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The Army Corps of Engineers' Short-Term Response to the Eruption of Mount St. Helens

AT 8:32 ON THE MORNING OF MAY 18, 1980, an earthquake of magnitude 5 on the Richter scale precipitated a massive landslide on Mount St. Helens's outwardly bulging north flank. The collapse of roughly 12 percent of the mountain, the largest landslide ever recorded, exposed gas-charged magma that had risen within the volcano. Instantaneously, billions of gallons of superheated groundwater, trapped inside the mountain, flashed into steam. Scientists later estimated the explosion at 24 megatons of energy — a blast five hundred times more powerful than the 20-kiloton atomic bomb that destroyed Hiroshima. The explosion ripped more than 1,200 feet off the top and center of Mount St. Helens, forming a huge crater over a mile in diameter. The onrushing avalanche debris displaced the water in Spirit Lake and raised the lake bed by 200 feet. Debris from the eruption covered 23 square miles of the North Fork Toutle River Valley to a depth of 150 feet.[1]

Approximately 3 billion cubic yards of material spewed out of the mountain. Some of the ejected material consisted of volcanic ash, which ascended 14 miles into the atmosphere over a 9-hour period. Other matter comprised mud and pyroclastic flows or surges that sped down the mountain at 100 miles an hour, pushing into the upper reaches of the North Fork and South Fork Toutle River drainages. These flows (averaging from 33 to 66 feet in depth) contained massive amounts of debris, rock, trees, water, and glacial ices in superheated condition. As the flows raced downstream, they filled in and leveled out the river beds, reducing chan-


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Approximately 3 billion cubic yards of material spewed out of Mount St. Helens when it erupted on May 18, 1980. Forest clearcuts form a checkerboard pattern in the foreground of this image.

nel capacity in the Cowlitz from 70,000 to 13,000 cubic feet per second (cfs). The mudflow deposited as much as 15 feet of sand, volcanic ash, and pumice in the river channels and 10 feet on the floodplain. The mudflow into the Columbia reduced the 40-foot-deep ship channel to 15 feet. The debris avalanche also created lakes in the Toutle River drainage, blocking them with eroded, unstable material. As these lakes retained rainwater or snowmelt, the danger of breaching and downstream flooding increased.

Flying over the devastated area shortly after the eruption, President Jimmy Carter mused, "I've never seen anything like it. . . . The moon looks like a golf course compared to what's up there."[2]

A deep-draft vessel was grounded in the Columbia River ship channel off the mouth of the Cowlitz River, and thirty-one other vessels were trapped in the Portland and Kalama harbors. Another fifty ships enroute to the area had to stand off or be diverted to other West Coast ports. It was a navigation emergency and a potential economic disaster for the ports, communities, and industries that depended on the ship channel. The lower Cowlitz drainage faced a flood-control problem from the mudflows. For 21 miles of the Cowlitz River, downstream from the Toutle to the Columbia, infill had eliminated natural channel capacities. Forty-five thousand people had been left without flood protection.[3]

The eruption was a major natural disaster. Fifty-seven people were killed and 150 square miles of valuable forest were turned into wasteland. The avalanche of mud and debris sent into the Toutle, Cowlitz, and Columbia rivers disrupted navigation on the Columbia and threatened to cause long-term navigation and flooding problems. The U.S. Army Corps of Engineers, the federal agency immediately responsible for dealing with the disaster, faced a difficult and uncertain situation. Could the Corps, a government agency that was considered highly bureaucratic and technically conservative in its engineering philosophy, respond with appropriate technical solutions to the immediate and long-term water problems caused by this unprecedented natural disaster?

The Corps' responsibility for responding to the Mount St. Helens emergency stemmed from its congressionally authorized mission. Since 1824, the Corps had been charged with improving the nation's rivers and harbors for navigation. In the twentieth century, the Corps also became responsible for flood control, the development of multiple-purpose water resources development projects on the nation's major waterways, and regulatory responsibilities under the Clean Water Act of 1972. Over time, the Corps amassed considerable expertise in the planning, construction, operation, and maintenance of water resources projects across the nation.

Although the Corps of Engineers' organizational structure appeared heavily bureaucratic — at that time the Corps consisted of thirty-seven districts and eleven divisions reporting to headquarters in Washington, D.C. — appeared heavily bureaucratic, it was in practice a fairly decentralized outfit. While the division and higher headquarters exercised technical review and oversight of the districts to ensure consistency and compliance with laws and regulations, each district had a large measure of

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Enormous quantities of blow-down debris and sediment clogged the Toutle and Cowlitz rivers immediately following the eruption of Mount St. Helens. This photograph was taken on May 18, 1980.

independence in carrying out the agency's water resources projects at the local level. This institutional flexibility and decentralized empowerment would prove essential in the Corps' short-term response to the Mount St. Helens disaster.

Immediately after the eruption, the Corps initiated emergency dredging to restore the shipping channel in the Columbia River and then devised and implemented both short- and long-term solutions to the flooding and navigation problems caused by continuing flows of volcanic material. In the immediate aftermath of the eruption, Corps staff implemented their response in the context of an anxious public and a skeptical political atmosphere in Washington, D.C. As the Corps developed its plans, the agency found itself caught between the fiscally frugal Reagan Administration, which was determined to hold down costs, and local interests that wanted complete flood protection as soon as possible and had little regard for the price tag. The Corps' short-term initiatives laid the groundwork for the cost-effective and technically sound engineering solutions that the agency ultimately developed to address long-term problems caused by the Mount St. Helens debris flow.

The Natural Setting

Prior to 1980, few people thought that a beautiful mountain in the Cascade Range contained the potential to cause devastating flooding in the Cowlitz drainage. Scientists considered Mount St. Helens and six other peaks in the Cascade Range as active volcanoes, each having erupted at least once during historical time. Because of its relative youth and explosive history, some volcanologists thought Mount St. Helens the most likely of the Cascade volcanoes to erupt in the near future. Planning for an event whose timing was impossible to accurately predict proved especially difficult, and geologists feared that the relative quiet of the Cascade volcanoes had lulled the public into a potentially dangerous disregard of volcanic hazards.[4]

Beginning in March 1980, frequent earthquakes, accompanied by minor steam and ash ejections, shook the mountain and announced a new phase in the geologic history of the volcano. No one, however, could be sure what to expect. As Dan Crandell, a leading geologist, observed at the time, "Mount St. Helens has done so many different things in the past that hardly anything would be a surprise. The only thing it hasn't done is blow itself apart."[5]

The eruption on May 18 was only the most recent event in 40,000 years of volcanic activity at Mount St. Helens. Typically, heavy winter rainfall accompanied by rapid snowmelt at the higher elevations of the Cascade Mountains can quickly convert the Cowlitz and its tributaries into torrents during the rainy season, from November to May. From the earliest days of white settlement, the Cowlitz River had offered both economic promise and potential ruin. The river provided rich bottomlands for farming and a means of transporting their produce to market but also posed a periodic danger from flooding. But the flooding that raged on the Cowlitz and Toutle rivers in the aftermath of the May 1980 eruption was an especially devastating form of that regularly encountered event.

Between the 1870s and 1920s, the Corps of Engineers, through its Portland District, had carried out channel improvement projects on the Cowlitz River to support navigation by shallow draft steamers. Each year, they removed hundreds of snags and other debris and occasionally built wing dams and bank revetments. In 1904, Congress authorized Corps dredging on the Cowlitz in combination with the other channel improve-

In the aftermath of the eruption, pyroclastic mudflows destroyed property along the Toutle River, depositing mud to a depth of several feet.

ments. By the 1920s, however, navigation on the Cowlitz began to decline as railroads and highways provided more convenient alternatives to river traffic. The Corps did less and less work on the river.[6]

As the use of the Cowlitz River changed, local people's overall perception of it changed as well. As long as it served as a vital transportation link, the river seemed an ally rather than an opponent. As the benefits from river navigation declined, however, losses from flooding became less acceptable. Steady economic development and population growth along the Cowlitz floodplain meant increasing devastation with each major flood. The heavy destruction accompanying the floods of 1894, 1896, and 1906 sorely tested popular fatalism. Flood-control efforts were not undertaken, however, until the 1920s, when extensive industrial activity in the Cowlitz Valley floodplain fostered a new attitude toward flooding. In 1925, attracted by large stands of old-growth Douglas fir, the Long-Bell Lumber Company built the largest lumber mill in the world near the mouth of the Cowlitz River at Longview, Washington. Other lumber companies soon followed. Between 1920 and 1930, Cowlitz County's population jumped 270 percent, to 31,906.

