible for the landscape around us, the productivity and capacity of our agricultural and wild lands, and the changing scenery in front of us.

#6 Tsunami: Erosion and sedimentation and the associated processes are both naturally occurring and anthropogenically accelerated; they are occurring at geologic and epoch time-scale, example - Mississippi river delta formation, and eventual silting in of Fort Peck. Correspondingly, these processes are occurring as nearly every day cataclysmic events, example - the recent LaConcilla mud slides of California and the Indonesian tsunami.

#7 Definitions: Simply put, erosion is the removal of soil, sediment, regolith, and rock fragments from the landscape - either by wind or water - or gravity. In contrast, or as a follow-up to erosion is sedimentation - the deposition of transported material in a new location.

#8 Relationships: Cause and Effect: Intuitively, erosion and sedimentation go hand in hand: erosion leading to sedimentation; sedimentation being a 'sink' and also serving as the 'source' material for subsequent erosion. When forces of sedimentation exceed forces of erosion, the latter process ceases to occur. When forces of erosion exceed forces of sedimentation, erosion continues with inevitable sedimentation.

#9 Types of Water Erosion: The science of erosion and sedimentation is sufficiently advanced that water-induced erosion is 'typed' as rain splash, sheetwash, rilling,

#10 gulleying, piping, bank scour and slough, and bottom scour.

#11 Wind erosion, in contrast, is 'typed' as traction, creep, saltation, and suspension. As this slide illustrates, each of these type of erosion have been defined, and the events occur under specific sets of conditions.

#12 The energy relationships of erosion and sedimentation are intimately connected: Erosion, the rate and magnitude, and the concurrent transport of suspended material is velocity dependent. With time, reduced velocity, and dissipation of energy, the larger particles begin to settle out - resulting in stratified sedimentation. This time sequence of sedimentation helps illustrate this process - here in a quart jar, but it also occurs in much the same pattern in nature.

#13 One question needing attention is: Where does sedimentation occur? Sedimentation occurs on the landscape around us - sometimes very obvious, as in the case of floodplains, point bars, and lower gradient areas in streams and waterways. In some cases the occurrence is less obvious, as in the case of flatwater - reservoirs, ponds and impoundments, lakes, oceans.

#14 Erosion and sedimentation are actually sources and sinks - in some state of balance - sometimes stable, sometimes very much in flux. As suggested here - an aerial view of Hanging Woman Creek, an ephemeral stream on the Montana-Wyoming border, erosion removes sediment from sources and sedimentation correspondingly unloads sediment at sinks - eventually to become sources again.

#15 Additional details of the erosion and sedimentation processes consist of identification of sources (erosion) and sinks (sedimentation) and the balance of forces on the landscape. Let's for a moment take a look at some of the sources of sediment, or the contributing factors to erosion: In many lowland areas these include ag lands, highway and urban construction sites, and livestock management areas

#16 Additional sources consist of upland areas, which generally include range and forest land - impacted by livestock management, timber harvest, fires, recreation, roads, travel

#17 Even waterways, streams, rivers, and in-channel sources participate in the erosion event, contributing to sedimentation down gradient. Some of these are naturally contributing, some are the result of large magnitude storm and runoff events, and some are the consequence of externalities - events outside the domain or area but which affect what happens inside the source area - irrigation return flows, dam overflow, and numerous other events.

#18 As can be seen in this scenery, the erosion and sedimentation process is a cut - and - fill process - constantly repeating itself on the landscape. Ultimately with erosion winning the battle and sedimentation coming in on the bottom. If one looks closely across the landscape, it is possible to see the cut-and-fill process repeat itself. Here are illustrated at least 7 sequential events, with the eventual outcome being what is known as **peneplane development - flat surfaces**.

#19 Sinks - Just as the sources occur all around us, the sinks are the events and land forms that are a consequence of erosion and sedimentation. Some examples of sinks include lakes and reservoirs, deltas and beaches. And, as can be seen in this sedimentation tray photo on the right, the large scale, land form events of the Mississippi Delta seen from outer space can be easily reproduced and demonstrated at much smaller scales.

#20 Other sinks include those same areas we viewed previously as sources: point bars, low gradient areas, confluence areas. One that many of us may be familiar with is the lower left - a picture of Muddy Creek discharging into the Sun River near Great Falls, Montana.

#21 And, we should not overlook, floodplains and irrigated land

#22 - As fascinating as erosion and sedimentation appear from the science perspective, there are significant environmental, social, economic, and ecological consequences of these processes - whether in balance or disproportionately dominated by one process or the other. **We like to call it The Good, the Bad, the Ugly!** Erosion can and does cause loss of significant life, economic livelihood, resource product capacity, and functionality.

