KING COUNTY FLOOD CONTROL DISTRICT

King County
Department of Natural Resources and Parks
Water and Land Resources Division

Green River
External Advisory Review Panel Report

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GREEN RIVER EXTERNAL ADVISORY REVIEW PANEL REPORT

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Prepared for:

King County Department of Natural Resources and Parks
Water and Land Resources Division
River and Floodplain Management Section
201 South Jackson Street, Suite 600
Seattle, WA 98104
www.kingcounty.gov/environment/waterandland/flooding.aspx

Prepared by:

TETRA TECH

Engineering & Architecture Services
1420 Fifth Avenue, Suite 600, Seattle, WA 98101-2357
Tel 206.883.9300 Fax 206.883.9301 www.tetratech.com

and Associated Firms

Tetra Tech Project #135-12539-09001-06

King County Flood Control District
King County Water and Land Resources Division
Green River External Advisory Review Panel Report

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EXECUTIVE SUMMARY

The U.S. Army Corps of Engineers has reduced the flood-control storage volume available at Howard Hanson Dam in response to structural problems observed at the dam in early 2009. The reduction may persist for three to five years and presents a potential for increased flooding along the Green River downstream of the dam. In light of this increased flood risk, King County commissioned an independent review of its current flood hazard management plan for the Green River. An expert review panel was asked to respond to specific policy questions and to provide any other warranted recommendations for flood risk reduction along the Green River in light of changed operations at the Howard Hanson Dam.

BASIN AND RIVER DESCRIPTION

The Green-Duwamish River basin is located entirely within King County. The river flows through several cities, including Auburn, Kent, Renton, Tukwila and Seattle. The basin is divided into four sub-watersheds: upper watershed above Howard Hanson Dam; Middle Green; Lower Green; and the Duwamish estuary. Green River flood hazard mitigation strategies in the *2006 King County Flood Hazard Management Plan* primarily focus on two of these sub-watersheds (see Figure ES-1):

- The Middle Green River runs from the outlet of the Green River Gorge at about River Mile (RM) 45 near Flaming Geyser down to Auburn at about RM 31
- The Lower Green River runs from Auburn down to the Duwamish River at RM 11.

Major structural flood risk reduction features along the Green River include Howard Hanson Dam, which is in the upper Green River sub-watershed, and the levee system that lines the riverbanks along much of the Lower Green River and along portions of the Middle Green River. Howard Hanson Dam and the levee system combine to reduce flooding in the lower river to a fraction of its historical magnitude. The dam is designed to store over 100,000 acre-feet, converting large storm flows to a flow at the Auburn flow gage equivalent to the 2-year pre-dam event—12,000 cubic feet per second (cfs). The capacity of the leveed portion of the river is approximately 12,800 cfs, with approximately 2 feet of freeboard in most locations.

Since 1962, dam operations in combination with King County's Lower Green River levees have contained most major river flood events from Auburn downstream to the mouth of the Duwamish River. Prior to construction of the dam in 1962, the river exceeded the target 12,000 cfs 15 times since 1932. It is estimated that without the dam, the flows on the Green River would have exceeded this flood threshold 17 to 22 times since 1962.

REVIEW PANEL FINDINGS

King County provided the review panel with a specific set of issues and questions to address. Panel members reviewed materials provided by King County and then convened for a two-day workshop on October 19 and 20, 2009, including field visits to four Green River levees. Following the workshop, panel members continued to coordinate and prepare conclusions and recommendations.

The following sections summarize the review panel’s findings. Recommendations developed represent majority opinions of the review panel, although minority views were expressed throughout the review process. Panel conclusions and recommendations in this report should not be understood as consensus findings unless specifically identified as such.

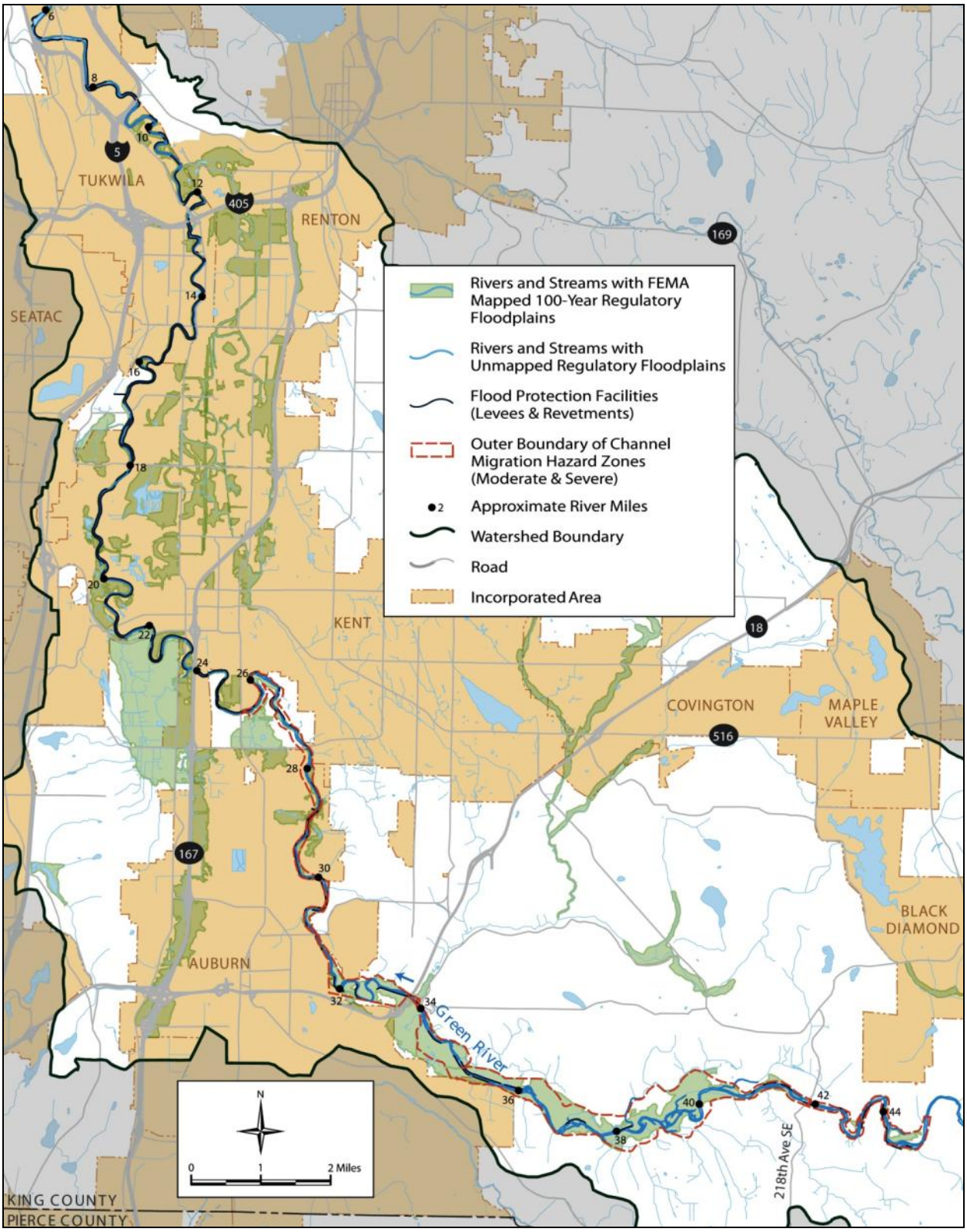

Figure ES-1. Lower and Middle Green River Basin

Core Concepts and Strategy Recommendation

The panel identified the following core concepts that needed to be discussed and understood in order to address several of the questions provided by King County:

- **Long-Term Goals for Flood Hazard Management**—The panel views King County's 2006 Flood Plan as being based on sound principles that should be reflected in all future actions of King County and its partners. Of particular merit are the following guiding principles outlined in the 2006 Flood Plan:
  - The primary purpose of the recommendations in the plan is to reduce risks to public safety and financial losses from flooding, while taking into account other floodplain uses such as existing development, fish and wildlife habitat, agriculture and recreation.
  - A river and its valley floor constitute a corridor through which floodwaters flow and within which opportunities exist for various land uses.
  - Protecting and working with, rather than against, natural riverine processes generally will reduce flood risks to people and property in a less costly manner than traditional structural approaches to flood hazard management while also benefiting native fish and wildlife and preserving aesthetic landscapes."
- **The Need to Reflect Change**—While flood hazard management planning efforts in the past may have been consistent with conditions in the valley at the time of those efforts, circumstances have changed enough to prompt an assessment of past practices and their appropriateness for current and future conditions. The review panel's discussion of changing conditions in the Green River valley is summarized as follows:
  - Possibility of Long-Term Future Flows Larger than 12,000 cfs—Even though repairs at the dam are estimated to be completed in about five years, other occurrences could arise in the future that again expose the Lower Green River to higher floods. For example, damage from an earthquake could prevent dam operation, or repairs being undertaken now could fail to provide a long-term permanent solution.
  - Extensive Development in the Green River Valley—A recent analysis by the Federal Emergency Management Agency (FEMA) estimates that Green River valley flood damage from a levee breach with flows of 12,000 cfs could total $3.77 billion and displace up to 21,900 residents. Based on the regional economic importance of the Green River valley, the review panel believes that long-term planning for the Green River levee system should assume flood flows higher than 12,000 cfs.
  - Environmental Concerns—Environment concerns were limited when the Howard Hanson Dam was constructed. Today a broad range of environmental programs affect construction and maintenance of dams, levees, and all types of development. FEMA and its partners now must undertake a broad range of activities concerning potential impacts of floodplain hazard management matters upon endangered species.
  - Climate Change—Climate change will significantly increase mean annual temperatures and resulting runoff from snow pack, although the magnitude of hydrologic impacts in Washington and, more specifically, on the Green River basin, remain to be seen. The Washington legislature has passed a bill requiring state agencies to develop an integrated climate change response strategy by 2011.
- **Condition of the Existing Green River Levee System**—The structural stability of the levee system cannot be easily quantified. Important levee-condition information to understand as part of flood hazard management planning includes the following:

- History of Levee Construction and Repair—Most of the Green River levees were constructed in the 1960s and 1970s using crane and dragline methods. Prior to 1990, repairs emphasized placing large amounts of riprap on damaged levees. Since the 1990s, repairs have instead emphasized biostabilization. Additional emphasis has been placed on installing thickened toe buttresses to increase resisting forces. Riverside slopes are flatter or mid-level benches are added to achieve an overall flatter slope angle.
- Uncertainty of Existing Levee Conditions—Inherent in the review panel discussion regarding consideration of higher flows is the need for a system-wide assessment of the levees' ability to contain flows and to withstand overtopping without washing out from backside erosion. The levee system must be sufficiently investigated to document system-wide knowledge of the levee's structural integrity.

Based on the discussions about the three core concepts, the review panel recommends the following elements for a future planning strategy:

- **Floodplain Management Should Consider a Wider Flood Corridor**—The review panel believes that a long-term strategy needs to be more aggressive in identifying a plan to create a much wider river corridor. Moving levees farther from the channel would provide many advantages over the current, more constraining levee network, such as reduced flood elevations and flow velocities.
- **Future Management Should Use a Risk-Based Approach**—The review panel supports King County's continued use of a risk-based approach to identifying and prioritizing floodplain management projects. A risk-based approach to floodplain management should clearly measure the pre-project and post-project risk, so that the net risk reduction of one project can be compared to another for prioritization.
- **Future Management Should Be Multi-Objective**—Future management strategies should simultaneously address environmental concerns and flood risks. Local government wetland, floodplain, and other critical area and open space plans should be supported.
- **Regulatory Authority Must Be Adapted for Floodplain Management**—The Green River and its floodplain are continuous physical features, but jurisdiction and regulatory authority for development along the river are divided among King County and neighboring cities. Currently, there is no consistency in the scope of floodplain management regulations among the jurisdictions. The panel recommends that King County consider the following:
  - Strengthen the definition of "regional consistency" in the 2006 Flood Plan to include regionally acceptable/applicable higher regulatory standards.
  - Establish ramifications for the lack of consistency under the 2006 Flood Plan.
  - Establish incentives for municipalities to adopt the 2006 Flood Plan or regional policies consistent with those in the plan.
  - Consider expanding the regulatory scope of the King County floodplain management program into areas with identified exposure to residual risk.
- **Levee Design Considerations and Need for Ongoing Monitoring**—Some of King County's levee design approaches for the Green River differ from design approaches implemented by the Corps of Engineers. Because of these differences, the review panel believes that monitoring of levee performance is needed. A monitoring program would provide a more formalized process under which observation of results can lead to changes in a management approach. This recommendation is consistent with the review panel's

Summary of Panel Responses to Questions

Table ES-1 presents the issues and questions that King County asked the review panel to consider, along with a summary of the panel's response to each question.

TABLE ES-1.
SUMMARY OF REVIEW PANEL RESPONSES TO KING COUNTY QUESTIONS

Question	Summary of Panel Response
Issue 1—The *2006 King County Flood Hazard Management Plan* and capital program were developed assuming the full flood protection capacity of the Corps of Engineers Howard Hanson Dam. Revised operational plans for Howard Hanson Dam could result in increased duration of high flows, rapid rise and drawdown of the river as well as increased saturation of levees and adjacent ground.	
Question 1A—Do the required operational changes at Howard Hanson Dam affect the risk of levee failure downstream of the dam? If so, how?	Higher flows and velocities increase the potential for bed and bank scour. Higher river flows and longer duration flows will saturate levees more frequently. Rapid river-level drawdown from saturated levee conditions presents additional risk. Additional weight from temporary flood protection measures on top of levees (sandbags, Super Sacks, etc.) may exacerbate the failure risk. Raising levees will result in higher-pressure gradients from the river to the landward toe; these higher gradients can lead to water piping through or beneath the levee, landward boils, and decreased landward slope stability that could lead to non-overtopping levee breaches. Overtopping of levees by flows greater than 12,000 cfs is likely to erode the generally unarmored back slope of the levees, leading to levee breaches.
Question 1B—What steps can be taken to reduce this risk, whether the risk be increased or remain the same?	The plan to run the river at 12,000 cfs for as long as necessary to keep the reservoir at an acceptable level increases the risk of levee failure. Running lower flow levels would decrease the risk of levee failure because it would reduce saturation in the levee prism. To the extent possible, it is wise to avoid or minimize rapid drawdown of river levels. Existing protocols stipulate a maximum drawdown of river levels of 1 foot per hour. To the extent possible, this protocol, or even slower drawdowns, should be employed. Because of the possibility of multiple floods before the Corps of Engineers completes improvements at Howard Hanson Dam, levee inspections are critical to monitoring system performance. Stockpile materials along the levee system to quickly repair distressed levees. Develop a pool of contractors available to respond to emergency flood fighting measures. Perform after-action analyses of levees; use established protocols; evaluate performance issues beyond immediate maintenance needs. Consider installing monitoring equipment to increase King County's predictive capacity for levee failure risk.

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Question	Summary of Panel Response
Question 1C— Should King County's Flood Warning Program be modified to address any increased risk? If so, how?	Much of the preparedness planning focuses on flooding caused by levee overtopping. Flooding from a levee breach could be more dangerous due to localized deep, fast-flowing water. This flood hazard is also more unpredictable. The public should be educated on the difference between the levee-overtopping and levee-breach flooding scenarios. Relevant real-time data, such as rainfall intensities, dam release rates, flow levels, and levee breaks, should be made available through a variety of sources, including web sites, emergency radio broadcasts, and TV news outlets. Coordinated evacuation plans should be in place that are the same for cities and King County lands. Standardized evacuation levels (i.e., alert, request, or order) should be established.
Issue 2—King County's adopted 2006 FHMP includes basin characterizations of hydrologic, geologic, and ecological factors, as well as land use and development.	
Question 2Ai—In what ways should the elements of the basin characterization of the Green River Basin be modified in light of the new situation at the Howard Hanson Dam?	A characterization of the basin without the dam functioning would better prepare the region to determine its best strategy. The revised characterization should consider three conditions: Howard Hanson Dam providing flow control as it has historically, at a reduced level, or not at all. A basin characterization for the three flood scenarios should be done for the upcoming five years, as well as for the long-term. A new characterization analysis also would be valuable in evaluating possible higher flows caused by climate change or future problems with the dam. Recent high-resolution topography could greatly inform analysis of overbank flow paths and identification of high flood risk areas. A risk assessment should address what happens for flows over 12,000 cfs, or what happens if the dam or levee system fails or otherwise does not function as designed.
Question 2Aii—Will any recommended actions (both capital and programmatic) in the Green River basin reduce risks to people and property and to what extent, both short term and long term?	Short Term—With existing high-value development in the floodplain, a likelihood that Howard Hanson Dam will be repaired, a tightly constrained river corridor, and an existing substandard levee system, continuing to implement the 2006 Flood Plan actions should reduce risk in the short term. Long Term—Unquestioned reliance on a flood control dam and levee system provides opportunities for nearly unrestrained economic development of floodplain land; however, the risks if elements of this flood protection strategy fail may make this an undesirable strategy in the long term.

TABLE ES-1.
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Question	Summary of Panel Response
Question 2B— Should King County's priority strategy change with the new situation at Howard Hanson Dam?	King County's priority strategy should be guided by four main objectives: reduced flood risk, environmental benefit, cost effectiveness, and sustainability. It is imperative that King County's strategy extend to considering flows above 12,000 cfs and no flow regulation from Howard Hanson Dam. King County's short-term priority strategy for the Lower Green River must be guided by the "do no harm" approach, which includes the flood preparations underway, together with continued implementation of selected projects from the 2006 Flood Plan that address the most critical shortcomings. An increased focus on vulnerabilities is warranted, such as protection of electrical equipment on the first floor of buildings in the flood risk area. Some members of the panel believe it is worth evaluating a long-term priority strategy for the Lower Green River that seeks to establish a wider river corridor to accommodate higher flows and to allow for more natural riverine processes. This long-term goal would be more sustainable than the current strategy, would provide greatly increased environmental and habitat value, and may be economically justifiable if implemented over a 20- to 50-year time horizon. The review panel considered the current priority strategy for the Middle Green River and felt that it is appropriate in both the short and long-term.
Issue 3—The river and floodplain management program consists of levee reconstruction, regular maintenance of levees, acquisition of frequently flooded homes, operation of a flood-warning center, education and outreach about the hazards of living in the floodplain, and technical studies that include sediment transport and mapping.	
Question 3A—In light of total available resources, should King County consider reallocating resources to implement these actions given the new flood risks posed by changes in dam operations?	Under the emergency situation that exists, it is reasonable for King County to reallocate resources to implement actions that would address the added flood risk. At least for the time period when dam operation will not follow original assumptions, new steps have to be taken to address that change. Using a risk-based approach, it is likely that the Green River would score highest for priority and therefore these additional resources are justified. To avoid creating an inequitable, unjustifiable resource reallocation, criteria should be developed and followed to guide reallocation of resources. As long as dam operation changes are temporary, then any reallocation of resources should not be permanent. If the situation ends up being long-term, King County should consider creating a new revenue stream, such as an additional levy on Green River valley properties.

TABLE ES-1.
SUMMARY OF REVIEW PANEL RESPONSES TO KING COUNTY QUESTIONS

Question	Summary of Panel Response
Issue 4—The adopted 2006 FHMP recommends a series of capital projects on the Lower Green River that are intended to increase the conveyance capacity of the channel and strengthen the integrity of the facilities by laying back the slope of the levee to meet current federal design standards. These projects typically include bioengineering techniques that incorporate large wood and native vegetation as structural elements of the project. Projects have been designed and constructed by King County and the Corps of Engineers.	
Question 4A—Upon review of the project designs and documentation regarding the Management Alternatives identified in the 2006 Flood Plan, are there any recommendations for addressing the consistency of these projects and Management Alternatives with best professional practices for the reduction of flood and channel migration risks?	It is troubling that there is no permanent agreement between King County and the Corps of Engineers about a vegetation management strategy for the Green River. Because of these differences in levee design, and the use of more bio-engineered techniques on the Green River, the review panel believes that monitoring the different types of levee performance is needed. Levee designs are based on a maximum flow of 12,000 cfs, which is reasonable only if historical levels of flood control from Howard Hanson Dam would always be provided. This assumption is no longer recommended. The geotechnical/hydraulic basis for levee design is not clear; it appears to rely on generic designs that have been successful in the past, but which have undergone minimal analysis and only a short period of actual implementation. There is no systematic monitoring or program of adaptive management mechanism to identify deficiencies and incorporate findings into future designs. Many slopes on existing levees are greater than 2:1 and these levees do not appear to incorporate "toe-down" or "toe rock protection" (excavation below the levee toe with rock placement). Panelists raised concerns about the geotechnical stability of these slopes.
Question 4B—Does the potential for increased flows (from approximately 12,000 cfs to 13,900 cfs or as much as 17,600 cfs) and an increased duration of high flows impact the decision to use traditional or bioengineering approaches to levee rehabilitation?	At higher flows, it may be necessary to use harder elements, such as larger rock, but it will still be possible to incorporate significant bioengineering elements. Bioengineering elements may have to be higher on the levee (not near river level), and possibly overlapped with harder elements. Hydraulic modeling and sediment scour analyses for higher flows in the Green River will be important in estimating flow velocities and erosion potential. The model results, combined with performance information gathered during high flows, will allow an assessment of whether a bioengineered approach is stable for high flows.
Question 4C—Under what circumstances do bioengineered and traditionally engineered levees, respectively, offer enhanced stability under increased flow regimes?	The review panel does not support a single, universal answer to the question of when and where to use bioengineered and traditional levee features. The panel endorses an approach that considers bioengineered levee features as a preference but ultimately evaluates local site conditions as part of the design process before making final decisions. A unique feature of the Lower Green River is the relatively flat gradient of its river channel. This results in lower flow velocities and shear stresses along river banks and levees than on more dynamic, steeper river segments. This is one reason why past bioengineered design features on the Lower Green River levees have been successful. The Corps of Engineers' Engineering Research and Development Center is currently conducting a nationwide evaluation of vegetation management effect on levee stability. The study is due to be completed in December 2010. The panel encourages King County to offer Green River sites to the Corps of Engineers for field testing and research.

TABLE ES-1.
SUMMARY OF REVIEW PANEL RESPONSES TO KING COUNTY QUESTIONS

Question	Summary of Panel Response
Question 4D—Are there other techniques King County should consider to rehabilitate levees along the Green River?	The review panel believes it would be beneficial to evaluate the feasibility of greater levee setbacks. Such a strategy would move King County away from being locked into the current levee system scenario, which requires significant ongoing maintenance and carries high residual risk. Land uses suitable for flood prone areas, such as parks, farmland, and golf courses, could exist within the levee corridor. A low levee/high levee configuration could be feasible; the low levee along the river bank prevents flooding from more frequent events and allows floodwater to spill over a designated armored weir section during less frequent events while remaining confined within the higher setback levee. The approach outlined above is not possible without coordination among jurisdictions in the Green River basin. A coordinated approach would have to include consistent floodplain management policies (e.g., King County's current zero-rise floodplain restriction does not apply in incorporated areas) and a regionally managed floodway corridor.
Issue 5—Levee setbacks often require the acquisition of new rights of way for construction that require lengthy real estate negotiations with property owners, with the potential to expedite this process through the controversial use of condemnation authority.	
Question 5A—Given the increased sense of urgency in the need to contain higher flows, should we focus on repairs within the existing footprint that can be completed relatively quickly while engaging in longer-term negotiations to obtain right-of-way for setback projects?	The review panel agrees with focusing on repairs within the existing footprint that can be completed relatively quickly, while engaging in longer-term negotiations to obtain right-of-way for setback projects. This effort should avoid investing short-term money in places where there may be future opportunity for setback levees, except where the location is a critical area with high risk. Where an opportunity exists for setback levees, the current emergency should not override long-term strategic thinking. A feasibility survey for additional setback opportunities along the river corridor, beyond those identified in the 2006 Flood Plan, would be an important first step toward a long-term strategy to address the possibility of increased future flows.
Question 5B—Should King County continue efforts to rehabilitate facilities with slopes that meet federal design standards or should it apply some other standard?	At a minimum, all new levee and levee rehabilitation projects should meet federal design standards. In particular, the steep levee side slopes that exist along many segments of the Green River should be flattened to stable slopes whenever new projects are implemented or local repairs made. Flatter side slopes provide greater slope stability as well as opportunities for bioengineered features to be included in the design. In order to qualify for participation in the Corps of Engineers' Rehabilitation and Inspection Program (RIP), levees must meet the Corps of Engineers' levee maintenance standards. If King County wishes to have its levees accredited by FEMA to provide 100-year flood protection, levees must meet the minimum design, operation, and maintenance standards of the National Flood Insurance Program (NFIP) regulations. King County can benefit from accreditation by reducing flood insurance rates or requirements behind a certified levee. Some local governments in the Puget Sound region are questioning the goal of having an accredited levee system. With levee accreditation, floodplain regulations would not apply in some current floodplains, which could perpetuate aggressive development in these areas. The review panel makes no recommendation as to whether King County should seek levee certification at every levee improvement site along the Green River.

TABLE ES-1.
SUMMARY OF REVIEW PANEL RESPONSES TO KING COUNTY QUESTIONS

Question	Summary of Panel Response
Question 5C—Is the urgency of project completion so great that King County should consider the use of condemnation to acquire right-of-way for levee setback projects when sufficient right-of-way is not available to construct the project in accordance with federal design standards?	While not precluding the use of condemnation, the panel does not feel the urgency of the current situation warrants a unilateral condemnation policy to acquire right-of-way. King County may not have condemnation authority within city jurisdictional areas. Acquisition of property through condemnation is not an eligible activity under FEMA hazard mitigation grant programs. In the long-term, property acquisition through condemnation may be critical to implementing consistent flood hazard measures along the Lower Green River. For example, a more aggressive approach to acquiring land for setback levees may identify a few key properties necessary to implement a setback strategy over long segments of the river. Condemnation for limited properties may be necessary to implement a more comprehensive flood hazard management scheme in the Lower Green River valley.
Issue 6—Sediment in the Green River is largely controlled by the operation of the Dam and the river is not observed to be rich in sediment and gravel. The adopted Flood Plan does not contemplate sediment removal on the Lower Green River to create more channel capacity.	
Question 6A—In light of the changed conditions at Howard Hanson Dam, is it advisable to reconsider sediment removal?	It is unlikely that sediment removal would achieve the goal of increased hydraulic capacity. There is probably very little "excess" sediment, so replenishment of the sand and finer sized sediment would likely occur rapidly from local sources. Local removal of the sediment could induce additional local scour, which in turn could undermine existing revetments and levees. Dredging is usually a last resort because of environmental issues associated with in-channel impacts, disposal of dredge spoils, and the challenges of receiving regulatory approvals. Prior to any further consideration of sediment removal, additional data such as sediment load characteristics, flow velocities at the expected range of flows, channel slope and cross section geometry would be needed to assess the impacts of sediment removal on channel stability.
Question 6B—Is sediment removal an appropriate short-term or long-term strategy to increase channel capacity and decrease flood risk along the confined Lower Green River under increased flow scenarios?	Unless indicated by additional analyses, sediment removal is not appropriate as either a short-term or long-term strategy to increase channel capacity and decrease flood risk along the confined Lower Green River. Sediment removal may destabilize nearby structures, it rarely provides significant additional channel capacity, and its benefits tend to be temporary as the river works to fill back in to readjust its profile.
Question 6B—Should sediment depositional areas be incorporated into a redesign of the current levee system?	Since excess sedimentation does not seem to be an issue in the Lower Green River, the review panel sees no reason to incorporate sediment depositional areas.

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Question	Summary of Panel Response
Issue 7—King County's flood risk reduction efforts are subject to a wide range of environmental regulations, including the Endangered Species Act (ESA), Clean Water Act, and local regulations to protect critical areas. Protected salmon species include Chinook, steelhead, and bull trout, and there is a federally adopted ESA recovery plan for Puget Sound Chinook that was developed and endorsed by local governments in each watershed. These federal, state, and local regulations require that flood risk reduction actions are implemented in ways that protect water quality and habitat for multiple public uses, including recovery of salmonid species listed under the Endangered Species Act. Among other things, this has resulted in policies aimed at allowing naturally occurring large wood to remain in the river channel unless it poses an imminent threat to public safety, as well as the use of large wood as a structural element of flood facilities.	
Question 7A—How can King County best integrate public safety and environmental mandates, particularly in the case of large wood?	The review panel believes that current King County policies and practices to integrate public safety and environmental mandates are sound and should be continued. King County is the only Puget Sound county with policies relating to natural large wood and recreational boater safety at this time. King County's current policy calls for judgment on a case-by-case basis in determining whether large wood creates a public safety hazard and should be removed. The review panel considers this to be a reasonable policy that should be continued. Considering the importance of large wood in the structural integrity of current levee and revetment designs, health-and-safety concerns of adjacent floodplain occupants need to have at least equivalent standing to those of recreational boaters. King County is also under federal and state mandates to protect ecological functions as characterized by "best available science," and under this guidance the continued inclusion of large wood in river-modification projects is virtually inescapable. In the Pacific Northwest, the Corps of Engineers honors a policy of allowing woody vegetation up to a 4-inch in diameter trunk in 4-foot diameter clumps at a spacing of 30 feet. The removal of trees above that size may be counterproductive. Cutting down large vegetation encourages more small growth in greater density, which makes it more difficult to inspect the levee for cracks and boils, and may increase the net roughness of the channel, thus raising flood elevations. The review panel believes that the best resolution to this apparent conflict will be in the careful performance review of alternatively designed and constructed levees, incorporated within an adaptive management framework. The Puget Sound Chinook Recovery Plan does not explicitly address wood in rivers but addresses general habitat conditions, which would include recruited wood and log jams. It names protection and restoration of spawning habitat in the Middle Green River and upper portion of the Lower Green River as one of three watershed-wide priorities.

TABLE ES-1.
SUMMARY OF REVIEW PANEL RESPONSES TO KING COUNTY QUESTIONS

Question	Summary of Panel Response
Question 7B—Any recommendations regarding the balance that must be struck in complying with these regulations?	In September 2008 the National Marine Fisheries Service (NMFS) issued a biological opinion on the effects of the NFIP on endangered species throughout Puget Sound. The opinion identifies "reasonable and prudent alternatives" (RPAs) that FEMA and partners can take to avoid destruction or adverse modification of critical habitat for endangered species. Potential conflicts between the RPAs and what may be done by FEMA, local governments or others in Green River flood preparation activities that could conflict with the RPAs include raising levees, removing vegetation from levees, removing large wood from the river, building new levees, modifying channels, or constructing development in the floodway. The review panel believes that current King County policies to protect endangered species are sound and should be continued. The RPAs will not impede most of the emergency flood loss reduction measures now being discussed with regard to the Howard Hanson Dam, particularly if these measures are temporary in nature. The biological opinion will have greater impact on more permanent measures under FEMA's control, such as remapping the floodplain, setting strict standards for new development in the floodplain, relating flood insurance policies to the raising or construction of dikes or levees, and increasing incentives for habitat protection and restoration under the Community Rating System. The review panel recognizes a direct conflict between the Corps of Engineers' levee-vegetation standards and NMFS's biological opinion. A similar conflict between the Corps of Engineers' and King County's design and maintenance guidelines for levees is recognized by all parties. A conscious evaluation of alternative vegetation-management approaches, if incorporated into the process of setting future actions, would offer a credible way to resolve existing differences in approach.
Issue 8—The current approach to reducing channel migration risks and increasing channel capacity for the Middle Green River includes removing old levees and revetments that no longer protect homes or roads, and allowing the river to reclaim the flood plain and side channels.	
Question 8A—Given the increased probability of significant flows from the river, is this a viable strategy?	A channel migration zone (CMZ) along the Middle Green River was mapped based on flood control and conditions at the time of the mapping. According to the CMZ study, by cutting the size of flood peaks, Howard Hanson Dam has reduced the number of avulsions and the tendency of the river to braid, behaviors associated with the highest migration rates. It is possible that the sediment deficit in the Middle Green River incurred as a result of sediment trapping by the dam may have increased the rate of bank erosion and channel migration, especially since the 12,000 cfs flow is about the pre-dam 2-year event and the duration of sediment transport has been increased by the dam releases. If the system experiences higher flows more often, the rate of migration may increase over what residents have become accustomed to since Howard Hanson Dam has regulated flows. Therefore, it is even more important that King County maintain its no-build policy for the channel migration zone. The highest channel migration rates are associated with the development of avulsion channels and rapid growth bends in the middle section of the river. Continuing to remove old levees that no longer protect homes or roads is the right approach for the Middle Green River. This will continue to communicate to residents and those who may consider moving to the area that King County is not providing flood protection.