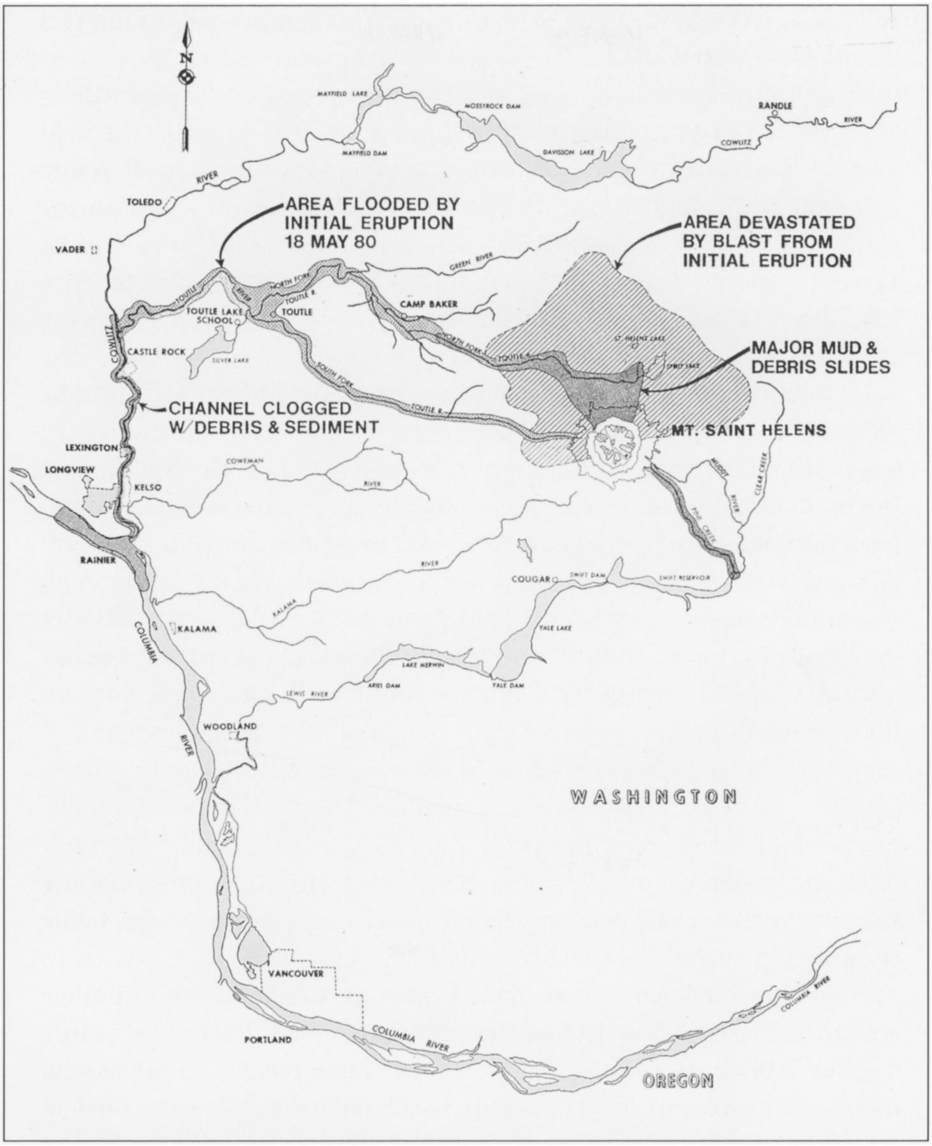
Destructive flooding on the Cowlitz in 1933 produced calls for federal assistance to repair and improve damaged flood-control works that had been built by private interests. In 1936, similar concerns about flooding throughout the nation led Congress to accept flood control as a proper activity of the federal government, and the Corps of Engineers took on the responsibility for constructing federal flood-control projects. With this authority, the Corps built levees and other protective works along the lower Cowlitz River between 1939 and 1966.

The relative security afforded by the protective works constructed by the Corps and local interests encouraged industrial development on the lower Cowlitz floodplain after World War II. Two new dams built by a public utility district on the upper Cowlitz in the late 1960s also alleviated flooding fears. In spite of several destructive floods in the 1960s and 1970s, the existence of levees and dams seemed to make periodic high water on the Cowlitz a tolerable nuisance rather than a potential disaster for life and property. The devastating aftermath of Mount St. Helens's eruption in 1980 would trigger yet another phase in the Corps' work on the Cowlitz River.

The Corps Responds

As the magnitude of the effects of the Mount St. Helens eruption became known, the Corps of Engineers joined emergency response efforts being coordinated by the Federal Emergency Management Agency (FEMA). To properly formulate an emergency response, the Corps had to accurately assess the extent of the destruction. While staff from the Corps' Seattle and Walla Walla districts conducted damage assessments and gauged ash cleanup requirements, Portland District planners and engineers focused on the extent of the channel blockages on the Columbia, Cowlitz, and lower Toutle rivers. Preliminary findings indicated that dredging and restoration of flood protection would cost $213.5 million.[7]

A frenzy of media coverage surrounded the Corps' recovery and restoration work. National and international media joined the local press, television, and radio in telling the story of the eruption and its aftermath. Local residents were shocked and could barely comprehend the immediate damage. They would remain on edge for months as the mountain continued intermittent volcanic activity during the remainder of the year. The



This map depicts the areas devastated by the initial eruption of Mount St. Helens and the river drainages affected by the subsequent debris and mudflows. Debris and sediment blocked channels on the Toutle, Cowlitz, and Columbia rivers, halting navigation on the Columbia River and threatening both short- and long-term flooding on the Toutle and Cowlitz rivers.

early estimate of the cost of the destruction — $2 to 3 billion — proved to be excessive, but the International Trade Commission's more considered assessment of $1.1 billion, made at the request of Congress, was a clear measure of the heavy damage sustained. In late June, Warren Magnuson and Henry Jackson, Washington state's powerful senators, pushed Congress to appropriate $951 million for disaster relief. Most of this money went to the Small Business Administration, the Corps of Engineers, and FEMA. The Corps' initial funding for relief efforts was $173 million.[8]

Debris clogs in the rivers forced the Portland District to cope simultaneously with a flood threat on the Cowlitz and navigation blockage on the Columbia. The district immediately deployed flood-fight personnel to the Cowlitz to respond to the flood danger. On May 19, the District Emergency Management Branch began 24-hour operations and opened an emergency office in Kelso, Washington. Between four and six [**five?**] flood engineers [**from what agency?**] assisted city and county officials. Early information indicated an immediate need to raise and strengthen levees at Castle Rock and Lexington, Washington, to provide better drainage in the flood-prone areas, to remove debris, and drain ponded areas. Portland District personnel also assessed flood-caused problems with domestic water systems. The flood-fight operation lasted until June 6 and cost about $307,000.[9]

As part of the effort, the Corps' Portland District performed detailed inspections for all emergency repair and restoration work and provided a full-time coordinator to oversee the activities of the federal-state damage survey teams. The Corps coordinator reviewed all FEMA damage survey reports and advised on engineering matters. The Portland District also carried out final inspection reports for FEMA activities and supplied forty thousand sandbags to Cowlitz County. As concern for serious flooding abated, the district then turned its resources to restoring the hydraulic carrying capacity of the Cowlitz.[10]

While the emergency flood-flight operation was underway, the Portland District began clearing the Columbia River navigation channel. Logs, floating debris, and silt filled the river for 25 miles downstream from the mouth of the Cowlitz River, reducing the channel depth from its normal 40 feet to only 15. The Corps immediately ordered all federal dredges to mobilize on the Columbia. Four Corps hopper dredges and the Port of Portland's large pipeline dredge began emergency operations. Preliminary estimates indicated that at least 10 million cubic yards of sediment clogged the channel (later readings confirmed that 55 million cubic yards filled 9.5 miles of the navigation channel).[11]

By May 20, the Corps had hammered out a five-phased restoration plan that called for cutting alternate parallel channels on either side of the normal center line until the channel was returned to its full dimensions. Under phase 1, the *Biddle*, one of the Corps's dredges, cut an emergency

Pipeline and hopper dredges at work removing sediment clogging the shipping channel in the Columbia River below the Trojan nuclear power plant on the Oregon shore.