#23 Examples include: the **LaConcilla mud slides we all recently heard about in the news**

#24 And the sometimes entertaining consequences, such as this, again from the **LaConcilla mud slides**

#25 Another example, closer to home, is the aftermath of the Missouri River floods

#26 and mining sediment of Milltown dam. And not only is sediment an issue but what is contained in that sediment can be even more significant, as the information on this slide illustrates.

#27 Other examples include loss of Palouse landscape and productive agricultural land

#28 It has been estimated that more than 100 million acres of U.S. agricultural land is excessively eroded - nearly 10 times the cultivated acreage of Montana; the result is estimated to be equivalent to 1.3 billion tons of eroded material annually - to become sediment in another location.

#29 Sedimentation: The Bad: Let's for a moment take a look at the sedimentation component of this cycle - and the 'bad' aspect of sedimentation. For one thing, sedimentation results in loss of reservoir capacity and results in siltation of irrigation ditches and waterways. This watershed in northwest Iowa illustrates well the consequence of erosion and subsequent sedimentation.

#30 Sedimentation: The Bad: Here's a simple example to illustrate how quickly or insidiously it happens. In our example here, with 12 months of inflow to this reservoir, 3 of which are high flow by high sediment and 9 months of which are low flow and low sediment and a corresponding steady outflow - accounting for some degree of sedimentation: we calculated a sediment deposition load of 61,500 tons per year, resulting in a loss of 90 acre feet of storage per year.

#31 Another implication or consequence of sedimentation is externatilies - things beyond the immediate: fisheries habitat loss and population decline. As illustrated here, sedimentation and scour of spawning gravel have been shown to cause as much as 90% mortality of salmonid egg pockets. One needs to take only a cursory look at the 303(d) list of impaired streams across the U.S. and discover that siltation and sedimentation are two of the most frequently cited sources of water quality impairment. In fact, the two most frequently treated for water quality impairments are sediment and bacteria, which often go hand-in-hand.

#32. But, let's not give out just black eyes and red check marks for these two geologic processes - erosion and sedimentation. There is some Good in the picture. Erosion, combined with other geologic events such as uplift, faulting, flooding of a geologic scale, mass uplift, broad-scale sedimentation presents opportunities for scenic beauty and exploration - examples (the Grand Tetons, the Grand Canyon, Glacier National Park, to name a few.)

#33 In fact, sedimentation actually can enhance economic development, improved agricultural utilization, and efficient water dispersals for irrigation.

#34 and we are all aware that floodplains help dissipate flood events and are highly productive agricultural lands - only to be over-run by urban development - partly because it's easy to dig foundations there.

#35 - Let us not forget there are some other benefits and opportunities which arise as a result of the erosion and sedimentation processes - deltas, sandbars, beaches - for recreation and wildlife. And the erosion and sedimentation processes provide a map or blueprint of sorts of natural history.

#36 Model Slide - Methods of Erosion Quantification: The science of erosion and sedimentation is also now sufficiently advanced that complex models, such as RUSLE2, WEPP, GIS x DEM, and WEPS help us better understand the erosion process. These models help us to define the integral components of the processes, help us to organize our thoughts and understanding, help us identify data sources and gaps, help us understand functional relationships, provide tools to complete sensitivity analyses and assessments, and predict the consequences of changes in causal factors and land management practices.

They serve as valuable tools to - at least conceptually and theoretically - assess benefits of implementation of conservation practices.

#37 In addition to predictive models, research tools have been perfected to help enhance our ability to measure, quantify, and understand of the erosion and sedimentation processes. Tools and techniques such as plot isolation and runoff sampling, rainfall simulators, sedimentation tables and channels, sedimentation sampling, real-time sediment transport measurements, all help us make sense of the processes on the landscape.

#38 RUSLE2 Factors: The physically based erosion models that have been developed, assuming they have reasonably reliable predictive capacity, provide some very good insights into the key components in the erosion process. For example, inspection of the RUSLE2 (Revised Universal Soil Loss Equation) reveals that prediction of erosion amounts is based on such inputs as runoff and rainfall ratios, some measure of soil erodibility, the slope length and steepness, cover characteristics - representing management - and other supporting practices, which are generally engineering in nature. These factors provide us clues to what affects erosion - and what we can do about it. One needs to simply turn these factors around to get an appreciation for sedimentation.

#39 The same exercise can be completed with the WEPP erosion prediction model, which relates to stream and watershed erosion events.

#40 The wind erosion prediction system attempts to estimate potential average annual soil loss due to wind erosion, using input factors such as soil erodibility, roughness, climatic conditions, field size, and cover. Looking at each of these three previous predictive tools, it should become evident that there are some commonalities to the field scale water erosion events, in-channel erosion events, and wind erosion events. Soil, cover, management, climate.