TABLE ES-1.
SUMMARY OF REVIEW PANEL RESPONSES TO KING COUNTY QUESTIONS

Question	Summary of Panel Response
Question 8B—Are there other ways to increase channel and floodplain capacity in the Middle Green River that we should consider?	The review panel did not identify any reasonable alternatives for increasing channel and floodplain capacity along the Middle Green River.
Question 8C—To what extent would any increased storage in the Middle Green have any impact on flows in the Lower Green?	Enhancement of floodplain wetlands would marginally increase flood storage, but probably would not have a significant impact on decreasing flows downstream during a major flood.
Issue 9—The Middle Green River accumulates naturally occurring fallen trees. Also, as part of the required mitigation for the operations of the Howard Hansen Dam as a water supply facility, Tacoma Public Utilities is required to add wood that is trapped in the reservoir to the flow of the river below the dam. Two known large debris jams have formed on the Middle Green sub-basin over the last 30 years.	
Question 9A—Would increased flows consistent with the reduced capacity of Howard Hanson Dam result in an increased risk of mobilizing existing debris jams, or are these jams more likely to remain and collect additional debris that would have otherwise moved downstream?	The lower log jam, located at about RM 32.5, is a net collector of logs moving downriver. Although individual pieces may be floated off or washed downstream, its net effect is to reduce the downstream transport of large woody debris. Although the release of individual logs is likely, particularly those that have recently been washed into the jam and are only loosely lying on top of others, we find little basis to expect entire sections of the jam to mobilize. The jam at RM 38.5 is a much smaller accumulation and is located on a side channel, not the main channel, of the Middle Green River. Its effect on flood levels is not obviously significant. Increased flows might increase the likelihood of mobilizing individual logs, but the likelihood of transport down the length of the Middle Green River is considered low (and past the jam at RM 32.5, extremely improbable). We strongly recommend the continued passive management practices currently being followed.
Question 9B—Are there actions that should be taken to address the potential risks to downstream residents and property posed by fallen trees and log jams in the river?	We cannot guarantee absolute jam stability, particularly under flows that increase water levels by the maximum potential amount. At more modest increases of a foot or two, however, two factors mitigate against a massive release of logs: the interlocked architecture of the jam and the degree to which logs are partly buried by sediment; and the absence of a full channel-spanning structure that could impound water behind it. Still, any increase in flow depth will likely mobilize a number of logs that are presently perched in unstable positions on the jam, particularly the portion on the inside of the bend. The Middle Green River farther upstream is likely to continue receiving significant influxes of new logs and other debris during future storms. This material may pose a risk to downstream infrastructure if not removed from active transport by "log-straining" features in the channel or the adjacent floodplain. The RM 32.5 jam has been performing this function for many years and should continue to be highly effective under all but the most extreme of discharges.

TABLE ES-1.
SUMMARY OF REVIEW PANEL RESPONSES TO KING COUNTY QUESTIONS

Question	Summary of Panel Response
Question 9C—What, if any, are the likely impacts of debris management actions on other riverine processes such as sediment transport?	Removal of the jam at RM 38.5 would result in a sediment-transport increase that would tend to redistribute sediment along the next several bends of the river downstream. Removal of the jam at RM 32.5 has a high probability of increasing the flux of bedload sediment through this reach. Because this jam is near the upstream end of the depositional zone between the Middle and Lower Green River, sediment aggradation in areas of limited flood capacity through Auburn is likely. Should the present passive management of log jams change, the review panel strongly recommends that a full analysis of sediment transport at and downstream of RM 32.5 be undertaken before any action is taken. The panel does not have the same level of concern for unintended channel-capacity problems with active management of the jam at RM 38.5.
Issue 10—King County and the cities of the Lower Green River valley are considering the possibility of using temporary protective measures to enhance levee capacity under increased flows resulting from the changed operations of Howard Hanson Dam.	
Question 10A—Are there temporary protective measures such as flood fighting that King County should consider to increase the protective capacity of the levee system until permanent repairs are constructed supporting the Dam? Please identify, and describe the probable consequences and impacts of such measures on the functioning of the levee system.	Systems selected so far for temporarily raising levees generally have been used in the past on a short-term basis only. For the Green River, the systems may be needed for six years or more. Issues related to seepage, UV resistance, vandalism, repair, and deformation under repeated loading may be more important than for shorter-term uses in the past. Regardless of the system installed, monitoring will be required. Materials should be stockpiled in advance. We recommend that a common entity have review authority to ensure the use of appropriate levee-raising practices. Earthen levee raising may be an alternative in some areas where adequate space is available or only a short raise is required. 2-D modeling would be needed to determine the potential benefit of sacrificial levees (areas that could be breached as a relief valve during a flood if needed). Also, prior agreement with landowners for flooding (flood easement) would be necessary. Accepted flood fighting techniques should be employed. A list of potential flood-fighting measures and simple implementation methods should be developed by King County before those measures are needed.
Question 10B—Are there temporary protective measures such as flood fighting that should be avoided (e.g. those that could cause more damage should they be deployed) given the current status of our levees? Please identify, and describe the probable consequences and impacts of such measures on the functioning of the levee system.	Temporary measures that provide a false sense of security to the public should be avoided. Temporary measures that jeopardize the safety of workers should not be allowed. Temporary measures that do not meet the threshold of "strong probability of success" should not be allowed. The result of temporary levee raises will be an increase in the probability of failure and a decrease in the factor of safety of the stability of the levees. The magnitude of this change will be a function of the actual levee raise constructed, the elevation of the river level during flooding, the duration of a higher river flow, the actual geometry of the levee, and the subsurface conditions. Raising a levee system excessively is not recommended, as the added weight on the levee will reduce the stability of that levee. Without site-specific geotechnical investigation, it is impossible for the panel to comment on a safe level of levee raising. In the opinion of the review panel, the most likely causes of increased probability of failure or decreased factor of safety will be rapid drawdown, land-side slope instability and seepage.

CHAPTER 1.
INTRODUCTION

PURPOSE

A reduction in the flood-control storage volume available at the U.S. Army Corps of Engineers' Howard Hanson Dam, which may persist for three to five years beginning in 2009, presents a potential for increased flooding along the Green River downstream of the dam. In light of this increased flood risk, King County commissioned an independent advisory review of its current flood hazard management plan for the Green River.

An expert panel was convened to review the *2006 King County Flood Hazard Management Plan's* overall approach to capital projects, levee improvements, maintenance and operations, application of federal safety factors, stream channel management, and regulatory compliance. The review panel was asked to respond to specific river engineering, geotechnical, floodplain management, and environmental policy questions. The review panel was also asked to provide any other recommendations deemed warranted for King County's flood risk reduction strategy for the Green River Basin, in light of the changed operations at the Howard Hanson Dam. This report presents the review panel's conclusions and recommendations.

REVIEW PANEL MEMBERS

The following experts were selected for participation on the review panel:

- Derek Booth, PhD, PE, PG—Senior Geologist, Stillwater Sciences; Affiliate Professor, University of Washington Department of Earth and Space Sciences and Department of Civil and Environmental Engineering
- Cynthia Carlstad, LHG—Senior Project Manager, Tetra Tech
- Greg Fischer, PhD, PE—Senior Geotechnical Engineer, Shannon & Wilson
- Rob Flaner, CFM—Hazard Mitigation Specialist, Tetra Tech
- Mike Harvey, PhD, PG—Senior Geomorphologist, Tetra Tech
- Jon Kusler, PhD, JD—Associate Director, Association of State Wetland Managers
- Larry Larson, PE, CFM—Executive Director, Association of State Floodplain Managers
- Tony Melone, PhD, PE, CFM—Water Resources Program Manager, Tetra Tech
- David Montgomery, PhD—Professor, University of Washington Department of Earth and Space Sciences

The members of the review panel provide the following expertise:

- Licensed civil engineers with experience:
  - Designing and constructing river engineering projects
  - Assessing flood damages to levees
  - Conducting geotechnical evaluation of levees
  - Designing and constructing flood facilities within the context of Endangered Species Act listings for anadromous salmonids.

- PhD in geomorphology or geology, with experience analyzing the relationship between landscape processes, riverine processes, and the assessment of flood and/or channel migration risks.
- Certified Floodplain Managers with expertise implementing National Flood Insurance Program (NFIP) and Community Rating System (CRS) activities in local government
- Environmental policy expertise, including familiarity with the Clean Water Act and Endangered Species Act and their application to flood risk reduction activities in the Pacific Northwest.

Professional resumes of each panel member are provided as an attachment at the back of this report.

ISSUES AND QUESTIONS

King County provided the review panel with a specific set of issues and questions to address in the workshop. Ten issues were presented, in four broad categories, with one to four specific questions associated with each issue (26 questions total). Table 1 presents the issues and questions provided by King County. King County worked with the review panel to identify interdependencies among the questions and prioritize the questions.

TABLE 1.
ISSUES AND QUESTIONS TO BE ADDRESSED BY REVIEW PANEL

Issue	Questions
Category: Fundamental Assumptions	
1. The *2006 King County Flood Hazard Management Plan* and capital program were developed assuming the full flood protection capacity of the Corps of Engineers Howard Hanson Dam. Revised operational plans for Howard Hanson Dam could result in increased duration of high flows, rapid rise and drawdown of the river as well as increased saturation of levees and adjacent ground.	A. Do the required operational changes at Howard Hanson Dam affect the risk of levee failure downstream of the dam? If so, how? B. What steps can be taken to reduce this risk, whether the risk be increased or remain the same? C. Should King County's Flood Warning Program be modified to address any increased risk? If so, how?
Category: Overall Strategy	
2. King County's adopted 2006 Flood Plan includes basin characterizations of hydrologic, geologic, and ecological factors, as well as land use and development.	A. In what ways should the elements of the basin characterization of the Green River Basin be modified in light of the new situation at the Howard Hanson Dam? Will any recommended actions (both capital and programmatic) in the Green River basin reduce risks to people and property and to what extent, both short term and long term? B. Should King County's priority strategy change with the new situation at Howard Hanson Dam?
3. The river and floodplain management program consists of levee reconstruction, regular maintenance of levees, acquisition of frequently flooded homes, operation of a flood-warning center, education and outreach about the hazards of living in the flood plain, and technical studies that include sediment transport and mapping.	A. In light of total available resources, should King County consider reallocating resources to implement these actions given the new flood risks posed by changes in dam operations?

TABLE 1 (continued).
ISSUES AND QUESTIONS TO BE ADDRESSED BY REVIEW PANEL

Issue	Questions
Category: Capital Projects	
4. The adopted Flood Plan recommends a series of capital projects on the Lower Green River that are intended to increase the conveyance capacity of the channel and strengthen the integrity of the facilities by laying back the slope of the levee to meet current federal design standards. These projects typically include bioengineering techniques that incorporate large wood and native vegetation as structural elements of the project. Projects have been designed and constructed by King County and the Corps of Engineers.	A. Upon review of the project designs and documentation regarding the Management Alternatives identified in the 2006 Flood Plan, are there any recommendations for addressing the consistency of these projects and Management Alternatives with best professional practices for the reduction of flood and channel migration risks? B. Does the potential for increased flows (from approximately 12,000 cubic feet/second (cfs) to 13,900 cfs or as much as 17,600 cfs) and an increased duration of high flows impact the decision to use traditional or bioengineering approaches to levee rehabilitation? C. Under what circumstances do bioengineered and traditionally engineered levees, respectively, offer enhanced stability under increased flow regimes? D. Are there other techniques should King County consider to rehabilitate levees along the Green River?
5. Levee setbacks often require the acquisition of new rights of way for construction that requires lengthy real estate negotiations with property owners, with the potential to expedite this process through the controversial use of condemnation authority.	A. Given the increased sense of urgency in the need to contain higher flows, should we focus on repairs within the existing footprint that can be completed relatively quickly while engaging in longer-term negotiations to obtain right-of-way for setback projects? B. Should King County continue efforts to rehabilitate facilities with slopes that meet federal design standards or should it apply some other standard? C. Is the urgency of project completion so great that King County should consider the use of condemnation to acquire right-of-way for levee setback projects when sufficient right-of-way is not available to construct the project in accordance with federal design standards?
6. Sediment in the Green River is largely controlled by the operation of the Dam and the river is not observed to be rich in sediment and gravel. The adopted Flood Plan does not contemplate sediment removal on the Lower Green River to create more channel capacity.	A. In light of the changed conditions at Howard Hanson Dam, is it advisable to reconsider sediment removal? B. Is sediment removal an appropriate short-term or long-term strategy to increase channel capacity and decrease flood risk along the confined Lower Green River under increased flow scenarios? C. Should sediment depositional areas be incorporated into a redesign of the current levee system?

TABLE 1 (continued).
ISSUES AND QUESTIONS TO BE ADDRESSED BY REVIEW PANEL

Issue	Questions
Category: Capital Projects (continued)	
7. King County's flood risk reduction efforts are subject to a wide range of environmental regulations, including the Endangered Species Act, Clean Water Act, and local regulations to protect critical areas. Protected salmon species include Chinook, steelhead, and bull trout, and there is a federally adopted Endangered Species Act recovery plan for Puget Sound Chinook that was developed and endorsed by local governments in each watershed. These federal, state, and local regulations require that flood risk reduction actions are implemented in ways that protect water quality and habitat for multiple public uses, including recovery of salmonid species listed under the Endangered Species Act. Among other things, this has resulted in policies aimed at allowing naturally occurring large wood to remain in the river channel unless it poses an imminent threat to public safety, as well as the use of large wood as a structural element of flood facilities.	A. How can King County best integrate public safety and environmental mandates, particularly in the case of large wood? B. Any recommendations regarding the balance that must be struck in complying with these regulations?
8. The current approach to reducing channel migration risks and increasing channel capacity for the Middle Green River includes removing old levees and revetments that no longer protect homes or roads, and allowing the river to reclaim the flood plain and side channels.	A. Given the increased probability of significant flows from the river, is this a viable strategy? B. Are there other ways to increase channel and floodplain capacity in the Middle Green River that we should consider? C. To what extent would any increased storage in the Middle Green River have any impact on flows in the Lower Green River?
9. The Middle Green River accumulates naturally occurring fallen trees. Also, as part of the required mitigation for the operations of the dam as a water supply facility, Tacoma Public Utilities is required to add wood that is trapped in the reservoir to the flow of the river below the dam. Two known large debris jams have formed on the Middle Green sub-basin over the last 30 years.	A. Would increased flows consistent with the reduced capacity of Howard Hanson Dam result in an increased risk of mobilizing existing debris jams, or are these jams more likely to remain and collect additional debris that would have otherwise moved downstream? B. Are there actions that should be taken to address the potential risks to downstream residents and property posed by fallen trees and logjams in the river? C. What, if any, are the likely impacts of debris management actions on other riverine processes such as sediment transport?

TABLE 1 (continued).
ISSUES AND QUESTIONS TO BE ADDRESSED BY REVIEW PANEL

Issue	Questions
Category: Flood Response Activities	
10. King County and the cities of the Lower Green River valley are considering the possibility of using of temporary protective measures to enhance levee capacity under increased flows resulting from the changed operations of the Howard Hanson Dam.	A. Are there temporary protective measures such as flood fighting that King County should consider to increase the protective capacity of the levee system until permanent repairs are constructed supporting the Dam? Please identify, and describe the probable consequences and impacts of such measures on the functioning of the levee system. B. Are there temporary protective measures such as flood fighting that should be avoided (e.g. those that could cause more damage should they be deployed) given the current status of our levees? Please identify, and describe the probable consequences and impacts of such measures on the functioning of the levee system.

REVIEW PANEL WORK EFFORT AND REPORT ORGANIZATION

Panel members reviewed reference documents provided by King County and then convened for a two-day workshop in Seattle on October 19 and 20, 2009. The workshop was held in Tetra Tech's offices in Seattle. Before beginning the workshop discussions, panel members made field visits to four Green River levees (shown in Figure 1), accompanied by King County staff who explained past and planned levee projects and answered panel members' questions. After the half-day field visit, the remainder of the workshop consisted of discussions about each question provided by King County. Significant observations, conclusions and recommendations associated with each question were recorded for incorporation into this report. After completing its review of the specific questions, the review panel spent the final half-day of the workshop summarizing the most significant concepts that arose during the workshop and developing a recommendation for a new overall floodplain management strategy for the Green River.

Following the two-day workshop, panel members continued to coordinate and prepare the conclusions and recommendations presented in this report. Panel members working individually or in subgroups performed additional research and assessment to supplement the panel responses developed during the workshop. All panel members reviewed and commented on early complete drafts of this report, and follow-up gatherings of team members were conducted by teleconference.

This report was developed collaboratively by the review panel members based on the workshop discussions and subsequent additional discussion and analysis. The report is organized as follows:

- Chapter 1 describes the project purpose and lists the questions posed by King County for consideration by the review panel.
- Chapter 2 provides background information necessary to understand the historical development of the basin and its current condition. It provides a context for assessing the 2006 Flood Plan and developing responses to the review panel's assigned questions.

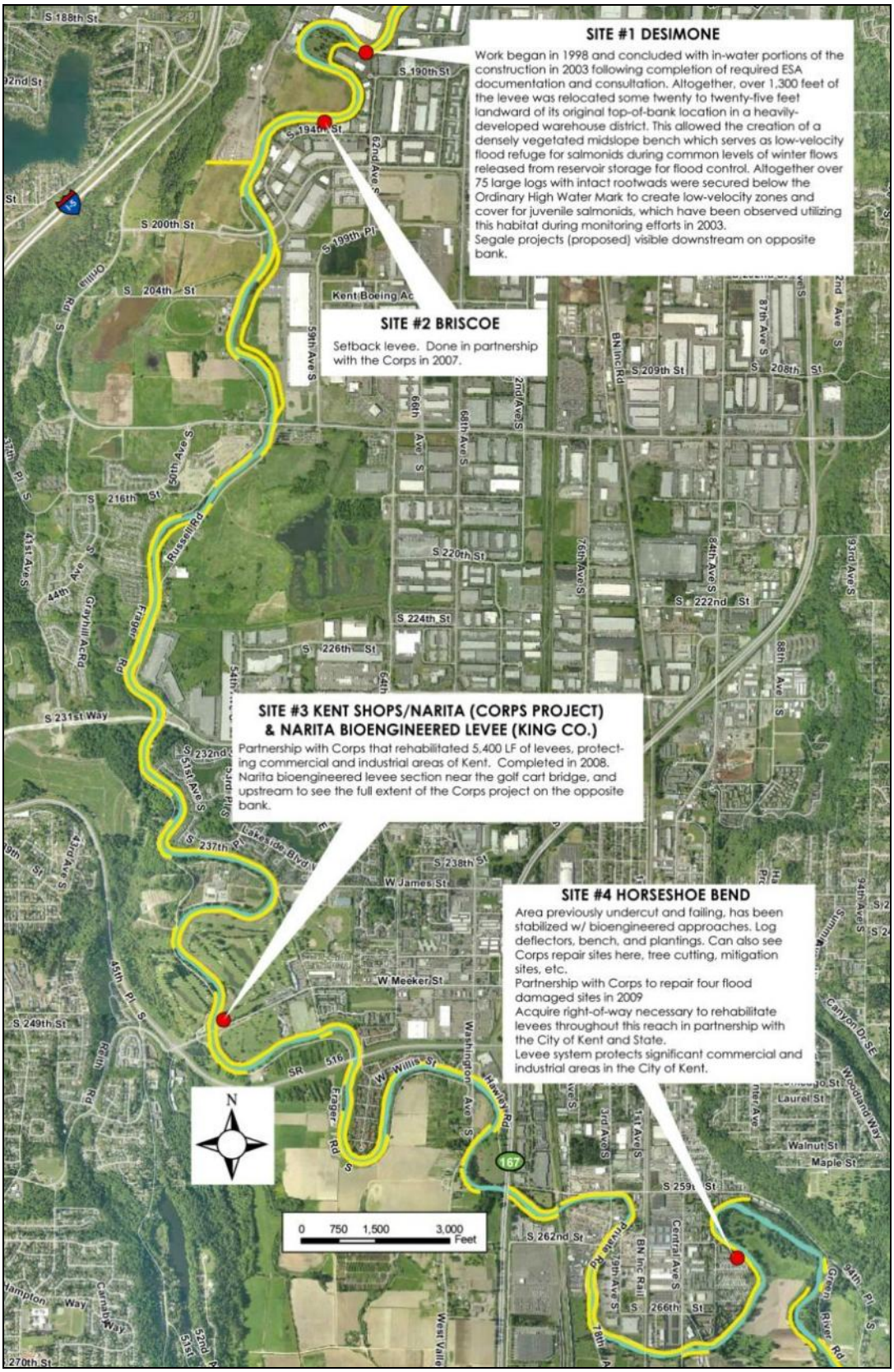


Figure 1. Levees Visited by Review Panel During Field Visit

- Chapter 3 provides discussion by the review panel on strategy recommendations for the future. This discussion is in response to King County's directive in the project statement of work to "provide any other recommendations deemed necessary or warranted in [the panel's] review of King County's flood risk reduction strategy for the Green River basin in light of changed operations at the Army Corps Howard Hanson Dam." This discussion is presented before the discussion of the specific questions, because it provides context for how some the specific questions are discussed.
- Chapters 4 through 13 provide responses and discussion for each question posed by King County, grouped by issues, as shown in Table 1.
- King County provided the review panel with extensive material relevant to the issues to be addressed in advance of the workshop. Key documents provided are identified in the reference list at the end of this report.

Recommendations presented in this report represent majority opinions of the review panel. Minority views were expressed throughout the review process but not all are presented in this report. Panel conclusions and recommendations in this report should not be understood as consensus findings unless specifically identified as such.

CHAPTER 2.
BACKGROUND

BASIN AND RIVER DESCRIPTION

The Green-Duwamish River basin is located entirely within King County. The river flows through several cities, primarily in its lower reaches, including Auburn, Kent, Renton, Tukwila and Seattle. The basin typically is divided into four sub-watersheds (upper watershed above Howard Hanson Dam, Middle Green, Lower Green, and the Duwamish estuary). The flood hazard mitigation strategies for the Green River as set forth in the 2006 Flood Plan primarily focus on two of these sub-watersheds:

- The Middle Green River runs from the outlet of the Green River Gorge at about River Mile (RM) 45 near Flaming Geyser down to Auburn at about River Mile 31
- The Lower Green River runs from Auburn down to the Duwamish River at RM 11.

Flood Hazard Management Network

Major structural flood risk reduction features along the Green River include Howard Hanson Dam, which is in the upper Green River sub-watershed, and the levee system that lines the riverbanks along much of the Lower Green River and along portions of the Middle Green River. Howard Hanson Dam and the levee system combine to reduce flooding in the lower river to a fraction of its historical magnitude. The dam is designed to store over 100,000 acre-feet, converting large storm events to a discharge at the Auburn gage equivalent to the 2-year pre-dam event at 12,000 cubic feet per second (cfs) over an extended duration.

The Lower Green River levees and revetments form a nearly continuous bank protection and flood containment system from the downstream end of the City of Auburn to about River Mile 5 in the City of Tukwila (see Figure 2). The capacity of the leveed portion of the river is approximately 12,800 cfs, with approximately 2 feet of freeboard in most locations.

Many levees and revetments along the Lower Green River were originally constructed by farmers as protection for the formerly agricultural lands of the area. Because of the uncertain construction methods, materials used for these levees, and steep slopes associated with most of the facilities, much of the levee system does not meet current construction standards for new flood protection facilities. In particular, Lower Green River flood protection facilities typically have over-steepened banks, areas with inadequate toe buttressing, and a lack of habitat-enhancing features such as overhanging vegetation or large woody debris. Although Howard Hanson Dam operations significantly reduce flood peaks, they can result in longer durations of lower flows with rapid rates of change in water levels. Such operations can stress the levee and revetment system along the Lower Green River, with potential to increase the occurrence of slump failures. Because of these design and construction shortcomings, the flood protection facilities require frequent maintenance, and the Green River levee system has not always performed as intended to confine flooding within the river channel.

Land Use

With major historical flooding largely reduced by a dam and levees, commercial and industrial land use in the largely flat and generally accessible Lower Green River and Duwamish River valleys has proliferated in what were formerly less populated rural and agricultural communities. The Lower Green River valley is now home to major commercial and industrial enterprises, aerospace manufacturing, warehouse distribution centers and transportation corridors.

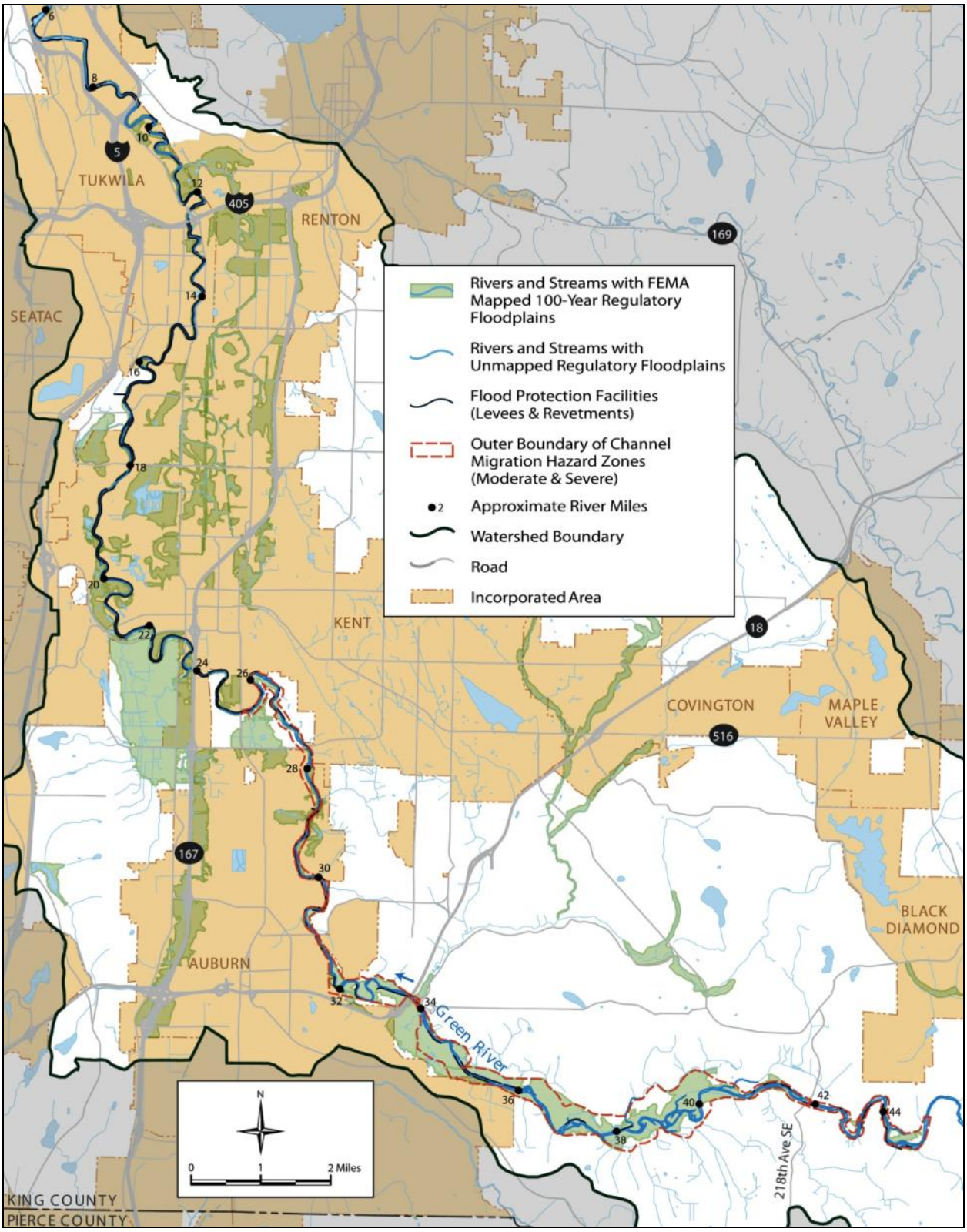


Figure 2. Lower and Middle Green River Basin

By restraining floodwaters from the commercial and industrial areas of Southcenter in the City of Tukwila and other nearby areas, the flood protection facilities reduce flood hazard to the highest land and improvement values in any floodplain in King County.

Historical River Changes

Prior to the 20th century, the river drained over 1,600 square miles, including the present-day watersheds of not only the Green River but also the Cedar River (which joined the Green near what is now Tukwila) and the White River (which joined the Green near the city of Auburn). In 1911, the White River was permanently diverted from the Green to the Puyallup River for flood control, reducing the Green River watershed area by 30 percent. Five years later, the Black and Cedar Rivers were diverted from the Duwamish River to Lake Washington to improve navigation, further reducing the watershed area by 40 percent from its original size. Finally, in 1962 Howard Hanson Dam was completed for flood control purposes. The river thus has only 30 percent of its original total drainage area, and about half of its original contributing area between Renton and Auburn. Of that remaining watershed area, nearly half is controlled by Howard Hanson Dam and thus has dramatically reduced both discharges and sediment input.

Flooding History

Since 1962, dam operations in combination with King County's Lower Green River levees have contained most major river flood events from Auburn downstream to the mouth of the Duwamish River. Prior to construction of the dam in 1962, the river exceeded the target 12,000 cfs 15 times since 1932. It is estimated that without the dam, the flows on the Green River would have exceeded this flood threshold 17 to 22 times since 1962 (Triplett, 2009).

Recent floods in King County occurred in November 1990, November 1995, February 1996, November 2006 and January 2009. Typical flood damage included undermining by scour along the toe of levees and revetments in the Lower Green River, slumping of banks and levee side slopes, and erosion of flood protection facilities. While these events ranged from the 10- to 100-year event on other King County rivers, the cap of 12,000 cfs on Green River flows meant that these events were the equivalent of a 2-year event pre-dam, extended over a longer duration. Inflows to the Howard Hanson Dam Reservoir in January 2009 were approximately 30,000 cfs.

GREEN RIVER FLOOD HAZARD MANAGEMENT

Capital Improvements

Many of King County’s levees no longer function as originally designed. The 2006 Flood Plan proposed system-wide improvements to the aging system of levees and revetments. The 2006 Flood Plan recommends contemporary flood hazard mitigation strategies to reduce flood risks throughout all of King County’s major river basins, including the Green River basin.

To correct the structural deficiencies of the levee system in the Lower Green River, the 2006 Flood Plan outlines a series of capital projects largely based on modifying the slope geometry of the levees by setting back the levee fill prism away from the top of the riverbank to create an overall levee slope of 2.5:1 horizontal-to-vertical (2.5H:1V) and to allow for increased flood conveyance; the slope of most of the existing levees ranges from 1.5H:1V to 1.75H:1V, and the slopes of some segments are even steeper. Such steep slope angles are a primary cause of chronic structural instability and flood protection facility damage, and this instability is exacerbated by saturated soil conditions combined with rapid drawdowns. Figure 3 shows the status of recent and proposed Green River levee improvement projects as of May 2009.

