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# Science

FINDINGS

*“Science affects the way we think together.”*

Lewis Thomas

## CLARIFYING MUDDY WATER: PROBING THE LINKAGES TO MUNICIPAL WATER QUALITY



Debris flows and earthflows contain smectitic clays, which muddied Detroit Reservoir, and became concentrated in the water delivered downstream to Salem.

*“Water, water everywhere,  
nor any drop to drink.”*

—Samuel Taylor Coleridge

In the first issue of *Science Findings*, which tracked the results of the 100-year flood of 1996, Gordon Grant, a research hydrologist with the Pacific Northwest Research Station in Corvallis, Oregon, inimitably stated that the story of flood-plain development was characterized by “decades of boredom punctuated by hours of chaos.” In a clear bid to avoid the decades of boredom, he has returned to those hours of chaos—floods and their aftermath. In this case, he’s interested not so much in what floods do as in what they can teach us to do, during the quiet decades.

“Floods such as those of 1964 and 1996 galvanize and make manifest a set of relationships across the landscape. Until a flood, people kind of know about these relationships but

they don’t necessarily think about them and their implications all at once,” he says. “When the flood comes, those relationships stop murmuring in the background, they come roaring to the forefront, and everything is rapidly and compellingly linked across the landscape.”

Grant is referring to the full spectrum of interactions among the natural production of sediment by the landscape, the role of forest management activities such as timber harvest and road building, the role of reservoirs as huge sediment traps, the water quality goals of municipal water supplies, and the ecosystem effects of raised levels of sediment in the aquatic system.

The basic storyline about sediment loads in streams—the stuff that causes murkiness, or turbidity, during and after floods—is that it’s not so simple as pointing to one culprit as the source. Like everything else that matters, it is far from simple, and it’s about tradeoffs and compromises.

### I N S U M M A R Y

*In the Pacific Northwest, several recent and dramatic “muddy waters” events have created major problems for water utilities. Resulting from floods and measures to retrofit dams to reduce impacts on temperature, these events also have focused public and scientific attention on interactions among dams, forest-land use, and municipal water supplies. Far from being a simple cause and effect, the key agent is tradeoffs.*

*The large Cascade watersheds that provide drinking water for Oregon’s biggest cities (Portland, Salem, Eugene) include actively managed forest lands, large flood-control dams and reservoirs, and urban and agricultural areas. Historically, the impacts of these various land use practices on rivers, aquatic systems, and water supplies have been evaluated individually. But the connections can no longer be ignored.*

*Recent research at the Pacific Northwest (PNW) Research Station has explored these linkages and their implications for river and watershed management. The Salem water supply was closed down during the 1996 flood because of excess turbidity. And when the Cougar Reservoir east of Eugene, Oregon, was drawn down to be retrofitted with a temperature control structure in spring 2002, sediments in the reservoir were remobilized. The unanticipated result was a sustained release of turbid water.*

*Building on the lessons from 1996, PNW researchers investigated the rate of movement of the Cougar Reservoir sediment downstream and whether the sediment that intruded into the river created potentially negative consequences for spawning fish and other aquatic biota.*

## KEY FINDINGS

- X-ray diffraction techniques allow us to “fingerprint” the source of clays that are the primary cause of turbidity in rivers. This technique distinguishes between background erosion sources and human-accelerated sources such as timber harvest or road building.
- Storms can deliver large volumes of clay-rich sediment to streams, but short periods between storms reduce this risk, as the landscape “remembers” when the last large flood was.
- Large flood control reservoirs play a particularly important role in determining downstream turbidity by storing upstream sediment, changing the clay mineralogy fingerprint of water during floods, and sustaining turbidity releases downstream over much longer periods than would naturally occur.
- When reservoirs are drawn down, the long-term history of sedimentation events stored in them can reassert itself in complex ways, affecting turbidity, water quality, and ecosystem impacts downstream.

## SHUTTING OFF THE SPIGOT

**I**t is instructive to return briefly to the story of Salem’s water supply after the February 1996 flood.

Salem’s water supply comes from the North Santiam River, a source of nearly pristine water. After the February storm in 1996, which brought recordbreaking rain and warm temperatures, the river experienced extremely high turbidity along its entire length. Turbidity readings climbed as much as 14 times higher than the maximum treatment capability of Salem’s water treatment intake plant.

Because most of the time the city’s water is of very high quality, Salem uses a slow-sand filtration system that can treat pathogens and

moderate turbidity and has relatively low operating costs. High turbidity, however, may damage the slow-sand filters, Grant explains.

