M. Fliegel
2-8-84
From GSB
1-20C

United States Department of the Interior
GEOLOGICAL SURVEY
BOX 25046 M.S. 966
DENVER FEDERAL CENTER
DENVER, COLORADO 80225

IN REPLY REFER TO:

February 7, 1984

Dr. Robert E. Jackson
Chief, Geosciences Branch
Divison of Engineering
U.S. Nuclear Regulatory Commission
7920 Norfolk Avenue
Bethesda, Maryland 20014

Dear Bob,

Enclosed are copies of Geologic Hazards Bulletin 84-5, 84-7, and 84-8, and an internal review of "A Comprehensive Plan for Responding to the Long-Term Threat Created by the Eruption of Mount St. Helens, Washington" prepared by the Corps of Engineers. All of these documents are pertinent to the increased volcanic and seismic activity over the past few days of Mount St. Helens. I do not have a copy of the comprehensive plan but presumably one can be obtained from the Corps. I hope these reports are of use in your continuing evaluation of the Mount St. Helens problem.

Sincerely,

Ted

S. T. Algermissen

Enclosures

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Office of Earthquakes, Volcanoes, and Engineering

GEOLOGIC HAZARDS BULLETIN
Issue Number 84-5
(internal distribution only)

January 31, 1984, 2:30 p.m. (EST)

Mt. St. Helens, Washington

INFORMATION STATEMENT
Cascades Volcano Observatory
University of Washington

Measurements in the crater of Mount St. Helens show significant increases in the rate of spreading of the north and west sides of the dome over the last 10 days, and rates are now higher than at any time in the past year. Movement of the southeast sector, previously the most active part, has slowed and is now barely perceptible. Increased incandescence on the north and west sides of the dome and ground cracking on top of the dome have also been observed. Emission rates of sulfur dioxide gas have decreased in the last 10 days. Gas and ash events continue to occur several times each day, but have become more vigorous. Seismicity has generally been slightly elevated, occasionally decreasing to background levels. A crater seismometer and field observations indicate an increased number of small earthquakes and a shift in location from the south side of the dome to the north side.

The recent changes in activity in the north sector of the dome have increased the chances of a large rockfall or small lateral explosion from the north side of the dome. Rapid snowmelt from such activity could produce a mudflow north of the crater. More extensive mudflows could result if the snowpack thickens.

VOLCANO ADVISORY OF February 4, 1984, 7:45 p.m. PST

Shallow seismicity and ground deformation near the lava dome of Mt. St. Helens have accelerated since our previous statement of January 31. Many small earthquakes are occurring within and just beneath the dome. Much and possibly all of the dome and some parts of the crater floor are deforming. It appears that magma is rising beneath the dome at an increased rate.

The present activity resembles the preliminary signs of the episodic, dominantly non-explosive 1981-82 eruptions, superimposed on the continuous dome growth that began in February 1983. If the analogy to the 1981-82 eruptions is valid, we might expect a pulse of magma to rise close to or onto the surface of the dome within the next few days. A pulse rising through the dome would further deform it and increase the chance of a landslide or small explosion.

USGS Cascade Volcano Observatory
University of Washington, Geophysics Program

Office of Earthquakes, Volcanoes, and Engineering

GEOLOGIC HAZARDS BULLETIN
Issue Number 84-8
(internal distribution only)

February 7, 1984, 6:30 a.m. (EST)

Mt. St. Helens, Washington

VOLCANO ALERT UPDATE (issued February 6, 1984, 9:10 p.m. PST)
U.S. Geological Survey Cascades Volcano Observatory, Vancouver, WA
University of Washington, Geophysics Program, Seattle, WA

At 8:16 p.m. PST (Monday, February 6) a small landslide from the east side of the lava dome reached the east crater wall and has caused minor snow melt. No mudflow has occurred. A plume with a little ash rose to 13,000 ft and is drifting to the east. This probably marks the onset of the expected eruptive pulse; further activity including rock avalanches, slow lava extrusion, and small explosions may follow over the next few days.