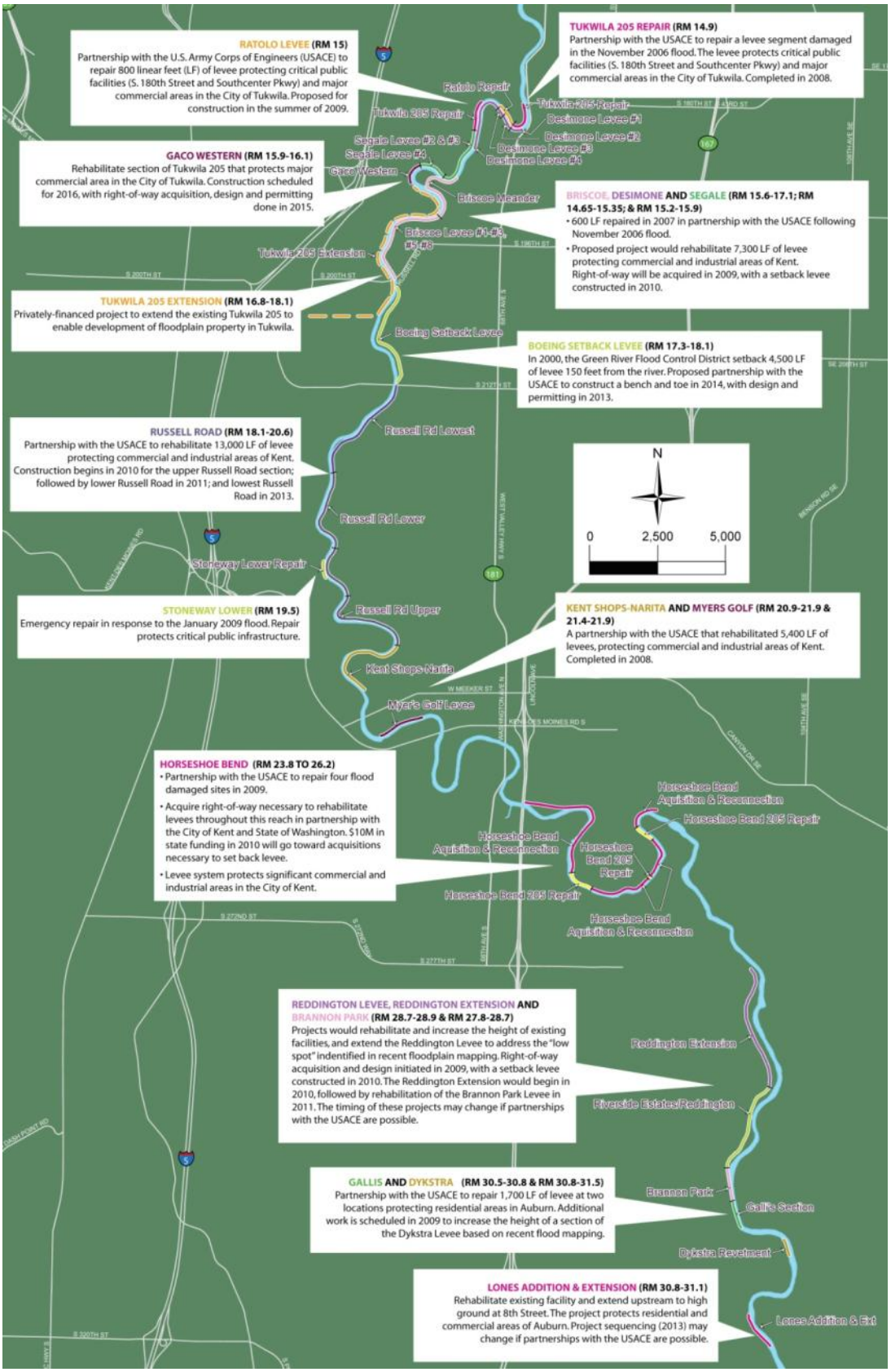


Figure 3. Recent and Planned Lower and Middle Green River Levee Projects as of May 2009

Strategies and Objectives

In April 2007, the Metropolitan King County Council created a new countywide special purpose district, the King County Flood Control District. A board of supervisors made up of all nine King County council members oversees the Flood Control District. It is responsible for planning and funding maintenance and repairs of the flood control system. The new Flood Control District is aimed at saving lives, protecting property and ensuring that a significant portion of King County's economic infrastructure is safe from the damage that can be caused by fall and winter storms.

The primary flood risk reduction objective for the ***Lower Green River***, identified in the 2006 Flood Plan, is to maintain the structural integrity of the levee system so that it can continue to contain releases from Howard Hanson Dam and protect public safety. At the same time, levee stability studies (Shannon & Wilson, Levee Assessment Technical Memoranda, 2007-2009) performed along the Lower Green River indicate that the existing levees fail to provide the minimum factors of safety against potential structural levee failures, based on published federal guidelines. A more thorough evaluation of individual levees and a more refined risk analysis are now underway. As recommended in the 2006 Flood Plan, a program of major levee rehabilitation and reconstruction is the single overarching need within the Lower Green River.

Agriculture and rural residential development are the primary land uses in the ***Middle Green River***. There are discontinuous bank protection revetments and training levees along the Middle Green River at several river bends. They are not intended to prevent inundation but to inhibit bank erosion and channel migration. These flood protection facilities have had varying levels of success in constraining channel migration. In the Middle Green River, the primary strategy is to acquire and remove residential structures at risk from channel migration, and to reconnect the river to its floodplain. The long-term goal in the Middle Green River is to set back existing flood protection facilities and allow unconstrained or less constrained channel migration.

Flood mitigation strategies for the Green River also include public education and outreach, operation of King County's Flood Warning Center, routine maintenance of facilities (mowing, weed removal, native vegetation planting, pump station operation and maintenance, etc.), and coordination with cities, state and federal agencies, and other stakeholders throughout the Green River basin. Overall, the flood risk reduction management strategies for the Green River are predicated on the full operational capacity of the Howard Hanson Dam.

HOWARD HANSON DAM

The primary control on flooding throughout the Green River basin is Howard Hanson Dam, at approximately RM 64, which was completed in 1962 and is owned, operated and maintained by the Corps of Engineers. The dam was constructed with a primary purpose of flood control and secondary purposes of water conservation and municipal water supply. It is a concrete structure with abutments comprised of natural earthen material that existed prior to construction of the dam.

The target flood control parameter for Howard Hanson Dam is a congressionally authorized flow of 12,000 cfs at the Green River near Auburn gage, at about RM 31 in the City of Auburn. Operations at Howard Hanson Dam that target flows at Auburn must also consider the magnitude and timing of local inflows from upstream tributaries such as Soos and Newaukum Creeks. Placing a cap of 12,000 cfs on Green River flood flows at Auburn has reduced flood events to what would be the pre-dam equivalent of a 2-year event at 12,000 cfs at Auburn.

Howard Hanson Dam was designed to store inflows from flow events up to and including an approximately 500-year reservoir inflow event and converting them to a discharge at Auburn of the

historical 2-year flood, with the low flows downstream extending over a much longer duration than they would under natural conditions. Dam operations in combination with the Lower Green River levees have contained most major river flood events from Auburn downstream to the mouth of the Duwamish River. Flooding still occurs in the Middle Green River and along tributary systems of the Green River.

Following a record high level of water behind Howard Hanson Dam in January 2009, the Corps of Engineers became concerned after discovery of two depressions on the right abutment (see Figure 4), increased water levels in groundwater monitoring wells, and the appearance of silty water entering the abutment drainage tunnel.

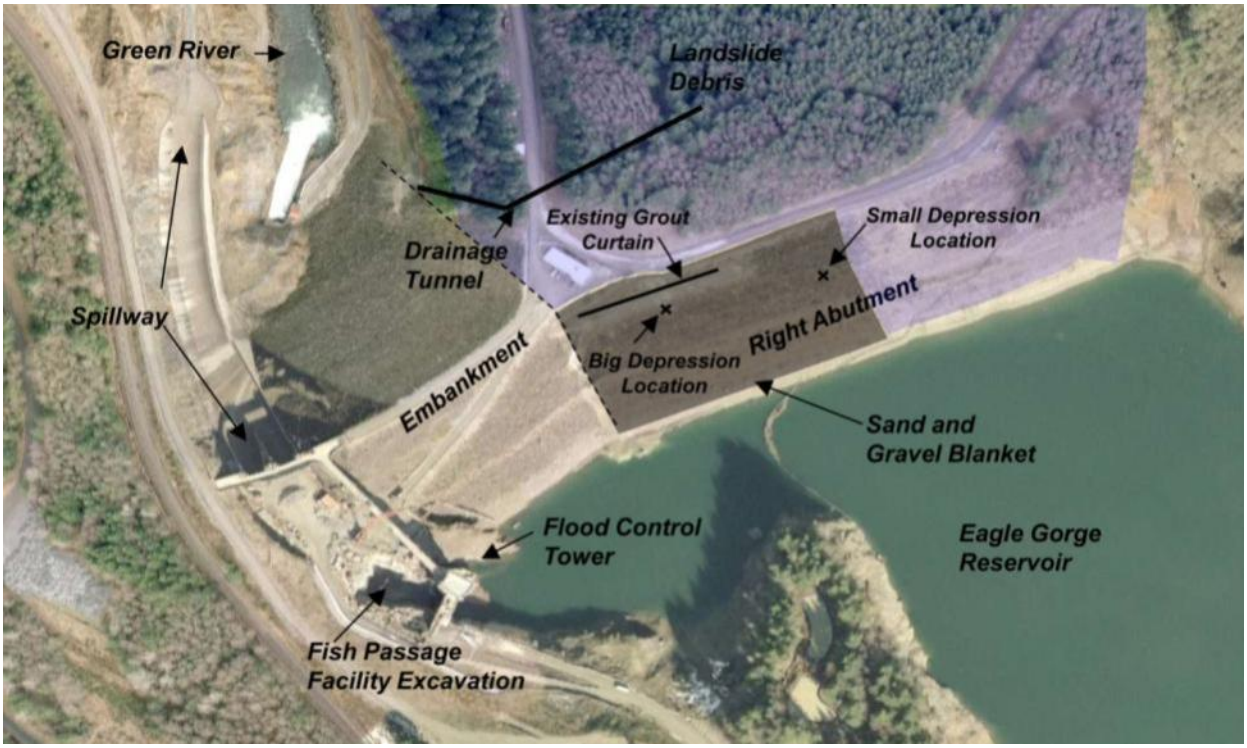


Figure 4. Howard Hanson Dam

The Corps of Engineers conducted monitoring and evaluation over the spring and summer of 2009. On October 31, 2009, they completed construction of an interim seepage barrier wall (grout curtain) and improvements to drainage in the right abutment, directing seepage into the drainage tunnel. The Corps of Engineers has conducted limited evaluation of the new seepage barrier wall, but does not intend to test the reliability of the new grout curtain during a major winter storm in the 2009-2010 wet season. Testing will occur in spring 2010. Therefore, the pool restriction will remain in effect, at some level, for the duration of the 2009-2010 wet season and possibly for approximately five years until the Corps of Engineers has implemented a permanent fix to address the seepage problems; the current long-term plan is to construct a concrete cutoff wall within the right abutment.

NEW PLANNING IN RESPONSE TO DAM OPERATION CHANGES

Corps of Engineers

The Corps of Engineers has placed restrictions on the pool elevation at the Howard Hanson Dam until engineers' concerns have been addressed. In addition to completing the grout curtain at the dam, the Corps of Engineers has committed to having significant flood fighting materials and capabilities on hand

in case of flooding or a breach of a levee, increasing patrols along the levees and debris management at bridges, and enhancing communications (Triplett, 2009).

King County and Local Municipalities

Because of the pool elevation restriction, there is an increased risk to the downstream communities for higher flood levels. Should a major flood event occur with the temporary restrictions on pool elevation, it is possible that levees in the lower valley could be overtopped and even fail. King County and local jurisdictions are addressing this increased risk for the 2009 wet-weather season through a series of measures outlined in the King County Executive's September 17, 2009 supplemental appropriation request, as summarized in the following sections.

Levee Improvements

In partnership with the Corps of Engineers, the Flood Control District completed repairs of 2,200 feet at the Horseshoe Bend levee in Kent, fixed low spots in the Dykstra Levee and repaired a failing flap-gate at the Reddington Levee. The Flood Control District also completed emergency repairs at three other sites in Tukwila and Kent to protect critical public infrastructure and commercial and industrial land uses.

The Flood Control District is actively pursuing the acquisition of sufficient right of way to reconstruct over 18,000 feet of levees at 14 sites. This will allow reconstruction efforts to continue on the Capital Improvement Program throughout the 2010 – 2015 period.

Engineering Studies and Temporary Levee Enhancements

King County commissioned several engineering studies to determine the ability of the existing levees to withstand the expected increased volume, duration and frequency of high flows, and to determine whether there are additional improvements King County can make to provide additional protection for the valley.

King County's Flood Warning Center produced maps of the levee system where concerns exist regarding the structural stability of the levees due to age and over-steepened slopes (see Figures 5 through 7) for the cities, county and Corps of Engineers staff to use in upcoming flood patrols and to estimate the height and length of temporary facilities to potentially contain a portion of the flood waters.

King County and the cities adjoining the Lower Green River have temporarily raised the Lower Green River levees to contain the higher flows of 13,900 cfs plus 3 feet of freeboard using TRANSCO "super sacks" and HESCO container units (see Figure 8). It is estimated that containing 13,900 cfs plus 3 feet of free board in selected locations would require 25 miles of temporary structures 1 to 3 feet high.

Flood Fighting and Emergency Response

The Corps of Engineers provided flood inundation maps to the local agencies for emergency response planning based on four release and storm scenarios as described in Table 2: 13,900 cfs, 17,600 cfs, 19,500 cfs, and 25,000 cfs measured at the Auburn gage. The modeling estimated these downstream river flows based on 25-, 50-, and 100-year inflow floods to the reservoir and two different restricted pool elevations. Collaborating with the Corps of Engineers, the National Weather Service and the valley cities resulted in regional agreement to plan overall for the 17,600-cfs scenario.

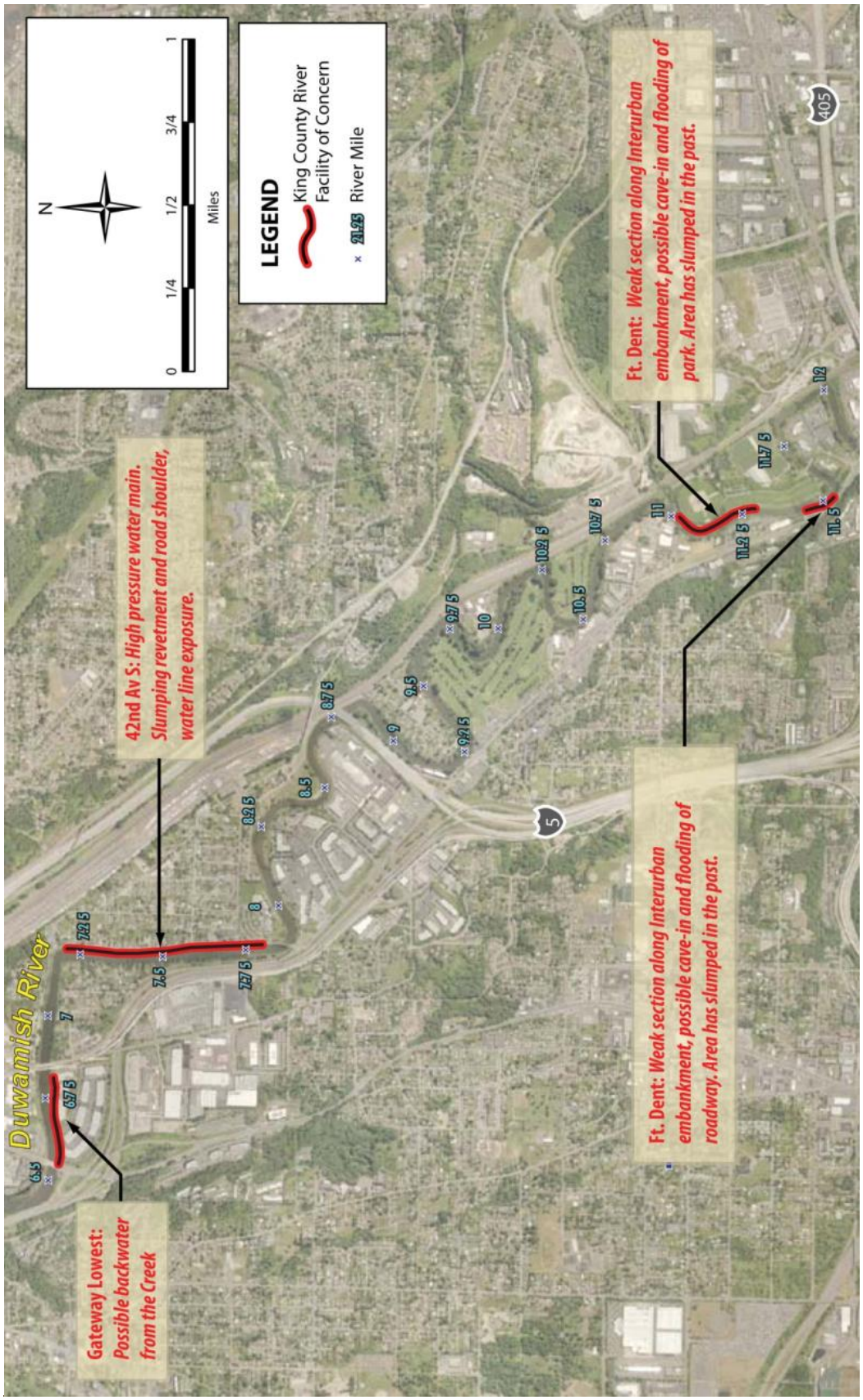


Figure 5. Green River Flood Protection Facilities of Concern, River Mile 6.5 to River Mile 12

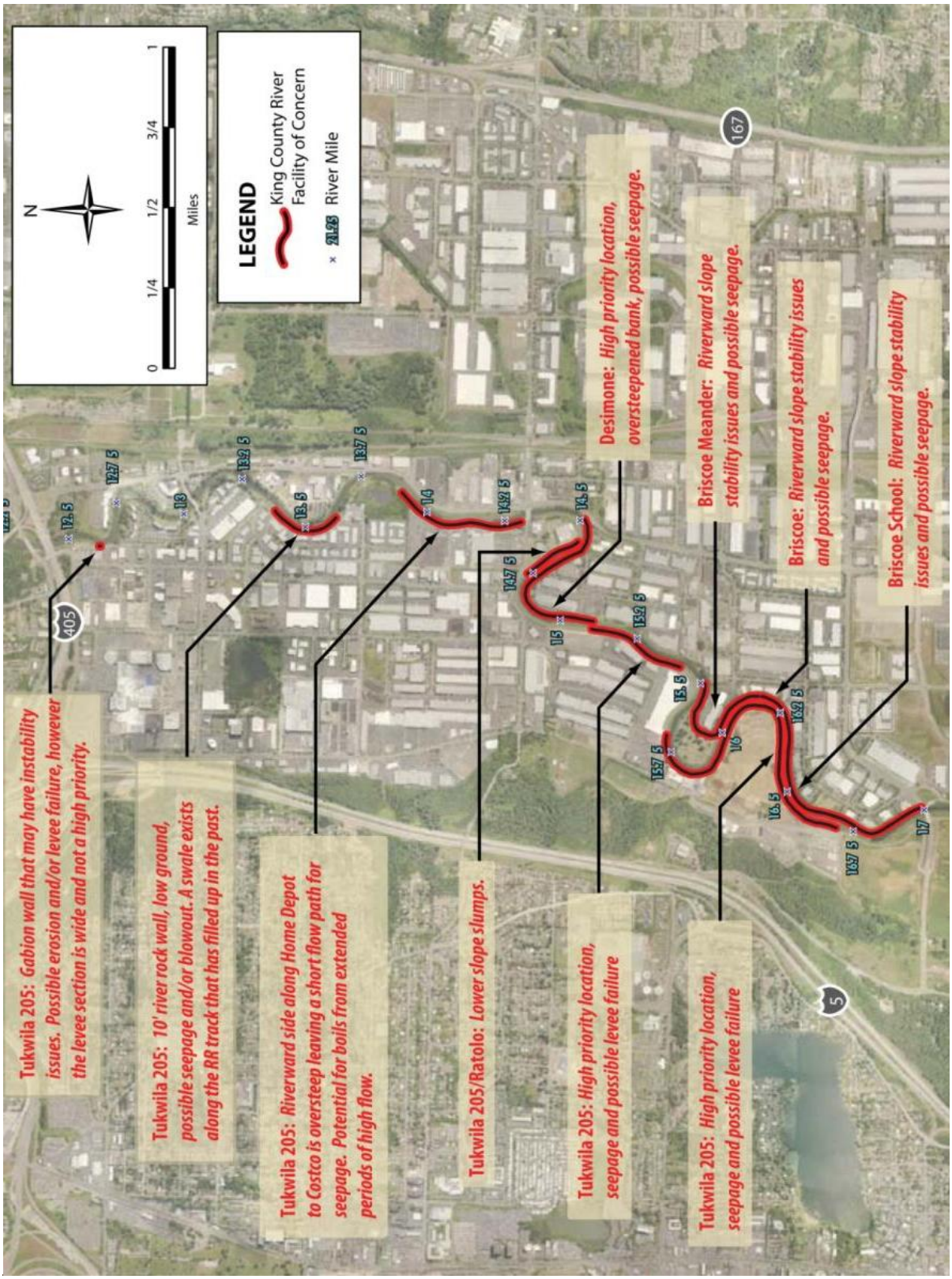


Figure 6. Green River Flood Protection Facilities of Concern, River Mile 12.25 to River Mile 17

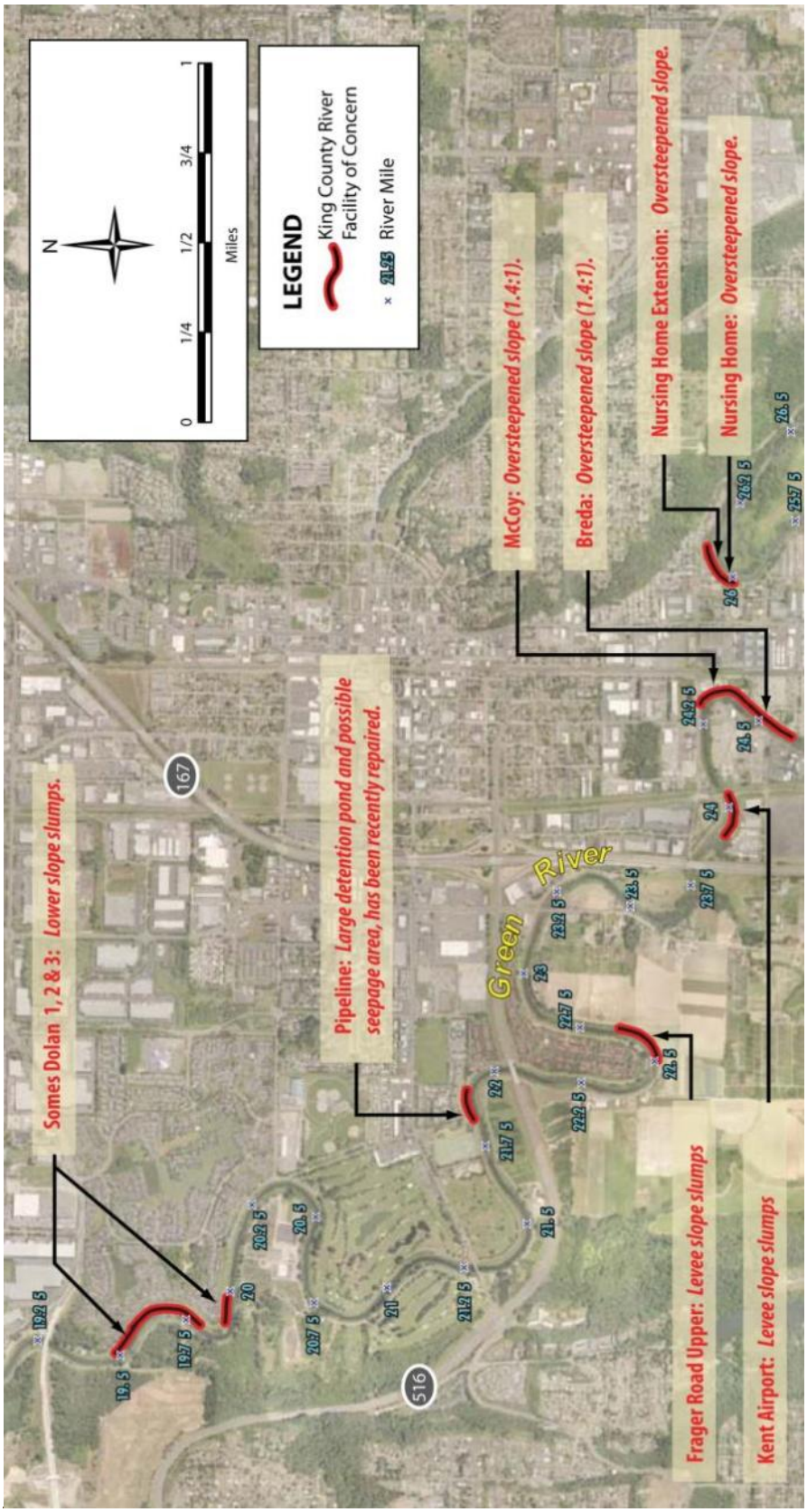


Figure 7. Green River Flood Protection Facilities of Concern, River Mile 19.25 to River Mile 26.5

Figure 8. Super Sacks Installed to Temporarily Raise Levee Height at Riverfront Park in Kent

TABLE 2.
GREEN RIVER FLOOD FLOWS WITH REVISED HOWARD HANSON DAM OPERATION

Recurrence Interval of Flood Entering Howard Hanson Dam	Reservoir Pool Elevation	Flow in Lower Green River Flow Measured at Auburn Gage
100-year	1,167 feet	25,000 cfs
50-year	1,167 feet	19,500 cfs
25-year	1,167 feet	13,900 cfs
100-year	1,185 feet	17,600 cfs

At this juncture it is unlikely that the levees can provide protection at the 17,600-cfs planning scenario, and not at all for the more extreme scenario of 25,000 cfs. Therefore evacuation will be a critical element of the response. Any releases that exceed approximately 10,000 cfs will trigger a recommendation for residents to leave the rural areas along the Middle Green River. A release of water from the dam reaches the area in about four hours. Flows from the dam take approximately eight hours to reach the City of Auburn. Flows exceeding 13,000 cfs at the Auburn gage will likely trigger a recommendation for at least some residents to evacuate in the Lower Green River, depending on the nature of the storm and information from the National Weather Service. King County, in conjunction with the valley cities and State Emergency Management, is developing plans for mass sheltering, evacuation routes, and public communications in the event that evacuation is recommended.

Key information pertaining to ongoing emergency response efforts, as collected from the 2006 Flood Plan, King County Washington Comprehensive Emergency Management Plan, local jurisdiction web sites and other sources, is summarized in Table 3.

TABLE 3. EMERGENCY RESPONSE PROGRAM SUMMARY	
Flood Hazard Education and Flood Preparedness	• King County conducts public education and outreach on flooding issues in conjunction with area cities
Flood Warning	• King County operates flood the Flood Warning Center and Emergency Coordination Center to provide information to municipalities in conjunction with Corps of Engineers information from Howard Hanson Dam and the National Weather Service • The Flood Warning Center operates under a four-phase response system depending on Green River flows at the Auburn gage • Reverse 911 systems are available through King County and Green River valley cities • King County provides financial support to the U.S. Geological Survey for maintenance and operation of a river gage network
Emergency Response Actions	• The Corps of Engineers has a dam safety and emergency response plan in place for Howard Hanson Dam • King County staff may begin patrolling flood control facilities at Phase III during flood events • King County may make available sandbags to citizens; however, citizens should not rely on King County, as demand may exceed supply
Evacuation	• Evacuation routes have been designated and road signage has been installed • Cities individually make the decision when to evacuate.

This information is dynamic and may change; the table represents a snapshot summary of emergency response planning as of November 2009. More current information is available on agency websites, such as the following:

- http://www.kingcounty.gov/safety/FloodPlan/GreenRiverValley.aspx
  http://www.wsdot.wa.gov/northwest/greenriver
- http://www.nws.usace.army.mil/PublicMenu/Menu.cfm?sitename=HHD&pagename=mainpage
- http://rentonwa.gov/government/default.aspx?id=26157
- http://www.ci.tukwila.wa.us/hhdam.html#documents
- http://www.ci.kent.wa.us/emergencymanagement/index.aspx?id=2636
- http://www.auburnwa.gov/Emergency/disaster/Green_River_and_Howard_Hanson_Dam_Information.asp

CHAPTER 3.
CORE CONCEPTS AND STRATEGY RECOMMENDATION

In the course of addressing the issues and questions provided by King County, the review panel recognized that several fundamental concepts arose repeatedly that affected how the panel would respond to each question:

- What is the long-term goal of flood hazard management on the Green River?
- How have the loss of flood control by Howard Hanson Dam and other factors caused conditions to change along the river?
- What do we know already, and what do we need to know, about the levee system?

It is the panel's conclusion that a discussion of these core concepts is necessary to the review process, even though it goes beyond specific responses to questions posed by King County. The following discussion is provided in response to the guidance that "additional suggestions and recommendations beyond these specific questions are also welcome."

Because of the significance of the identified core concepts and their effect on river management strategy, this chapter presents a discussion of concepts and strategies as the first findings of the review process. The panel's responses to King County's specific questions are presented in subsequent chapters.

LONG-TERM GOAL OF FLOOD HAZARD MANAGEMENT

King County is in the process of implementing a flood loss reduction program through the 2006 Flood Plan. The panel views the program as being based on sound principles that should be reflected in all future actions of King County and its flood hazard management partners. King County's long-term vision for floodplain management simultaneously considers public safety and environmental concerns. Guiding principles outlined in the 2006 Flood Plan include the following:

> *"The primary purpose of the recommendations in this plan is to reduce risks to public safety and financial losses from flooding and channel migration on main stem river corridors and floodplains within King County. This responsibility is undertaken while taking into account other uses within floodplains such as existing development, fish and wildlife habitat, open space, and agriculture and recreation.…*
>
> *A river and its valley floor, including adjacent floodplains, floodways, and potential channel migration areas, constitute a corridor through which floodwaters flow and within which opportunities exist for various land uses, including agriculture, recreation, and open space.…*
>
> *Protecting and working with, rather than against, natural riverine processes generally will reduce flood risks to people and property in a less costly manner than traditional structural approaches to flood hazard management while also benefiting native fish and wildlife and preserving aesthetic landscapes."*

These principles are reflected in King County's ongoing efforts to map floodplains and channel migration zones, regulate activities in the floodway and floodplains, and maintain and repair culverts, concrete channels, dams, levees, floodwalls, and storm sewers.

THE NEED TO REFLECT CHANGE

The significance of changed conditions in the Green River valley emerged as an important theme in the review panel discussions. While flood hazard management planning efforts in the past may have been consistent with conditions in the valley at the time of those efforts, circumstances have changed enough to prompt an assessment of past practices and their appropriateness for current and future conditions. A significant change is the increased development in the Green River valley since the dam was completed in 1962. Even with controlled flood flows of 12,000 cfs, development in the Green River valley has resulted in an increased flood risk. In addition, the flood conditions that pertain while remedial measures are underway at Howard Hansen Dam have increased the awareness of ***residual risk*** in the valley for flows greater than 12,000 cfs. Residual risk is the risk that remains after safeguards (mitigation strategies) have been implemented. It can be thought of as the risk of events outside those for which facilities were planned or designed. These events include instances when river flows exceed the design flow and when flood-protection facilities fail to provide the protection for which they were designed.

The review panel believes that changed conditions in the Green River valley since 1962 require a different long-term planning strategy. Even after Howard Hanson dam is repaired, the current situation demonstrates that the potential for flood flows greater than 12,000 cfs will remain permanently. Considering the substantial regional economic impacts of floods on the Lower Green River, the review panel believes that food hazard management measures should be based on flood flows greater than 12,000 cfs. The regional economic consequences of levee overtopping or failure are far greater today than when the Howard Hanson Dam was constructed.

In particular, with the Howard Hanson Dam in full flood-control operation, flood flows in the Lower Green River valley were limited to 12,000 cfs (measured at Auburn) for floods with an annual chance of occurrence estimated at up to 0.2 percent (i.e., a “500-year flood”). The Lower Green River levee system has functioned fairly successfully since the dam became operational. However, even with this successful track record, there have been levee failures—such as in 1965, when floodwaters covered nearly the entire eastern portion of the Lower Green River valley to a depth of 3 to 4 feet in areas near the present-day location of State Route 167 in the City of Renton. Floods in 1983, 1986, 1990, 1991, 1995 and 1996 also resulted in significant flood-related damage to levees throughout the Green River valley. Recent levee improvement projects and those proposed in the 2006 Flood Plan are in response to these recognized deficiencies in the existing levee network.

The Corps of Engineers is currently estimating that remedial measures to limit excessive seepage and erosion at the right abutment of the Howard Hanson Dam will take about two years to design and another three years to construct, or a total of at least five years before the authorized level of flood control at the dam can be re-established. The review panel recognizes that emergency measures are underway to respond to the immediate danger posed by increased flooding in the Lower Green River. However, the panel also discussed whether planning for flood flows of 12,000 cfs long into the future is prudent.

The review panel promotes consideration of a flood hazard management strategy for the future that is different from the past approach based on a maximum flood flow of 12,000 cfs. The strategy consists of the following primary elements:

- Emergency response efforts to mitigate the impacts of larger flood flows while Howard Hanson Dam is being repaired
- A near-term strategy that mirrors recommendations in the 2006 Flood Plan to address levees with known deficiencies
- A longer-term strategy that recognizes that conditions have changed and emphasizes the concept of residual risk.

The review panel's discussion of changing conditions in the Green River valley is summarized in the following sections.