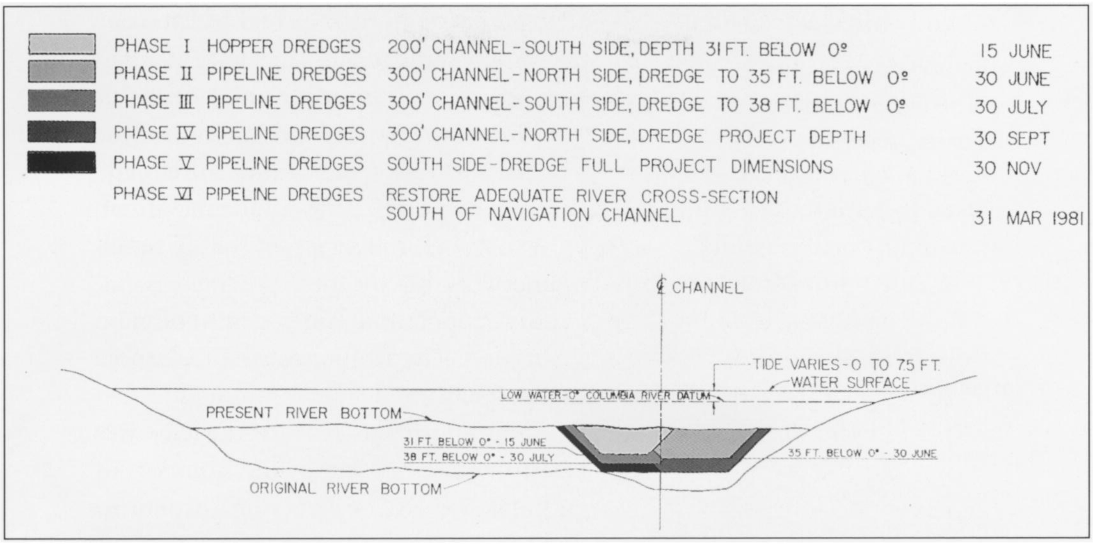
30-by-200-foot channel on the south edge of the 600-foot-wide authorized channel. Columbia River pilots and the Coast Guard could then guide ships through during a 2-hour window in which the rising tide allowed passage. Within 2 weeks after the eruption, ships with a 30-foot draft could use the pilot channel, and by June 13 vessels with a 36-foot draft could pass. The emergency channel permitted over 75 percent of the normal shipping traffic to resume operation. In the meantime, the district received approval to begin the main channel work. After canvassing marine contractors throughout the nation, on May 23 the district contracted with Riedel International of Portland to furnish and operate five large pipeline dredges for the emergency restoration effort.[12]

On June 7, the mobilized dredges and support equipment began work on phase 2. This effort provided a 35-by-300-foot channel on the north side of the ship channel's center line. After completing that phase on June 22, the dredges began cutting the south side to a depth of 38 feet. Operations proved complicated. Disposal areas for the dredged materials sat on the Washington shore, so materials had to be piped across the river. Dredge crews had to disassemble the pipelines across the north channel each day to allow for ship passage. In addition, sediments continued to refill areas already dredged, requiring a hopper dredge to remove the new deposits. Completion of phase 3 by July 25 allowed a return to the north side of the channel, where the final 45-by-300-foot cut was finished. Phase 5 dredging, completed by November 30, restored the full navigation channel depth on the south side. In all, the dredges removed 14 million cubic yards of infill with a minimum disruption of shipping.[13]

The Corps' efforts were not without controversy. Cowlitz floodplain residents were unhappy with the Corps' decision to tackle the Columbia River's clogged navigation channel first. Given the Corps' admission that the Cowlitz River faced probable flooding if its channel capacity was not quickly restored, people in Washington complained that the Port of Portland's interests were being put ahead of theirs. The Corps explained that the congressionally approved maintenance funds for dredging the Columbia could not be transferred for emergency purposes, but anxious citizens were not mollified. Critics considered the response a "cop-out," a case of putting shipping interests ahead of lives and private property.[14]

BECAUSE CHANNEL RESTORATION CONSTITUTED an emergency, federal and state natural resources agencies relaxed environmental requirements while the work proceeded. The Corps convened a task force of federal, state, and local resource agency officials to advise on minimizing the environmental effects of recovery operations. Coordination began on May 29 and continued throughout the restoration work. The Portland District developed an Environmental Impact Statement (EIS) covering the Cowlitz-Toutle flood protection work as well as the ship channel restoration work.[15] The emergency actions to protect human life and property had to be accomplished without complete knowledge of their potential environmental consequences. The chief environmental concerns focused on the potential effects of recovery operations on wetland, water quality, fish passage, and fish and wildlife habitat. Even though the EIS was completed in a fraction of the time normally required, the report considered probable environmental effects from work underway or proposed and represented the best guess of what would happen. The Corps planned to update the EIS as new alternatives developed.[16]

Even as the Corps carried out the restoration of the Columbia River navigation channel at the mouth of the Cowlitz River, they worried about maintaining it. The natural width of the Columbia, coupled with extensive dredging, had created an area prone to accelerated shoaling. Now, the mil-



This section drawing of the Columbia River at Longview shows the progress of phases in the dredging project.

lions of cubic yards of mudflow infill immediately upstream in the Cowlitz coupled with the probable large volume of erodible deposits in the Toutle River system placed additional pressure on the Corps' ability to maintain adequate navigation depths. A Portland District consultant recommended disposing of 6 million cubic yards of mudflow material on the Oregon shore at Rainier. Narrowing the river channel would help keep the eroded material flowing through the area and depositing downstream in less critical locations. To stabilize the hydraulic section of the restored navigation channel, another consultant recommended removing an additional 9 million cubic yards over time. Finally, to collect the expected outwash of materials from the Toutle and Cowlitz River valleys, the engineers excavated a sump at the mouth of the river. Materials would collect in the sump, and a large dredge could remove them before they reached the Columbia River channel. As much as 2 million cubic yards of sediments were removed from the sump and placed in a specially prepared disposal area at an area known as the Collins estate near the mouth of the Cowlitz.[17]

Initial Corps surveys and field reconnaissance determined that mudflow deposits had eliminated 85 percent of the flood-carrying capacity on the lower 9 miles of the Cowlitz River. Channel restoration would be difficult in this reach because the adjacent area was heavily urbanized and disposal locations were unavailable or at some distance from the river. Engineers decided that pipeline dredges, which could pump dredged

Glossary

BANK REVETMENT: Woven brush mattresses or stones placed on stream banks to prevent erosion.

GABION: A basket or cage filled with earth or rocks and used in building a support or abutment.

HOPPER DREDGE: A hydraulic dredge that sucks sediments from the channel bottom and stores it in large bins, or hoppers, inside the hull of the dredge before transporting it to the disposal area.

HYDRAULIC DREDGE: A dredge that removes material by mixing it with water and sucking it from the channel bottom.

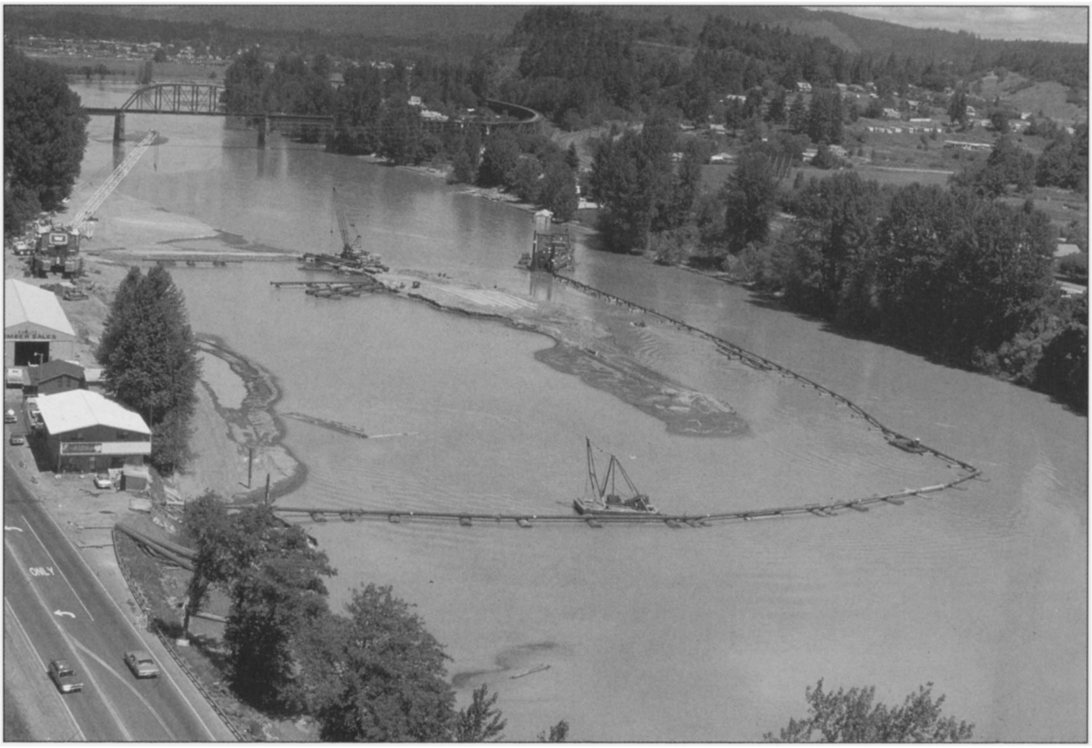
PIPELINE DREDGE: A hydraulic dredge that sucks dredged material into an intake pipe and pushes it out of a discharge pipeline directly into the disposal site. They usually have a "cutterhead" — a tool with rotating blades or teeth — at the end of the intake pipe to break up or loosen the bottom material so that it can be sucked through the dredge.