Office of Earthquakes, Volcanoes, and Engineering

GEOLOGIC HAZARDS BULLETIN
Issue Number 84-7
(internal distribution only)

February 6, 1984, 7:30 a.m. (EST)

Mount St. Helens

VOLCANO ALERT (issued February 5, 1984, 9:45 p.m. PST)
Cascades Volcano Observatory
University of Washington

Frequent earthquakes and rapid expansion of the lava dome indicate that an eruptive pulse is likely to begin within the next 48 hours, probably within the next 24 hours. Similarities to seismicity before the eruption of March 19, 1982, suggest that an explosive onset is likely. Such an explosion, were one to occur, could affect areas within a few miles of the dome, but would probably not pose hazards to nearby communities.

Review of "A Comprehensive Plan for Responding to the Long-Term Threat Created by the Eruption of Mount St. Helens, Washington"

by

U.S. Geological Survey

January 4, 1984

The eruption of Mount St. Helens in May 1980 altered the geologic and hydrologic conditions in the immediate vicinity of the volcano to the extent that threats to public safety and welfare continue unchecked or unresolved. The salient problems are the stabilization of the water level of Spirit Lake and sediment control in nearby drainage systems. The Corps of Engineers has prepared and published "A Comprehensive Plan for Responding to the Long-Term Threat Created by the Eruption of Mount St. Helens, Washington," and has invited comment on this plan. The Comprehensive Plan presents various options for engineering actions to solve or mitigate the problems of lake stabilization and sediment control at Mount St. Helens.

The purpose of this paper is to provide a review of the Comprehensive Plan to the Corps of Engineers by the U.S. Geological Survey. We address only geologic and hydrologic matters, fully recognizing that other considerations must be included in decisions on options presented in the Comprehensive Plan. Nevertheless, we hold the general opinion that geologic and hydrologic issues, although they may have been considered in the development of the Plan, are not fully acknowledged and weighed in the discussions of the various options presented in the Plan. This paper is presented with the goal of ensuring that decisions on solutions to the remaining problems at Mount St. Helens are made with a full understanding of geologic and hydrologic considerations.

Our general concern is that the violent eruption and massive sediment flows of May 18, 1980, are viewed as a singular event after which the mountain and its associated drainage system will return directly and rapidly to a preeruption state. Unfortunately, scientific measurements and observations at Mount St. Helens and at other active volcanoes indicate that the major eruption marks the beginning, not the end, of a period of geologic and hydrologic instability.

Thus the geologic and hydrologic processes of concern can be expected to remain active for an extended period.

Our geologic concerns are based upon detailed studies of the volcanic deposits and landforms created by Mount St. Helens over the last 4,500 years, and upon our ongoing monitoring of ground deformation, gas emissions, and seismicity. Our hydrologic concerns are based upon time-sequential aerial photographs, measurements of daily water and sediment discharge at a number of stations, and periodic measurements of stream channel geometry at sites throughout the Toutle-lower Cowlitz and Smith-Muddy River systems.

The dome in the crater of Mount St. Helens has grown continuously since early February 1983. This growth, although mostly passive, is punctuated by mildly explosive steam and ash emissions that deposit ash on the crater floor and adjacent flanks of the volcano. As the dome grows, it becomes unstable and increases the possibility of collapse accompanied by hot block-and-ash flows. Continued differential compaction of the debris avalanche deposit is indicated by new surficial collapse pits and frequent microearthquakes within the deposit. Larger earthquakes continue to occur in a linear seismic zone that passes under Mount St. Helens and just west of Spirit Lake. Headward extension and enlargement of gullies on the downvalley face of the Spirit Lake blockage started again with the onset of autumn rains. During low intensity storms in early November 1983, the amount of sediment transported by the North Fork and the main stem of the Toutle River was equal to or slightly greater than that typically transported by the same range of water discharges during the 1981 through 1983 water years. During these storms, the larger channels on the debris avalanche completely reworked their beds and gave rise to bank erosion from a few tenths of a meter, to slightly more than 10 meters. Considerable fill occurred in the dredged reach of the Cowlitz River near Castle Rock and other places. Clearly the processes that began abruptly in May 1980 are still active.