And so the city closed its overwhelmed filtration plant. It was able to reopen after only 8 days, largely because of some extraordinary measures by local industry and residents. But turbidity continued to exceed drinking water standards set by the U.S. Environmental Protection Agency through mid-July, and levels of turbidity remained unusually high for 5 months thereafter.

In total, the economic damages summed their way above \$5 million.

## AFTER THE FLOOD

**I**n the weeks and months following the February floods that year, controversy raged over the causes of the water supply problems. Finger pointing was rampant,” Grant recalls. Possible guilt was assigned to upland forest land management, particularly the Forest Service, and poor crisis decision-making. Later, institutional inadequacies and reservoir management decisions joined the list.

“In a real sense, the flood’s muddy waters revealed the complex and often contradic-

tory web of management objectives among the agencies and parties responsible for water management in the Santiam,” he says. “It specifically highlighted how management for one narrow set of objectives might exacerbate problems in another sector.”

Everyone had been just doing their job. The Forest Service, as mandated for many forgoing decades, had been “getting the cut out,” potentially increasing sediment production both by baring steep hillsides and by road building. The Army Corps of Engineers had

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been operating its dams for flood control, capturing and thereby prolonging the release of persistently turbid waters after a flood. The city, seeking high water quality at low cost to its citizens, relied on the *normal* behavior of a watershed to produce clean water under all circumstances.

“What you see happening with all these missions interacting is the increase of societal vulnerability to inherent geological hazards and their interactions with land and water use decisions,” Grant says. “Ultimately, tradeoffs involved in reducing this kind of persistent turbidity turned out to be much more complex in space, in resource management decisions, and in time than was previously assumed.”

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The time and space interaction was demonstrated just 10 months later, when a similar storm event produced far less turbidity in the city's water supply river. Not enough time had passed between the two flood events to produce the extreme and persistent turbidity experienced after the first flood. But during the more typical decades of quiet—Grant's decades of boredom—land use and geomorphic processes may combine to progressively increase downstream risk.

And by storing sediment during this period, the landscape "remembers" the time since the last flood.



## LAND MANAGEMENT IMPLICATIONS



- Reducing risks from future turbidity events requires a collaborative and interagency watershed strategy involving multiple players, as opposed to unilateral action.
- Risk to downstream suppliers and users of water to high-turbidity events changes over time. Risk audits and advance warning systems can reduce the likelihood of "surprises" during large recurring events such as floods.
- Attempts to fix or mitigate one environmental problem may exacerbate another or have unintended consequences. This has major implications for the current national debate on the pros and cons of dam removal.
- Tradeoffs among forest harvest of protection, flood-control reduction, and investments for water treatment are complex and may require new or redesigned forums. At a minimum, effects of activities by various players cannot be evaluated in isolation from each other.

## IDENTIFYING THE CULPRIT

**T**he volcanic landscape surrounding the Cascades is rife with large deep-seated landslides, or earthflows, that are full of clay. Loaded with it, in fact. The widely abundant clay is the product of the physical weathering and breakdown of the parent volcanic rocks in a wet climate, and is delivered to streams by a variety of processes. The public is more familiar with the debris-flow type of landslide, fast and shallow, and far less productive of the fine sediments such as clay, that are the turbidity monsters.

Through natural processes, therefore, fine sediment is writ large in the Oregon landscape. The first question is: What is the fraction of it that contributes to sustained turbidity events such as the North Santiam case, the fraction that did not settle out to river beds or reservoir deltas?

That answer was revealed by X-ray diffraction techniques. This technology can distin-

guish between the various clay constituents in a sample of turbid water, and it uncovered the smectites, widely though not uniformly distributed across the Oregon landscape. Smectites are the finest of the fine clays that contribute to the persistent turbidity muddying the waters after floods, Grant explains. They are *so* fine, he explains, that they are carried on the bonds between hydrogen and oxygen in water.

The question of where smectites come from, however, requires further detective work, so the same techniques were used to identify the clay constituents in various landforms and soils.

"We can thus find our way from the persistent turbidity, through the clay mineralogy, to particular landforms that have high quantities of smectite," Grant says. "We 'fingerprint' the clays causing the persistent turbidity, and we can therefore know where the clays come from." Using this technique, researchers can

begin to discriminate between background or natural erosion, and erosion accelerated by human activities such as timber harvest or road construction. They also can evaluate how large reservoirs mix and separate water and sediment from various sources.