WING DAM: Permeable timber and stone structures built into a river to deflect the current.

materials some distance, could best accomplish the work. The lower Cowlitz restoration project would require all three of the appropriate-sized dredges on the West Coast, and the Corps quickly mobilized them for the effort. It soon became apparent that to finish the work before the fall rainy season, large pipeline dredges would also be needed. The Corps secured two more dredges.[18]

Dredging to restore the Cowlitz River channel began on June 13. To meet the November 1 deadline and beat the winter rains, the Corps pushed the restoration effort at a frenzied 20-hour-a-day pace. By early October, the Portland District had 25 contractors at work on $100 million in contracts. Using 850 on-site employees, 22 pipeline dredges, 49 draglines, and 12 large backhoes, the contractors removed nearly 300,000 cubic yards of sand and rock each day. By November, contractors had removed and hauled or piped to onshore disposal areas almost 16 million cubic yards of material from the stretch of river between miles 9 and 21. By early December, the Corps had reached its goal of a creating a channel that could handle 50,000 cubic feet of water per second. A channel of this capacity would control a 5-year flood and reduce peak flows of larger floods. At the project's completion, in the summer of 1981, contractors had removed nearly 56 million cubic yards of material from the Cowlitz River.[19]

Even with restoration of a 50,000 cfs flood-control channel, a need existed to protect against larger floods on the Cowlitz. The Corps' solution was to improve levees to 500-year protection levels for all urbanized areas downstream of the Toutle River. During the winter and spring of



A pipeline dredge at work on the Toutle River, vacuuming material from the river bottom and moving it through the pipeline to shore for disposal.

1980–1981, the Corps raised 14,700 feet of levees and extended existing levees 21,400 feet at a cost of $11.2 million. The Portland District Real Estate Division conducted a massive effort to obtain the necessary rights-of-way for the levee project. Existing law required local sponsors for levee projects to provide all lands, easements, and rights-of-way to the Corps. After investigation, however, local sponsors of the improvements discovered that they lacked adequate bonding capacity for the projects. Upon the approval of the Office of the Chief of Engineers, the Portland District supplied the necessary funds for acquiring the rights-of-way or easements, and the District Real Estate Office obtained right-of way entry or permanent easements for eighty-five parcels of land.[20]

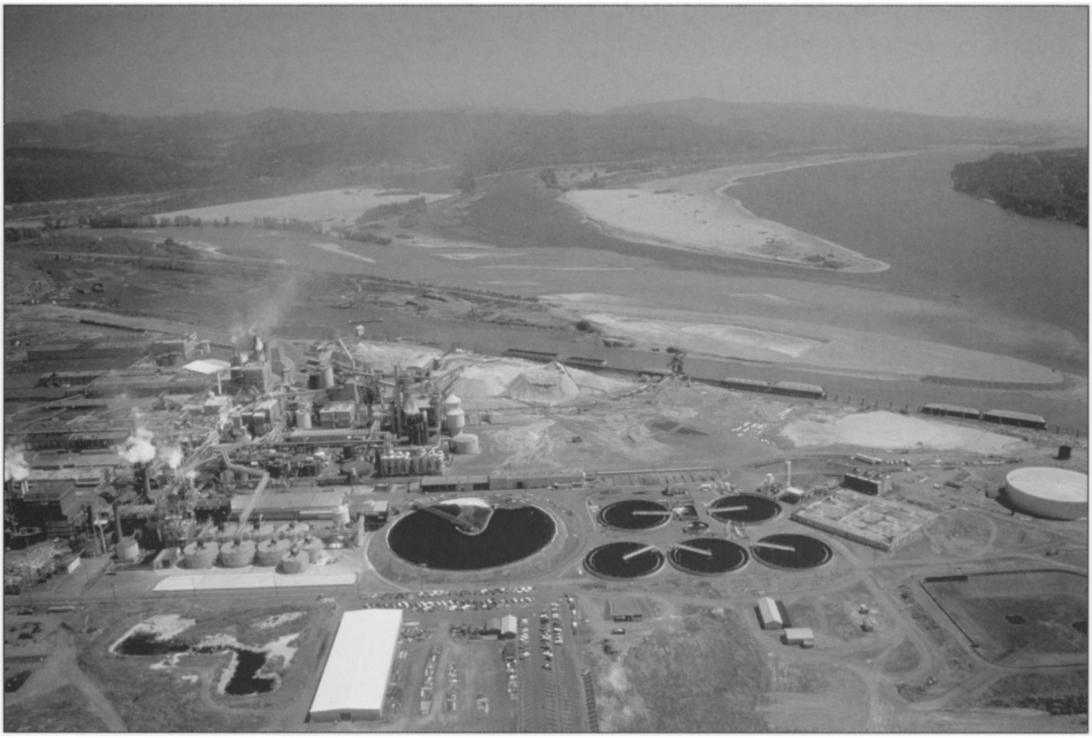
The Corps also had to develop a strategy for limiting the channel-clogging effects of the mudflow material in the Toutle River valley. To hold back the rapidly eroding layers of debris, engineers channelized the river where it cut through the mudflow material. This program only partially reduced the sediment flow, so the engineers tried constructing weir-like rock retaining structures, or debris dams, which were more successful in controlling the infill from the estimated 3 billion cubic yards of debris in the Toutle River valley.[21]

The Corps built two debris dams. One, at the foot of the main mudflow deposit on the North Fork Toutle River, extended 6,100 feet in length and reached 43 feet in height. The other, on the South Fork, was smaller — only 500 feet long and 20 feet high. Gabion — wire baskets filled with rock — was covered with several inches of concrete mortar to form spillways in each structure. The debris dams held back the eroded material from upstream so that excavation equipment could remove it to nearby spoil areas. The Corps expected the debris dams to trap 60 percent of the bedload sediments.[22]

Rapid planning, design, and contracting permitted completion of the structures by November 1980. Built at a cost of about $12.3 million, the debris dams performed well until December, when a large freshet took out one of two spillways on the North Fork structure. To replace the destroyed spillway, the Corps constructed a new spillway of roller-compacted concrete and raised the entire structure by 5 feet. By August 1981, 9.7 million cubic yards of sediment had been excavated from behind the debris dams.[23]

To trap additional sediment and stabilize the river channel, the Corps excavated eight sediment basins on the lower two forks and the main stem of the Toutle River. A sediment basin was also placed on the Green River to trap flows and allow the sediments to settle before the runoff is discharged. Sediment basins help stabilize sediment movement by lowering water tables in the flood deposits (draining water away from clogged drainage ways) and by removing sediment and other debris from congested river channels. The Corps projected that the basins would capture about 10 percent of the migrating sands and gravel. Periodically, the Corps dredged the trapped sediments and removed them to disposal areas. The sediment basins cost $14.9 million to construct.[24]

The massive debris avalanche at the base of Mount St. Helens also posed other potential flooding hazards. An estimated 3 billion cubic yards of material filled the upper 14 miles of the North Fork Toutle River Valley from wall to wall, reaching depths of from 200 to 600 feet. This mudfill blocked the natural drainage paths of many side valleys, creating ponds or small lakes. Several of these impoundments overtopped in the late summer of 1980, causing minor flooding and increased erosion of debris sediment. Scientists and engineers feared that the overtopping of the larger impoundments could create more hazardous flooding in the near future, so the



This view of the mouth of the Cowlitz River (left) at its junction with the Columbia River shows the area prone to shoaling. The Longview industrial zone and sewage plant are in the foreground, and the Collins disposal site is the light-colored area in the upper left.