SPIRIT LAKE STABILIZATION

The threat from volcanic, seismic, and erosional activity is discussed in a number of places throughout the Comprehensive Plan, and it is obvious that the Corps has recognized the possibility of both future eruptions and earthquakes. However, because the announced preferred solution to lowering the level of Spirit Lake is a partially-buried conduit within the debris avalanche, and because, in our view, this solution is particularly vulnerable to future volcanic, seismic, and erosional activity, we discuss below the potential impact of these three types of activity at Mount St. Helens.

Volcanic Problems--Mount St. Helens entered an eruptive period in 1980. Once an eruptive period begins, the frequency of all types of volcanic events is much greater than implied in the Appendix to the Plan. We must point out that during an eruptive period, there is a continuing strong likelihood of volcanic events whose products and effects would reach the site of a construction project on the debris avalanche.

We concur that a large directed blast or debris avalanche, such as those of May 18, 1980, is highly improbable within the next few decades. However, other phenomena that occurred on May 18, particularly pyroclastic flows, are possible. The pyroclastic flows of May 18 had a volume of at least 160 million cubic yards; the successive additional eruptions through the summer and autumn emitted from 1 to 13 million cubic yards each. The distribution of these deposits indicates that any pyroclastic flow of more than 5 million cubic yards would probably affect a construction site on the debris avalanche.

The volcano has remained episodically active since 1980 and continuously active throughout 1983. This activity has been largely nonexplosive and has offered risk only to activities within and near the summit crater. However, comparison with similar volcanoes elsewhere in the world (such as some in Indonesia, Central America, and Kamchatka (USSR), that demonstrate sustained growth of lava domes) suggests a high probability that the quiet activity will be interrupted periodically by explosive eruption of pyroclastic flows and airfall tephra, as well as by collapse of parts of the lava dome resulting in hot block-and-ash avalanches and possibly lateral explosions. If any of these events were to occur at a time of heavy snowpack, the consequences would include floods and lahars generated by rapid snowmelt. An example occurred on March 19, 1982, when a small explosion triggered a lahar and flood because of snowpack.

The term lahar is applied to a broad range of debris flows and mudflows that result from volcanic activity.

The Comprehensive Plan indicates that the excavation for the conduit through the debris avalanche will not be completely refilled, and that an open trench would remain. A possibility exists for material from either pyroclastic flows or lahars to be deposited in the open trench, with substantial consequences. Pyroclastic flows have high emplacement temperatures, generally between 600 and 900 degrees Celsius, depending on volume and rate of transport. Sufficient concentration of this hot material in a trench, to thicknesses of many tens of feet, would have consequences that have not yet been fully considered. For example, we are not certain what the physical effects would be on the pipeline itself, protected by only 15 feet of fill. Presumably, this would be enough to protect it from actual mechanical damage. On a few occasions, however, channelized pyroclastic flows are known to have eroded their bed. Another possible set of problems relate to the temperature that might be attained by water within the pipe, following the emplacement of a pyroclastic flow in the open trench. Several questions arise: Would the water boil? How long would this take? Would the pipe withstand the pressures generated?

The ground-water table continues to rise and the floor of the trench may eventually lie below the general level of the ground-water table in the blockage. If so, the emplacement of hot material in the trench would probably result in phreatic explosions, such as occurred in the same area for many months following May 18, 1980, again in March 1982, and later as a result of the discharge from pumping that began in late 1982. We don't know whether such explosions would damage the pipeline or how they might affect repair efforts if damage were to occur. But the explosions should be recognized as a likely consequence if a hot pyroclastic flow were to be deposited in a largely unfilled trench.

A further consideration is that any pyroclastic flow deposited in the trench would remain hot for a prolonged period; interior parts of the pyroclastic flows of 1980 were still at temperatures far above boiling in 1983. Thus if a pyroclastic flow were to cause damage to the facilities, repair and restoration might have to proceed in a hot environment. This potential problem should be considered in assessing the feasibility of a pipeline across the blockage.