As sediments are caught by reservoirs between floods, a process of fractionation, or separation, occurs, by which most sediment settles out by weight from the water column to the lake bottom. During floods, however, the sediment eroded from watersheds and transported by streams to the reservoir doesn't settle out in the pool behind the dam. It stays in the water.

"The irony of the Salem problem was that if the Corps had not retained the water behind the dam to control the flood, the turbidity would have disappeared in a week, as it did for streams without a dam, but because of all the development in the flood plain, flood control was crucial," Grant notes.

## INTERACTING MISSIONS, INTERWOVEN PROBLEMS

**F**ast forward to spring 2002. The Army Corps of Engineers responding to its public mandate to improve the Nation's waterways, plans to retrofit many of its dams with temperature control gauges that will allow water to be released from different levels in the reservoir. Why? Threatened and endangered fish species are sensitive to water temperature.

Follow the ironies.

Cougar Reservoir is an Army Corps dam that holds back water on the South Fork McKenzie River east of Eugene. It was targeted for a drawdown (lowering of the reservoir's pool elevation by release of water) to allow access to the dam for the retrofit for temperature control.

"The drawdown exposed the delta to below-normal low water levels, a delta that had built up over the 40 years of the dam's life," Grant explains.

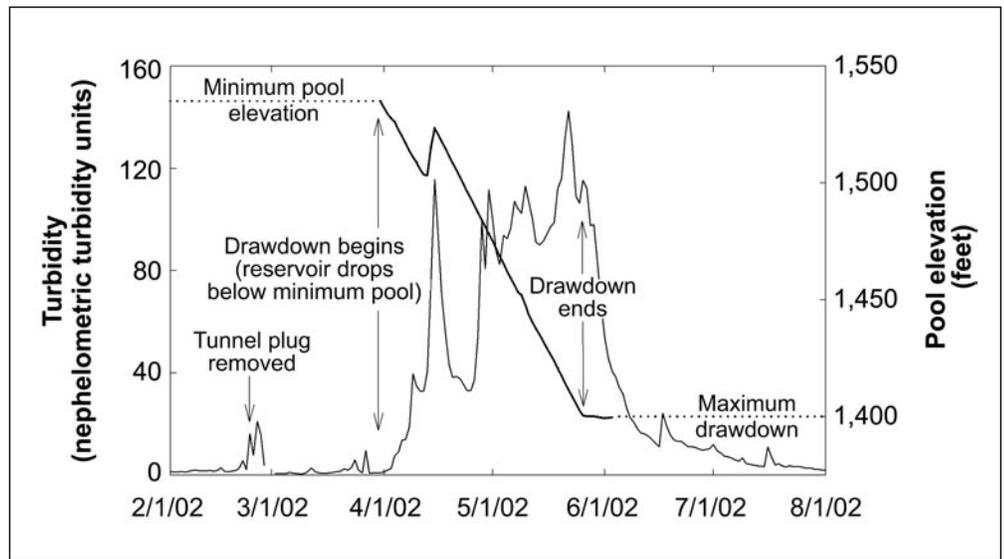


The water was visibly "muddy" in Cougar Reservoir during drawdown.

“As the river got its teeth back into the sediment, it progressively mobilized layers of the delta, and out came all the smectite. Now add to this the fact that they are steadily releasing water, at a time when more sediment than usual is being eroded from the delta and entering the pool. Thus the concentration of sediment is increasing.”

After the Salem story had unfolded, and after ongoing conversations with fellow hydrologists, biologists, economists, and anyone else interested, there were some clear lessons that had stuck with Grant.

“I don’t take credit for predicting many things, but I did predict that turbidity would continue to go up under such conditions as Cougar offered, and quite rapidly!” He was right, although neither he nor the Corps had anticipated the scale of the turbidity.



*Turbidity during Cougar Reservoir drawdown. Average daily turbidity (solid line) from the U.S. Geological Survey gage below Cougar Reservoir; Cougar Reservoir pool elevation data (dotted line) provided by the U.S. Army Corps of Engineers. Once the reservoir level dropped below minimum pool, turbidity rose until the drawdown was stopped. Water released from Cougar Reservoir remained turbid throughout the summer.*

## FISH CRY FOUL

Neither had the local fishermen. The 2002 turbidity plume was visible for over 100 miles. All this murk hit right in fishing season, and on a fishing mecca like the McKenzie, it’s going to be noticed. It captured public attention and raised concerns over possible downstream impacts on fish and wildlife

“Our first research question was: To what extent would the sediment contained within the turbidity plume intrude into river gravels and negatively affect fish and other aquatic biota?” Grant explains. Other questions addressed how much of the sediment was still left in the river, and once again, where it had come from.