Corps established a monitoring program and mobilized equipment to cut artificial channels in lakes likely to overtop. Because scientists considered Coldwater and Castle Creek lakes to be most susceptible to catastrophic failure, the Corps studied the lakes' foundations and constructed outlet channels during the summer and fall of 1981.[25]

As the Portland District planned and conducted its early recovery efforts, Col. Terry Connell, the district engineer, decided on June 22 that a special organization should coordinate the recovery activities. The magnitude and uniqueness of the emergency called for a response beyond that required of the district's emergency operations manager.[26]

Pat Keough was named a special assistant for Mount St. Helens activities with direct authority over recovery activities of all district elements and the power to cut through the supervisory chain and assign duties to any person or organization in the district. As special assistant, Keough also served as the primary public contact on recovery efforts. Between

June 6, 1980, and January 5, 1981, Keough held fifty public and interagency meetings, twenty of them in July 1980 alone. The meetings ranged from open forums for the general public to small briefings for public and private organizations. Keough's staff — an engineer for technical problems, an administrative aide, and one secretary — developed the concepts and procedures necessary to expedite the district's emergency response. They quickly decided to use a fast-track design approach. Ken Ray, the district engineer's executive assistant, later explained:

> Basically it was a simple critical path that was developed on the spot in a meeting with all of the major participants. The first step was the determination of work completion dates which were set to precede the winter rains of the fall of 1980. The next step was to estimate the number of days it would take to perform the work. This estimate was made by the Construction Division based on their experience. This then determined a contract award date. From that point the designers, the Real Estate people, the Reproduction people, the Estimates and Specs people, and personnel from Procurement and Supply would establish a schedule using the critical path method which would produce a time schedule down to days and hours in which each of the activities would completed. On a daily basis the administrative person and an expediter from Engineering Division would review the progress on the schedule and initiate actions which would ensure that the schedule was maintained.[27]

By May 1981, the Corps' recovery and flood-prevention efforts resulted in the removal of 57 million cubic yards of sediments from the Cowlitz River and the mouth of the Toutle River. Debris-retaining structures on the North and South Fork of the Toutle River trapped another 12 million cubic yards before it could clog the Cowlitz, and eight sediment stabilization basins collected an additional 5.4 million cubic yards of material. Levee improvements and bank stabilization provided further protection during the first flooding season following the May 1980 eruption. Future work would build on the planning and structural work accomplished by May 1981.[28]

Planning the Corps' Response

An intense planning effort by the Portland District had been necessary to complete the flood reduction and emergency restoration work in the spring of 1981. To get the flood-protection works in place before the onset of winter rains, the district had completed its plan for restoration along the Cowlitz in 2 weeks rather than the initially proposed 6 weeks. All of the planning had to be coordinated with other federal agencies; local, state, and federal elected officials; and an anxious public.[29] The district

Workers spraying the cement slurry on the rock-filled gabions forming the spillway of one of the temporary debris dams constructed on the forks of the Toutle River.

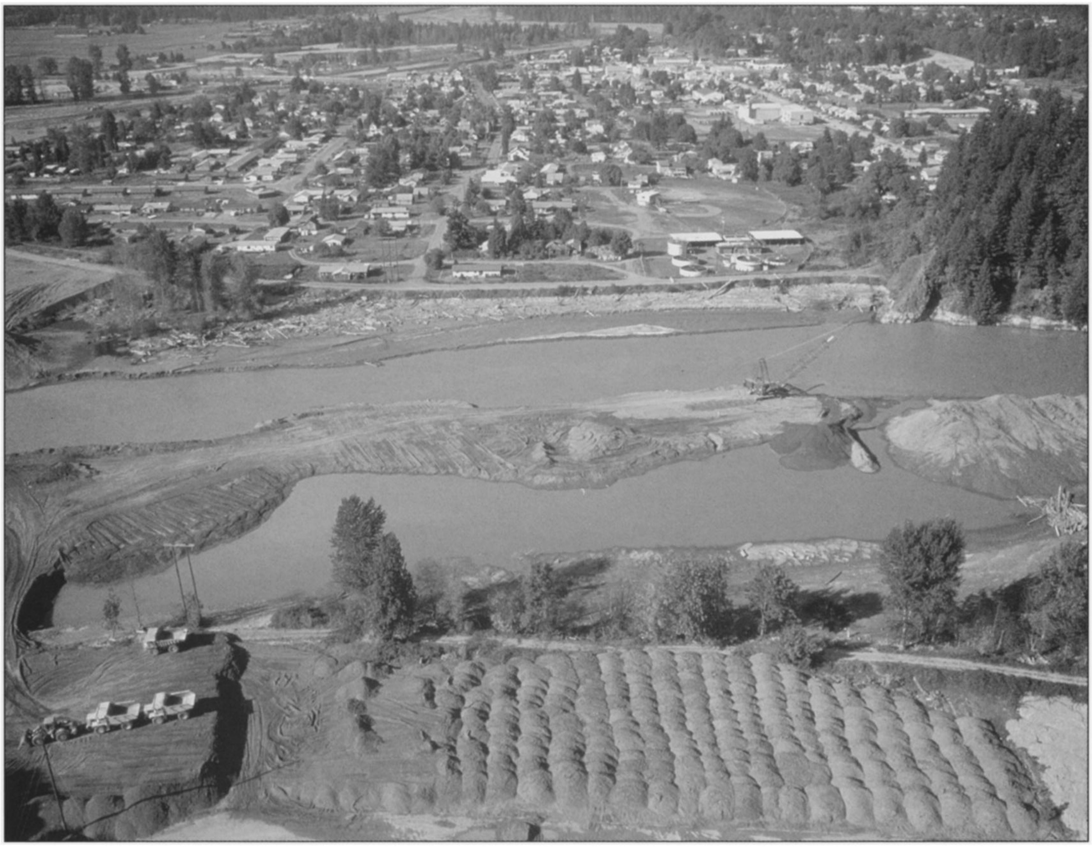
proposals also had to undergo evaluation at both the division level and the Chief of Engineers' office. Even with the Corps' rigorous review and coordination process, the Portland District produced a series of carefully developed, cost-effective measures in record time.

Three legal authorities permitted the Corps to respond to the Mount St. Helens emergency. Public Law 84-99 provided the Corps with emergency funds for flood preparation, flood fighting, rescue operations, and repair and restoration of flood-control works endangered or destroyed by floods. Under this law, the Corps worked to restore the flood-control capacity in the Cowlitz and at the mouth of the Toutle River. Once President Jimmy Carter declared the state of Washington a disaster area, the Corps provided assistance to FEMA under Public Law 93-288. The Corps' damage survey reports, technical support for repairing municipal water systems, and personnel to assist with coordination at the FEMA Disaster Field Office in Vancouver, Washington. Finally, regular Corps operations and maintenance funding enabled the Portland District to quickly respond to shoaling in the authorized Columbia River ship channel. The Corps initially spent $200,000 in emergency funding under P.L. 84-99, but the program that soon took shape totaled approximately $173 million for the remainder of 1980 and at least another $56 million for 1981. To implement the short- and long-term plan of action as well as emergency restoration measures, the Portland District set up temporary field offices at Rainier, Oregon, and at Castle Rock and Toutle, Washington. These offices administered the massive contract work and employed an area engineer and from twenty to thirty field personnel.[30]

Various district elements produced, under P.L. 84-99, the advance measures reports that recommended channel dredging and structural works. The advance measures team, drawing on the district's professional expertise, assembled the reports at a cost of $500,000 in an extremely short timeframe. Between May 27 and June 17, the district completed Advance Measures Reports Nos. 1 and 4 through 7, which called for restoration of the Cowlitz River channel from the mouth to river mile 25, at a cost of about $50 million. Staff in the district's Navigation and Engineering divisions prepared the reports and forwarded them for review by the North Pacific Division and the Office of the Chief of Engineers.[31]

The Chief of Engineers' office approved Advanced Measures Report No. 1 on June 6. The report, rushed to completion in one week, called for dredging the lower 7 miles of the Cowlitz and sought $2.4 million to initiate the work. The report emphasized dredging as the only feasible alternative to widespread flooding and the potential loss of $1 billion in property during the next winter rainy season. By June 12, the initial funding request had been increased to $5.4 million. The report anticipated a high cost for the removal of the estimated 7.3 million cubic yards of material because of the long pumping distance and the abrasiveness of the material. The plan also included one sediment basin at the mouth of the Cowlitz.

The Corps' engineers had considered various alternatives to dredging but had rejected them. They argued, for instance, that evacuation of the floodplain was not economically or politically acceptable for the heavily populated and developed lower Cowlitz area. They also discovered that varying flows from upstream reservoirs to flush sediment would not be practicable because of the amount of material present. Flushing, moreover, would simply deposit the material in the Columbia River, increasing the needed dredging at that location. Finally, flushing would adversely affect the remaining fishery in the Cowlitz River. Because local authorities had previously allowed construction on existing dikes, raising the levees alone did not constitute an economical approach.[32] Subsequent reports based



An example of dragline dredging on the Toutle River. Dredged material has been deposited in mounds or rows in a disposal area in the foreground of the photograph.

on further analysis did call for levee improvements in combination with dredging on the lower 10 miles of the Cowlitz and at Castle Rock.