Lahars can be generated by several different processes, including those strictly related to weather (rapid high precipitation, rain falling on snowpack, rapid thawing of snowpack) and those induced by volcanic activity. Turbulent admixing of hot particulate matter with snow will generate a lahar through rapid melting and incorporation of the particulates in the meltwater. Although any of the lake stabilization plans could sustain damage from a large lahar, the alternatives on the debris avalanche are particularly vulnerable because of their position in a potential path of flow. An open trench on the debris avalanche could channel and focus a lahar just as it could a pyroclastic flow, increasing downstream damage.

Volcanic events do not lend themselves readily to probability analysis because of the very brief historic records, the highly variable nature of volcanic activity, and the fact that eruptions are not random in time but occur in clustered groups. Thus it is difficult to provide reliable probabilities for any of the classes of events discussed in the preceding paragraphs. Nonetheless, an attempt is made here to estimate the probability of pyroclastic flows and lahar events. A small event, such as the lahar that occurred on March 19, 1982, can be estimated to have an annual probability of about 0.2, based on a frequency of an appropriate volcanic event of one every 2 years, and a 5-month per year duration of sufficient snowpack. A tentative projection can thus be made of as many as 10 such events (with a possible range of 5 to 15) during the estimated 50-year lifespan of the project. The event of March 19, 1982, would have placed the buried conduit project in considerable jeopardy, although the amount of resulting damage would be uncertain. This event was small owing to small volume of ejecta, light snowpack, and low moisture content of snow. A more voluminous lahar could be expected if any of these factors were larger. Furthermore, the duration of snowpack in the crater has been increasing, and in 1983 some snow fields on the crater floor with thickness as great as 30 feet remained through the entire summer.

The probability of a pyroclastic flow of the size of that of which occurred on June 12, 1980, is more difficult to estimate. With due allowance for the uncertainties, and drawing heavily on the prehistoric record of Mount St. Helens and similar volcanoes, we might estimate that at least one, and as many as three, such events will occur within the next 50 years. Such an event could produce many of the more serious consequences described above, including possible damage to the buried pipeline itself. The June 12 flow had a volume of about 13 million cubic yards (mcy). If a pyroclastic flow of this size is erupted on snowpack, the resulting lahar would be many times the volume of that of March 19, 1982. The probability of larger pyroclastic flows, such as those of the size of May 18, 1980, is small but distinct. Within the constraints described above, we might estimate that a pyroclastic flow, or closely spaced series of flows, totalling about 100 mcy would have a 20 to 50 percent chance of occurring within the 50-year lifespan of the project.

It can be argued that insufficient data are available to defend the frequency of events outlined in the above paragraphs. However, based on a consideration of the behavior of both Mount St. Helens and similar volcanoes on a worldwide basis, and allowing for the many uncertainties, we feel that these estimates are reasonable. More importantly, we would find it extremely difficult to scientifically justify an assumption that allows for only a single volcanic event of sufficient magnitude to interfere with the workings of the buried conduit alternative.

The Corps analysis summarized on pages E-59 and E-60 allows for volcano-induced damage, but assumes only a single, relatively small-damage event. As the above discussion illustrates, more events are possible, and some may be of much larger volume and produce greater consequences than is considered in

Table E-9[1]. To reiterate, pyroclastic flows and lahars within the expected volume range could engulf the trench containing the buried conduit and could damage or destroy the conduit inlet works, positive closure structures, impervious barriers, and stilling basin, rendering the project inoperative for an extended period. Such events could also deposit new material on the bed of Spirit Lake, raising the water level. This contingency was considered in selecting the safe level, but it would be of added concern, and would reduce the margin of safety, if it were to occur while the flow of water was interrupted.

It seems likely that the estimated one-time repair cost given in Table E-9 would not be sufficient to correct damages which would result from a major pyroclastic flow or lahar event, to say nothing of the damages if several such events were to occur. We conclude that the annual costs allotted for repair and maintenance are considerably less than would most likely be experienced.

Earthquake Problems.--A seismic zone about 60 miles long trends north-northwest through Mount St. Helens and passes near the site of the proposed buried conduit. During recent decades, several significant earthquakes have occurred along this zone; the largest of these was of magnitude 5.5 on February 14, 1981. Seismologists of the USGS and the University of Washington consider that the seismic zone is capable of producing an earthquake of between magnitude 6 and 7. The Comprehensive Plan recognizes the seismic risk; it is an element of the comparison matrix and is, along with volcanic risk, among the disadvantages listed for the buried conduit alternative.