#41 Sedimentation Quantified: Just as erosion is modeled and reasonably predictable, such is the case for sedimentation. And, just as the erosion model inputs provide us clues to the causal factors, the same is true for models such as WEPP: the Water Erosion Prediction Project, which looks at watershed impoundment components such as particle size, impoundment size, inflow rate and outflow rate.

#42 - Sedimentation Quantification: Sometimes we find it necessary to get out of the office and into the field - either to gather input data for model execution or to gather data to help define the algorithms of the models. One approach is sediment core sampling, which helps provide a history of sedimentation events and provides clues or revelations about sources of sediment.

#43 - Alan and Kim on Muddy Creek: And, as is my case, one is not certain whether the role being played is instructor or student. Here Alan Rollo, Sun River Watershed Coordinator, and Kim Hershberger, MSU Water Quality Associate, collect flow and sediment data at a sampling location on Muddy Creek, a tributary to the Sun River near Great Falls.

#44- Data collection and modeling don't go without their faults or challenges. Sometimes the data don't fall on straight lines - or even in well defined relationships, as is the case in 2002 on one of our Muddy Creek projects. In fact, contrary to our expectations, sediment concentration in Muddy Creek in 2002 actually decreased with increasing flow - quite contrary to our expectations. In contrast, in 2003 we discovered a multitude of relatively commonly occurring relationships between sediment and flow - and much more like we expected. The difference - increased flow in 2002 was due to rainfall events in non-erosive areas and relatively gradual increases in flow while increased flow in 2003 resulted from significant operational spills from an upstream irrigation project. Sometimes the anthropogenic activities that contribute to either sedimentation or erosion are outside the domain of our data collection - and understanding the erosion and sedimentation processes.

#45 Once in a while it's good to take advantage of tools and opportunities that help us put reality into perspective. Just as a little knowledge can help in the long run, a little sediment can go a long ways. As this example illustrates - it might not look too dirty, but the 1,000 milligrams per liter on the left, only 1 gram per liter, is equivalent to 2,600 pounds of sediment per acre foot. 100 milligrams per liter, almost indiscernible, is 260 pounds per acre foot of water.

#46 So, what can we or what should we do about this erosion and sedimentation issue - aside from attending this conference? Understanding of the erosion and sedimentation processes has provided the knowledge, resources, and tools to effectively manage to minimize the adverse impacts and consequences on the landscape. Management requires combining **Best Management Practices (BMPs)** with **Best Engineering Practices (BEPs)**. The latter help correct the consequences, while the former (BMPs) serve to prevent or minimize erosion. Managing causes or treating symptoms.

#47 Today's BEPs consist of such avenues as armoring stream crossings, fencing livestock areas and facilitating off-stream watering, and such practices as relocating AFOs away from stream corridors and water resources.

#48 Construction of armored stream banks, revegetation, installation of stream barbs and rip-rapping, and grade stabilization. And, each of these practices is effective to some degree in treating the consequences of erosion, i.e., dealing with the symptom, which is sediment in channel or off-site.

#49 In contrast, BMPs attempt to treat the cause rather than the symptom. Frequently used BMPs include mulching, reseeding burned or disturbed areas, use of wattles and other stabilization techniques,

#50 Conservation tillage practices, precision irrigation, and land use conversion have all proven effective erosion prevention BMPs.

#51 Erosion BMPs have even been designed for irrigated areas. For example, conversion from furrow to sprinkler irrigation as part of an EQIP contract might result in significant reductions in erosion.

#52 Another practice that has proven effective is adoption of use of vegetative filter strips. As this example illustrates, sediment is the most significantly reduced impairment when filter strips are used in connection with erosion situations.

#53 In the final assessment of erosion and sedimentation processes, the intimidating challenge is one of gaining a clear understanding of the balance between these **two naturally occurring processes** of geologic magnitude and the imposition of anthropogenic impacts. The other challenge is one of selecting and **implementing the BEPs and BMPs most appropriate to minimize erosion** and validate the effectiveness of the conservation practices addressed during this conference. Hopefully this conference will help each of us appreciate that erosion and sedimentation are natural processes which are easily set out of balance by lack of appropriate management. At the same time, it is critical that we appreciate that **methods exist to prevent erosion and control sedimentation**. In the long run, the most effective tool to stop excessive sedimentation is to treat the cause and address the erosion source - an ounce of prevention is worth tons of sedimentation prevention.

#54 Conference Topics

Sediment Monitoring and Assessment - some case studies

Sediment Sourcing, Tracking, and In-Stream Management

Watersheds, Stream Channels, and Sediment Dynamics

The Realities of Defining, Dealing With, and Managing Sediment:
Muddy Creek, Missouri River, Thompson Creek

Predictions, Prediction Tools and Modeling the Sediment Processes

And not to forget a very rewarding and diverse Poster Session

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