Possibility of Long-Term Future Flows Larger than 12,000 cfs

Even though repairs at the dam are estimated to be completed in about five years, at which time the river should regain the level of flood protection that has generally proven adequate since 1962, other occurrences could arise in the future that again expose the Lower Green River to higher floods. For example, damage from an earthquake could prevent dam operation, or repairs being undertaken now could fail to provide a long-term permanent solution. Any flow changes associated with climate change also would have the potential for significant impacts on flood control facilities throughout the Pacific Northwest.

Extensive Development in the Green River Valley

Development along the Lower Green River has been substantial since 1962. A recent independent economic analysis found that a shutdown of King County's floodplains would result in $46 million per day in reduced economic output, with the vast majority of this centered on the Green River valley. A preliminary flood risk assessment completed in 2001 concluded that the Green River levee system provides up to $62 million (2001 dollars) in annual avoided damage. A more recent analysis by the Federal Emergency Management Agency (FEMA) estimates that flood damage from a levee breach under flows of 12,800 cfs could total $1.34 to $3.77 billion, and displace 15,400 to 21,900 residents.

Based on the regional economic value and importance of the Green River valley, the review panel believes that, in the long-term, planning for the Green River levee system should assume flood flows higher than 12,000 cfs. Higher flows could occur after the near-term repair to the Howard Hanson Dam, and the resulting economic consequences to the Lower Green River would be considerable. Because of this, the review panel does not believe that continuing to plan for maximum flood flows of 12,000 cfs in the Lower Green River valley is wise.

Environmental Concerns

Environment concerns were limited in 1962 when the Howard Hanson Dam was constructed. Today a broad range of environmental programs apply to construction and maintenance of dams, levees, stormwater systems, roads, bridges, and all types of development. These environmental programs include, at the federal level, the National Environmental Policy Act, the Clean Water Act (particularly Section 404), and the Endangered Species Act. At the state level, they include shoreline regulations, critical area regulations, pollution control regulations and floodplain regulations. At the local level, they include wetland regulations; floodplain regulations; growth management regulations; and a broad range of zoning, subdivision controls and building codes.

Consistent with a federal district court's directive (National Wildlife Federation v. FEMA, 345 F. Supp. 2d 1151, W.D. Wash. 2004) and a 2008 biological opinion on the NFIP prepared by the National Marine Fisheries Service (NMFS), FEMA and its partners are to undertake a broad range of activities concerning potential impacts of floodplain hazard management matters upon endangered species, including Chinook salmon, Puget Sound steelhead, Hood Canal summer-run chum salmon, Lake Ozette sockeye salmon and Southern Resident killer whales. The resulting biological opinion contains a broad range of "reasonable and prudent alternatives" that FEMA and partners are to take to avoid destruction or adverse modification of critical habitat for these species. These are discussed in greater depth in Chapter 10.

Climate Change

Climate change will significantly increase mean annual temperatures and resulting runoff from snow pack, although the magnitude of hydrologic impacts in Washington and, more specifically, on the Green River basin, remain to be seen (see *Implications of 21st Century Climate Change for the Hydrology of Washington State*, http://cses.washington.edu/db/pdf/wacciach3hydrology644.pdf).

On May 21, 2009, Washington Governor Chris Gregoire issued an executive order setting forth state actions to reduce climate-changing greenhouse gas emissions, to increase transportation and fuel-conservation options for Washington residents, and to protect the state's water supplies and vulnerable coastal areas. The Washington legislature has also passed a bill requiring state agencies to develop an integrated climate change response strategy (Chapter 519, Laws of 2009) by 2011.

CONDITION OF THE EXISTING GREEN RIVER LEVEE SYSTEM

Another important theme emerging from the review panel discussions was the importance of understanding the condition of the levee system. The structural stability of the levee system cannot be easily quantified. It can be said, however, that the existing levee system has performed reasonably well since Howard Hanson Dam was constructed in 1962—historical levee damage events notwithstanding.

History of Levee Construction and Repair

Most of the Green River levees were constructed in the 1960s and 1970s using crane and dragline methods that resulted in slopes varying from 1.5 horizontal to 1 vertical (1.5H:1V) to 1.75H:1V. The riverside levee face and raised levee fill were constructed with a combination of native alluvial and imported pit run gravel and cobbles. Finished slopes were covered with 2 to 3 feet of 8-inch- to 2-foot-diameter spalls or riprap.

Prior to 1990, the design for repairing compromised portions of the levees emphasized placing large amounts of riprap on the face and launching apron. It is likely that most repairs completed during this period conformed to design approaches suggested in the 1970s by the Corps of Engineers and the Federal Highway Administration.

During the 1990s, there was a significant change in King County's levee repair methodology. Repairs completed during the 1990s emphasized biostabilization. Repairs to revetment slopes and toe buttresses incorporated live willow and dogwood cuttings, and large woody debris. In general, failed revetment slopes above the ordinary high water mark were replaced with clean sand and gravel fill, typically with geogrid layers and live willow inclusions. The stabilization design varied at individual project sites to accommodate site conditions.

Recent repairs to the levees and revetments along the Green River continue to emphasize biostabilization. Improvements and repairs continue to incorporate the use of geogrids with live willow inclusions, logs anchored into rock-ballasted trenches and toe buttress materials, and surface soil stabilization with riparian vegetation enhancements. The review panel's document review suggests that the repair approach has evolved in the following ways:

- Toe Buttress—Additional emphasis has been placed on installing thickened toe buttresses to increase resisting forces. This rock slope protection intrudes into the stream channel and must be implemented with adequate protection of habitat. In recent years, greater care to protect habitat has included the use of turbidity control curtains during construction along with other erosion and sediment control measures. Rock toe buttresses do not provide the type of habitat that would typically occur in the unaltered Lower Green River. Uniform application of rock

toe buttresses also do not provide the diversity of substrate and habitat that would occur naturally. The riverbanks in the Lower Green River would naturally have a variety of substrate and bank forms, including sand, gravel and cobble bars, mudflats, embedded and loose large woody debris, tree and shrub roots. However the toe of a levee, especially in a confined channel, is a critical section of the structure and must be constructed robustly. Covering rock toes with native river materials is an option for incorporating habitat features into the levee toe design. Also, setting levees further back from the river channel also provides opportunities for habitat enhancement features being placed over the top of structural elements of the levee side slope and toe. In the current regulatory and financial situation these designs must also be acceptable to the Corps of Engineers.

- Reduced Side Slopes—Riverside slopes are flatter or mid-level benches are added to achieve an overall flatter slope angle. This change can be difficult to accomplish in some areas because of the lack of right-of-way, but it is been preferred because of its compatibility with habitat restoration goals. Slopes are now generally regraded to 2H:1V or as close to that angle as possible given site-specific conditions. Installing a mid-slope bench helps to achieve the desired overall slope angle, while also providing a working platform for heavy equipment to reach deep into the toe for buttress repairs and greatly aiding in riparian vegetation enhancement efforts.

Uncertainty of Existing Levee Conditions

The levee system has never experienced large floods, such as the 25,000 cfs estimate identified by the Corps of Engineers as one of the flood scenarios for the next few years. Therefore, inherent in the review panel discussion regarding consideration of higher flows is the need for a system-wide structural stability assessment of the levees. This includes an assessment of the structural stability of the levees to contain flows and to withstand overtopping without washing out from backside erosion. Much of what is known today results from observations following flood events, inspections of “hot spots” identified along the levee system, knowledge of past levee damage locations, and limited comprehensive geotechnical field investigations. In the long-term, especially considering the regional economic value of the Green River valley, the levee system must be sufficiently investigated that system-wide knowledge of the levee’s structural integrity is documented.

CHALLENGES TO FUTURE PLANNING STRATEGY

Based on the discussions about the three central themes—long-term flood-management goals, changing conditions, and understanding of the levee conditions—the review panel identified a number of challenges to future planning strategy as described in the following sections.

Floodplain Management Should Consider a Wider Flood Corridor

A floodplain management strategy that addresses flood flows greater than 12,000 cfs will generally require either larger, higher levees or a wider flood corridor. King County recognizes the benefits of a wider flood corridor and has already identified many opportunities for setting levees farther back from the river channel. Moving levees farther from the channel would provide many advantages over the current, more constraining levee network, such as reduced flood elevations and flow velocities for a given flow. It would also provide environmental benefits.

Most recent levee setback projects have been undertaken as opportunities for land acquisition arise and to the extent possible before being restricted by existing development. Each of these projects provides enhanced levee stability at local areas along the levee network. The existence of highly built-out commercial and industrial areas in the Green River valley pose the greatest challenge to implementing a

management strategy that considers flood flows greater than 12,000 cfs. The review panel recognizes that many of the properties adjacent to the Green River have already been developed, but a long-term plan should still consider acquisition of select properties where possible. The panel believes that a long-term strategy needs to be more aggressive in identifying a plan that provides for a much wider river corridor.

A long-term strategy to develop a wider river corridor should also consider other floodplain management measures. For example, hydraulic modeling associated with the setback levee analysis would also identify low-lying areas in the floodplain, which can provide overbank flood storage areas. Similarly, overtopping levee segments can be considered to direct floodwaters to these storage areas.

Future Management Should Use a Risk-Based Approach

In hazard mitigation planning, risk is defined as the probability of occurrence of a hazard event multiplied by the impact of that event on the people, property and economy of a planning area:

- Risk = Probability x Impact (people, property, economy)

This formula allows local governments to quantitatively compare one hazard to another, and one hazard-mitigation project versus another. Impact is usually measured in terms of dollar loss, which allows for comparison of impact costs and project costs in order to measure the cost-effectiveness of a project.

Another concept that should be considered in future management of the Green River floodplain is the concept of residual risk. In terms of structural flood control, this would be the risk associated with events larger than the maximum for which a facility is designed or not considered in the design of the facility. In the Green River valley, this is the risk associated with flows greater than 12,000 cfs.

A risk-based approach to floodplain management should clearly identify the residual risk for any project being implemented. This quantitative approach should clearly measure the pre-project and post-project risk, so that the net risk reduction of one project can be compared to another for prioritization. The parameters for this quantitative evaluation should be based on countywide goals and objectives for floodplain management, taking into account both short-term and long-term benefits of a project. This will better position King County in defending its decision-making process.

Recently, King County completed a risk-based analysis of flooding at select breach locations along the Green River using the Corps of Engineers HEC-FDA software. HEC-FDA performs an integrated risk-based hydrologic, hydraulic, geotechnical, and economic analysis using a Monte Carlo simulation technique to compute the expected annual damage due to flooding. King County used HEC-FDA to estimate the potential economic damage associated with breaches of existing levees. The review panel supports continued County use of a risk-based approach to identifying and prioritizing floodplain management projects, not only in the Green River floodplain, but countywide.

Future Management Should Be Multi-Objective

Future management strategies should simultaneously address environmental concerns and flood risks. Strategies should involve the protection, enhancement, and restoration of aquatic and riparian habitat, including implementation of salmon habitat recovery plans. Local government wetland, floodplain, and other critical area and open space plans should be supported. Additional buy-outs could simultaneously reduce flood losses and meet habitat and recreation needs.

Regulatory Authority Must Be Adapted for Floodplain Management

The Green River channel and floodplain are continuous physical features of the valley, but jurisdiction and regulatory authority for development along the river are divided among King County and neighboring cities such as Auburn, Kent, Renton and Tukwila. Even though each entity complies with FEMA's NFIP, this does not necessarily lead to coordinated policies for floodplain management along the Green River. There is a significant difference between King County's floodplain management policies and regulations and those specified as minimum requirements of the NFIP. Because of these higher local standards, King County has achieved a Class 2 rating under the CRS, the highest rating of any county in the nation and the second highest rating of any community.

Although Washington state regulations stress regional consistency in floodplain management (RCW 86.12), these mandates carry few ramifications for non-compliance. Currently, there is no consistency in the scope of floodplain management regulations among the jurisdictions along the Green River. Considering the development that has occurred in the Lower Green River floodplain, it is evident to the review panel that this lack of regulatory consistency has resulted in a significant increase in risk exposure over time. Therefore, the panel recommends that King County consider the following:

- Strengthen the definition of "regional consistency" in the 2006 Flood Plan to include regionally acceptable/applicable higher regulatory standards.
- Establish ramifications for the lack of regional consistency under the 2006 Flood Plan. The recent formation of the King County Flood Control District creates options for promoting regional consistency.
- Establish incentives for municipalities to adopt the 2006 Flood Plan or regional policies consistent with those in the plan. Incentives could include increased funding under County capital project programs and the potential to access this additional funding.
- In areas where there is potential for significant residual risk from structural flood control facilities, consider expanding the regulatory scope of the King County floodplain management program into areas with identified exposure to residual risk.

While none of these recommendations will offer any short-term relief to the concerns in the Green River floodplain, they could provide significant reduction in risk exposure over the long term.

Levee Design Considerations and Need for Ongoing Monitoring

Through the years, King County has been active in implementing flood hazard management measures in the Green River valley, including rehabilitation of existing levees and construction of new levees. Many of the improvements have been targeted at levees identified as being in most need of repair, such as at the location of over-steepened side slopes or where erosion or bank failures have been observed. In these instances, King County has endeavored to set levees farther back from the river channel whenever possible, and provide flatter side slopes, rock toes for erosion protection, and vegetation and large woody debris for habitat enhancement.

Some of King County's levee design approaches for the Green River differ from design approaches implemented by the Corps of Engineers. The Corps of Engineers prefers a larger volume of rock protection at the toe of the levee and less reliance on vegetation for erosion protection. Both of these design approaches have functioned well for their relatively short design life on the Green River. In contrast, levees on some other rivers in King County and Washington State are far more structural, with a greater use of large rock along the entire levee side slope and minimal use of vegetation and large woody debris for habitat enhancement. Because of these differences in levee design, and the use of more bio-engineered techniques on the Green River, the review panel believes that monitoring the levee

performance is needed. This includes levee inspections during low flow periods and especially following flood events.

A monitoring program would provide a more formalized process under which observation of results can lead to changes in a management approach. For example, a monitoring program allows the bio-engineered design approaches being implemented on the Green River to be evaluated and, more important, allows for design changes to be made in the future based on the results of the monitoring program. Similarly, differences in design practices between King County and the Corps of Engineers can be evaluated further through performance monitoring. If floods occur during the next few years while Howard Hanson Dam is being repaired, the high flows will provide a unique opportunity for assessing the performance of recent levee rehabilitation efforts.

This recommendation for levee monitoring is consistent with the review panel's recommendation for a more comprehensive system-wide structural assessment of the levee system. Inherent in these comments is the need to have better documentation of the physical condition of the levee network and an understanding of how past design approaches have functioned on the Green River.

CHAPTER 4.
FUNDAMENTAL ASSUMPTIONS, ISSUE 1

Issue 1 was presented to the review panel as follows:

- The *2006 King County Flood Hazard Management Plan* and capital program were developed assuming the full flood protection capacity of the Corps of Engineers Howard Hanson Dam. Revised operational plans for Howard Hanson Dam could result in increased duration of high flows, rapid rise and drawdown of the river as well as increased saturation of levees and adjacent ground.

King County's questions related to this issue are addressed in the following sections. Each question is shown in a blue side-box as it was provided to the review panel. The section text represents the panel's response.

QUESTION 1A—DAM OPERATION EFFECT ON LEVEE FAILURE

Do the required operational changes at Howard Hanson Dam affect the risk of levee failure downstream of the dam? If so, how?

The required operational changes at Howard Hanson Dam will affect the risk of levee failure downstream of the dam. Historically, the Corps of Engineers has operated the dam in the following manner:

- Draw down the reservoir to empty (elevation 1,075 feet) at start of flood season.
- Release water at inflow rates up to approximately 12,000 cfs.
- Beyond inflow rates of 12,000 cfs, hold additional water to maintain 12,000 cfs at Auburn gage, resulting in water level rise in the reservoir (flood storage).
- As storm event subsides, continue to release water (at 12,000 cfs) to draw down the reservoir to empty.
- Do not exceed the maximum reservoir level of 1,206 feet (without use of spillway).

The Corps of Engineers has completed installation of a grout curtain and is continuing to evaluate dam conditions. The result of this evaluation will determine the safe reservoir level and how the dam will be operated during this flood season. With the compromised condition of Howard Hanson Dam, the Corps of Engineers intends to operate the dam in the following general manner during the 2009-2010 flood season (and potentially beyond this season):

- Maintain the reservoir level as low as possible (elevation 1,075 feet) before storm events during the flood season.
- During storm events, continue releasing flow at some rate up to 12,000 cfs (measured at Auburn) and store excess flows up to the safe reservoir water level (as determined by the Corps of Engineers).
- Once the safe reservoir level is reached, release all further flows (return to run-of-the-river dam operation). This could result in flows greater than 12,000 cfs at Auburn.
- If a major storm event is anticipated, release flows greater than 12,000 cfs as needed before the dam reaches the safe reservoir level to provide additional storage at the dam.

- As a storm event subsides, release water at rates at or below 12,000 cfs to draw the reservoir back down to empty.

The magnitude of downstream flows is likely to be significantly different due to these operational changes. Since 1962, the Green River has been regulated to limit flows to about 12,000 cfs. This flow represents a pre-dam flood in the Lower Green River with an annual chance of occurrence of 50 percent (the two-year flow). Without Howard Hanson Dam, the Green River would have experienced flows above 12,000 cfs on many occasions since 1962; flow fluctuations would have been much more dramatic, driven primarily by intensity and distribution of rainfall, rain-on-snow conditions, and antecedent moisture conditions. The energy of higher flows could have resulted in dramatic morphologic changes, particularly channel avulsions.

With the flood protection provided by Howard Hanson Dam, the duration of flows at the 12,000-cfs level likely often exceeds that of natural conditions, as the Corps of Engineers releases 12,000-cfs flow following a flood event until the reservoir is lowered to its target level. For example, in November 2006, the Corps of Engineers released 12,000 cfs for several days following the flood peak. In contrast, under natural conditions, the flow may have risen from 6,000 cfs to 20,000 cfs, and then returned to 8,000 cfs within a few days.

The following are the likely changes to the flow regime with the newly revised dam operations:

- Flows below but closely approaching 12,000 cfs will occur more frequently as the Corps of Engineers releases water and attempts to keep the reservoir level as low as possible prior to the flood season.
- Flows of 12,000 cfs after storm events will be released more frequently, for longer durations, and with a faster rise and fall to maintain storage at the dam for extreme events.
- Depending on available storage in the reservoir, storm characteristics, and rain-on-snow conditions, flows exceeding 12,000 cfs may occur.

The change in duration of high flows, both below and above 12,000 cfs, may have a significant impact on levee stability. A major concern with the required operational changes at the dam is that much of the levee system in the Green River was built with a maximum design flow of 12,000 cfs (as measured at the Auburn gage). In most places, the levees are designed to contain Green River flood flows up to about 12,000 cfs with 3 feet of freeboard. Low flows are contained by natural banks in a channel below the ground elevation of adjacent lands. As flows increase, water levels rise above the elevation of the natural banks and begin to be contained by the levee network. Overtopping or failure of these levees thus poses a flood risk to areas landward of the levees.

Because of past dam operations, there is no previous experience or historical data to indicate how the levee network will respond at flows higher than 12,000 cfs. However, it can generally be assumed that higher, longer duration flows with more rapid fluctuations can have the following impacts:

- Higher flows and velocities increase the potential for bed and bank scour. Toe scour, in particular, is a leading cause of levee failure, especially where levee slopes are oversteepened.
- Higher river flows and longer duration flows will saturate levees more frequently. Saturated levees have a lower factor of safety against instability on the landward slope.
- Rapid river-level drawdown from saturated levee conditions presents additional risk. The Corps of Engineers has indicated that it may not be possible to adhere to the current drawdown rate limit of 1 foot per hour.

- Additional weight from temporary flood protection measures on top of levees (sandbags, Super Sacks, etc.) may exacerbate the failure risk.
- Raising levees will result in higher pressure gradients from the river to the landward toe; these higher gradients can lead to water piping through or beneath the levee, landward boils, and decreased landward slope stability that could lead to non-overtopping levee breaches.
- Overtopping of levees by flows greater than 12,000 cfs is likely to erode the generally unarmored back slope of the levees, leading to levee breaches.

QUESTION 1B—STEPS TO REDUCE RISK OF LEVEE FAILURE

What steps can be taken to reduce this risk, whether the risk be increased or remain the same?

King County and the cities of Auburn, Kent, Renton and Tukwila have been very active in developing emergency response measures to address the possibility of higher flood flows in the Green River. The discussion in this section relates specifically to reducing risks related to instabilities in the levee system. The following steps would help to reduce risks of levee failure and to reduce the magnitude of damage associated with any failures that do occur:

- The current plan to run the river at 12,000 cfs for as long as necessary to keep the reservoir at an acceptable level is appropriate given the situation, but it increases the risk of levee failure. Running lower flow levels would decrease the risk of levee failure because it would reduce saturation and buildup of pore water pressure within the levee prism above ground surface.
- To the extent possible, it is wise to avoid or minimize rapid drawdown of river levels. Slumping and other levee failures often occur as water levels drop following a flood peak. When bank and levee material becomes saturated during high water, the pore pressure caused by the water becomes part of the bank/levee support. When water drains out rapidly, the support from the interstitial water is removed and the bank or levee may slump out. Existing protocols stipulate a maximum drawdown of river levels of 1 foot per hour. To the extent possible, this protocol, or even slower drawdowns, should be employed.
- Because of the possibility of multiple floods before the Corps of Engineers completes improvements at Howard Hanson Dam, levee inspections are critical to monitoring the performance of the system. Information gained during and after a flood event provides valuable performance data that can be used to guide levee repairs between floods:
  - Trained staff should conduct extensive levee monitoring during high-flow periods. Levee patrols should be trained to observe signs of distress, such as sand boils, seepage emanating from the face of the levee, slumps and cracks. These patrols may need to operate 24/7 during high flows; provisions will be needed for night-time inspections. A training course should be established and attended by all who will be on patrol. Particular attention should be made to high levee sections.
  - Trained staff should conduct a full levee inspection after each significant drawdown event. This will allow repair of levees before the next high water event. Inspectors should be trained to spot signs of failure, such as loss of toe support, evidence of sand boils, slumps, cracks and loss of levee facing. A training course should be conducted for all who will complete post-high-water levee inspections.
- Stockpile materials along the levee system to quickly repair distressed levees. Such materials could include riprap for additional toe protection, sand bags for ring dikes at boils, and crushed rock.

- Develop a pool of contractors available to respond to emergency flood fighting measures on short notice.
- Perform after-action analyses of levees; use established protocols; evaluate ***performance*** issues beyond immediate maintenance needs. While this relates to the increased inspections recommended above and draws from the data collected during these inspections, a performance evaluation goes beyond identifying maintenance needs. It should focus on identifying where weaknesses in the levee system may warrant revising future Green River project priorities and strategies.
- Consider installing monitoring equipment to increase King County's predictive capacity for levee failure risk:
  - Piezometers—Install additional piezometers on the levees and at the landward toe of the levees to enable monitoring of groundwater levels within the levee prism and at the landward toe. This information would be used to determine if elevated pore pressures build up within the levee or if flows under high heads are located below the toe of the levee
  - Seismometers—King County may wish to investigate the potential for using seismometers to provide real-time monitoring of potential levee breaks during critical periods.
  - Fiber optic lines that could be installed and instrumented in the levee to measure strain and potential breaches.

QUESTION 1C—MODIFICATIONS TO FLOOD WARNING PROGRAM

Should King County's Flood Warning Program be modified to address any increased risk? If so, how?

An extensive amount of preparation for possible flooding has been done by King County, the cities of Tukwila, Renton, Kent, and Auburn, and individual landowners and businesses in the flood risk area. The review panel was asked to identify possible gaps or additional elements that should be included. Table 2 (in Chapter 2) provides a summary of key information pertaining to ongoing emergency response efforts.

The flood warning program being developed by King County and cities in the Green River valley is extensive and addresses a myriad of complex issues associated with emergency management. The review panel believes that this topic is being addressed comprehensively by King County and others, but the panel offers the following comments to emphasize particular elements of the current planning efforts:

- Much of the preparedness planning focuses on flooding caused by levee overtopping, with floodwater spilling onto the floodplain and inundating farmland, residents, businesses, industry, and public facilities. The inundation mapping provided by the Corps of Engineers and used by all the cities illustrates this type of flooding. However, potential flooding from a levee breach could be more dangerous due to localized deep, fast-flowing water. This flood hazard is also more unpredictable as to where and when it may occur. In addition, flooding from a levee breach could occur for river levels below levee-overtopping levels. In this case, local flooding with high velocities could occur with little or no warning to affected residents. The public should be educated on the difference between the levee-overtopping and levee-breach flooding scenarios.
- The need for real-time data is critical. This includes all relevant information, especially rainfall intensities, dam release rates, flow levels, levee breaks, road conditions, evacuation advisories, and general emergency communications. In an emergency situation, people will

need ready access to current information. This should be made available through a variety of previously publicized information, including web sites, emergency radio broadcasts, and TV news outlets.

- Coordinated evacuation plans should be in place that are the same for cities and King County lands. Standardized evacuation levels (i.e., alert, request, or order) should be established. While each city may customize its information to address geographic specifics, everything else should be standardized and coordinated (mapping, evacuation procedures and routes, etc.). Ideally, an evacuation drill would be conducted, even if it were just for a portion of the flood risk area.

CHAPTER 5.
OVERALL STRATEGY, ISSUE 2

Issue 2 was presented to the review panel as follows:

- King County's adopted 2006 FHMP includes basin characterizations of hydrologic, geologic, and ecological factors, as well as land use and development.

King County's questions related to this issue are addressed in the following sections. Each question is shown in a blue side-box as it was provided to the review panel. The section text represents the panel's response.

QUESTION 2A—CURRENT 2006 FLOOD PLAN GREEN RIVER BASIN CHARACTERIZATION AND RECOMMENDED ACTIONS

In what ways should the elements of the basin characterization of the Green River Basin be modified in light of the new situation at the Howard Hanson Dam? Will any recommended actions (both capital and programmatic) in the Green River basin reduce risks to people and property and to what extent, both short term and long term?

Characterization

Much of the Green River Basin characterization in the 2006 Flood Plan is based on Howard Hanson Dam providing flow control to downstream areas. The geomorphology, hydrology and hydraulics, ecological context, salmonid use, King County facilities, history of flooding and flood damages, and analysis of flood risks are described entirely within the context of Howard Hanson Dam continuing to provide absolute flow control at 12,000 cfs. It is now clear that a characterization of basin features without the dam functioning would better prepare the region to determine its best priority strategy. The revised basin characterization should consider three conditions:

- Howard Hanson Dam providing flow control as it has historically
- Howard Hanson Dam providing reduced flow control
- Howard Hanson Dam providing no flow control (such as if the dam were deemed unsafe for operation)

New data developed after the 2006 Flood Plan would be valuable to this characterization. For example, new high-resolution overbank topography (photogrammetric or LiDAR) shows that the channel of the Green River is commonly located at high points in the valley, meaning that many structures in the floodplain are at lower elevations than the river level. The topographic patterns revealed by this high-resolution topography could greatly inform analysis of overbank flow paths and identification of high flood risk areas. This new topographic information is already being used in the most recent floodplain mapping conducted for King County, and the modeling results are providing key insight to overbank flow patterns.

It is important to evaluate how the river's natural processes may impact facilities and development at flows higher than the dam-regulated maximum of 12,000 cfs. As described in the 2006 Flood Plan, the Green River system has been extensively modified by humans. Diversion of the White River into the Puyallup and the Black River into the Cedar removed approximately two-thirds of the drainage area that originally contributed to the Green–Duwamish system.

Although it could be argued that it is unnecessary for King County to invest in a no-dam analysis if the dam will be functioning again in five years, this disregards the possibility that a similar situation could occur again at a future time when the economic value of development in the Lower Green River will be even greater than today. A basin characterization for the three flood scenarios should be done for the upcoming five years, as well as for the long-term. A new characterization analysis also would be valuable in evaluating possible higher flows caused by climate change or future problems with the dam.

A risk-based analysis is needed. The 2006 Flood Plan includes a county-wide risk assessment but assumes a 100-year floodplain with functioning levees in the Green River basin. The risk assessment should examine residual risk, which includes the risk of no flood control from Howard Hanson Dam. The risk-based analysis should address what happens for flows over 12,000 cfs, or what happens if the dam or levee system fails or otherwise does not function as designed. Risk has increased mainly because of increased potential loss (primarily due to floodplain development) rather than because of increased probability of flooding. King County needs a greater understanding of these risks, particularly over the next five years; beyond that, there is also a need to plan for the longer term.

Will 2006 Flood Plan Recommendations Reduce Risk?

The 2006 Flood Plan lays out a program of recommended actions, countywide and for the Green River valley (see Table 4). These recommended actions will reduce risk to people and property in the short term. Whether all the recommended capital projects will reduce risk in the long term is more complex.

Short Term

With existing high-value development in the floodplain, a likelihood that Howard Hanson Dam will be repaired, a tightly constrained river corridor, and an existing substandard levee system, continuing to implement the 2006 Flood Plan actions should reduce risk in the short term. For the Lower Green River, these actions focus on rehabilitating existing levees to increase stability, including reducing the levee slopes.

Long Term

The financial impact on all affected parties will be an important indicator of whether the recommended projects in the 2006 Flood Plan will reduce risk to people and property at an acceptable benefit-cost ratio. Unquestioned reliance on a flood control dam and levee system provides opportunities for nearly unrestrained economic development of floodplain land; however, the risks (including cost) if elements of this flood protection strategy fail may make this an undesirable strategy in the long term.

King County should update the basin characterization to include the possibility of flows higher than 12,000 cfs and provide a comprehensive assessment of the true flood risks in the Green River Basin. As discussed in Chapter 3, updated flood plan strategy recommendations should consider pursuit of a wider river corridor as a long-range goal to address the residual risk of dam or levee failures. The strategy should also include consideration of potential increased flows associated with climate change.

TABLE 4.
2006 FLOOD PLAN RECOMMENDED ACTIONS FOR THE GREEN RIVER VALLEY

Proposed Action	Description	Estimated 10-Year Cost
Status Quo Funding		
Pump Station Operation	Maintain and operate Black River, P-17 and Segale/Southcenter pump stations in Green River Flood Control Zone District.	$2,100,000
Green River Flood Study	Complete flood study and corresponding FEMA Flood Insurance Studies and Flood Insurance Rate Maps for the Green River between River Mile 5.0 and River Mile 45.0.	$1,000,000
Desimone Levee Project 3	Rehabilitate levees to reduce risk of flooding in the Lower Green River.	$650,000
Segale Levee Project 1	Rehabilitate levees to reduce risk of flooding in the Lower Green River.	$1,913,000
Briscoe Levee Project 4	Rehabilitate levees to reduce risk of flooding in the Lower Green River.	$1,135,000
Nursing Home Levee Project	Rehabilitate levees to reduce risk of flooding in the Lower Green River	$2,438,000
Salmon Habitat Recovery Cost Share	Provide financial support to and participate in Salmon Recovery Funding Board and Corps of Engineers Ecosystem Recovery Project habitat projects.	$1,000,000
Green River Flood Control Zone District Program Management	Provide program management and administration to Green River Flood Control Zone District projects, programs and other related activities.	$1,000,000
Enhanced Funding		
Desimone Levee Project 1	Rehabilitate levees to reduce the risk of flooding in Lower Green River.	$860,000
Desimone Levee Project 2	Rehabilitate levees to reduce the risk of flooding in Lower Green River.	$1,071,000
Desimone Levee Project 4	Rehabilitate levees to reduce the risk of flooding in Lower Green River.	$3,491,000
Segale Levee Project 2	Rehabilitate levees to reduce the risk of flooding in Lower Green River.	$1,913,000
Briscoe Levee Projects 1-3, 5-8	Rehabilitate levees to reduce the risk of flooding in Lower Green River.	$14,970,000
Russell Upper Levee Project	Rehabilitate levees to reduce the risk of flooding in Lower Green River.	$472,000
Kent Shops Levee Project	Rehabilitate levees to reduce the risk of flooding in Lower Green River.	$3,596,000
Narita Levee Project	Rehabilitate levees to reduce the risk of flooding in Lower Green River.	$1,913,000
Myer's Golf Levee Project	Rehabilitate levees to reduce the risk of flooding in Lower Green River.	$4,967,000
Middle Green River Floodplain Acquisition	Purchase two at-risk homes and associated property in Middle Green River valley.	$1,204,000

QUESTION 2B—CHANGE IN PRIORITY STRATEGY

Should King County's priority strategy change with the new situation at Howard Hanson Dam?

The changed awareness of conditions at Howard Hanson Dam raises many immediate needs as well as longer term questions regarding priority strategies for flood risk reduction, both in the Green River Basin and elsewhere in King County.