1/ All references to figures and tables are to those in the Plan of the Corps of Engineers.

Definitive data are not yet available to anticipate the response of the material of the debris avalanche to an earthquake of magnitude 6 or greater. Instruments were emplaced this past summer in an experiment designed to help determine the response. However, the experiment depends on the actual occurrence of a number of earthquakes of various magnitudes, from which projections can be made to estimate the dynamic response of the avalanche to large earthquakes. Current public concerns will not allow the decision on a preferred solution to wait for nature to perform her part of the experiment. Even so, the construction of a conduit in the unconsolidated, heterogenous material of the debris avalanche in which there has not been time for natural settling and compaction, and which lies in a known earthquake zone, seems fraught with uncertain consequences.

Members of our Engineering Seismology Branch have analyzed the possible consequences of seismic activity on a buried conduit. If a magnitude 6.5 earthquake were to occur on the Elk Lake seismic zone with an epicenter within 10 kilometers of the conduit, the resulting linear strain on the conduit would range between 10^{-3} and 2×10^{-3}. The result, on a 4,800-foot conduit, would be a potential displacement between the two ends of 5 to 10 feet. This strain was computed by a response analysis based on known properties of the material in the debris avalanche, the expected wave length and other properties of the seismic waves, the character of typical ground motion, and the amounts of displacement observed in earthquakes of this size. The Comprehensive Plan does not include a discussion of engineering measures that might be developed to deal with this type of strain.

The consensus judgment, based on studies of the debris avalanche by both the Corps and the USGS, is that the debris avalanche as a whole is strong enough to withstand any expected earthquake. Massive liquefaction or other types of total failure are unlikely. However, owing to the still uncompacted character of the deposit, its heterogeneous character (including lenses of readily liquefiable material), and a still-rising water table, local pockets of liquefaction could be induced by a strong earthquake. The conduit could be disrupted if such liquefaction were to occur nearby. Even though plans for the conduit include artificially compacting the underlying bed, during strong earthquakes artificial landfill and abruptly-emplaced debris shake more violently than nearby bedrock.

Erosion Problems--Discharge from Spirit Lake will inevitably influence erosion along the receiving stream (North Fork Toutle River, South Fork Coldwater Creek, or Smith Creek). The degree of erosion will differ significantly from one stream to another. The impact along any of the streams will depend upon the manner in which the lake is drawn down to 3,440 feet, the degree to which seasonal fluctuations in flow are controlled, and the degree to which energy dissipation, sediment traps, and riprap are employed.

The erosional consequences of Spirit Lake discharge are addressed in a number of places in the Comprehensive Plan. The degree to which each alternative minimizes the sediment yield from debris avalanche erosion is an element in the comparison matrix (Table VII-I). The preferred alternative, the buried conduit within the debris avalanche, rates poorly (5) in minimizing sediment yield. Inasmuch as sediment yield affects the stability of the debris blockage, the integrity of the buried conduit, and the choice of sediment retention strategies, we are concerned whether the decision fully considered the debris avalanche erosion problem.

On page E 9-11, a discussion is presented on the consequences of diverting Spirit Lake drainage to South Coldwater Creek. General concerns over the long-term stability of the Coldwater Lake blockage are discussed. The erosion due to the additional flow from Spirit Lake, if this alternative were to be selected, would further decrease the stability of the blockage. Thus we agree with the report's assessment of the problems with this alternative.

At present the discharge from Spirit Lake is pumped into the North Fork Toutle River. A buried conduit through the debris avalanche would essentially make this the permanent route of discharge. In effect, this arrangement brings the flow from Spirit Lake across the steepest, thickest, and most erodible part of the debris avalanche. While it is difficult to quantify the long-term consequences, this routing clearly intensifies erosional problems around the Spirit Lake, Coldwater Lake, and South Castle Lake blockages, and has the potential to bring very high volumes of sediment into downstream areas.