While increasing the authorized funding for Advance Measures Report No. 1 on June 12, the Office of the Chief of Engineers also committed $33 million to implement Advance Measures Report Nos. 2 and 3. Work on these plans began on May 29. Measure 3 called for construction of settlement ponds to trap sediment in the Cowlitz, while Measure 2 proposed creating debris-retaining structures for the North and South Forks of the Toutle River to catch material before it reached the Cowlitz. Of the five structures requested in Measure 2, the chief's office authorized one each for the North and South Forks.

The Engineering Division of the Portland District completed Advance Measures Report Nos. 4 through 7 on June 17, and the Office of the Chief of Engineers approved them on July 1, authorizing $26.3 million for the proposed work. These reports covered the dredging of an estimated 14 million cubic yards of material between river miles 7 and 25 on the Cowlitz. As the first Cowlitz-Toutle advance measures were approved and the work got underway, Portland District staff produced three supplements further refining and justifying specific recovery efforts.

Supplement 1 amplified the original advanced measures report on the Toutle River debris-retaining structures and recommended dredging 1 mile above the mouth of the Toutle. Supplement 2 proposed a series of levee improvements in combination with dredging between Cowlitz river miles 0 and 25 to provide protection in the event of a 500-year flood. Supplement 3 proposed that the Corps purchase 240,000 acre-feet of additional flood-control storage space in Mossyrock Reservoir for an estimated $8 million. Existing authorized flood-control storage amounted to 360,000 acre-feet.

The federal cost of the proposed flood-protection plan came to $10,485,000. Local governments were expected to contribute $7,318,000 through existing and new diking districts and would be responsible for future maintenance of levee work. The Portland District's cost-benefit analysis demonstrated that the combination of levee improvements and dredging was the most economical plan. Still, officials in the Chief of Engineers' office were skeptical, and at a review conference on August 13, they requested further study. The Portland District responded by preparing Supplement 4. Submitted on November 4, the supplement explained why the levees were being built to meet permanent rather than temporary Corps standards, why the levees would be constructed to provide 500-year flood protection, and why the measures were designed to achieve a 50,000 cfs channel rather than the pre-eruption 70,000 cfs capacity.

In justifying the plans' proposed levee work, the Portland District argued that it had followed Corps' policy and guidelines in basing its recommendations on economic feasibility and cost effectiveness. For instance, engineers considered levees primarily for areas of concentrated development, where annual benefits were most likely to exceed annual cost for a given level of protection. The engineers' analysis of alternatives such as ring levees in specific locations, evacuation of isolated areas, flood-proofing of structures, floodplain regulations, and channel flushing showed them to be insufficient or not cost-effective.

The Portland District recommended building levees to permanent standards for both economic and engineering reasons. The costs for both

The Corps built this retention structure on the South Fork Toutle River to trap debris, which was then excavated and removed to disposal areas away from the river.

kinds of levees were comparable, and temporary levees would not permit the major utility relocations needed along the proposed alignments. The Portland District also followed Corps levee policy for urbanized areas, which required protection against a Standard Project Flood (SPF). Along the lower Cowlitz River, an SPF constituted a 500-year flood. A channel excavated to 50,000 cfs provided such protection and achieved the most beneficial combination of economic and engineering factors. It also represented the maximum channel capacity that could be obtained before the onset of the flood season.

Portland District engineers also argued that levees must be combined with channel excavation. Without channel excavation, they explained, drainage culverts, pump station discharge lines, and tributary streams would remain blocked, increasing flood damage potential along the Cowlitz. Channel excavation, moreover, would remove sediments before they reached the Columbia River navigation channel. Excavation would also allow for reduction in the size of levees, thereby lowering real estate costs and reducing the possibility of condemnation delays. Finally, engineers argued that channel excavation could be accomplished more rapidly than levee construction alone and would speed the environmental recovery of the river and its salmon fishery.

THE CORPS SUCCESSFULLY prevented flooding on the Cowlitz during the winter of 1980–1981, but longer-term actions were needed to cope with the continued flooding potential of sediment eroding off the mountain. To protect recently completed work and prevent flooding of transportation facilities and urban areas during the 1981–1982 winter season, the Portland District proposed a number of new construction projects. Corps planners and engineers based this new work on the recently completed advanced measures reports and the results of preliminary hydraulic model studies. District staff drafted an interim report, Advanced Measures Report No. 10, requesting authorization to construct additional water, sediment, and erosion-control works prior to the onset of the annual flood season. The study, issued in July 1981, also proposed projects that would be incorporated in a subsequent long-term plan for the Cowlitz and Toutle River basins.

Previous work had provided flood protection on the Cowlitz River by excavating over 56 million cubic yards of sediment and constructing levees. The new hydrologic conditions in the Toutle River basin heightened the danger of flooding on the Cowlitz River by increasing the peak water discharges and sediment load from the Toutle. Sediment studies estimated that 1 billion cubic yards of material would be transported to the Cowlitz and Columbia over a 15-year period, 40 percent of which would be deposited in the two rivers. If no action was taken, potential economic damages could exceed $3 billion, with two-thirds of that amount related to transportation losses and the rest to physical improvements.

The Portland District proposed nine projects to maintain the existing level of protection on the Cowlitz based on projected sediment transport levels. The specific measures for the Cowlitz would stabilize the river banks, prevent dredged material from reentering the river, and halt realignment of the river channel. Engineers also recommended erecting pumping stations at Lexington and Castle Rock to prevent interior flooding behind the recently completed levees. The Toutle River measures would protect or extend existing sediment-control works.[33]

A freshet temporarily breached the spillway on the North Fork Toutle River debris retention dam in December 1980. The Corps repaired the breach and subsequently strengthened the structure.

On the Toutle, the Corps assigned highest priority to constructing an outlet from South Castle Lake, which had been created when the Mount St. Helens debris avalanche blocked tributaries of the North Fork Toutle River. Without a controlled outlet, South Castle Lake would flood its banks and the debris plug that had dammed the lake would fail. The sudden release of 25,000 acre-feet of water from South Castle Canyon would flood the Toutle and Cowlitz basins, release a large volume of sediment, and damage the Corps' North Fork Toutle River debris-retention structure. Creating an exit channel represented the least expensive alternative. Additional Toutle River measures included the continued operation and maintenance of the highly effective debris-retaining structures, construction of two sediment stabilization basins, and other channel improvements such as bank stabilization. Widening and deepening the river channel to form sediment basins would reduce flow velocities, causing sediment to deposit. The sediment would later be removed to a disposal area.

The Portland District judged Advance Measures Report No. 10 to be the minimum program necessary to protect against erosion, sedimentation, and flooding during the winter of 1981–1982. Because scientists were unable to determine the precise amount and location of sediment deposition, the district believed that its program provided the best balance between reasonable protection and the flexibility needed to adapt to changing conditions. Removal of sediment on the Toutle, moreover, proved less expensive and nearly as effective as reducing the sediment once it reached the Cowlitz. The lack of adequate, environmentally suitable, nearby disposal areas greatly increased the cost of excavation and removal along the Cowlitz. Total cost of the recommended work came to $80.6 million. If the report could be approved by higher authority, work would begin in August and reach completion by late 1981 or early January 1982.