King County's Current Priority Strategy

King County's policy on "Criteria for Taking Action" related to structural and non-structural projects (2006 Flood Plan, p. 17) provides overall guidance on considering priority strategies:

> *"Hundreds of public and private properties in King County are vulnerable to flood-related hazards. If no action is taken to address a flooding or channel migration risk, King County needs to assess the consequences that will result. Some risks may need to be addressed sooner than others depending on the severity of the risk and what is vulnerable. Under certain circumstances, King County may have legal responsibility to take action to address flooding risks, such as when there is a contractual agreement with a property owner or another agency to maintain a flood protection facility."*

Lower Green River Basin

The 2006 Flood Plan (p. 240) describes King County's priority strategy and objectives for the Lower Green River Basin as follows:

> *"Preliminary risk assessments for the Lower Green River indicate that the existing levee system prevents more than $60 million in flood damages each year, on average.* ***The primary objective for the lower river is to maintain the structural integrity of the levee system*** [emphasis added] *so that it can continue to provide this essential public service and to protect public safety. At the same time, initial levee stability studies performed at four locations along the Lower Green River indicate that the existing levees fail to provide the minimum factors of safety against potential structural levee failures, based on published federal guidelines. . . . . Thus, it is safe to say that a program of major levee rehabilitation and reconstruction is the single overarching need within the Lower Green River."*

The 2006 Flood Plan further elaborates that King County's approach to completing the levee rehabilitation and reconstruction will be through a setback template of up to 110 feet landward from the aquatic edge of the river channel along each bank. This provides enough width to correct the too-steep slope geometry and gain access to the toe of the levee. This template will be applied throughout the river corridor in a systematic fashion, prioritizing identified weak areas and integrating opportunities associated with relocating riverside roads (i.e. Frager and Russel Roads) and locating the Green River trail system. As redevelopment occurs, the current strategy is to require levee setbacks as a condition of redevelopment.

Middle Green River Basin

The 2006 Flood Plan (p. 241) states:

> *"The primary strategy for the Middle Green River is keyed to the risk to residential structures in channel migration hazard areas. Over the short term, flood protection facilities should be repaired and maintained so as to protect public safety, without precluding long-term opportunities to modify the facilities. The primary long-term goal is*

> *to set back existing flood protection facilities and allow unconstrained or less constrained channel migration. Existing at-risk structures would best be acquired and removed."*

King County also acknowledges the reality of a long implementation timeframe due to potentially conflicting land-use policies, acquisition costs, and funding limitations.

Consideration of Changes to Priority Strategy

The changed awareness of conditions at Howard Hanson Dam may justify modifications to King County's priority strategy for addressing flood risk in the Green River basin, and possibly elsewhere in King County as well. The review panel's overarching recommendation on priority strategy is that King County's priority strategy should be guided by four main objectives: reduced flood risk, environmental benefit, cost effectiveness, and sustainability. Reducing maintenance commitments (and associated costs) and habitat restoration are important, but secondary, priorities. Guiding principles in the 2006 Flood Plan focus on reducing flood risks through structural flood protection measures as well as protecting and working with natural riverine processes. Inherent in these principles is environmental benefit and sustainability, as these serve to shape a long-term comprehensive flood hazard management strategy. Given the considerable economic development in the Lower Green River valley, the panel believes that flood protection measures must consider sustainable practices to ensure the needs of the present are met without compromising the ability of future generations to meet their own needs.

Reflecting on King County's "Criteria for Taking Action" policy, the consequences for taking no action in the Green River Basin would be considerable. For this reason, it is imperative that King County's strategy extend to considering flows above 12,000 cfs and no flow regulation from Howard Hanson Dam. One panelist compared the current scenario to New Orleans planning for a Category 3 hurricane rather than a Category 5 and encouraged King County to plan for more extreme scenarios than it has previously believed were likely to occur.

Lower Green River

The current Lower Green River priority strategy relying heavily on rehabilitating and reconstructing levees has several shortcomings:

- Levees are never 100-percent reliable and may provide a false sense of flood protection to floodplain residents.
- Flooding that occurs due to levee overtopping or levee failure is usually worse than flooding without levees, which can disperse more readily and find its way back to the river channel.
- Levees constrain the river system, focusing the river's energy on a narrow corridor.
- Levees are in need of ongoing maintenance and frequent repairs; these perpetual needs highlight the non-sustainable aspect of a levee approach to flood risk reduction.
- If anticipated flood levels rise, either because of a physical change in the watershed or because of refined flood frequency analysis, the region has little choice but to raise the levees.
- The strategy continues to encourage development in the floodplain, with resultant increase in residual risk associated with flooding.
- Given the need to plan for flows above 12,000 cfs in the Green River, viability and sustainability of the Green River levee system may be compromised.

Still, levees provide a traditional, time-tested approach to containing floodwater in the river channel and are a reasonable strategy where the defined goal is to reduce flood frequency in order to allow expansion of development in a flood-prone area. The flood protection historically provided by Howard Hanson Dam has achieved a similar goal; however, dam operation represents a significant, ongoing financial commitment and may be warranted only in combination with a more robust leveed river system.

Short-Term Priority Strategy

With the above considerations in mind, the panel offers the following regarding short-term priority strategy for the Lower Green River:

- King County's priority strategy must be guided by the "do no harm" approach. This includes the flood preparations underway, together with continued implementation of selected projects and priorities articulated in the 2006 Flood Plan that address the most critical shortcomings in protection from flows at or above 12,000 cfs, as informed by any new data that may indicate shifting of priority projects.
- An increased focus on vulnerabilities is warranted, such as protection of electrical equipment on the first floor of buildings in the flood risk area.

Long-Term Priority Strategy

The review panel's overarching recommendation is that King County's long-term priority strategy should be guided by reducing flood risk and achieving environmental benefit, cost effectiveness, and sustainability. Reducing maintenance commitments and associated costs and habitat restoration are also important priorities.

Given the need to employ a more comprehensive risk-based analysis that includes higher flows and reduced or no flow regulation provided by Howard Hanson Dam, some members of the panel believe it is worth evaluating a priority strategy that seeks to establish a wider river corridor to accommodate higher flows and to allow for more natural riverine processes. A wider river corridor would also decrease the erosive pressure on the levees, reducing the risk of levee failures. This long-term goal would be more sustainable than the current strategy, would provide greatly increased environmental and habitat value, and may be economically justifiable if implemented over a 20- to 50-year time horizon.

The panel envisioned elements of this strategy to include the following:

- Convene a forum with the cities to discuss and agree on how this process will be coordinated. Formal agreements will be necessary. Requires all jurisdictions on board at the outset; discussion of this can begin with discussion of changed flood warning/evacuation needs.
- Identify potential setback levees locations that would create a minimum 500-foot-wide river corridor. This effort should be aggressive in identifying sites, even if land is currently developed – for example a warehouse structure may be ready for redevelopment in 20 years and at that time could be purchased for river corridor.
- Identify land uses that may be compatible with inside-the-levee locations—such as parks, farmland, and golf courses—and then move levees to outside these locations instead of repairing them where they presently exist.
- Restrict further development that is incompatible with periodic inundation on undeveloped lands in the floodplain.
- Identify and plan to purchase permanent floodplain easements.

- Do not miss out on opportunities in areas that have not been built out yet; do not repeat historical steps that led to current problems.

Implementing this new strategy would require establishment of a sustainable vision and future action toward achieving that vision when opportunities arise. Centered on the theme of comprehensive long-term risk reduction, the panel believes that this would ultimately be the most cost-effective strategy.

Middle Green River

The review panel considered the current priority strategy for the Middle Green River and felt that it is appropriate in both the short and long-term.

CHAPTER 6.
OVERALL STRATEGY, ISSUE 3

Issue 3 was presented to the review panel as follows:

- The river and floodplain management program consists of levee reconstruction, regular maintenance of levees, acquisition of frequently flooded homes, operation of a flood-warning center, education and outreach about the hazards of living in the floodplain, and technical studies that include sediment transport and mapping.

King County's question related to this issue is addressed in the following section. The question is shown in a side-box as it was provided to the review panel. The section text represents the panel's response.

QUESTION 3A—MODIFICATIONS TO RESOURCE ALLOCATION STRATEGY

In light of total available resources, should King County consider reallocating resources to implement these actions given the new flood risks posed by changes in dam operations?

The King County Flood Control District is a special-purpose agency created to provide funding and policy oversight for flood protection projects and programs in King County. The Flood Control District's board is composed of the members of the King County Council. The Water and Land Resources Division of the King County Department of Natural Resources and Parks carries out the approved flood protection projects and programs.

The Flood Control District Board of Supervisors directs the use of the Flood Control District's funds. The majority of funds allocated to the flood program come from the Flood Control District and originate from property tax levies. The flood program allocates resources to Flood Control District administration, operating expenditures and the capital improvement program (CIP). According to the King County Flood Program 2010 proposed financial plan, the vast majority of the flood program resources are dedicated to the CIP.

Basin committees develop flood control projects for each major river basin in King County, based on technical, economic and environmental criteria. The Flood Control District board selects the King County CIP program from these basin lists. Proposed annual CIP expenditures in the Green River Basin are approximately one-third to one-quarter of total flood program annual expenditures from 2010 to 2015. With finite resources, King County is faced with difficult choices in allocating resources among the many river and floodplain management program needs. The review panel considered the urgent situation posed by changes in Howard Hanson Dam operations, and also the importance of long-term equitable distribution of resources.

Under the emergency situation that exists, it is reasonable for King County to reallocate resources to implement actions that would address the added flood risk. At least for the time period when dam operation will not follow original assumptions, new steps have to be taken to address that change. Using a risk-based approach, it is likely that the Green River would score highest for priority and therefore these additional resources are justified.

It must be acknowledged, however, that storm events that cause flooding on the Green River will also cause flooding in other King County rivers. County resources should not be so focused on the Green River that basic emergency services elsewhere in King County cannot be provided.

To avoid creating an inequitable, unjustifiable resource reallocation, criteria should be developed and followed to guide reallocation of resources. Examples of criteria include the following:

- Unless justifiable in the long-term, do not make long-term changes based on a short-term situation.
- Consider probability of occurrence and establish a threshold for resource allocation.
- Consider risk in all basins; use this to compare Green River Basin needs, and the benefit-cost ratio of addressing those needs.
- Make long-term changes if warranted, particularly if the need is urgent and the change also fits into the long-term strategy.
- Do not forgo opportunities to obtain buyouts that would provide long-term solutions. Consider acquiring flood-prone properties while imminent threat of flooding depresses market valuation.
- Establish parameters that can be used in the future for deciding if and when reallocations are warranted.

As long as dam operation changes are temporary, then any reallocation of resources should not be permanent. If the situation ends up being long-term, King County should consider creating a new revenue stream, such as an additional levy on Green River valley properties.

CHAPTER 7.
CAPITAL PROJECTS, ISSUE 4

Issue 4 was presented to the review panel as follows:

- The adopted 2006 FHMP recommends a series of capital projects on the Lower Green River that are intended to increase the conveyance capacity of the channel and strengthen the integrity of the facilities by laying back the slope of the levee to meet current federal design standards. These projects typically include bioengineering techniques that incorporate large wood and native vegetation as structural elements of the project. Projects have been designed and constructed by King County and the Corps of Engineers.

King County's questions related to this issue are addressed in the following sections. Each question is shown in a blue side-box as it was provided to the review panel. The section text represents the panel's response.

QUESTION 4A—CONSISTENCY OF PROJECTS WITH BEST PROFESSIONAL PRACTICES

Upon review of the project designs and documentation regarding the Management Alternatives identified in the 2006 Flood Plan, are there any recommendations for addressing the consistency of these projects and Management Alternatives with best professional practices for the reduction of flood and channel migration risks?

Levees in the Lower Green River consist of three types: old levees generally with steep side slopes and built years ago using unknown materials and construction methods; King County bioengineered projects dating back to 1993 that include features such as vegetated side slopes and large woody debris habitat enhancement elements; and Corps of Engineers designs that commonly have more rock armor protection and less vegetation than recent King County bioengineered levees. The review panel visited the sites of several King County and Corps of Engineers levee rehabilitation projects identified in the 2006 Flood Plan:

- **Desimone Levee**—Between 1998 and 2003, over 1,300 feet of this levee was relocated 20 to 25 feet landward of its original top-of-bank location in a heavily developed warehouse district. This allowed the creation of a densely vegetated mid-slope bench that serves as low-velocity flood refuge for salmonids during common levels of winter flows. Over 75 large logs with intact rootwads were secured below the ordinary high water mark to create low-velocity zones and cover for juvenile salmonids. The 2006 Flood Plan identified several sections of this levee as oversteepened and identified four improvement projects. Further rehabilitation and setback is included in the Flood Control District's most recent six-year capital plan for the Green River. From the site of the review panel visit, the Segale/Tukwila 205 levee was visible on the opposite bank; this Corps of Engineers-constructed levee is the only federally certified levee along the Lower Green River.
- **Briscoe Levee**—The 2006 Flood Plan identified multiple rehabilitation projects along this levee to address oversteepened banks and, at one location, indications of structural damage. The review panel visited a 600-foot section that was rehabilitated and set back in 2007 as a joint King County/Corps of Engineers project. Further Briscoe Levee rehabilitation work is included in the Flood Control District's most recent six-year capital plan for the Green River. From the site of the review panel visit, the Segale/Tukwila 205 levee was visible on the opposite bank.

- **Kent Shops and Narita Levees**—Two levees were visited at the Riverbend Golf Complex in Kent. On the right bank just downstream from West Meeker Street, the King-County-designed Narita Levee incorporates bioengineering techniques, with significant vegetation on the levee side slopes. This levee was identified in the 2006 Flood Plan as needing rehabilitation to address oversteepened slopes and visible settlement and cracking. Immediately downstream from the Narita Levee project is the Corps of Engineers-designed Kent Shops Levee project, a 5,400-foot project completed in 2008, which addressed oversteepened slopes. Super Sacks had been installed along the trail atop these two levees by the time of the review panel's visit.
- **Horseshoe Bend Levee**—A portion of this federally authorized levee was identified as the Nursing Home Levee in the 2006 Flood Plan and was targeted for rehabilitation to address oversteepened slopes. King County, in partnership with the Corps of Engineers, repaired four flood-damaged segments of this levee in 2009. Plans for future repairs along this levee in partnership with the state and the City of Kent will require the acquisition of new right of way. Super Sacks had been installed along the trail atop these two levees by the time of the review panel's visit (see Figure 9).

Figure 9. Review Panel Site Visit to Horseshoe Bend Levee Project, Super Sacks on Top of Levee

The visits highlighted some of the differences between King County projects and Corps of Engineers projects. Through the years, King County has been active in implementing flood hazard management measures in the Green River valley, including rehabilitation of existing levees and construction of new levees. Many of the improvements have been targeted at levees identified as being most in need of repair, such as having over-steepened, unstable side slopes or having experienced erosion or bank failures during a flood event. In these instances, King County has endeavored to set levees farther back from the river

channel whenever possible, and provide flatter side slopes, rock toes for erosion protection, and vegetation and large woody debris for habitat enhancement.

Some of King County's levee design approaches for the Green River differ from design approaches implemented by the Corps of Engineers. The Corps of Engineers prefers a larger volume of rock protection at the toe of the levee and less reliance on vegetation for erosion protection. Both of these design approaches have functioned well for their relatively short design life on the Green River. In contrast to both design approaches, levees on some other rivers in King County and Washington State are far more structural, with a greater use of large rock along the entire levee side slope and minimal use of vegetation and large woody debris for habitat enhancement.

The role and function of vegetation on levees is one of the major differences between Corps of Engineers and King County levee designs. King County levees incorporate more vegetation, both on the inside levee bench and on the levee itself. Corps of Engineers designs rely more heavily on rock. The review panel considered all of the levee sites visited to be hybrid bioengineered/traditional levee designs. All agreed that some amount of vegetation promotes stability on the levee. It is troubling that there is no permanent agreement between King County and the Corps of Engineers about a vegetation management strategy for the Green River. Because of these differences in levee design, and the use of more bio-engineered techniques on the Green River, the review panel believes that monitoring the different types of levee performance is needed.

A monitoring program for habitat enhancement features such as side slope vegetation and large woody debris should note location of damage to levee surface, stability of large woody debris, stability of levee surface around large trees or stumps, evidence of piping along tree/shrub roots, and occurrence of animal burrows. As alternative designs may be more feasible in low energy areas monitoring should assess the performance of designs under a variety of levee environments (i.e. inside and outside of bends, confined and setback river sections, steep and flat river sections etc.). Monitoring should include photo documentation of test sites. Monitoring to assess alternative levees designs should be performed at least annually during low flow periods and especially following flood events.

In addition to differences in the levee designs, other levee issues were evident on the projects visited by the review panel. For example, the lack of continuity between projects observed at the Narita site, where the recently constructed Corps of Engineers project does not connect to the upstream King County project, leaves a gap between completed projects. The segment of levee between projects may be a weak point that could eventually provide a pathway for floodwater to undermine the new Corps of Engineers project.

The review panel has a number of overall concerns about the levee designs:

- Designs are based on a maximum flow of 12,000 cfs, which is reasonable only if historical levels of flood control from Howard Hanson Dam would always be provided. This assumption is no longer recommended (see Chapter 3).
- The geotechnical/hydraulic basis for levee design is not clear; it appears to rely on generic designs that have been successful in the past, but which have undergone minimal analysis and only a short period of actual implementation. There is no systematic monitoring or program of adaptive management mechanism to identify deficiencies and incorporate findings into future designs.
- Many slopes on existing levees are greater than 2:1 and these levees do not appear to incorporate "toe-down" or "toe rock protection" (excavation below the levee toe with rock placement). Panelists raised concerns about the geotechnical stability of these steep slopes with rock covering (of unknown material) and no toe-down.

QUESTION 4B—EFFECT OF INCREASED FLOWS ON LEVEE REHABILITATION APPROACH

Does the potential for increased flows (from approximately 12,000 cfs to 13,900 cfs or as much as 17,600 cfs) and an increased duration of high flows impact the decision to use traditional or bioengineering approaches to levee rehabilitation?

Higher flows and increased duration of high flows will impact the choice between traditional and bioengineered components for levee rehabilitation. At higher flows, it may be necessary to use harder elements, such as larger rock, but it will still be possible to incorporate significant bioengineering elements. Bioengineering elements may have to be placed further up the side slope of levee (not near river level), and possibly overlapped with harder elements. This would allow habitat enhancement features to be included levee designs for higher flows. Because there is no recent history of flows greater than 12,000 cfs, performance information for assessing the impact of higher flows on the existing levee network on the Green River is not available.

In the short term construction of setback levees may result in lower water levels, lower velocities and lower shear stress at the levee and possibly require less hardening. However in the long term if the river is allowed to meander the channel could return to the levee edge and additional levee hardening may be required. Therefore even setback levees need to consider local site conditions and the potential for shifts in flow path directions in the future.

Needed design and performance data for the existing levee network are identified in various responses to questions in this report. These include more detailed inventory information on the condition and stability of the existing levees; monitoring information on the performance of recently completed bioengineered levee segments; and agreement on a consistent vegetation management plan for the Green River. Many of these factors affect consideration of the impact of flows greater than 12,000 cfs.

The review panel endorses bioengineering techniques for the Green River, but recommends that future levees should be designed for a higher flow standard. This may necessitate integration of more “hard” elements into the bioengineered/traditional hybrid levee design currently used by King County and the Corps of Engineers on the Lower Green River. Hydraulic modeling and sediment scour analyses for higher flows in the Green River will be important in estimating flow velocities and erosion potential. The model results, combined with performance information gathered during high flows, will allow an assessment of whether a bioengineered approach is stable for high flows. With the appropriate analysis for high flows, the review panel endorses the continued implementation of bioengineered levee design features on the Green River.

QUESTION 4C—LEVEE STABILITY FOR TRADITIONAL AND BIOENGINEERED APPROACHES

Under what circumstances do bioengineered and traditionally engineered levees, respectively, offer enhanced stability under increased flow regimes?

Many recently completed levee improvement projects on the Green River have been a hybrid of traditional and bioengineered methods. It appears that past projects have performed adequately since Howard Hanson Dam was constructed and flows have been limited to about 12,000 cfs. However, it is advisable to design and build future levees to withstand flows higher than 12,000 cfs.

A unique feature of the Lower Green River, in comparison to some other King County rivers, is the relatively flat gradient of the river channel. This results in lower flow velocities and shear stresses in the river channel and along river banks and levees than on other more dynamic, steeper river segments elsewhere. This is one reason why past bioengineered design features on the Lower Green River levees have been successful. Any site being considered for a levee improvement project, whether on the Green River or another King County river, needs to consider the local conditions. This includes

local flow conditions during floods, such as flow velocities, water surface elevations, shear stress, local channel bed scour, and flow impingement on the channel banks. Similarly, local soil conditions affect levee foundation considerations as well as design materials for the levee prism itself. These local conditions affect design decisions and highlight the importance of site-specific evaluations. Through this design process the appropriateness of bioengineered levee features and more traditional hardened, rock features can be evaluated. Decisions on use of bioengineered and traditional levee features should be made as part of the design development process.

The review panel endorses the use of bioengineered features in levee designs as a goal or policy guideline. However, the panel also recognizes that local conditions will dictate the features necessary for a stable levee design and does not believe these decisions should be made before local conditions at a specific site are evaluated. For example, bioengineering alone is seldom adequate for stabilization along a river. Toes, where shear forces are greater, should be armored, with bioengineering installed higher up the levee where shear forces are reduced. The question is where to make the transition from rock to vegetation. It is possible to have an overlap zone between the rock armor and bioengineered section. Site hydraulics and toe scour potential should be used to determine the elevation of the overlap zone.

Evaluation of traditional and bioengineered approaches to levee design on the Green River focuses primarily on the use of vegetation on the levee side slope rather than rock armoring. As noted above, these design decisions must ultimately be made based on an analysis of local site conditions. But, perhaps more importantly, the use of vegetated side slopes is an unresolved design issue between agencies such as the Corps of Engineers and other levee designers and managers. Support from the Corps of Engineers for bioengineered approaches to levee design on the Green River will probably require more research before a common understanding evolves.

The Corps of Engineers Engineering Research and Development Center is currently conducting a nationwide evaluation of vegetation management effects on levee stability (Corps of Engineers, 2009f). The study includes literature reviews, laboratory experiments, computer modeling and field assessments. Field assessments will be conducted on abandoned levees in four areas of the country. Field assessments include pulling trees from levees to determine levee stability before and after tree fall. The study is due to be completed in December 2010.

In their study outline the Corps of Engineers indicates an interest in conducting field testing in the Seattle area. The panel encourages King County to offer Green River sites to the Corps of Engineers for their field testing and research. Cooperation between the Corps of Engineers and King County on this study will help address the question of when bioengineered approaches would best be suited on the Green River and develop a common understanding to resolve design concerns in the future.

In summary, the review panel does not support a single, universal answer to the question of when and where to use bioengineered and traditional levee features. The panel endorses an approach that considers bioengineered levee features as a preference but ultimately evaluates local site conditions as part of the design process before making final decisions.

QUESTION 4D—LEVEE REHABILITATION ALTERNATIVE APPROACHES

Are there other techniques King County should consider to rehabilitate levees along the Green River?

In general, the review panel supports bioengineering techniques to the extent possible considering the possibility of higher future flows. Given changed flow conditions, the narrow levee corridor, and the current problems at Howard Hanson Dam, the review panel also believes it would be beneficial to evaluate the feasibility of greater levee setbacks. Larger levee setbacks would provide more flood storage inside the

levees, would allow more natural river processes that would benefit habitat, and may have upstream and downstream flood reduction benefits. Larger setbacks also lead to reduced seepage through the levees and scour on the levee surface, and they alleviate pressure on the levee that results from constriction of the river. Such a strategy would move King County away from being locked into the current levee system scenario, which requires significant ongoing maintenance and carries high residual risk.

Certain land uses are suitable for flood prone areas. Parks, farmland, and golf courses could exist within the levee corridor, for example, allowing for greater setbacks and a more natural river corridor. A low levee/high levee configuration could also be feasible; the low levee along the river bank prevents flooding from more frequent events and allows floodwater to spill over a designated armored weir section (but remain confined within the higher setback levee) during less frequent events. Although the Green River is currently fairly constrained by adjacent land uses, many of the structures near the river are warehouses that may be suitable for redevelopment within a 20-year timeframe, making this a feasible long-term goal.

The approach outlined above is not possible without coordination among the patchwork of jurisdictions in the Green River basin. A coordinated approach would have to include consistent floodplain management policies (e.g., King County's current zero-rise floodplain restriction does not apply in incorporated areas) and a regionally managed floodway corridor.

CHAPTER 8.
CAPITAL PROJECTS, ISSUE 5

Issue 5 was presented to the review panel as follows:

- Levee setbacks often require the acquisition of new rights of way for construction that require lengthy real estate negotiations with property owners, with the potential to expedite this process through the controversial use of condemnation authority.

King County's questions related to this issue are addressed in the following sections. Each question is shown in a blue side-box as it was provided to the review panel. The section text represents the panel's response.

QUESTION 5A—SHORT-TERM FOCUS ON REPAIRS IN EXISTING LEVEE FOOTPRINT

Given the increased sense of urgency in the need to contain higher flows, should we focus on repairs within the existing footprint that can be completed relatively quickly while engaging in longer-term negotiations to obtain right-of-way for setback projects?

Understanding that there are urgent needs and projects already identified in the 2006 Flood Plan, the review panel agrees with focusing on repairs within the existing footprint that can be completed relatively quickly, while engaging in longer-term negotiations to obtain right-of-way for setback projects. However, this effort should avoid investing short-term money in places where there may be future opportunity for setback levees, except where the location is a critical area with high risk.

A feasibility survey for additional setback opportunities along the river corridor, beyond those identified in the 2006 Flood Plan, would be an important first step toward a long-term strategy to address the possibility of increased future flows. In many areas along the Lower Green River, levee setbacks would require obtaining additional land, much of which currently has existing infrastructure (i.e. buildings, parking lots etc.). At these locations, construction of setback levees may not be practical in the short or medium term and, hence, short-term improvements to existing levees safety and stability should proceed. Where an opportunity exists for setback levees, the current emergency should not override long-term strategic thinking.

QUESTION 5B—STANDARDS FOR LEVEE SLOPES

Should King County continue efforts to rehabilitate facilities with slopes that meet federal design standards or should it apply some other standard?

At a minimum, all new levee and levee rehabilitation projects should meet federal design standards. In particular, the steep levee side slopes that exist along many segments of the Green River should be flattened to stable slopes whenever new projects are implemented or local repairs made. There are many reasons for making this standard design practice. Most important, flatter side slopes provide greater slope stability as well as opportunities for bioengineered features to be included in the design. In addition, various levee design requirements must be met in order to participate in federal programs administered by FEMA and the Corps of Engineers. FEMA administers the NFIP and accredits levees for the purpose of floodplain mapping. The Corps of Engineers administers the levee Rehabilitation and Inspection Program (RIP) a voluntary program through which local governments can share cost of repair of flood control works with the Corps of Engineers.

If King County wishes to have its levees accredited by FEMA to provide 100-year flood protection, levees must meet the minimum design, operation, and maintenance standards of 44 CFR 65.10 of the NFIP regulations. These regulations include design criteria for freeboard, closures, embankment protection, embankment and foundation stability analyses, settlement analyses and interior drainage. In addition, levee accreditation requires an operation plan for a flood warning system, periodic operation closures, and an interior drainage plan. While levee accreditation requirements are described in 44 CFR 65.10, technical guidance for meeting levee design requirements is generally provided by the Corps of Engineers through various engineering reports and manuals.

Separate from FEMA's levee accreditation for floodplain mapping purposes, the Corps of Engineers administers the RIP. In order to qualify for participation in the Corps of Engineers' RIP, levees must meet the Corps of Engineers' levee maintenance standards, but do not need to be accredited by FEMA for 100-year flood protection. The RIP was enacted under Flood Control and Coastal Emergency Act – Public Law 84-99, to ensure that flood control works provide reliable protection so that lives, communities, and improved property are protected from floods. The principal benefit of the RIP is that through this program King County can receive federal assistance to help repair a levee if it becomes damaged in a flood.

According to the Corps of Engineers' *Design and Construction of Levees* (April 2000), the use of standard sections is generally limited to levees of moderate height (less than 25 feet) in reaches where there are no serious under-seepage problems, weak foundation soils, or undesirable borrow materials (very wet or very organic). The minimum levee section must have a crown width of at least 10 feet and a side slope flatter than or equal to 2H:1V, regardless of levee height or any less stringent requirements indicated by the results of stability and seepage analyses. In many cases the standard levee section has more than the minimum allowable factor of safety relative to slope stability, its slopes being established primarily on the basis of construction and maintenance considerations. Where high levees or levees on foundations presenting special under-seepage or stability problems are to be built, the uppermost riverside and landside slopes of the levee are often the same as those of the standard section, with the lower slopes flattened or stability berms provided as needed. There may be reasons for other standards. For example, flattening the levee slope creates a more stable section that could accommodate additional vegetation. Also, King County may consider more conservative standards if scientifically justified, or to accommodate varying factors of safety at levee locations where the residual risk is high. In all cases, side slopes should be appropriate for the project site and soils.

Levee accreditation by FEMA is not required under federal law, but King County can benefit from accreditation by reducing flood insurance rates or development requirements behind a certified levee. However, some local governments in the Puget Sound region are questioning the goal of having an accredited levee system. These concerns are driven by recent levee failures across the Country, especially in the New Orleans area where extreme flood damage occurred. Currently, King County applies floodplain regulation behind levees that are not accredited by FEMA for 100-year flood protection. With levee accreditation, floodplain regulations would not apply in these locations, which could perpetuate the aggressive development of floodplain lands, increase overall risks and create conflicts with environmental and endangered species needs.

Building a certifiable levee, however, may lead to pressure to get FEMA accreditation. The FEMA certification and accreditation process and requirements are changing over time and municipalities are finding this process to be expensive and time consuming. The review panel makes no recommendation as to whether King County should seek levee certification at every levee improvement site along the Green River; the issue is discussed here in relation to the question regarding levee slope standards.

QUESTION 5C—CONDEMNATION FOR LEVEE RIGHT-OF-WAY

Is the urgency of project completion so great that King County should consider the use of condemnation to acquire right-of-way for levee setback projects when sufficient right-of-way is not available to construct the project in accordance with federal design standards?

The review panel recognizes that it is controversial to use condemnation to acquire right-of-way and supports King County's efforts in the past to negotiate with property owners along the river. While not precluding the use of condemnation, the panel does not feel the urgency of the current situation warrants a unilateral condemnation policy to acquire right-of-way. Moreover, King County may not have condemnation authority within city jurisdictional areas. The King County Flood Control District has condemnation authority under RCW 86.15, but it requires agreement by the affected city.

Acquisition of property through condemnation is not an eligible activity under FEMA hazard mitigation grant programs. This even applies to properties not directly affiliated with properties specified in a grant application. Under established precedent, FEMA Region X does not view the use of condemnation for hazard mitigation actions favorably, even if no FEMA funds are used. Therefore, all ramifications need to be taken into account before deciding to pursue condemnation.

In the long-term, however, the review panel envisions situations where property acquisition through condemnation may be critical to implementing consistent flood hazard measures along the Lower Green River. For example, a more aggressive approach to acquiring land for setback levees may identify a few key properties necessary to implement a setback strategy over long segments of the river. Condemnation for limited properties may be necessary to implement a more comprehensive flood hazard management scheme in the Lower Green River valley. Alternately in these situations, the current levee could simply be abandoned, the property ownership left intact, and a setback levee built landward from the property in question. The review panel did not seek a consensus on these alternatives because their application will always be site-specific, but the ability to provide current protection (i.e., protection for flows up to 12,000 cfs) to unwilling sellers while pursing more comprehensive flood protection with a landward setback levee should always be an explored alternative.

CHAPTER 9.
CAPITAL PROJECTS, ISSUE 6

Issue 6 was presented to the review panel as follows:

- Sediment in the Green River is largely controlled by the operation of the Dam and the river is not observed to be rich in sediment and gravel. The adopted Flood Plan does not contemplate sediment removal on the Lower Green River to create more channel capacity.

King County's questions related to this issue are addressed in the following sections. Each question is shown in a blue side-box as it was provided to the review panel. The section text represents the panel's response.

QUESTION 6A—RECONSIDERATION OF SEDIMENT REMOVAL

In light of the changed conditions at Howard Hanson Dam, is it advisable to reconsider sediment removal?