This time the techniques included X-ray diffraction but added freeze cores, or “gravel popsicles” as Grant dubbed them for the local media. Their purpose was to identify changes in grain size with depth to assess the possible pathways of the so-called “fines,” the smectite or other clays.

The measurements established that as much as one-third of the sediment might still be in the river 4 months after the drawdown ceased. An appreciable, and distinctly increased, fraction of this sediment was

stored in spawning gravels immediately downstream of the dam, with potentially negative implications for fish.

Grant notes, however, that these measurements showed a rapidly diminishing pattern

with distance below the dam. The mineralogical character of in-stream gravels in the McKenzie River varies dramatically with location along the river, he explains.



*Freeze core or “gravel popsicle” taken from the South Fork of the McKenzie River below Cougar Reservoir. This river bed sediment was analyzed for grain size and clay mineralogy by X-ray diffraction.*

Credit: Gregory Stewart

## WRITER’S PROFILE

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“Tributary watersheds with unusual geologic character exert greater influence on fine sediment composition within instream

gravels over time than the sustained turbidity released from Cougar Reservoir.” These results suggest, he says, that intrusion of very

fine clays into gravel substrate can occur even when the clay is moving during the decades of boredom.

## THE RESERVOIR PRINT

“The other important finding was that a distinct reservoir fingerprint existed, due in part to water management decisions during floods,” he notes. Under normal flows, reservoirs store sediment derived from upstream as large deltas of mixed grain sizes. During storms, turbid water enters reservoirs, coarse material settles out, but very fine clays remain suspended in the water column.

“These fine clays then provide the material for persistent turbidity, and the release schedule of water from the dam determines in large part the downstream impact.”

## JUGGLING TRADEOFFS

A stark truth, truly muddying the decision waters, is that the risk to downstream suppliers and users of water from high-turbidity events changes over time. It changes in relation to evolving land use practices, the timing and magnitude of major floods, population and development pressures, and reservoir management objectives.

“Although the risk profile of downstream communities evolves with time, it may take extreme events, such as the major flood of 1996, to expose the extent to which risk has changed,” Grant says. “Risk audits and advance warning systems can reduce the likelihood of ‘surprises’ during large but recurring events such as floods. In particular, risk audits need to identify how actions by one institutional player may heighten or exacerbate risks posed by another player.”

Implied in these observations is the need for forest and reservoir management strategies to account explicitly for the consequences of their actions on water quality and quantity.

It is Grant’s opinion that the kind of tradeoff illustrated first by the Salem/Santiam River story, and then by the McKenzie/Cougar story, will increasingly be the kind of challenge we will have to reckon with.

“Our tradeoff space is far more complicated than we give it credit for,” he says. “Do we mitigate or exacerbate with any particular action? It becomes the role of the science community to describe what that tradeoff space may look like, and to do that *before* the disaster occurs.”

It should be noted, he adds, that the reservoir fingerprint is not necessarily tied only to the drawdown. For the fact is, reservoirs record the long-term history of sedimentation events in watersheds, so when those reservoirs are drawn down—for dam retrofitting in this case—that history can reassert itself in complex ways, resulting in turbidity, water quality, and other ecosystem impacts downstream.

“To underscore the historic nature of what reservoirs store, the Cougar Reservoir drawdown also released DDT sprayed decades ago, when it was still legal, to control forest

pests. The chemical, albeit in very small quantities, is now bound to reservoir sediment,” Grant says.

The Cougar Reservoir experience, he points out, has great significance for the current national debate on the pros and cons of dam removal.

At a minimum, effects of activities by various players cannot be evaluated in isolation from each other. “Tradeoffs among forest harvest or protection, flood-control reduction, and investments for water treatment are complex and may require new or redesigned forums for deliberation.”

Further, he notes, legally mandated and therefore inflexible management strategies, such as the “rule curves” used by the Army Corps to determine reservoir levels, may need to be revisited to better accommodate changing environmental and ecological conditions.

Otherwise, those hours of chaos produced by floods may continue to produce persistently murky waters, and the public dismay that goes with them.

*The knowledge of man  
is as the waters,  
some descending from  
above, and some  
springing from beneath.*

—Francis Bacon

## FOR FURTHER READING

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