The Plan does not document the extensive erosion which has accompanied the present pumpage from Spirit Lake. Analysis of this erosion should be undertaken to provide an indication of the potential effects of permanent drainage through a buried conduit in the debris avalanche. In this connection, however, it must be recognized that the pumpage to date has been maintained at a constant rate of 180 cubic feet per second (ft^3/s). Gravity flow through a permanent buried conduit would fluctuate in response to variations in lake inflow, and would reach peak flows substantially higher than 180 ft^3/s, generating correspondingly greater erosion.

We also note that if the trench is not completely backfilled, ground-water seepage and surface-water drainage patterns can be expected to develop along its surface, increasing the chances for piping and slope failures. In general, the location of the buried conduit will increase opportunities for erosion of the debris pile.

Discharge of Spirit Lake into Smith Creek would induce accelerated erosion of the blast pyroclastic flow deposits along the upper Smith Creek Valley. However, there appears to be much greater potential for downstream attenuation of negative impacts along Smith Creek than along South Coldwater Creek or along the North Fork Toutle River. Moreover, erosion in the Smith Creek drainage poses no threat to the stability of the lake blockages.

Water-Quality Problems--The impact of Spirit Lake discharge on the chemical and biological quality of alternative receiving waters is addressed to a limited extent in the Plan. Elevated concentrations of oxygen-consuming and toxic chemicals as well as potentially pathogenic bacteria in the once essentially anoxic waters of Spirit Lake have been documented. Chemical constituents of concern include phenolic compounds, hydrogen sulphide, reduced iron and manganese, reduced trace metals, ammonia, N_2O, dissolved organic nitrogen, and carbon, CO, methane and H_2. Bacteria of concern includes Legionella sp., Klebsiella pneumonia, and Pseudomonas aeruginosu. Conditions favorable for development of these chemicals and organisms exist in the seeps draining the organic-rich blast pyroclastic flow deposits in South Coldwater Canyon and upper Smith Creek as well as at Spirit Lake. Water quality in South Coldwater Canyon and upper Smith Creek is not as well documented as at Spirit Lake.

U.S. Forest Service and Oregon State University scientists have documented the remarkable rate of improvement in water quality at Spirit Lake. Considerable seasonal variation exists, but specific conductance and bacterial concentrations are significantly lower, dissolved oxygen and transparency are significantly greater than in 1980. A sizeable population of zooplankton now inhabits the lake. Moreover, these scientists expect these trends to continue even though the lake still retains an enormous amount of organic debris.

All of the potential receiving water streams have steep gradients and irregular channel patterns that should cause rapid mixing and aeration, and all exhibit rapid downstream expansion of drainage area, providing the potential for dilution. In summary, therefore, the chemical and biological quality of Spirit Lake (particularly the surface layer) have improved markedly since 1980, and downstream aeration and dilution should rapidly reduce the concentration of harmful substances in receiving waters.

If the Smith Creek tunnel alternative were to be selected, additional water-quality problems could be caused by ground-water drainage. The tunnel alinement crosses a mineralized contact zone between diorite and metavolcanic rocks. Since pyrite and other sulfite minerals are common in this zone, the potential for acid drainage exists.

Prior to the eruption, the 2-year recurrence, 7-day low flow from Spirit Lake was 30 ft^3/s, while that for the Toutle River near Silver Lake was 369 ft^3/s. Our data indicate that the drastic change in basin hydrology wrought by the 1980 eruption has apparently not significantly changed this ratio. In August 1983, the Spirit Lake pumps were closed for maintenance and no water was released from the lake. However, if Spirit Lake had been freely draining during that month, it would have accounted for 14 percent of the flow above the Green River, 9.7 percent of the flow at Kid Valley, and only 7.5 percent of the flow at Tower Road bridge. Thus, the contribution of Spirit Lake to the low flow of the Toutle remains small, and the associated benefit to fisheries or water use is correspondingly small. In contrast, some of the sediment problems discussed previously would pose a substantial threat to fisheries.

Summary--On page E-59 of the Plan, very serious disadvantages are cited for the alternative of a buried conduit to the North Fork Toutle River. The report points out that this alternative is vulnerable to future eruptive and seismic events, that it would increase erosion of the debris avalanche materials, that it would increase the disturbed areas of the debris avalanche, and that it is not flexible. We agree fully with this evaluation. In terms of flexibility, this alternative provides only for a fixed lake level of 3,440 feet; thus should future contingencies require a change in lake level, it could not readily be accommodated.