Before any assessment can be made of the advisability of sediment removal, the existing sediment conditions in the river need to be evaluated. Although the closure of Howard Hansen Dam in 1962 significantly reduced the sediment supply to the Middle and Lower Green River, some sands and gravels are still supplied to the Green River below the dam by Mill, Soos and Newaukum Creeks and by landslides along the Middle Green River valley walls. Construction of the levees of the Lower Green River flood control system by the 1970s effectively increased the sediment transport capacity by retaining long-duration flows up to 12,000 cfs in-bank. Due to these changes, coupled with the dramatic reduction in loads from the sediment-rich White River, the lower reaches of the Green River are undoubtedly in a sediment-deficit condition relative to their pre-modification history. The same is likely true for the Middle Green River, although the reduction in sediment delivery from above Howard Hanson Dam is partly offset by sediment inputs farther downstream and by the decreased flows exiting the dam. Locally abundant sediment accumulations in the Middle Green River have been observed, for example, in the area of Metzler–O'Grady County Park (~RM 40); similar accumulations, however, are entirely absent downstream of Auburn.

Immediately below the dam, gravel augmentation to provide spawning habitat has been required, in order to mitigate for the elimination of the upstream sediment supply; the volumes introduced are very small compared to the pre-dam flux. Down to about RM 26 in the Middle Green River, the bed material is composed of gravel, and it is possible that the remaining sediment deficit is largely compensated by bed material coarsening and potentially by bed armoring. Bed armoring or the remaining sediment deficit could also be causing accelerated bank erosion in the reach, thereby increasing the risks associated with channel migration. Between RM 26 and RM 19, where some gravel is present in the predominantly sand bed of the river and where the slope is moderate, it is possible that the channel has degraded in response to the sediment deficit from upstream; this could be adversely affecting the stability of levees and revetments. In the sand-bed reach of the Lower Green River downstream of RM 19, there is potential for significant bed degradation. The very flat river slope (~0.02%) may mitigate against general degradation. However, there may still be a high potential for local scour, especially on the outside of bends that could undermine existing revetments and levees.

Given the existing conditions within the Lower Green River, it is unlikely that sediment removal would achieve the goal of increased hydraulic capacity. There is probably very little "excess" sediment, so replenishment of the sand and finer sized sediment would likely occur rapidly from local sources.

Furthermore, local removal of the sediment could induce additional local scour, which in turn could undermine existing revetments and levees. Rather than reduce risks associated with flooding, dredging is likely to exacerbate them. Moreover, dredging is usually a last resort in modern times because of environmental issues associated with in-channel impacts, disposal of dredge spoils, and the challenges of receiving regulatory approvals.

Prior to any further consideration of sediment removal, additional data such as sediment load characteristics, flow velocities at the expected range of flows, channel slope and cross section geometry would be needed to assess sediment transport and the impacts of sediment removal on channel stability, recognizing that the likelihood of a favorable result would be very low.

QUESTION 6B—CAPACITY/FLOOD RISK BENEFITS FROM SEDIMENT REMOVAL

Is sediment removal an appropriate short-term or long-term strategy to increase channel capacity and decrease flood risk along the confined Lower Green River under increased flow scenarios?

Unless indicated by additional analyses, sediment removal is not appropriate as either a short-term or long-term strategy to increase channel capacity and decrease flood risk along the confined Lower Green River. Sediment removal may destabilize nearby structures, it rarely provides significant additional channel capacity, and its benefits tend to be temporary as the river works to fill back in to readjust its profile.

QUESTION 6C—INCORPORATION OF SEDIMENT DEPOSITIONAL AREAS

Should sediment depositional areas be incorporated into a redesign of the current levee system?

The only effective way to create depositional areas would be to create a wider river corridor between the levees. Within the existing channel corridor, any dredged areas would quickly refill as the river readjusts its profile. Since excess sedimentation does not seem to be an issue in the Lower Green River, the review panel sees no reason to incorporate sediment depositional areas. Several substantial benefits arising from a wider river corridor are noted in other sections of this report. But we do not anticipate any additional value from the purported function as a repository of deposited sediment.

CHAPTER 10.
CAPITAL PROJECTS, ISSUE 7

Issue 7 was presented to the review panel as follows:

- King County's flood risk reduction efforts are subject to a wide range of environmental regulations, including the Endangered Species Act (ESA), Clean Water Act, and local regulations to protect critical areas. Protected salmon species include Chinook, steelhead, and bull trout, and there is a federally adopted ESA recovery plan for Puget Sound Chinook that was developed and endorsed by local governments in each watershed. These federal, state, and local regulations require that flood risk reduction actions are implemented in ways that protect water quality and habitat for multiple public uses, including recovery of salmonid species listed under the Endangered Species Act. Among other things, this has resulted in policies aimed at allowing naturally occurring large wood to remain in the river channel unless it poses an imminent threat to public safety, as well as the use of large wood as a structural element of flood facilities.

King County's questions related to this issue are addressed in the following sections. Each question is shown in a blue side-box as it was provided to the review panel. The section text represents the panel's response.

QUESTION 7A—INTEGRATING PUBLIC SAFETY AND ENVIRONMENTAL MANDATES

How can King County best integrate public safety and environmental mandates, particularly in the case of large wood?

Current King County Policies and Practices

The review panel believes that current King County policies and practices to integrate public safety and environmental mandates are sound and should be continued. The 2006 Flood Plan states that:

> *Protecting and working with, rather than against, natural riverine processes generally will reduce flood risks to people and property in a less costly manner than traditional structural approaches to flood hazard management while also benefiting native fish and wildlife and preserving aesthetic landscapes.*

The review panel knows of no scientific reason or special local conditions that would modify this fundamental approach.

King County is undertaking a variety of other initiatives that both protect public safety and meet environmental needs:

- Mapping floodplains and channel migration areas, taking into account future development
- Tightly regulating development in floodways and broader floodplain in cooperation with state and federal agencies
- Acquiring natural areas in the floodplain
- Adopting regulations for critical areas, such as wetlands and floodplains, as well as broader zoning, subdivision and building codes

- Working with federal agencies and regulations to minimize and compensate for environmental impacts through the Endangered Species Act, the National Environmental Policy Act and the Clean Water Act, including Section 402 (point source pollution controls) and Section 404 (permitting for wetlands and other waters)
- Working with state agencies and regulations to minimize and compensate for environmental impacts through pollution controls, floodplain, wetland and other "critical area regulations, and "shoreline" regulations
- Working with local partners on two environmental issues that pertain to floodplain vegetation:
  - Large wooded debris in the stream channel and adjacent areas
  - Vegetation on levees.

Large Wood

The Lower Green River is heavily altered from its natural conditions in many ways, including flows, channel form, adjacent land use and large wood content. Large wood is a natural part of the riverine ecosystem in the Pacific Northwest. Trees fall across and into stream channels during floods, channel migration events, and wind storms. Until the late 1970s, government agencies removed large wood from rivers to improve navigability and control flooding. However, scientists now understand that large wood plays a critical role in the ecosystem, helping to form habitat, stabilize and form channels, store sediment and organic matter, and provide refuge from flood events to fish and other aquatic creatures.

Current environmental regulations discourage removal of woody debris. As a result, in the 1970s King County and most other government agencies in the Pacific Northwest stopped removing wood from river channels, and indeed have begun placing large wood in streams to improve habitat until riparian forests regenerate enough to provide sufficient large wood naturally. Wood material is introduced to the Green River system downstream from Howard Hanson Dam by wind-throw and bank erosion, and through bank protection projects.

However, rivers in King County also provide recreational opportunities, including swimming, boating, floating, kayaking, and other pursuits. In some cases, large wood has created perceived safety issues for boaters. For example, earlier bioengineered levee projects placed wood at the toe of the levee in a configuration that might snag passing boaters. King County has now modified the design so that log ends point downstream to minimize the hazard to boaters while still providing structural and ecological benefits.

The King County Council passed Motion 2007-0622 directing the Department of Natural Resources and Parks to address public safety concerns in the placement of large wood in the waterways of King County. King County is the only Puget Sound county with policies relating to natural large wood and recreational boater safety at this time. In March 2008, King County released a response report for Motion 2007-0622 concluding that placement of wood in King County rivers is essential to fish and wildlife habitat restoration, flood protection facility design, and road and bridge construction, but that it is also essential to implement clear and transparent methodology for consideration of public safety issues in the design of future projects.

King County's current policy calls for judgment on a case-by-case basis in determining whether large wood creates a public safety hazard and should be removed. The review panel considers this to be a reasonable policy that should be continued. Considering the importance of large wood in the structural integrity of current levee and revetment designs, health-and-safety concerns of adjacent floodplain

occupants need to have at least equivalent standing to those of recreational boaters. King County is also under federal and state mandates to protect ecological functions as characterized by "best available science," and under this guidance the continued inclusion of large wood in river-modification projects is virtually inescapable. Furthermore, maintenance practice must not be aggressive in removing naturally occurring wood except in the case of immediate threats to public health and safety, in order to fulfill environmental mandates.

Despite the fact that government agencies have not removed wood from rivers routinely for 30 years, some boaters are still accustomed to the more open river and stream systems that were typical as a result of these past practices. While all water sports carry inherent risks, many recreational users regard large wood in rivers as an inappropriate hazard. Some members of the recreational boating community have expressed concern about the potential hazards associated with installation of large wood in rivers in King County.

Levee Vegetation

Many of King County's levees are enrolled in the Corps of Engineers' RIP program and are eligible for cost sharing with the Corps of Engineers to repair flood damage. Corps of Engineers' vegetation standards limit large vegetation on levees. The review panel's understanding is that the Corps of Engineers' concern about vegetation on levees is related to large trees falling and creating large divots in the levee that could compromise its integrity, and restricting access and visibility for inspection and flood-fighting.

In the Pacific Northwest, the Corps of Engineers honors an alternate policy (Corps of Engineers 2001a) of allowing woody vegetation up to a 4-inch in diameter trunk in 4-foot diameter clumps at a spacing of 30 feet . While this policy provides some relief to King County in responding to Endangered Species Act issues, the removal of trees above that size may be counterproductive. Cutting down large vegetation encourages more small growth in greater density, which makes it more difficult to inspect the levee for cracks and boils, and may increase the net roughness of the channel, thus raising flood elevations. The review panel believes that the best resolution to this apparent conflict will be in the careful performance review of alternatively designed and constructed levees, incorporated within an adaptive management framework.

Assessment of alternative (e.g. bioengineering) levee designs is discussed in Chapter 4.

Puget Sound Chinook Recovery Plan

The Chinook Recovery Plan was examined to determine how its priorities and projects relate to the Middle and Lower Green River. The Recovery Plan does not explicitly address wood in rivers but addresses general habitat conditions, which would include recruited wood and log jams. It names protection and restoration of spawning habitat in the Middle Green River and upper portion of the Lower Green River as one of three watershed-wide priorities. Goals for the plan include the following:

- Restore functioning habitats to about 65 percent of historical habitat area
- Improve sediment recruitment and transport rates to:
  - Increase the productivity of spawning areas
  - Maintain and develop spawning riffles, shallow channel edge, and other habitat
- Maintain surface and ground water sources of cool, clean water.

QUESTION 7B—BALANCE IN ENVIRONMENTAL COMPLIANCE

Any recommendations regarding the balance that must be struck in complying with these regulations?

Designing and constructing flood protection measures is particularly challenging because of the need to provide engineered structures capable of withstanding extreme flood conditions, yet meet environmental permitting requirements posed by ESA, the NFIP biological opinion, and other state and federal regulations. To achieve this balance on the Green River, King County has promoted bioengineering in their levee designs, including use of vegetation and large woody debris for habitat enhancement. In contrast, the Corps of Engineers prefers less reliance on vegetation for erosion protection and greater use of rock armoring. These are conflicting design considerations. Nonetheless, King County has been successful in obtaining agency approvals for their bioengineered approach to levee design and also maintaining levee participation in the RIP program. This suggests that even in an environment of apparent contradictions among engineering design needs and environmental enhancement mandates, ongoing coordination among permitting agencies may be the process that has to continue to be pursued in the future to obtain new project approvals and for levee construction and operation.

In the near-term, the NFIP biological opinion poses new and untested challenges to design and construction of flood protection measures within the floodplain. FEMA will be issuing a draft model ordinance and checklist in March 2010 to assist communities in complying with the biological opinion. The following sections describe how the biological opinion may affect implementation of flood protection measures along the Green River.

Reasonable and Prudent Alternatives

In September 2008, NMFS issued a biological opinion on the effects of the NFIP on endangered species throughout Puget Sound. The opinion identifies the following "reasonable and prudent alternatives" (RPAs) that FEMA and partners can take to avoid destruction or adverse modification of critical habitat for Puget Sound area endangered species:

- Notify communities participating in the NFIP that existing practices threaten endangered species; establish a temporary, voluntary moratorium on new development.
- Change the criteria for floodplain maps to reflect impacts on habitat, including prioritization of floodplain mapping based on salmon populations, modification of map modeling to include future conditions, and consideration of residual risk behind 100-year levees.
- Change the criteria for development in FEMA-mapped floodplains to minimize impact on critical habitat, including no development in the floodway and riparian buffer, no development in the floodplain or, if development is to occur, a requirement to avoid or compensate for negative impacts on flood storage. Communities are also to track and report on floodplain permits to FEMA annually.
- Provide incentives in FEMA's CRS for low impact development, preservation of open space, retaining and increasing riparian functions, setting back levees, encouraging use of levee vegetation management maintenance practices, and increasing buyout programs. Reduce credits for structural changes in the floodplain.
- Change the levee vegetation maintenance and construction policies so that they address runoff and modified flood hydrographs from development. New levees and floodwalls are to be recognized by FEMA only under limited conditions, including maintenance of natural channel migration patterns, use of bioengineering, incorporation of large wood into levee setback area, and inclusion of riparian vegetation in design.

- Undertake additional floodplain mitigation activities for development that damages floodplains while other RPA activities are in the process of being implemented.
- Monitor and adapt policies as experience is gained. FEMA is to report to NMFS on an annual basis and provide mitigation if adverse effects on channels or floodplains occur.

Potential Conflicts

Potential conflicts between the RPAs and what may be done by FEMA, local governments or others in preparation for flooding on the Green River include the following:

- Raising the levees—Efforts are now underway to raise some of the Green River levees through the use of sandbags and other techniques. This will prevent fish from entering floodplain areas behind levees, with potential adverse impact on endangered salmon. The Endangered Species Act allows "emergency" actions prior to consultation on Endangered Species, providing consultation occurs after the emergency. Whether raising the levees far in advance of any flooding would be considered an emergency is not clear. The removal of temporary sandbags or other temporary measures after a flood event could reduce long-term impacts.
- Removal of vegetation on the levees—Removal of vegetation on the levees may adversely impact salmon. If removal were carried out in an emergency, the Endangered Species Act provisions referenced above with regard to raising levees would apply.
- Removal of large wood from the Green River—Removal of wood from the Green River would reduce fish habitat. If done in response to a local emergency condition, the emergency Endangered Species Act provisions would apply; if done programmatically, little basis for such action could be marshaled, and the outcome of an ESA review would likely be much less favorable.
- Additional conflicts would occur if new levees or channel modifications are constructed, development is allowed in floodways, or other actions are allowed contrary to the RPAs.

Impacts of the Biological Opinion on Flood Loss Reduction Measures

The review panel believes that current King County policies to protect endangered species and to support FEMA and NMFS are sound and should be continued. The opinion represents important consensus-building as well as legal standard-setting for long-term floodplain management and habitat protection and restoration for the Green River and other rivers flowing into Puget Sound.

The RPAs will not impede most of the emergency flood loss reduction measures now being discussed with regard to the Howard Hanson Dam, particularly if these measures are temporary in nature. The biological opinion will have greater impact on more permanent measures under FEMA's control, such as remapping the floodplain, setting strict standards for new development in the floodplain, relating flood insurance policies to the raising or construction of dikes or levees, and increasing incentives for habitat protection and restoration under the CRS program.

Benefit of Adaptive Management

The review panel recognizes a direct conflict between the Corps of Engineers' levee-vegetation standards and NMFS' biological opinion. A similar conflict between the Corps of Engineers' and King County's design and maintenance guidelines for levees is recognized by all parties. Because there are no clear-cut answers or obviously unsafe practices being advocated by any party, we propose an adaptive management approach. Already, two alternative levee designs have been constructed along the right bank of the Lower

Green River immediately adjacent to each other (at the Riverbend Golf Complex), offering a direct opportunity to evaluate their performance. Similarly, a conscious evaluation of alternative vegetation-management approaches, if incorporated into the process of setting future actions, would offer a credible way to resolve existing differences in approach.

CHAPTER 11.
CAPITAL PROJECTS, ISSUE 8

Issue 8 was presented to the review panel as follows:

- The current approach to reducing channel migration risks and increasing channel capacity for the Middle Green River includes removing old levees and revetments that no longer protect homes or roads, and allowing the river to reclaim the flood plain and side channels.

King County's questions related to this issue are addressed in the following sections. Each question is shown in a blue side-box as it was provided to the review panel. The section text represents the panel's response.

QUESTION 8A—VIABILITY OF LEVEE REMOVAL ALONG MIDDLE GREEN RIVER WITH INCREASED FLOWS

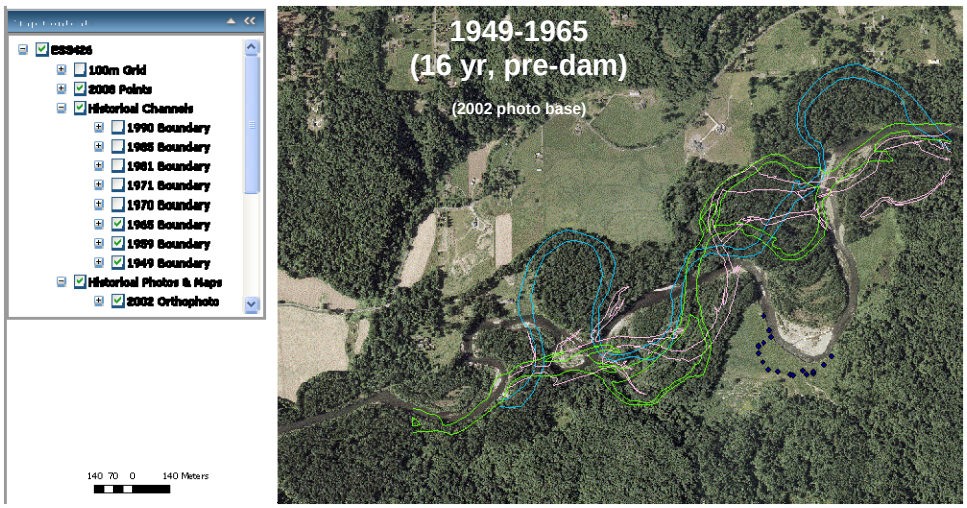
Given the increased probability of significant flows from the river, is this a viable strategy?

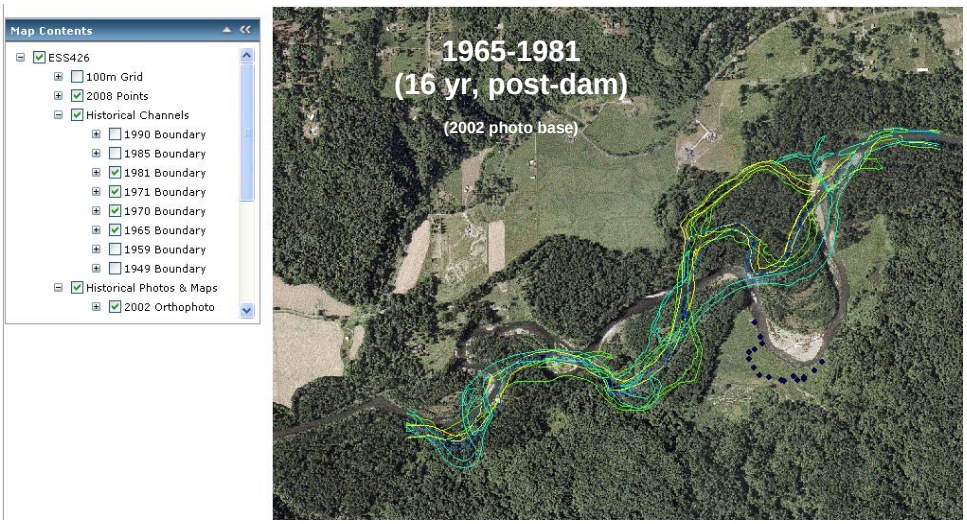
Channel migration rates have varied dramatically from 1898 to the present day. A channel migration zone (CMZ) along the Middle Green River was mapped based on flood control and conditions at the time of the mapping. The probable limits of channel migration were defined using historical meander belt widths and bend amplitudes.

According to the CMZ study, by cutting the size of flood peaks, Howard Hanson Dam has reduced the number of avulsions and the tendency of the river to braid, behaviors associated with the highest migration rates. It has also trapped sediment behind the dam, which likely reduces downstream sediment deposition and consequent bank erosion. Thus during periods of large storms, the dam has probably reduced channel migration rates significantly. Still, the effects of Howard Hanson Dam are not straightforward. The dam has reduced the occurrence of extreme floods but has increased the duration of bedload-transporting flows.

Aerial photos and field data from 1949 through 2008 (Figure 10) illustrate the difficulties in drawing general conclusions about trends in channel-migration rates or intensity. In the vicinity of Metzler-O'Grady County park, the degree of channel migration from 1949–1965 (top photo, spanning 16 years, nearly all prior to dam operations) is not markedly different from 1965–1981 (middle photo, also spanning 16 years, following commencement of dam operations). Indeed, some of the largest magnitude of channel migration has occurred since 1985 (bottom photo), when a meander loop in the southeast part of the area began growing to the south. As of 2008, it had continued to expand (blue dots on all three photos mark the outer channel bank location) and now extends well beyond any recent evidence of historical channel migration, despite the imposition of both flow and sediment reductions as a result of the dam. It is possible that the sediment deficit in the Middle Green River incurred as a result of sediment trapping by the dam may well have increased the rate of bank erosion and channel migration, especially since the 12,000 cfs flow is about the pre-dam 2-year event and the duration of sediment transport has been increased by the dam releases.

The CMZ study found that levees constructed during the 1960s are not associated with any large-scale reduction in erosion on unprotected banks. Rather, the levees influence, to some extent, the location of erosion by deflecting flows and redirecting the energy in the system to specific points. This could change, however, if pre-dam conditions reoccur in the river system.





Channel boundaries were traced from historical air photos from the years indicated (and checked) in the figure legends; the 2008 dots mark GPS-recorded locations of a walking traverse of the outer bank.

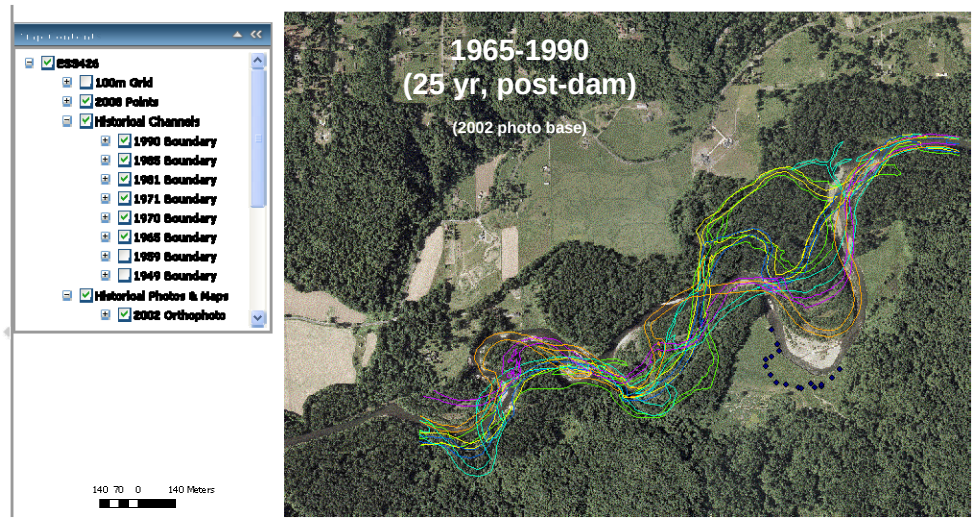


Figure 10. Historical Channel Migration in the Vicinity of Metzler-O'Grady County Park.

If the system does experience higher flows more often, the rate of migration may increase over what residents have become accustomed to since Howard Hanson Dam has regulated flows. Therefore, it is even more important that King County maintain its no-build policy for the channel migration zone. The highest channel migration rates are associated with the development of avulsion channels and rapid growth bends in the middle section of the river.

Continuing to remove old levees and revetments that no longer protect homes or roads is the right approach for the Middle Green River. This approach will continue to communicate to area residents and those who may consider moving to the area that King County is not providing flood protection.

QUESTION 8B—OTHER MEANS TO INCREASE CAPACITY ALONG THE MIDDLE GREEN RIVER

Are there other ways to increase channel and floodplain capacity in the Middle Green River that we should consider?

The review panel did not identify any reasonable alternatives for increasing channel and floodplain capacity along the Middle Green River. The panel believes that the strategy for the Middle Green River outlined in the 2006 Flood Plan is the most effective and most sustainable approach.

QUESTION 8C—MIDDLE GREEN STORAGE IMPACT ON LOWER GREEN FLOW

To what extent would any increased storage in the Middle Green have any impact on flows in the Lower Green?

The review panel considered whether additional flood storage could be created in the Middle Green River. Enhancement of floodplain wetlands would marginally increase flood storage, but probably would not have a significant impact on decreasing flows downstream during a major flood.

CHAPTER 12.
CAPITAL PROJECTS, ISSUE 9

Issue 9 was presented to the review panel as follows:

- The Middle Green River accumulates naturally occurring fallen trees. Also, as part of the required mitigation for the operations of the Howard Hansen Dam as a water supply facility, Tacoma Public Utilities is required to add wood that is trapped in the reservoir to the flow of the river below the dam. Two known large debris jams have formed on the Middle Green sub-basin over the last 30 years.

King County's questions related to this issue are addressed in the following sections. Each question is shown in a blue side-box as it was provided to the review panel. The section text represents the panel's response.

QUESTION 9A—EFFECT OF INCREASED FLOW ON DEBRIS JAMS

Would increased flows consistent with the reduced capacity of Howard Hanson Dam result in an increased risk of mobilizing existing debris jams, or are these jams more likely to remain and collect additional debris that would have otherwise moved downstream?

The lower log jam (Figure 11), located at about RM 32.5, is a net collector of logs moving downriver. Although individual pieces may be floated off or washed downstream, its net effect is to reduce the downstream transport of large woody debris. As such, it has provided a significant benefit to constricted reaches farther downstream for many years. The primary risk that it might pose, relative to the risk of having no jam present here at all, is the sudden release of many logs that had accumulated over multiple flood episodes.

Although the release of individual logs is likely, particularly those that have recently been washed into the jam and are only loosely lying on top of others, we find little basis to expect entire sections of the jam to mobilize. The logs are interwoven and stacked, a number are partly or largely buried by sediment, and although there are few true key pieces (if any), many of the framework pieces are 16 to 30 inches in diameter and up to about 100 feet long, providing ample opportunity for interlocking with other pieces and relatively limited *en masse* mobility.

The various accumulations of interlaced and loose logs that together constitute the log jam are built up generally to the level of the surrounding terrace. Together with the interlaced orientation of the individual logs, the framework of the jam indicated that the accumulations form through a process of relatively passive floating-in and accretion during high flow. The ultimate level of these log accumulations has been controlled by the maximum level of controlled flows out of Howard Hanson Dam and the near-equivalent level of the surrounding forested terrace, once no doubt part of the active floodplain but now largely inactive by virtue of upstream flow control.

The part of the log jam that presently forces the main bend in the river is structured as a result of high-flow accretion, with logs aligned and interlaced from the effects of being washed in. This part of the jam is sufficiently stable to bear the direct impact of high flows and to have progressively diverted the flow into its current bend. Some of the larger pieces of wood have proven stable enough during recent high flows that flow diversion around them has scoured out pools in the streambed gravel.

Figure 11. Logjam on Middle Green River at Approx. RM 32.5, About Three-Quarters of a Mile Downstream of SR 18; View is About 0.22 Miles by 0.15 Miles; North is to the Top

The floodplain immediately adjacent to the log jam on the inside (left bank) of the bend provides evidence of multi-year log accretion and stabilization. Moving away from the active channel, we observed a progression from recently floated logs to those partly buried by sediment to regions partly underlain by logs and partly colonized by woody vegetation a few years to as much as a decade or more in age. These features are indicative of long-term log accretion. Reviewing readily available on-line aerial photos, the view from 1990 shows no log jam but a growing accumulation of wood at the location of the present outer-bend jams, adjacent to the active (single-thread) channel. By 2002, the basic architecture of the jam and the channel that is present today had been established.

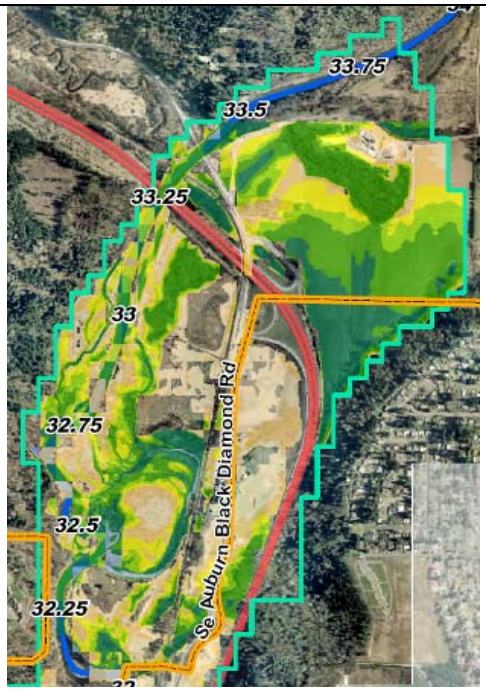
A site visit was also made to the jam at RM 38.5. It is a much smaller accumulation and is located on a side channel, not the main channel, of the Middle Green River. Its effect on flood levels is not obviously significant. Increased flows might increase the likelihood of mobilizing individual logs, but the likelihood of transport down the length of the Middle Green River is considered low (and past the jam at RM 32.5, extremely improbable). As such, we strongly recommend the continued (passive) management practices currently being followed.

QUESTION 9B—ACTIONS TO REDUCE RISK FROM DEBRIS

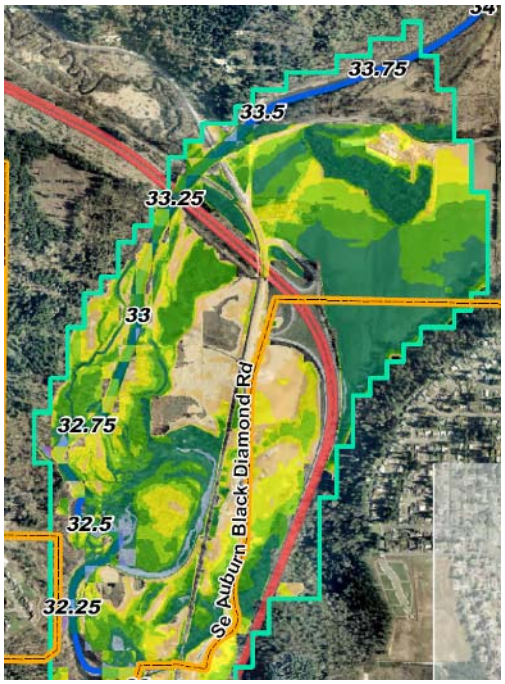
Are there actions that should be taken to address the potential risks to downstream residents and property posed by fallen trees and log jams in the river?

Although the value of passive "management" of the log jam under the recent flow regime is unequivocal, the risk now posed by potential increased flow releases from Howard Hanson Dam merits attention. That risk, however, depends on two elements: the potential increase in flow elevation at the log jam, and the likelihood of change in delivery of logs from upstream.

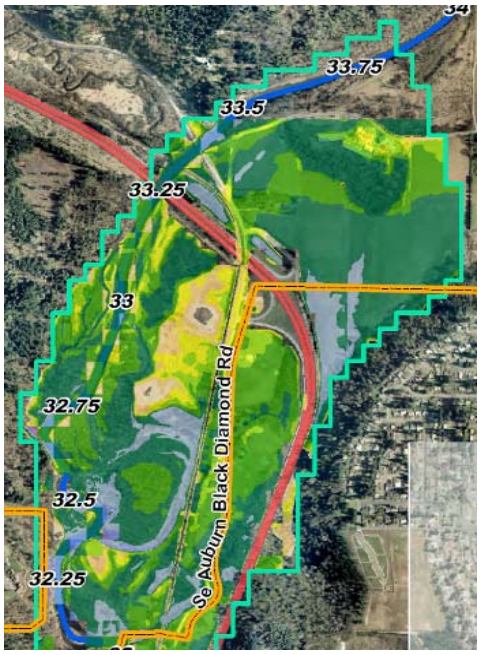
Recent flood modeling suggests that flow depths will increase above the prior maximum (12,000 cfs at the Auburn gage) by less than 1 foot for flows below 14,000 cfs; and by about 2 to 3 feet for flows up to 25,000 cfs (see Figure 12).