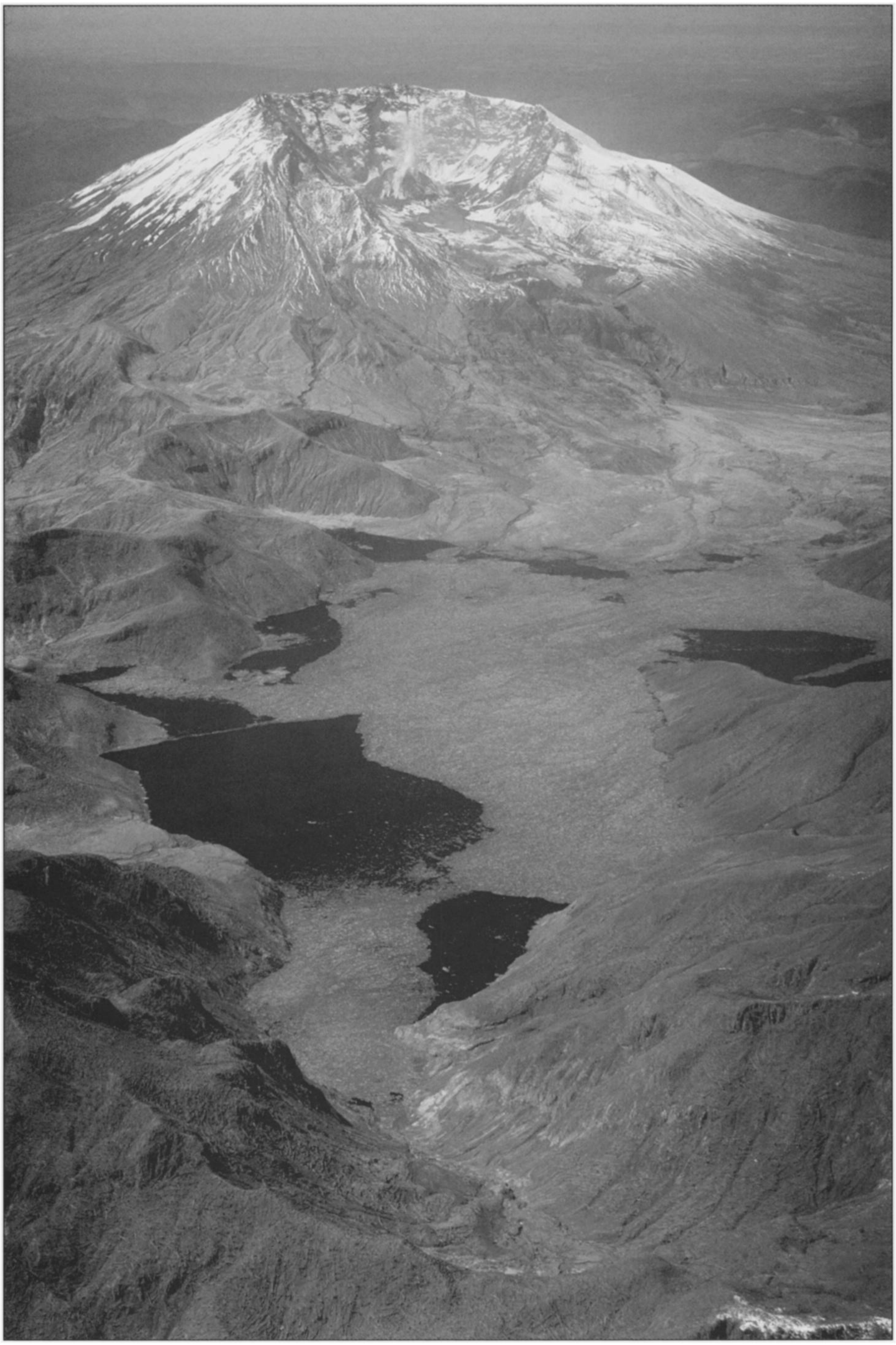
BY MID-1981, short-term emergency measures had restored the Columbia River ship channel and prevented major flooding on the Cowlitz-Toutle watershed, but volcanic debris from the Mount St. Helens avalanche continued to wash downstream. Efforts to stabilize the outflow had only begun. Corps planners were concerned especially about long-term erosion from the debris avalanche in the upper North Fork Toutle River valley, where water was flowing through 3 billion cubic yards of volcanic material. Initial estimates suggested that as much as 1 billion cubic yards might erode downstream during the next decade and settle in the Cowlitz and Columbia rivers. Emergency dredging had removed just over 100 million cubic yards of debris in the first year, indicating that dredging alone could not handle the amount of sediment projected for the future.

To prevent catastrophic loss from flooding and channel sedimentation, the Portland District's long-range recovery program proposed a number of measures to trap sediment before it could enter the Cowlitz and to stabilize Cowlitz riverbanks and monitor sediment infill. The Corps would continue to operate and maintain the existing Toutle River debris-retention structures and sediment stabilization basins and to monitor the North Fork, Toutle, and Cowlitz river channels and lakes formed in tributary drainages. The program proposed spending $939 million between October 1982 and October 1997 for the total package, providing construction, maintenance, and stabilization of flood-protection measures in the Cowlitz River basin.[34]

By May 1982, the Corps had expended $287 million on Mount St. Helens recovery efforts. Local interests and their congressional representatives pushed for quick approval of the Corps' expensive long-term plan, but the thought of spending another $900 million to prevent flooding in the Cowlitz-Toutle river basin and renewed plugging of the Columbia River ship channel shocked Reagan administration officials. The skeptical administration was determined to cut the federal budget by reducing government spending, so in May 1982 it directed the Corps to rethink its plans and prepare a comprehensive plan for long-term flood control and navigation. The president ordered the study completed within 18 months, and the chief of engineers allocated $1.25 million to cover its cost. The administration believed that the Corps' sediment transport estimates were too high and that more study would lead to a less expensive solution. According to William Gianelli, the assistant secretary of the army for civil works, the administration wanted "a more thoughtful orderly process for the solution to the Mount St. Helens' problem." Over the next several years, the Portland District would carry out the necessary studies and produce the reports for an acceptable long-range plan to deal with the Mount St. Helens recovery effort.[35]

THE CORPS' PORTLAND DISTRICT received generally high marks for its Mount St. Helens emergency response work. Trained to respond to disastrous floods and expert in dredging matters, Corps staff had swung into action quickly. The Portland District had mobilized dredges and with a round-the-clock effort reopened the Columbia River ship channel in a matter of days. At the same time, it had developed and implemented a plan to deepen the Cowlitz River channel, preventing future flooding as debris continued to wash down off Mount St. Helens. The emergency response took its toll on agency staff, however. Jerry Christensen, a Portland District section chief for civil and environmental engineering, later remembered, "We were working 10 to 12 hour days and six or seven days a week for the first two years."[36]

The Corps' $327 million emergency response — including dredging, building levee improvements, constructing two debris dams, and excavating sediment stabilization basins — required engineering expertise



A view of Mount St. Helens during the winter of 1980, showing the blast-devastated landscape north of the volcano. Debris deposits created by pyroclastic flows following the eruption in turn caused the unstable impoundments of water shown in the foreground.

combined with high-level planning and skilled project execution. The Portland District would continue to build on this solid engineering base as it planned and implemented a long-term response to the continuing sediment flow from Mount St. Helens. Washington Senator Slade Gorton praised the Corps' response: "The 1980 eruption unleashed massive destruction on the Pacific Northwest. The volcano ejected billions of cubic yards of debris, rock, mud, and ash; but this was only the beginning. The Corps responded immediately to the challenge of maintaining control in an uncontrollable time and region."[37]

The Corps' short-term response to the Mount St. Helens eruption demonstrated the effectiveness of a decentralized professional organization in a crisis of initially unknown proportions. Drawing on its long-standing engineering and planning expertise, the Corps' Portland District quickly devised and implemented an emergency dredging operation and then devised both short- and long-term solutions to the flooding and navigation problems resulting from the flows of volcanic debris. It had to formulate and carry out this emergency response, moreover, while carrying on the normal planning, construction, and operations work of a large civil works program over a region that embraced the Columbia and Willamette watersheds and the coastal harbors.

The Corps' leadership at the district level showed great initiative in modifying organizational structures and procedures in order to respond quickly to the effects of the eruption. The agency's engineers and planners improvised to cope with the massive emergency flooding and navigation issues. All the while, they gathered data on sediment flows so they could devise cost-effective strategies that would respond to the dangerous situation in the Cowlitz-Toutle watershed over time. Although the short-term measures were accomplished in a couple of years, development and implementation of the long-term solutions would require another decade.

Notes

1. Bruce L. Foxworthy and Mary Hill, *Volcanic Eruptions of 1980 at Mount St. Helen: The first 100 Days,* U.S. Geological Survey Professional Paper 1249 (Washington, D.C.: GPO, 1982), 44–114; Robert I. Tilling, Lyn Topinka, and Donald A. Swanson, *Eruptions of Mount St. Helens: Past, Present, and Future,* rev. ed. (Washington, D.C.: GPO, 1990), 10–33; Peter W. Lipman and Donal R. Mullineaux, eds., *The 1980 Eruptions of Mount St. Helens, Washington*, U. S. Geological Survey Professional Paper 1250 (Washington, D.C.: GPO, 1981), 378–458, 460–512, 577–99, 693–756; "Random Rubble," *The Military Engineer* (July 1990): 82–4; U. S. Army Corps of Engineers, *Mount St. Helens Eruption: The Challenge to Restore and Protect* (Portland, Ore.: Army Engineer District, Portland, Oct. 1981), 1–6.

2. Ibid.; quote in Don and Dianna Roberts, *Mount St. Helens, the Volcano of Our Time* (Portland, Ore.: Frank Amato, 1980), 7.