In view of the distinct potential for adverse impacts from volcanic activity, a large earthquake, or accelerated erosion, we think that the decision to select a drainage route through the debris avalanche requires further analysis. The reasons for the assumption of the risks associated with this alternative, and the advantages and costs of mitigating or avoiding those risks, need to be clarified. A discussion seems merited of the disadvantages of the other alternatives that caused them to be rejected in favor of one more vulnerable to volcanic, seismic, and erosional activity.

SEDIMENT MANAGEMENT STRATEGY

The Plan presents the conclusion based on a consensus of professional experts that at least 1 bcy of sediment will be eroded from the debris avalanche in the next several decades. The Geological Survey believes that the estimate may be low because our data suggest that the equilibrium channel gradient may be less and the final channel width greater than those assumed in arriving at the consensus. Various conceptual models have been used to estimate the rate and duration of erosion. The Geological Survey model differs from other models in having lower initial erosion rates, a period of accelerating erosion during the development of integrated drainage, and a longer period of elevated sediment discharge.

The Plan assumes that sediment yields would average 50 mcy for 10 years and then decrease exponentially with time. The normal yield is difficult to establish because there have been no major storms since 1980. Therefore, a long-term trend cannot be extrapolated from the record since 1980. Our investigations of sediment yields have shown that normal yields are expected to be in the range of 30-60 mcy per year through 1985; 15-50 mcy, 1986-1995; and 10 mcy per year, 1996-2005. However, observation in high sediment yield terrain in northern California, Japan, and New Zealand indicates that yields during extremely wet years often exceed yields during normal years by 2-5 times. In the previous section of this report, we expressed concern that these yields could be increased as a result of the construction on the debris pile.

Our analysis suggests that sediment yields of the same magnitude as the normal yield could be generated in a short period of time by major volcanic, seismic, and hydrologic events. Hence, the sediment yield from a single major volcanic, seismic, or hydrologic event in combination with the normal yield could completely fill certain of the structures in a very short period of time. Were this to occur, it would appear that additional sediment would bypass the structures and be transported to the Cowlitz and Columbia Rivers. Therefore, it would be prudent to provide a large increment of storage (100 mcy or more) as early as possible during the construction sequence, to accommodate the possibility of a major event--particularly until we know more about the behavior of the debris pile and volcanic and seismic activity at Mount St. Helens.

In reviewing the report, we noted the proposed construction sequence of the sediment retention structures and the time required to complete the construction. Considering the multiple retention structure (MRS) alternative, the first structure, LT-3, would take 3 years to complete and store only 64 mcy. If LT-3, Kid Valley, and Green River are constructed sequentially, the total time to complete the system would be 12.5 years. The first stage of the alternative single retention structure (SRS) at Green River would take 3.5 years to construct and would store 252 mcy. Three planned subsequent stages could each be completed in 1 year and add 209, 160, and 91 mcy respectively for a total of 712 mcy. We understand that the SRS could be further enlarged if required to handle an excess of 1 bcy.

In the MRS without dredging, Kid Valley Stage 1 (272 mcy) and Green River Stage 1 (190 mcy), appear to offer sufficient capacity to store the sediment generated by a major event. In the SRS, Green River Stages 1, 2, and 3 with incremented capacities of 252, 209, and 160, would also provide sufficient capacity.

A further point which should be considered is that the negative impacts of downstream sediment transport can be minimized by controlling the sediment as close to its source as possible. The dominant sediment source for the Toutle

River is rapid channel erosion and streamside landslides on the massive North Fork Toutle debris avalanche deposit. Most of the gravel-size sediment is deposited along the Toutle River. However, the lower North Fork and main stem of the Toutle River are not simple sediment traps or conduits. The sediment derived from the debris avalanche causes channel instability and widespread streambank erosion as well as local scour and aggradation. These processes destroy roads and flood plain property as well as adding to the total sediment load. A sediment management strategy in which the sediment is impounded as closely as possible to its source would serve to minimize these effects.