(13,900 cfs): 4–6' through 6–10' over jam



(17,600) cfs: 4–6' through 10-15' over jam



(25,000 cfs): 6–10' through 10-15' over jam

Key

Flood Depth (feet)

- 0 -1
- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 6
- 6 - 10
- 10 - 15
- 15 - 20
- 20 - 30
- 30 - 40

- Auburn Gage
- 15.5 River Miles for Green River
- Jurisdictional Boundaries
- Major Highways
- Primary Roads
- Secondary Roads
- Model Extent

Note: the log jam is mostly obscured by the label "32.5" on these views; the range of flood depths is based on the colors immediately east and west of the label

Source: Northwest Hydraulic Consultants, 2009

Figure 12. Views of Flood Depth Maps

Absent a full engineering analysis, we cannot guarantee absolute jam stability, particularly under flows that increase water levels by the maximum potential amount. At more modest increases of a foot or two, however, two factors mitigate against a massive release of logs: the interlocked architecture of the jam and the degree to which logs are partly buried by sediment; and the absence of a full channel-spanning structure that could impound water behind it. Still, any such an increase in flow depth will likely mobilize a number of logs that are presently perched in unstable positions on the jam, particularly the portion on the inside of the bend.

The Middle Green River farther upstream is likely to continue receiving significant influxes of new logs and other debris during future storms, due to several factors:

- Active channel migration in forested areas
- Landslides on adjacent high terraces that are likely to be more unstable during times of high rainfall
- A variety of anthropogenic floodplain activities that have denuded large portions of the Green River valley of bottomland forests that might otherwise trap floating debris before it reaches the river channel.

This material may pose a risk to downstream infrastructure if not removed from active transport by functional "log-straining" features in the channel or the immediately adjacent floodplain. Based on observed conditions at the RM 32.5 jam, this feature has been performing this function for many years. We anticipate that it will continue to be highly effective under all but the most extreme of discharges, under which circumstances any increased release of logs would probably not constitute the major flood impacts on the Lower Green River valley.

QUESTION 9C—DEBRIS MANAGEMENT IMPACT ON OTHER RIVER PROCESSES

What, if any, are the likely impacts of debris management actions on other riverine processes such as sediment transport?

Because the review panel does not recommend any debris-management actions different from the present no-action approach, there are no ancillary impacts to consider. If, in contrast, either of the two existing debris jams in the Middle Green River were removed, an immediate increase in sediment-transport capacity would result. In the case of the jam at RM 38.5 (a significantly smaller structure than that at RM 32.5), any such increase would tend to redistribute sediment along the next several bends of the river downstream, still well within the Middle Green River. In contrast, removal of the jam at RM 32.5 has a high probability of increasing the flux of bedload sediment through this reach. Because this jam is near the upstream end of the depositional zone between the Middle and Lower Green River, sediment aggradation in areas of limited flood capacity through Auburn is likely.

Should the present passive management of log jams change, the review panel strongly recommends that a full analysis of sediment transport at and downstream of RM 32.5 be undertaken, presuming the absence of debris, before any action is taken. The panel does not have the same level of concern for unintended channel-capacity problems with active management of the jam at RM 38.5, but notes the absence of any obvious benefits and the unquestioned damage to ecological conditions that would result.

CHAPTER 13.
FLOOD RESPONSE ACTIVITIES, ISSUE 10

Issue 10 was presented to the review panel as follows:

- King County and the cities of the Lower Green River valley are considering the possibility of using temporary protective measures to enhance levee capacity under increased flows resulting from the changed operations of Howard Hanson Dam.

King County's questions related to this issue are addressed in the following section. The questions are shown in a blue side-box as they were provided to the review panel. The section text represents the panel's response.

At the time the review panel discussed these questions, temporary protective measures had already been put in place along portions of the Green River. King County and the cities of Auburn, Kent, Renton and Tukwila have taken steps to place Super Sacks, HESCO baskets and sandbags along the crest of the existing levees to increase the flow capacity of the Green River. Levee heights have been increased primarily at locations where floods would overtop levees first. Other segments of the existing levees have freeboard remaining at 13,000 cfs and some have freeboard for flows as high as 17,600 cfs. The following discussion provides considerations for this action that has already been implemented or is planned to be implemented ahead of flood season.

QUESTION 10A—TEMPORARY MEASURES TO PURSUE

Are there temporary protective measures such as flood fighting that King County should consider to increase the protective capacity of the levee system until permanent repairs are constructed supporting the Dam? Please identify, and describe the probable consequences and impacts of such measures on the functioning of the levee system.

The systems selected so far for temporarily raising levees along the Green River generally have been used in flood fighting on a short-term basis only. For the current circumstance, the systems may be needed in a repeated manner over six years or more. Thus, issues related to seepage, UV resistance, vandalism, repair, and deformation under repeated lateral loading may be more important for this project than for shorter-term flood fighting projects in the past. Seepage and stability should be evaluated for the specific system and installation conditions. Any capacity increase needs to go all the way down the river. Regardless of the system installed, monitoring will be required. Materials should be stockpiled in advance. We recommend that a common entity have review authority to ensure the use of appropriate levee-raising practices. The following factors should be considered in selection of a system for temporary raising of the levees:

- Stability; lateral loading, sliding and overturning
- Seepage; both through- and under-seepage
- Floating debris impact resistance
- UV exposure
- Vandalism resistance
- Construction time
- Removal considerations

- Re-usability
- Product cost.

Similarly, accepted flood fighting techniques should be employed. Methods need to be implemented such as completely stopping flow from a sand boil rather than using a ring dike to contain it. A list of potential flood-fighting measures and simple implementation methods should be developed by King County before those measures are needed. In addition, King County should consider a "stage" method of flood fighting, similar to the current stages of flood warning, that can be easily communicated and understood by the public and the adjoining cities and that is tied to specific public responses.

Earthen levee raising may be an alternative in some areas where adequate space is available or only a short raise is required. The review panel also discussed the concept of sacrificial levees – areas that could be breached as a relief valve during a flood if needed. Use of 2-D modeling to determine the potential benefit of this concept would be needed. Also, prior agreement with landowners for flooding (flood easement) would be necessary.

QUESTION 10B—TEMPORARY MEASURES TO AVOID

Are there temporary protective measures such as flood fighting that should be avoided (e.g. those that could cause more damage should they be deployed) given the current status of our levees? Please identify, and describe the probable consequences and impacts of such measures on the functioning of the levee system.

The review panel recognizes there is a balance between implementing proactive measures to reduce flooding from a potential high river event and flood fighting measures that are implemented during an actual flood event. This balance must consider several facets, including public perception, realistic flood prediction, cost, and consequences of failure if flood fighting is not successful.

The review panel believes that temporary measures that provide a false sense of security to the public should be avoided. Temporary measures that jeopardize the safety of workers should not be allowed. Similarly, temporary measures that do not meet the threshold of "strong probability of success" should not be allowed or should be treated as not being successful so that the public can safely evacuate in an orderly manner. The panel does not have any information indicating that the temporary measures currently in place create a hazard. It is important to emphasize, however, that these measures are temporary, and as such it would be unwise to depend on their reliability to protect against extreme consequences such as life-safety.

Shannon & Wilson, Inc. recently completed a draft report (Shannon and Wilson, 2009) evaluating the potential change in levee stability from temporary levee raise measures. The report presents the results of probabilistic and deterministic levee stability analyses, considering the effects of potential levee raising systems and higher discharges from Howard Hanson Dam.

To assess the potential impact of temporary levee raising and higher flows in the Green River, Shannon & Wilson completed probabilistic and deterministic levee stability analyses assuming a temporary levee raise of 4 feet. As part of the probabilistic analyses, the following potential failure modes were considered:

- Landside and riverside slope failure with steady-state seepage, static loading.
- Landside and riverside slope failure with steady-state seepage, seismic loading.
- Riverside slope failure during rapid drawdown.

- Landside slope failure resulting from piping and erosion of foundation material due to under-seepage.
- Landside slope failure resulting from piping and erosion of embankment material due to through-seepage.
- Judgment for other modes (such as erosion, vandalism, and failure of the temporary levee raising system) not considered above.

The results of the analyses generally indicate that temporary levee raising will result in a relatively small decrease in levee stability for river stages below the existing levee crest. However, the reliability of the levee system can generally be expected to decrease at a greater rate for river stages above the existing crest than for lower river stages. At most of the levee sections analyzed, reduced levee reliability at higher stages is primarily governed by under-seepage – not instability resulting from the additional weight of the levee raising system. At two of the locations analyzed, levee reliability at higher stages was governed by landside slope instability arising from seepage conditions unfavorable to slope stability.

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TM 900.13-2, Review And Analysis Of Existing Information April 2, 2007

TM 900.20-1, Geotechnical Exploration Methods And Results March 29, 2007

TM 900.20-2, As-Built Records Of Piezometer Installations February 2, 2007

TM 900.20-3, Laboratory Test Methods And Results March 27, 2007

TM 900.30-1, Preliminary River Segmentation For Risk Analysis May 15, 2007

TM 900.40-1, Results of Piezometer Studies April 2, 2007

TM 900.50.1, Slope Stability Analysis June 20, 2007

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Christian Brothers Revetment Repair, Green River, River Mile 17.15, Right Bank. King County Water and Land Resources Division. August 1998.

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Narita Levee Repair, Green River, River Mile 21.2, Right Bank. King County Water and Land Resources Division. February 1999.

Pipeline Revetment Repair, Green River, River Mile 21.9, Right Bank. King County Water and Land Resources Division. July 1998.

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Russell Road Upper Revetment Repair, Green River, River Mile 20.4, Right Bank. King County Water and Land Resources Division. August 1998.

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King County Water and Land Resources Division

Green River External Advisory Review Panel Report

REVIEW PANEL MEMBER RESUMES

February 2010

Curriculum Vitae—Derek B. Booth

1. General Biographical Information

1.1. Basic data

Derek Blake Booth

President and Senior Geologist, Stillwater Sciences, Inc.

Senior Editor, *Quaternary Research* (Elsevier Science Press)

Office: (206) 914-5031

Fax: (206) 632-0108

e-mail: dbooth@stillwatersci.com
dbooth@u.washington.edu

URLs: http://www.ess.washington.edu/People/faculty_bio/booth-bio.html (Earth & Space Sciences, UW)
http://faculty.washington.edu/dbooth/Booth_publication_links.htm (list and links to all publications)

1.2. Educational history

University of Washington, Seattle, Washington, Ph.D. in Geological Sciences, 1984: "Glacier dynamics and the development of glacial landforms in the eastern Puget lowland, Washington"

Stanford University, Stanford, California, M.S. in Geology, 1980

University of California, Berkeley, California, B.A. in Geology, 1978

Hampshire College, Amherst, Massachusetts, B.A. in Literature, 1974

1.3. Employment history

Current:

President (June 2007–present) and Senior Geologist (September 2006–present), Stillwater Sciences, Inc.

Affiliate Professor, University of Washington, Department of Civil & Environmental Engineering, Department of Earth & Space Sciences, and Interdisciplinary PhD Program in Urban Design and Planning (September 2006–present).

Senior Editor, *Quaternary Research* (September 2005–present).

Historic:

Research Professor, University of Washington, with joint appointment in Department of Civil & Environmental Engineering and Department of Earth & Space Sciences (July 2005–August 2006); adjunct faculty appointments in Quaternary Research Center, College of Forest Resources, Department of Landscape Architecture, and Department of Urban Design and Planning.

Visiting Associate Professor, Department of Geology and Geophysics, Louisiana State University (4/05-8/05).

Research Associate Professor, University of Washington, with joint appointment in Department of Civil & Environmental Engineering (1999–2005) and Department of Earth & Space Sciences (2003–2005).

Director, Center for Water and Watershed Studies, University of Washington (co-director 2002–2003; director 2003-2004).

Director, Center for Urban Water Resources Management, University of Washington, Department of Civil Engineering, 1995–2002 (reconstituted Sept. 2002 as Center for Water and Watershed Studies).

Research Assistant Professor, Department of Civil Engineering, 1995–1999.

Affiliate Assistant Professor, University of Washington, Department of Geological Sciences, 1986–1995; Department of Civil Engineering, 1992–1995; Department of Landscape Architecture, 1995.

Geologist, King County, Seattle, Washington, Basin Planning Program, Surface Water Management Division, Department of Public Works, 1987–1996.

Manager, King County, Seattle, Washington, Basin Planning Program, 1989–1990.

Geologist, King County, Seattle, Washington, Building and Land Development Division, Department of Parks, Planning, and Resources, 1985–1987.

Instructor, University of Washington, Department of Geological Sciences, 1984–1986.

Geologist, U.S. Geological Survey, Branch of Western Regional Geology, Menlo Park, California, 1979–1985.

Teaching Assistant, University of Washington, Department of Geological Sciences, 1980–1984.

Physical Science Technician, U.S. Geological Survey, Branch of Western Regional Geology, Menlo Park, California, 1978–1979.

1.4. Award and honors

Invited committee member, National Research Council, National Academies, 2007-2008.
Outstanding Contribution to Washington's Water Resources, American Water Resources Association, Washington State chapter, 2004.
Merit Award for Environmental Planning, American Planning Association, for the Chico Creek Watershed Planning Project, 2003 (with Mindy Roberts, Ph.C.)
Nominee, University of Washington Distinguished Graduate Mentor Award, 2000 and 2001
Fellow, Geological Society of America, 1999
University of Washington Graduate School Fellowship, 1983
Livingston Wernke Scholarship, 1981
National Science Foundation Graduate Fellowship, 1978–1981
Achievement Reward for College Scientists, 1978

2. Publications

2.1. Refereed archival journal publications (33 total)

E. A. Rosenberg, P. W. Keys, D. B. Booth, D. Hartley, J. Burkey, A. C. Steinemann, and D. P. Lettenmaier, in review, Precipitation extremes and the impacts of climate change on stormwater infrastructure in Washington State: submitted to *Climate Change*.

B. J. Visitacion, D. B. Booth and A. C. Steinemann, in press, Costs and Benefits of Stormwater Management: Case Study of the Puget Sound Region": *ASCE Journal of Urban Planning and Development.*

P. W. Downs, Y. Cui, J. K. Wooster, S. R. Dusterhoff, D. B. Booth, W. E. Dietrich, and L. S. Sklar, in press, Managing reservoir sediment release in dam removal projects: an approach informed by physical and numerical modelling of non-cohesive sediment: *Journal of River Basin Management*.

M. L. Roberts, R. E. Bilby, and D. B. Booth, 2008, Hydraulic dispersion and reach-averaged velocity as indicators of enhanced organic matter transport in small Puget Lowland streams across an urban gradient: *Fundamental and Applied Limnology*, v. 171/2, p. 145–159.

Alberti, M., D. B. Booth, K. Hill, B. Coburn, C. Avolio, S. Coe, and D. Spirandelli. 2007. The impact of urban patterns on aquatic ecosystems: an empirical analysis in Puget lowland sub-basins: Landscape and Urban Planning, Vol. 80(4), pp. 345-36.

D. B. Booth, 2005, Challenges and prospects for restoring urban streams: *Journal of the North American Benthological Society*, v. 24, p. 724-737.

C. P. Konrad, D. B. Booth, and S. J. Burges, 2005, Effects of urban development in the Puget Lowland, Washington, on interannual streamflow patterns: Consequences for channel form and streambed disturbance: Water Resources Research, v. 41(7), W07009, doi:10.1029/2005WR004097.

M. McBride and D. B. Booth, 2005, Urban impacts on physical stream conditions: effects of spatial scale, connectivity, and longitudinal trends: Journal of the American Water Resources Association, Vol. 41, No. 3, pp. 565-580.

D. B. Booth, J. R. Karr, S. Schauman, C. P. Konrad, S. A. Morley, M. G. Larson, and S. J. Burges, 2004, Reviving urban streams: land use, hydrology, biology, and human behavior: Journal of the American Water Resources Association, v. 40(5), p.1351-1364.

D. B. Booth, K. G. Troost, and J. T. Hagstrum, 2004, Deformation of Quaternary strata and its relationship to crustal folds and faults, central Puget Lowland, Washington: Geology, v. 32, p. 505-508.

D. B. Booth, R. E. Wells, and R. Givler, 2004, Chimney damage in the greater Seattle area from the Nisqually earthquake of February 28, 2001: Bulletin of the Seismological Society of America, v. 94(3), p. 1143-1158.

D. B. Booth and B. O. Brattebo, 2004, Permeable pavement update: Journal of the American Planning Association (research note), v. 70(1), p. 98.

B. O. Brattebo and D. B. Booth, 2003, Long-Term Stormwater Quantity and Quality Performance of Permeable Pavement Systems: Water Research, v. 37, p. 4369-4376.

J. T. Hagstrum, D. B. Booth, K. G. Troost, and R. J. Blakely, 2002, Magnetostratigraphy, paleomagnetic correlation, and deformation of Pleistocene deposits in the south-central Puget Lowland, Washington: Journal of Geophysical Research–Solid Earth 107 (B4): art. no. 2079 Apr 10 2002.

C. P. Konrad, D. B. Booth, S. J. Burges, and D. R. Montgomery, 2002, Partial entrainment of gravel bars during floods: Water Resources Research, v. 38, no. 7, 10.1029, p. 9–1 – 9–16.

D. B. Booth, D. Hartley, and C. R. Jackson, 2002, Forest cover, impervious-surface area, and the mitigation of stormwater impacts: Journal of the American Water Resources Association, v. 38, p. 835–845.

E. J. Nelson and D. B. Booth, 2002, Sediment budget of a mixed-land use, urbanizing watershed: Journal of Hydrology, v. 264, p. 51–68.

M. L. Larson, D. B. Booth, and S. M. Morley, 2001, Effectiveness of large woody debris in stream rehabilitation projects in urban basins: Ecological Engineering 18(2), p. 211–226.

J. G. Scholz and D. B. Booth, 2001, Monitoring small urban streams: Strategies and protocols for humid-region lowland systems: Environmental Monitoring and Assessment, 71(2), p. 143–164.

G. Mazer, D. B. Booth, and K. Ewing, 2001, Factors contributing to vegetation growth in biofiltration swales: Ecological Engineering 17(4), p. 429–443.

P. C. Henshaw and D. B. Booth, 2000, Natural restabilization of stream channels in urban watersheds: Journal of the American Water Resources Association, v. 36, no. 6, p. 1219–1236.

K. J. Comings, D. B. Booth, and R. R. Horner, 2000, Pollutant Removals by Two Wet Ponds in Bellevue, Washington: ASCE Journal of Environmental Engineering, vol. 126, no. 4, p. 321–330.

D. B. Booth and J. Leavitt, 1999, Field evaluation of permeable pavement systems for improved stormwater management: Journal of the American Planning Association, vol. 65, no. 3, p. 314–325.

D. B. Booth and C. R. Jackson, 1997, Urbanization of aquatic systems—degradation thresholds, stormwater detention, and limits of mitigation: *Journal of American Water Resources Association*: v. 33, no. 5, p. 1077–1090.

D. B. Booth, 1994, Glaciofluvial infilling and scour of the Puget Lowland, Washington, during ice-sheet glaciation: *Geology*, v. 22, p. 695–698.

D. B. Booth and B. Hallet, 1993, Channel networks carved by subglacial water: Observations and reconstruction in the eastern Puget Lowland of Washington: *Geological Society of America Bulletin*, v. 105, p. 671–683.

D. B. Booth, 1991, Glacier physics of the Puget lobe, southwest Cordilleran ice sheet: *Geographie Physique et Quaternaire*, v. 45, p. 301–316.

D. B. Booth, 1991, Urbanization and the Natural Drainage System—Impacts, Solutions, and Prognoses: *Northwest Environmental Journal*, v. 7, p. 93–118.

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D. B. Booth, 1986, Mass balance and sliding velocity of the Puget lobe of the Cordilleran ice sheet during the last glaciation: *Quaternary Research*, v. 25, p. 269–280.

D. B. Booth, 1986, The formation of ice-marginal embankments into ice-dammed lakes in the eastern Puget Lowland, Washington, U.S.A., during the late Pleistocene: *Boreas*, v. 15, p. 247–263.

D. B. Booth, 1981, Macroscopic behavior of freezing saturated silty soils: *Cold Regions Science and Technology*, v. 4, p. 163–174.

2.2. Fully refereed conference proceedings and other non-journal refereed publications (10 total)

Whitely Binder LC, Barcelos JK, Booth DB, Darzen M, Elsner MM, Graham TF, Hamlet AF, Hodges-Howell J, Huppert DD, Jackson JE, Karr C, Keys PW, Littell JS, Mantua N, Marlow J, McKenzie D, Robinson-Dorn M, Rosenberg EA, Stockle CO, Vano JA, 2009 (in press), Washington Climate Change Impacts Assessment: Evaluating Washington's Future in a Changing Climate—Washington State Department of Ecology, Olympia, WA.

D. B. Booth, K. G. Troost, Scott A. Shimel, Michael A. O'Neal, and A. P. Wisher, 2006, New geologic mapping and geologic database for the urbanized Puget Lowland, western Washington State, USA: in D.R. Soller, ed., Digital Mapping Techniques '05 -- Workshop Proceedings: U.S. Geological Survey Open-file Report 2005-1428, p. 259–266.

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J. Kay, R. N. Handcock, A. Gillespie, C. Konrad, S. Burges, N. Naveh, and D. B. Booth, 2001, Stream-temperature estimation from thermal infrared images: International Geoscience and remote Sensing Symposium, 9–13 July, 2001, Sydney, Australia.

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D. B. Booth, D. R. Montgomery, and J. P. Bethel, 1997, Large woody debris in urban streams of the Pacific Northwest: *in* Roesner, L. A., ed., Effects of watershed development and management on aquatic ecosystems: Engineering Foundation Conference, Proceedings, Snowbird, Utah, August 4–9, 1996 (invited).

R. R. Horner, D. B. Booth, A. Azous, and C. W. May, 1997, Watershed determinants of ecosystem functioning: in Roesner, L. A., ed., Effects of watershed development and management on aquatic ecosystems: Engineering Foundation Conference, Proceedings, Snowbird, Utah, August 4–9, 1996 (invited).

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D. B. Booth, K. G. Troost and, S. A. Shimel, 2005, Geologic map of northwestern Seattle (part of the Seattle North 7.5' x 15' quadrangle), King County, Washington: U.S. Geological Survey Scientific Investigations Map 2903, 1:12,000 (http://pubs.usgs.gov/sim/2005/2903/).

D. B. Booth and K. G. Troost, 2005, Geologic map of the Olalla 7.5-minute quadrangle, Washington: U.S. Geological Survey Scientific Investigations Map 2902, scale 1:24,000 (http://pubs.usgs.gov/sim/2005/2902/).

K. G. Troost, Booth, D. B., Wisher, A. P., and Shimel, S. A., 2005, The geologic map of Seattle: U.S. Geological Survey Open-File Report 2005-1252, scale 1:24,000 (http://pubs.usgs.gov/of/2005/1252/).

D. B. Booth and H. H. Waldron, 2004, Geologic map of the Des Moines 7.5-minute quadrangle, Washington: U.S. Geological Survey Scientific Investigation Map SIM-2855, scale 1:24,000 (http://pubs.usgs.gov/sim/2004/2855/).

D. B. Booth, H. H. Waldron, and K. G. Troost, 2004, Geologic map of the Poverty Bay 7.5-minute quadrangle, Washington: U.S. Geological Survey Scientific Investigation Map SIM-2854, scale 1:24,000 (http://pubs.usgs.gov/sim/2004/2854/).

R. W. Tabor, D. B. Booth, J. A. Vance, and A. B. Ford, 2003, Geologic map of the Sauk River 1:100,000 quadrangle, Washington: U.S. Geological Survey Miscellaneous Investigations Map I-2592, 2 sheets with pamphlet (: http://pubs.usgs.gov/imap/i2592/).

R. W. Tabor, V. A. Frizzell, Jr., D. B. Booth, and R. B. Waitt, Jr., 2000, Geologic map of the Snoqualmie Pass 30-minute by 60-minute quadrangle, Washington: U.S. Geological Survey Miscellaneous Investigations Map I-2538, scale 1:100,000, 57 pp.

D. B. Booth, 1995, Geologic map of the Maple Valley quadrangle, King County, Washington: U.S. Geological Survey Miscellaneous Field Studies Map MF-2297, scale 1:24,000.

R. W. Tabor, R. A. Haugerud, D. B. Booth, and E. H. Brown, 1994, Preliminary geologic map of the Mount Baker 30-minute by 60-minute quadrangle, Washington: U.S. Geological Survey Open-File Report 94-403, scale 1:100,000.

R. W. Tabor, V. A. Frizzell, Jr., D. B. Booth, R. B. Waitt, Jr., J. T. Whetten, and R. E. Zartman, 1993, Geologic map of the Skykomish River 30- by 60-minute quadrangle, Washington: U.S. Geological Survey Miscellaneous Investigations Map I-1963, scale 1:100,000.

D. B. Booth and J. P. Minard, 1992, Geologic map of the Issaquah quadrangle, King County, Washington: U.S. Geological Survey Miscellaneous Field Studies Map MF-2206, scale 1:24,000.

D. B. Booth, 1991, Geologic map of Vashon and Maury Islands, King County, Washington: U.S. Geological Survey Miscellaneous Field Investigations Map MF-2161, scale 1:24,000, 6 pp.

D. B. Booth, 1990, Surficial geology of the Skykomish and Snoqualmie Rivers area, Snohomish and King Counties, Washington: U.S. Geological Survey Miscellaneous Investigations Map I-1745, scale 1:50,000, 2 sheets with pamphlet.

D. B. Booth, 1989, Surficial geology of the Granite Falls 15' quadrangle, Snohomish County, Washington: U.S. Geological Survey Miscellaneous Investigations Map I-1852, scale 1:50,000.

F. Pessl, Jr., D. P. Dethier, D. B. Booth, and J. P. Minard, 1989, Surficial geology of the Port Townsend 1:100,000 quadrangle, Washington: U.S. Geological Survey Miscellaneous Investigations Map I-1198F, 2 sheets with pamphlet.

J. P. Minard and D. B. Booth, 1988, Geologic map of the Redmond quadrangle, King and Snohomish Counties, Washington: U.S. Geological Survey Miscellaneous Field Investigations Map MF-2016, scale 1:24,000.

R. W. Tabor, V. A. Frizzell, Jr., J. T. Whetten, D. A. Swanson, G. R. Byerly, D. B. Booth and others, 1980, Preliminary geologic map of the Chelan 1:100,000 quadrangle, Washington: U.S. Geological Survey Open-File Report 80-841.

D. B. Booth and K. G. Troost, in review, Geologic map of the Vashon quadrangle: U.S. Geological Survey Scientific Investigation Map, scale 1:24,000.

D. B. Booth, K. G. Troost, and T. J. Walsh, in review, Geologic map of the Issaquah quadrangle: U.S. Geological Survey Scientific Investigation Map, scale 1:24,000.

K. G. Troost, D. B. Booth, and S. A. Shimel, in review, Geologic map of the Seattle SE quadrangle: U.S. Geological Survey Scientific Investigation Map, scale 1:12,000.

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- D. R. Montgomery, D. B. Booth, and S. Bolton, *Puget Sound rivers and salmon recovery*, p. 1–13.
- D. B. Booth, R. A. Haugerud, and K. G. Troost, Geology, watersheds, and Puget Lowland rivers, p. 14–45.
- J. M. Buffington, R. D. Woodsmith, D. B. Booth, and D. R. Montgomery, *Fluvial processes in Puget Sound rivers in the Pacific Northwest*, p. 46–78.
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D. B. Booth, press, "Stormwater Management": entry *in* Trimble, S. W., ed., Encyclopedia of Water Science: New York, Marcel Dekker, Inc.

C. H. Hinman and D. B. Booth, in press, "Low-Impact Development": entry *in* Trimble, S. W., ed., Encyclopedia of Water Science: New York, Marcel Dekker, Inc.

Books edited

D. Montgomery, S. Bolton, D. B. Booth, and L. Wall, eds., 2003, Restoration of Puget Sound Rivers: University of Washington Press, 505 pp.

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2.4. Selected major project reports to sponsors

Title	Funding Agency	Report Number and Date	Co-Authors
Review of proposed methodology for ranking stream daylighting opportunities in urban creeks	Seattle Public Utilities	October 2007	S. Ralph
Geomorphic conditions of the Santa Paula Creek watershed, southern California	CA Dept. of Fish and Game	October 2007	S. Dusterhoff, P. Downs
Review of West Branch Hylebos Creek enhancement project, Federal Way, WA	Windward Environ-mental	April 2007	
Evaluation of restoration opportunities, lower Germany Creek, southwest	WA Trout; Cascade	January 2007	

Washington	Land Trust		
Damages and costs of stormwater runoff in the Puget Sound region (*http://www.psat.wa.gov/Programs/stormwater/SummaryReportPSATstormwaterFoundation_FINAL_08-30-06.pdf*)	Puget Sound Action Team	August 2006	B. Vistacion, A. Steinemann
Hydrologic trends and hydrologic monitoring in urbanizing streams of western Washington	WA Dept. of Ecology	2004	C. P. Konrad
Urban stream rehabilitation in the Pacific Northwest	U. S. EPA	R82-5284-010 (2004)	J. Karr, S. Schauman, C. Konrad, S. Morley, M. Larson, P. Henshaw, E. Nelson, S. Burges
A survey of ditches along county roads for their potential to affect storm runoff water quality	King Co., Snohomish County	2001	Shanti Colwell, Richard Horner, Dalius Gilvydis
First-year report of monitoring, Novelty Hill Urban Planned Developments	King County	2000	Karen Comings, Heidi Wachter
Stream Habitat Assessment Protocols: An Evaluation of Urbanizing Watersheds in the Puget Sound Lowlands	City of Bellevue	1999	Jennifer Scholz
Duwamish Basin Groundwater Pathways: Development of a three-dimensional , numerical groundwater flow model for the Duwamish River basin (*http://depts.washington.edu/cwws/Research/Reports/rc1.pdf*)	City of Seattle, King County	1998	Jason Fabritz, Joel Massmann
Duwamish Basin Groundwater Pathways: Conceptual model report	City of Seattle, King County	1998	Lori Herman (Hart Crowser Inc.)
The University of Washington permeable pavement demonstration project—background and first-year field results (3	King County, Olympia, WADOE	CUWRM report K19 (1997)	Jennifer Leavitt and Kim Peterson
Evaluation of filter berms in double-cell detention ponds, King County, Washington	King County	CUWRM report K13 (1997)	Karen Billica

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Keys, P.W., Rosenberg, E.A., Booth, D.B., Steinemann, A.C., and Lettenmaier, D.P., 2008, Precipitation extremes and the impacts of climate change on stormwater in Washington State: Eos Trans. AGU, 89, Fall Meet. Suppl. Abstract.

Booth, D.B., Bledsoe, B., and Stein, E., 2008, Four decades of research into stream-channel changes in urban environments, and their implications for southern California: H_2O Conference, Long Beach, CA.

Booth, D.B., Downs, P.W., Dusterhoff, S.R., and Leverich, G.T., 2008, Comparative rates of uplift and fluvial erosion in the Santa Paula and Sespe watersheds (western Transverse Ranges), CA: Geological Society of America, Abstracts with Programs, Annual Meeting, v. 40.

Booth, D.B., Ligon, F.K., Sloat, M.R., Amerson, B., and Ralph, S.C., 2007, Watershed processes, fish habitat, and salmonid distribution in the Tonsina River: Eos Trans. AGU, 88, Fall Meet. Suppl. Abstract.

Booth, D.B., 2007, Regional perspectives of stream restoration—the Pacific Northwest: article in The Stream Restoration Networker, Summer/Fall 2007 issue, published by the National Center for Earth-surface Dynamics, University of Minnesota (http://www.streamrestoration.net/).

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Troost, K.G. and Booth, D.B., 2004, Applications of a Geologic Database of the Greater Seattle Area, Western Washington, Program with Abstracts, 2004 Annual Meeting, Association of Engineering Geologists, Dearborn, Michigan, September 26-October 2, 2004, Changes to Program with Abstracts, p. 5.

Alberti, M., Hepinstall, J., Booth D., Coe, S., Spirandelli D., Jiang, Y., and C. Avolio, 2004, Modeling urban landscape patterns and their effects on aquatic ecosystems: Ecological Society of America, 89th Annual Meeting, Portland, Oregon, August 1-6, 2004.