3. Foxworthy and Hill, *Volcanic Eruptions*, 64; Corps of Engineers, *Challenge to Restore and Protect*, 1–15; U. S. Army Corps of Engineers, *Mount St. Helens Recovery* (Portland, Ore.: Army Engineer District, Portland, 1990), 3–4. Col. Terrence Connell, "The Mount St. Helens Emergency," *The Military Engineer* (Sept.-Oct. 1980): 311–12.

4. Kenneth L. Holmes, *Mount St. Helens, Lady with a Past* (Salem, Ore.: Salem Press, 1980), 7–47; Foxworthy and Hill, *Volcanic Eruptions*, 1–14; Lipman and Mullineaux, eds., *1980 Eruptions*, 1–30; Tilling, Topinka, and Swanson, *Eruptions of Mount St. Helens*, 1–9.

5. Foxworthy and Hill, *Volcanic Eruptions*, 14–44, quote on 26.

6. This and the following three paragraphs are based on U. S. Army Corps of Engineers, *Annual Reports of the Chief of Engineers, 1880*, 2331; *1881*, 2600; *1886*, 1952; *1891*, 3371; *1900*, 4366; *1909*, 871, 2240; *1910*, 962–3, 2412; *1915*, 2000; *1938*, 1763; *1939*, 1948–86; *1978*, 37–8, 49, 53, 54; U.S. Congress, House, *Cowlitz River, Washington*, 60th Cong., 2nd sess., 1908, H. Doc. 1167; U. S. Congress, House, *Cowlitz River, Washington*, 61st Cong., 2nd sess., 1909, H. Doc. 404; Gordon H. Warren and David E. Kaufman, *Come Hell and High Water: Mt. St. Helens and the Federal Response on the Lower Cowlitz River*, report to the Bureau of Reclamation (Washington, D.C., Dec. 1982), 1–135.

Mount St. Helens before the eruption

7. The Corps, by statute, was accountable for preventing flood damage (PL 84-99 [1955]) and authorized to assist FEMA (PL 93-288 [1974]) with other disasters. Corps of Engineers, *Challenge to Restore and Protect*, 17–20; Colonel Connell, "Mount St. Helens Emergency," 312; J.F. Bechly, "Mt. St. Helens Eruption: Restoration of Columbia and Cowlitz River Channels ," paper presented at Texas A&M University Dredging Seminar, Nov. 6, 1980, 15–17; Col. Terence Connell, interview by William Willingham, June 26, 1985, in author's possession.

8. Tilling, et al., *Eruptions of Mount St. Helens*, 31, 34–9; Warren and Kaufman, *Come Hell and High Water*, 67–9; U. S. Army Corps of Engineers, Portland District, Public Affairs Office, "Mount St. Helens After Action Report," Aug. 1982; Colonel Connell interview; Corps of Engineers, *Challenge to Restore and Protect*, 20–1.

9. Bechly, "Mt. St. Helens Eruption," 19; Corps of Engineers, *Challenge to Restore and Protect*, 17–19; U. S. Army Corps of Engineers, *Advance Measures Report No. 10* (Portland, Ore.: Army Engineer District, Portland, July 1981), I-2/I-4; Todd Jennings, Lisa Mighetto, and Jill Schnaiberg, *Currents of Change: A History of the Portland District, U. S. Army Corps of Engineers, 1980–2000* (Portland, Ore.: Army Engineer District, Portland, 2003), 151–2; Colonel Connell, "Mount St. Helens Emergency," 312–13; Colonel Connell interview.

10. Ibid.

11. Bechly, "Mt. St. Helens Eruption," 19–23; Colonel Connell, "Mount St. Helens Emergency," 312; Corps of Engineers, *Challenge to Restore and Protect*, 23–4.

12. Corps of Engineers, *Challenge to Restore and Protect*, 23–9; Colonel Connell, "Mount St. Helens Emergency," 312–13; Bechly, "Mt. St. Helens Eruption," 23.

13. Ibid.

14. Portland District, Public Affairs Office, "Mount St. Helens After Action Report"; Warren and Kaufman, *Come Hell and High Water*, 73.

15. District environmental specialists completed the EIS in 25 days, using accelerated and abbreviated procedures. An EIS normally required 18 months to prepare. *Corps'pondent*, Sept. 1980; Corps of Engineers, *Advance Measures Report No. 10*, I-4/I-5; U. S. Army Corps of Engineers, *Final Environmental Impact Statement, Subject, Mount St. Helens Recovery Operations* (Portland, Ore.: Army Engineer District, Portland, Sep. 1980); Corps of Engineers, *Challenge to Restore and Protect*, 82.

16. Ibid. The Office of Environmental Review of the Environmental Protection Agency allowed reducing the normal 45-day review period to 22 days. The Corps filed the final EIS on September 19, 1980.

17. Corps of Engineers, *Challenge to Restore and Protect,* 30–6; Bechly, "Mt. St. Helens Eruption," 26.

18. Corps of Engineers, *Challenge to Restore and Protect,* 37; Bechley, "Mt. St. Helens Eruption, 26–30.

19. Corps of Engineers, *Challenge to Restore and Protect,* 38–44; Bechley, "Mt. St. Helens Eruption," 39; *Corps'pondent,* Sep. 1980.

20. Corps of Engineers, *Challenge to Restore and Protect,* 53–5, 81; Bechly, "Mt. St. Helens Eruption," 43; U. S. Army Corps of Engineers, *Mount St. Helens Eruption: Long-Term Program for Cowlitz and Toutle River Basins* (Portland, Ore.: Army Engineer Division, Portland, July 1981), 4.

21. Corps of Engineers, *Challenge to Restore and Protect,* 58, 63; Bechly, "Mt. St. Helens Eruption," 42–3.

22. Corps of Engineers, *Challenge to Restore and Protect,* 64, 80–1; Corps of Engineers, *Advance Measures Report No. 10*; Corps of Engineers, *Final Environmental Impact Statement.*

23. Ibid.

24. Ibid.

25. Corps of Engineers, *Challenge to Restore and Protect,* 69–70.

26. The emergency operations manager retained his authority for training flood-fight teams and developing emergency evacuation procedures with local authorities. Colonel Connell interview; Ken Ray, "Comments for Post Disaster Report," May 30, 1981, in author's possession; Pat Keough, interview by William Willingham, March 8, 1985, in author's possession.

27. Ibid.; quote from Ray, "Comments."

28. Corps of Engineers, *Advance Measures Report No. 10,* I-6; Corps of Engineers, *Long-Term Program for Cowlitz and Toutle River Basins,* 3.

29. Corps of Engineers, *Challenge to Restore and Protect,* 17–19; Corps of Engineers, *Advance Measures Report No. 10,* I-4.

30. Corps of Engineers, *Advance Measures Report No. 10,* I-3; Corps of Engineers, *Long-Term Program for Cowlitz and Toutle River Basins,* 5.

31. The Advanced Measures reports upon which the following paragraphs are based can be found in the Technical Library of the Portland District, U.S. Army Corps of Engineers. A convenient summary of these reports is contained in Corps of Engineers, *Advance Measures Report No. 10.* Advance Measures reports are Corps studies that identify and recommend responses to anticipated yet extraordinary events such as floods.

32. Corps of Engineers, *Advance Measures Report No. 1.*

33. Corps of Engineers, *Advance Measures Report No. 10.*

34. Corps of Engineers, *Long-Term Program for Cowlitz and Toutle River Basins,* 9–40. Planners estimated a benefit-to-cost ratio of 1.89 to 1.00.

35. U.S. Army Corps of Engineers, *A Comprehensive Plan for Responding to the Long-Term Threat Created by the Eruption of Mount St. Helens, Washington* (Portland, Ore.: Army Engineer District, Portland, Nov. 1983); Jennings, Mighetto, and Schnaiberg, *Currents of Change,* 154–8; Leonard Shabman and Douglas Woolley, "Responding to the Aftermath of the Mount St. Helens Eruption: Analysis and Communication of Risk," n.d., 1–24, paper in author's possession; "Random Rubble," 83–4; William R. Gianelli, interview by Marty Reuss, 1985, transcript, Office of the Chief of Engineers, Washington, D.C., 12, 41, 50–1, 86–7, 89, 98, quote on 87.

Mount St. Helens from Spirit Lake

36. Thomas Saarinen and James Sell, *Warning and Response to the Mount St. Helens Eruption* (Albany, N.Y.: State University of New York Press, 1985), 104, 108, 110–11; Colonel Connell interview; quote in Jennings, Mighetto, and Schnaiberg, *Currents of Change,* 154.

37. Quote in Jennings, Mighetto, and Schnaiberg, *Currents of Change,* 155.