C. Segura Sossa and D.B. Booth, 2003, Morphological effects of channel confinement and riparian vegetation on urban and non-urban streams of the Pacific Northwest: Eos Trans. AGU, 84, Fall Meet. Suppl. Abstract.

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D. B. Booth, K. Bell, and K. X. Whipple, 1991, Sediment transport along the South Fork and mainstream of the Snoqualmie River: Seattle, King County Surface Water Management Division, 25 p.

D. B. Booth, 1990, Pleistocene deposits and subglacial landforms of the southeastern Puget Lowland: Northwest Geological Society, Field Trip Guidebook #1.

D. B. Booth, R. R. Fuerstenberg, and B. L. Barker, 1990, Frequency of disturbances in urban streams: Eos, American Geophysical Union, Fall Meeting, v. 71, p. 1322.

D. B. Booth, 1990, Physical processes of the Puget lobe, Cordilleran ice sheet: invited abstract for Geological Association of Canada, Annual Meeting, Vancouver, British Columbia, May 16–18, 1990.

D. B. Booth and R. R. Fuerstenberg, 1989, Watershed analysis of land-use changes: Western Society of Naturalists, 70th Annual Meeting, Program/Abstracts, p. 11–12.

D. B. Booth and B. L. Barker, 1988, Quantitative prediction of stream-channel changes in urbanizing drainage basins: Eos, American Geophysical Union, Fall Meeting, v. 69, p. 1224.

R. W. Tabor and D. B. Booth, 1985, Folded thrust fault between major melange units of the western North Cascades, Washington, and its relationship to the Shuksan Thrust: Geological Society of America, Abstracts with Programs, Cordilleran Section, v. 17, p. 412.

D. B. Booth, 1984, Ice-sheet reconstruction and erosion by subglacial meltwater in the eastern Puget Lowland, Washington: Geological Society of America, Abstracts with Programs, Annual Meeting, v. 16, p. 450.

Web sites
The Pacific Northwest Center for Geologic Mapping Studies:
http://geomapnw.ess.washington.edu

3. Other Scholarly Activities

3.1. Invited lectures and seminars (64 total)

Law Seminars International, Clean Water and Stormwater Conference, invited speaker, "Stormwater management—lessons from around the US," Seattle, April 6, 2009.

University of Delaware, Department of Geography, noontime colloquium, "A tale of three rivers," February 9, 2009.

Urban Ecosystem Research Consortium, annual symposium, opening keynote address, "Management, monitoring, and the ecological integrity of urban streams," Portland State University, January 26, 2009.

US Environmental Protection Agency, Region X, Climate Change and Water Infrastructure Forum, invited speaker, "Climate change impacts on water infrastructure—Washington State," Seattle, September 4, 2008.

University of Washington, Water Center Annual Review, invited speaker, "West coast watersheds and the streams they create," Seattle, February 14, 2008.

Stanford University, Society of Environmental Journalists, invited speaker and panelist, "Coastlines and estuaries: Awash in urban poisons," Palo Alto, CA, September 8, 2007.

University of Washington, The Water Center colloquium series, invited speaker, "A tale of two rivers," May 29, 2007.

California Stormwater Quality Association, quarterly meeting, keynote speaker, "Monitoring, management, and the ecological integrity of urban streams," Long Beach, CA, May 11, 2007.

Law Seminars International, Clean Water and Stormwater Conference, invited speaker, "Managing stormwater to meet the goals of the Puget Sound Partnership," Seattle, March 19, 2007.

University of Washington, Water Center Annual Review, invited speaker, "Just when we were getting it right—Pacific Northwest stormwater management for the 21st century," Seattle, February 14, 2007.

Stormcom Workshop and Exposition, regional conference, invited keynote speaker, "Stormwater management in the Puget Sound region," SeaTac, WA, December 1, 2006.

American Water Resources Association, Washington Chapter Meeting, "Rivers and cities," Seattle, June 1, 2006.

University of Washington, Landscape Architecture 341 (Site Planning), class lecture on Puget Lowland geology and hydrologic implications, October 28, 2005.

University of Washington, The Water Center colloquium series, invited speaker, “Some international observations on rivers through cities,” October 25, 2005.

California Stormwater Quality Association, Workshop on Hydromodification, “Changes in streamflow patterns from urbanization--a humid-region perspective,” Ontario, CA, October 3, 2005.

Louisiana State University, Department of Geology and Geophysics, departmental seminar, “Geologic databases, digital geologic maps, and geologic hazards”: April 29, 2005.

University of Vermont, Department of Civil and Environmental Engineering, departmental seminar, “River restoration and urban streams—status and challenges”: November 18, 2004.

City of Victoria, British Columbia, workshop presentation on “Permeable paving and stormwater”: Vancouver Island Technology Park, June 18, 2004.

University of California at Los Angeles, Department of Geography, departmental seminar, “Rehabilitation of urban streams,” June 11, 2004.

University of Washington, Landscape Architecture 433 (Large-Scale Site Construction), class lecture on hydrology, hydrologic modeling, and stormwater management, April 14, 2004.

U. S. Geological Survey, Water Resources Division, Tacoma, WA, monthly seminar, “Geology of the Puget Lowland,” April 8, 2004.

University of Washington, Civil Engineering 427 (Engineering Geology), class lecture on glacial geology, Puget Lowland landforms and deposits, and engineering applications of geology, April 6, 2004.

University of Washington, Landscape Architecture 341 (Site Planning), class lecture on Puget Lowland geology and site-planning considerations, October 29, 2003.

University of Washington, Biology 330 (Natural History of Marine Invertebrates), class lecture on the formation of Puget Sound, July 1, 2003.

American Water Resources Association, State Chapter monthly meeting, “Formation of Puget Sound landscapes,” Seattle, April 17, 2003.

U. S. Environmental Protection Agency, panel member, Watershed Science Workshop, University of Washington campus, August 26, 2002.

U. S. Army Corps of Engineers, Economic and Environmental Analysis conference, “Approaches, limitations, and outcomes of urban stream rehabilitation,” New Orleans, LA, July 16–18, 2002.

U. S. Army Corps of Engineers, Economic and Environmental Analysis conference, “Hydrologic changes and stormwater BMP's in urban streams,” New Orleans, LA, July 16–18, 2002.

Northwest Stream Restoration Design Symposium, invited plenary speaker, “Urban stream rehabilitation,” Skamania, WA, January 31, 2002.

International Erosion Control Association, Pacific Northwest Chapter annual meeting, invited speaker, “Urban Stream Rehabilitation,” Tacoma, WA, November 28, 2001.

University of Washington, Landscape Architecture 341 (Site Planning), class lecture on Puget Lowland geology and site-planning considerations, October 31, 2001.

Portland State University, Environmental Sciences and Resources Program, departmental seminar, “Urban Stream Rehabilitation,” October 5, 2001.

American Society of Civil Engineers, Seattle Section Conference, invited speaker, “Erosion Processes,” University of Washington, April 28, 2001.

Washington State Bar Association, continuing education seminar, *The Science and Law of Stormwater, Wetlands, and Groundwater:* “Who’ll stop the rain?”, invited speaker, Seattle, WA, February 2, 2001

Eighth Annual Regional Conference on the Endangered Species Act, invited speaker, January 25, 2001, Bellevue, WA.

U. S. Geological Survey and National Oceanographic and Atmospheric Administration, *Tsunami Hazards Workshop*: Panelist, January 24, 2001, Seattle, WA.

University of Washington, College of Forest Resources, invited speaker for Ecosystems Fall Seminar Series, “Hydrology, Stability, and Erosivity of Urban Soils,” November 8, 2000.

Stilly-Snohomish Fisheries Enhancement Task Force, invited speaker, “Geology and salmon,” October 11, 2000.

Streamkeepers of Pierce County, invited speaker, “Streams in urban areas,” May 12, 2000.

Washington State Bar Association Annual Real Estate Conference, invited panelist, Seattle, Washington, November 12, 1999.

U. S. Geological Survey, Urban Hazards Program review workshop, invited speaker, “Status, Results, and Prognoses for Geologic Mapping in the Seattle-Tacoma Urban Corridor,” Tacoma, Washington, October 17, 1999.

University of Washington, Department of Fisheries colloquium series, invited speaker, “Stream Channels in Urban Environments,” October 7, 1999.

University of Washington, Saturday Seminar Series, invited speaker, “Urban Development and Wild Salmon: Can They Get Along?” University of Washington campus, October 17, 1998.

Washington State Joint Natural Resources Cabinet (Governor’s Office), invited speaker, “Urban Watersheds and Stream Habitat,” Olympia, WA, June 9, 1998.

American Public Works Association, invited speaker and panelist, conference on “Salmon in the City,” Mt. Vernon, WA, May 21, 1998.

American Water Resources Association (state chapter), invited speaker, “Rehabilitating urban streams—optimistic goals with realistic outcomes,” Seattle, WA, May 13, 1998.

Washington State Department of Ecology, invited speaker and panelist, conference on “Partnerships in preventing polluted runoff,” Wenatchee, WA, March 31, 1998.

Association of Engineering Geologist, invited speaker, “Stream channel changes in urbanizing watersheds of western Washington,” Seattle, WA, March 19, 1998.

U. S. Geological Survey, Western Regional Mapping Team, invited workshop co-leader, “Directions in Quaternary Mapping and Analysis,” Menlo Park, CA, February 19, 1998.

Pacific Northwest Environmental Law and Management Conference, Invited presenter, Seattle, Washington, December 3, 1997.

ASCE Seattle Section Conference, invited speaker and panelist, “Wastewater Quality Management and Treatment”, University of Washington, April 21, 1997.

USGS Cascade Volcano Observatory, special colloquium, “Landscape Development of the Puget Lowland”, Vancouver, WA, October 8, 1996.

Second Annual Pacific Northwest Water Issues Conference, Oregon Water Resources Research Institute, “Urban Development and Flooding—Causes, Effects, and the Search for Solutions”, Portland, Oregon, October 7, 1996.

U. S. Environmental Protection Agency, Region 10, Watershed Restoration Workshop, “Identification and Prioritization of Aquatic Ecosystems Restoration and Protection Needs”, Workshop Coordinator, Seattle, September 23–27, 1996

Department of Forest Sciences, Oregon State University, Geomorphology, and Ecology, Departmental Seminar Series: Physical Processes in Forest Science, “Emerging Issues at the Interface of Hydrology, Consequences, thresholds, and mitigation of watershed urbanization”, Corvallis, Oregon, February 23, 1995.

American Water Resources Association Fall Conference, Interactions: River Dynamics, Land Forms and Land Use, “How stream channels change in response to urbanization”, Bellevue, Washington, November 10, 1994.

Center for Urban Horticulture, University of Washington, “Urbanization impacts on watershed hydrology,” Restoration Ecology of Urban Watersheds Workshop, Seattle, Washington, March 21, 1994.

Association of Engineering Geologists and Departments of Civil Engineering and Geological Sciences, University of Washington, Geological Hazards and the Growth Management Act Workshop, “Geology, growth, and land use in western Washington,” keynote address, Seattle, Washington, October 30, 1993.

Western Washington University and Washington State Department of Ecology, Floods and River Basin Management Workshop, “Flooding and floodplain dynamics”, Deming, Washington, June 26, 1993.

U. S. Environmental Protection Agency, Fundamentals of Watersheds Workshop, “Impacts of urbanization”, Seattle, Washington, April 8, 1993.

U. S. Environmental Protection Agency, Fundamentals of Watersheds Workshop, “Physical aspects of watersheds—geology and geomorphology”, Seattle, Washington, December 15, 1992.

American Public Works Association, Salmon in the City: Effects of Urbanization on Fish Habitat Workshop, “Geomorphic effects of urbanization”, Pack Forest, Washington, March 11–13, 1992.

Western Washington University, Department of Geology, Departmental Colloquium Series, “Glacial landforms of the Puget Lowland—subglacial processes of formation and postglacial processes of urbanization”, Bellingham, Washington, November 7, 1991.

University of Washington Faculty Committee on Science, Technology, and Society, Symposium on Understanding and Managing Risks in Modern Society, “Flood prediction and control”, Seattle, April 30, 1991.

American Water Resources Association, Hydrology and Erosion Aspects of Timberland Conversion Workshop, “Channel susceptibility to the impacts of urbanization”, Pack Forest, Washington, November 15–16, 1988.

3.2. Presentations given at conferences (43 total)

Washington State Climate Change Symposium, *Summary of effects of climate change on urban stormwater infrastructure,* Seattle Convention Center, February 12, 2009.

H_2O Conference (Headwaters to Ocean), Annual meeting, *Four decades of research into stream-channel changes in urban environments, and their implications for southern California*: Long Beach, CA, October 29, 2008.

Geological Society of America, Annual Meeting, *Ripple: a digital-terrain based model for linking fish to channel networks*, Houston, TX, October 8, 2008.

Geological Society of America, Annual Meeting, *Comparative rates of uplift and fluvial erosion in the Santa Paula and Sespe watersheds (western Transverse Ranges), CA*, Houston, TX, October 5, 2008.

Floodplain Management Association Annual Meeting: *Floodplain Management Strategies for the Santa Clara River, Ventura County, California,* San Diego, California, September 3, 2008 (invited).

Southern California Wetlands Recovery Symposium: *Patterns, rates, and consequences of sediment delivery into Santa Paula Creek, California*, San Diego, May 7, 2008 (invited).

American Geophysical Union Fall Meeting: *Watershed processes, fish habitat, and salmonid distribution in the Tonsina River (Copper River watershed), Alaska*, December 2007.

Northwest Stream Restoration Design Symposium, *Identifying future threats to watershed processes and salmonid populations in the Copper River, Alaska*, Skamania, WA, February 8, 2007.

East Baton Rouge Urban Watershed Protection Workshop, invited speaker and panelist, *Watershed Protection Principles—Suggestions and Caveats from the Pacific Northwest*, Baton Rouge, Louisiana, March 9, 2006.

California Stormwater Quality Association, Hydromodification Workshop, invited presentation, *Changes in streamflow patterns from urbanization--a humid-region perspective,* Ontario, California, October 3, 2005.

American Society of Civil Engineering, World Water and Environmental Resources Congress, invited keynote presentation for the River Restoration and Urban Streams Symposium, *Watershed determinants of urban stream degradation*, Salt Lake City, Utah, June 28, 2004.

Symposium on Urbanization and Stream Ecology, Cooperative Research Centre for Freshwater Ecology (Australia), invited keynote speaker, *Short- and long-term rehabilitation of urban streams*, University of Melbourne, December 10, 2003.

Geological Society of America, Annual Meeting, *Landfall of the Seattle fault zone, West Seattle, WA,* Seattle, Washington, November 4, 2003.

STREAMS Channel Protection and Restoration Conference, *Determinants of urban stream degradation* (invited), The Ohio State University, October 7, 2003.

Puget Sound Action Team, Puget Sound-Georgia Basin Research Conference 2003, *Management strategies for urban stream rehabilitation in the Pacific Northwest* (invited), Vancouver, BC, April 3, 2003.

U. S. Environmental Protection Agency, National Conference on Urban Storm Water, *Strategies and limitations for urban watershed planning* (invited) Chicago, IL, February 18, 2003.

U. S. Army Corps of Engineers, Economic and Environmental Analysis conference, invited speaker, *Approaches, limitations, and outcomes of urban stream rehabilitation* (invited): New Orleans, LA, July 16, 2002.

U. S. Army Corps of Engineers, Economic and Environmental Analysis conference, invited speaker, *Hydrologic changes and stormwater BMP's in urban streams* (invited): New Orleans, LA, July 16, 2002.

Northwest Stream Restoration Design Symposium, invited plenary speaker, *Urban stream rehabilitation*, Skamania, Washington, January 31, 2002.

Geological Society of America, Cordilleran Section meeting, *Landscapes of the Puget Lowland* (invited), May 14, 2002.

Society of Ecological Restoration: *Geology, watersheds, and Pacific Northwest rivers* (invited), April 5, 2001.

3rd Symposium on the Hydrogeology of Washington State: *Urban Stream Rehabilitation* (invited), October 18, 2000.

American Geophysical Union Spring Meeting: *Urban Stream Rehabilitation*, May 2000.

Geological Society of America, Cordilleran Section Meeting, *Geologic Evaluation of Tectonic Deformation in the Central Puget Lowland, Washington state*: April 28, 2000.

Seismological Society of America, Annual Meeting: *Character and age of tectonically deformed Pleistocene Deposits in the central Puget Lowland, Washington state*, May 4, 1999.

Association of Engineering Geologists, Annual Meeting: *Chronology, correlation, and deformation of Quaternary deposits in the central Puget Lowland, Washington State*, October 1, 1998.

American Geophysical Union Fall Meeting: *Long-term measurement of channel changes in urban and suburban watersheds*, December 11, 1997.

American Geophysical Union Spring Meeting: *Degradation of urban and suburban watersheds* (invited), May 1997.

American Geophysical Union Fall Meeting: *Limits to mitigating urban watershed degradation*, December 1996.

Second Annual Pacific Northwest Water Issues Conference: *Urban Development and Flooding—Causes, Effects, and the Search for Solutions*, October 7, 1996.

Engineering Foundation Conference: *Large woody debris in urban streams of the Pacific Northwest* (invited), August 5, 1996.

Quaternary Research Center conference on Quaternary Environmental Change in the Pacific Northwest: *Volcanic deposits in the Pleistocene "glacial" sequence of the east-central Puget Lowland,* May 2, 1996.

Geological Society of America Annual Meeting: *Disturbance frequency and channel alteration in urban streams,* October 1994.

American Water Resources Association Summer Symposium on "Effects of Human-Induced Changes in Hydrologic Systems": *Urbanization of aquatic systems—thresholds and the limits of mitigation*, July 1994.

American Fisheries Society Annual Meeting: *Consequences, thresholds, and mitigation of watershed urbanization* (invited), August 29, 1993.

Watersheds '93: *Consequences of urbanization on aquatic systems—Measured effects, degradation thresholds, and corrective strategies,* March 21, 1993.

Quaternary Research Center conference on "Chronology and Paleoenvironments of the Western and Southern Margins of the Cordilleran Ice Sheet During the Last Glaciation": *Mass balance and climatic responses of the Puget lobe during the Vashon stade*, April 30, 1992.

Geological Society of America Cordilleran Section Annual Meeting: *Patterns and processes of landscape development by the Puget lobe ice sheet*, April 1992.

American Geophysical Union Fall Meeting: *Frequency of disturbances in urban streams*, December 1990.

Geological Association of Canada Annual Meeting: *Physical processes of the Puget lobe, Cordilleran ice sheet* (invited), May 18, 1990.

Western Society of Naturalists 70th Annual Meeting: *Watershed analysis of land-use changes,* January 1989.

American Geophysical Union Fall Meeting: *Quantitative prediction of stream-channel changes in urbanizing drainage basins,* December 1988.

Geological Society of America Annual Meeting: *Ice-sheet reconstruction and erosion by subglacial meltwater in the eastern Puget Lowland, Washington*, October 1984.

3.3. Professional society memberships

American Society of Civil Engineers, 1997–present
Association of Engineering Geologists, 1988–present
Northwest Geological Society, 1987–present (President 1989)
American Geophysical Union, 1985–present
Geological Society of America, 1984–present (elected Fellow 1999)

Professional licenses

Professional Geologist: September 28, 2001 (State of Washington, License #195); June 22, 2007 (State of California, License #8402)
Professional Engineer—Civil: July 24, 2000 (State of Washington, License #36876)

3.4. Other

Reviews Made--journals

ASCE Journal of Construction Engineering and Management, 1 article.
ASCE Journal of Water Resources Planning and Management, 7 articles.
Ecological Applications, 1 article.
Encyclopedia of Water (Marcel Dekker publ.), 1 article.
Environment, Development and Sustainability, 1 article.
Environmental Management and Assessment, 1 article.
Geological Society of American Bulletin, 3 articles.
Geology (published by the Geological Society of America), 8 articles.
Journal of Environmental Management, 8 articles.
Journal of Glaciology, 1 article.
Journal of the American Water Resources Association, 19 articles.
Journal of the North American Benthological Society, 3 articles.
Land Degradation and Development, 1 article.
Landscape Ecology, 1 article.
Marine and Freshwater Research, 1 article.
North American Journal of Fisheries Management, 1 article.
Proceedings of the National Academy of Science, 1 article.
Quaternary Research (not as editor), 6 articles.
Quaternary Science Reviews, 1 article.
Water Practice, 1 article.
Water Research, 2 articles.
Water Resources Research, 2 articles.

Reviews Made--other

U. S. General Accounting Office, Evaluation of National Water-Quality Policy, Delphi review panelist, 2001.
U.S. Geological Survey, National Educational Mapping Program, Panel member 1997–2000.
U.S. Geological Survey, National Earthquake Hazard Reduction Program, Panel member 1992, 1993, 1996.
US Geological Survey, multiple (>20) map and manuscript reviews.

Olympic National Research Center, proposal reviews, 2004.

Review of “Beach Processes and Sedimentation” by Paul Komar: Journal of the American Water Resources Association, v. 34(3), p. 697–698, 1998.

Review of "Glacial Geologic Processes" by David Drewry: Quaternary Research, v. 28, p. 175, 1987.

Other mail reviews:

American Association for the Advancement of Science, Research Competitiveness Program.

CALFED Bay-Delta grant program

National Research Council, Watershed Management for Potable Water Supply: Assessing the New York City Strategy, National Academy Press, 2000.

National Science and Engineering Research Council (Canada).

National Science Foundation, Geosciences, Polar Research, Ecosystem Studies, Geomorphology and Land Use Dynamics, and Engineering programs.

National Science Foundation–US Environmental Protection Agency “Waters and Watersheds” program.

Natural Environment Research Council (UK)

Swiss National Science Foundation.

4. Graduate Students

4.1. Chaired doctoral degrees (4 total)

Student	Dissertation Title	Current Employer	Year Completed
Kathy Troost		Univ. of WA	In progress
Mindy Roberts	Sources, Transport and Fate of Terrestrial Organic Matter Inputs to Small Puget Lowland Streams: Effects of Urbanization, Floods and Salmon	Univ. of WA, WA Dept. of Ecology	2007
Michael O’Neal	Late Little Ice Age Glacier Fluctuations in the Cascade Range of Washington and Northern Oregon	Univ. of Delaware	2005
Christopher Konrad (as co-chair)	The frequency and extent of hydrologic disturbances in streams in the Puget Lowland, Washington	U. S. Geological Survey	2000

4.2. Chaired masters degrees (21 total)

Student	Thesis	Thesis/Project Title	Year Completed
Jacob Millard	no		2005

Susan Rosebrough	no		2005
Brent Zacharia	no		2004
Amy Engstrom	yes	Characterizing water quality of urban stormwater runoff	2004
Catalina Segura-Sossa	yes	Characterizing lowland streams: riparian and watershed influences on urban and non-urban channels	2003
Christina Avolio	yes	The local impacts of road crossings on Puget Lowland creeks	2003
Heidi Wachter	yes	Application of the benthic index of biological integrity (B-IBI) to headwater streams within the Puget Lowland	2003
Chase Barton	yes	Applications of a sediment budget to assist urban stream rehabilitation	2003
John Koreny	no		2003
Maeve McBride	yes	Spatial effects of urbanization on physical conditions in Puget Sound lowland streams	2001
Carolyn Butchart	yes	Using air conductivity and soil texture as indicators of infiltration rates for stormwater infiltration ponds	2001
Jay Cammermeyer	yes	The effects of vegetation in highway drainage ditches on flow characteristics and pollutant removal	2001
Shanti Colwell	yes	Characterization of performance predictors and evaluation of mowing practices in biofiltration swales	2000
Kathy Troost	yes	The Olympia nonglacial interval in the southern Puget Lowland	1999
Marit Larson	yes	Effectiveness of LWD in stream rehabilitation projects in urban basins	1999
Erin Nelson	yes	A sediment budget for the Issaquah Creek watershed	1999
Patricia Henshaw	yes	Restabilization of stream channels in urban watersheds	1999
Dalius Gilvydas	no	A meta-analysis of cattle-grazing impacts on salmonid stream habitat quality	1999
Cheryl Dunning	no	Urban stormwater management at Vet Clinic Wetland, McChord AF Base	1998
Jeanette Leavitt	no	The function of urban riparian buffers	1998
Karen Comings	yes	Stormwater pollutant removal by two wet ponds, Lk Sammamish watershed	1998

4.3. Other student supervision

Membership on degree committees (65 total):

Student	Degree	Thesis title	Year completed
Brian Collins	Earth and Space Sciences, Ph.D.	History of Puget Lowland rivers	2009

Christopher Brummer	Earth and Space Sciences, Ph.D.	Morphological indicators of downstream transitions in headwater channels	2006
Vivek Shandas	Urban Design and Planning, Ph.D.	Interactions between vegetation patterns, social preferences, and stream biotic conditions	2005
Karen Bobbitt Gran	Earth and Space Sciences, Ph.D.	Fluvial recovery following extreme sediment loading at Mount Pinatubo	2005
Ken Yocom	Landscape Architecture, MLA	Non-thesis	2005
James Packman	Forest Resources, MS	Land-use effects on suspended sediment in Puget Lowland salmonid streams	2004
Coleen Doten	Civil & Environmental Eng., MSCE	Prediction of sediment erosion with the distributed hydrology-soil-vegetation model	2004
Kris Jaeger	Forest Resources, MS	Channel-initiation and surface water expression in headwater streams of different lithology	2004
Catherine Reidy	Forest Resources, MS	Variability of hyporheic zones in Puget Sound Lowland streams	2004
Benjamin Brattebo	Civil & Environmental Eng., MSCE	Storm event and land cover impacts on stream phosphorus transport and speciation	2003
Sandra Kutzing	Civil & Environmental Eng., MSCE	Evaluating drought response plans for the Atlanta metropolitan region using a water management simulation model	2002
Sara Stanley	Civil & Environmental Eng., MSCE	A daily time series analysis of urbanization effects on stream phosphorus concentrations and transport in the greater Seattle region	2002
Christopher Brueske	Civil & Environmental Eng., MSE	Non-thesis	2002
Lamont Glass	Forest Resources, MS	Comparison of narrowleaf cottonwood forest condition and reproduction above and below a reservoir	2002
Bryan Berkompas	Forest Resources, MS	Evaluation of discharge-related channel changes in a small forested basin	2002
John Gardner Johnston	Forest Resources, MS	Riparian canopy cover in northeastern Washington : stream temperature response, historical reference conditions, and management effects	2002
Stephanie Stolar	Civil & Environmental Eng., MSCE	Evaluation of factors affecting infiltration pond performance	2001
Adrienne Miller	Civil & Environmental Eng.,	Hydrologic monitoring of the Seattle ultra-urban stormwater	2001

	MSCE	management projects	
Lynel Rabago	Civil & Environmental Eng., MSE	Non-thesis	2002
Sydney Elmer	Urban Design and Planning, MUP	Spatially explicit impervious surface modeling within land uses	2001
Michelle Kondo	Urban Design and Planning, MUP	The effect of connectivity on attenuation in nutrient export	2001
Philip Hartigan	Urban Design and Planning, MUP	Salmon and site planning : effects on residential development in Issaquah & Lake Forest Park	2001
David Knobloch	Geological Sciences, MS	withdrawn	—
Lenore Jensen	Civil & Environmental Eng., MS	The effects of plant abundance on a pilot scale treatment wetland	2000
Timothy Abbe	Geological Sciences, Ph.D.	Patterns, mechanics and geomorphic effects of wood debris accumulations in a forest river system	2000
John Small	Landscape Architecture, MLA	Riparian corridor rapid assessment technique for large lowland rivers of the Puget Sound region	2000
David Landsman	Forest Resources, MS	The strengths and weaknesses of the Washington State Salmon Recovery Funding Board (SRFB) process	2000
Kyle Comanor	Civil & Environmental Eng., Ph.D.	withdrawn	—
Kurt Marx	Civil & Environmental Eng., MS	Effects of loading and temperature on the performance of a Pacific Northwest treatment wetland	1999
Sherrill Nelligan-Doran	Civil & Environmental Eng., MS	Evaluating the benefits and costs of the endangered species act on water supply systems in Puget Sound	1999
Miranda Maupin	Landscape Architecture, MLA	Cognitive models of salmon health and water management in the Puget Sound	1999
Laura Landauer	Civil Engineering, MSCE	Aquifer storage and recovery and its application to aquifer systems typical of the Puget Sound Region	1998
Jonathan La Marche	Civil Engineering, MSE	Forest roads effects on flood flows in the Deschutes River basin, Washington	1998
Craig Doberstein	Civil Engineering, MS	The effects of subsampling on the performance of macroinvertebrate biomonitoring efforts	1998
Daniel Schultz	Civil Engineering, MSCE	Non-thesis	1998
Tracy Chollak	Civil Engineering, MSCE	Guidelines for landscaping with compost-amended soil	1998
John Buffington	Geological Sciences, Ph.D.	The use of streambed texture to interpret physical and biological	1998

		conditions at watershed, reach, and subreach scales	
Tim Beechie	Forest Resources, Ph.D.	Rates and pathways of recovery for sediment supply and woody debris recruitment in northwestern Washington streams, and implications for salmonid habitat restoration	1998
Kurt Nelson	Forest Resources, MS	The influence of sediment supply and large woody debris on pool characteristics and habitat diversity	1998
Ute Gigler	Urban Design and Planning, MUP	Effectiveness of a public/private water resource monitoring framework : a case study of large-site developments in King County, Washington	1998
Jason Fabritz	Civil Engineering, Ph.D.	withdrawn	
Robin Kirschbaum	Civil Engineering, MSCE	An evaluation of the effects of anthropogenic activity on streamflow in the Columbia River Basin	1997
Dan Mathias	Civil Engineering, MSCE	Multiple objective planning in a municipal watershed	1997
Alexandra Wydzga	Civil Engineering, MS	he effects of urbanization and fine sediment deposition in Puget Sound lowland streams	1997
Sandra Salisbury	Landscape Architecture, MLA	Factors in visual perception of stream restorations	1997
Kari Paulson	Forest Resources, MS	Estimating changes in sediment supply due to forest practices : a sediment budget approach applied to the Skagit River Basin in northwestern Washington	1997
Matthew Brennan	Civil Engineering, MSCE	Storm water sampling from storm drains influenced by tides	1996
Catherine Cooper	Civil Engineering, MSCE	Hydrologic effects of urbanization on Puget Sound lowland streams	1996
Timothy Kurtz	Civil Engineering, MSCE	Modeling the hydrologic response of lawns on till with and without compost amendments	1996
Barbara A. Freeman	Landscape Architecture, MLA	Neighborhood as ecosystem : Cascade waterflow vision and guidelines case study	1996
Robert Chandler	Civil Engineering, Ph.D.	Improving urban stormwater runoff monitoring practices	1995
Stephen Dowling	Civil Engineering, MSCE	Non-thesis	1995
Lee Benda	Geological Sciences, Ph.D.	Stochastic geomorphology in a humid mountain landscape	1994
Matthew D. O'Connor	Forest Resources, Ph.D.	Sediment transport in steep tributary streams and the influence of large organic debris	1994
Robert Salazar	Forest Resources,	Impacts of chronic inputs of fine	1994

	MS	grain sediment to a small mountain watershed, Summit County, Colorado	
Robert Chandler	Civil Engineering, MSCE	Modeling and nonpoint source pollution loading estimates in surface water management	1993
Carolyn S. Coho	Civil Engineering, MSE	Dam-break floods in low order mountain channels of the Pacific Northwest	1993
Brian L. Taylor	Civil Engineering, MSCE	The influence of wetland and watershed morphological characteristics on wetland hydrology and relationships to wetland vegetation communities	1993
Cynthia A. Carlstad	Geology MS, Western WA Univ.	Late Pleistocene deglaciation history at Point Partridge, central Whidbey Island, Washington	1992
Adelaide C. Johnson	Forest Resources, MS	Effects of landslide-dam-break floods on channel morphology	1991
Bruce A. Stoker	Civil Engineering, MSCE	Determination of hydrologic process zones for urban stormwater management /	1988
Bethany Plewe	Forest Resources, MS	withdrawn	—
Amber Pauley-Cawley	Forest Resources, MS	withdrawn	—
Anne Weekes	Forest Resources, Ph.D.	withdrawn	—
Martha Bean	Forest Resources, Ph.D.	withdrawn	—
Heungkook Lim	Civil & Environmental Eng., Ph.D.	withdrawn	—

Membership on Ph.D. reading committees:

Gregory Williams	Civil & Environmental Engineering, Ph.D.	2006
Karen Gran	Earth and Space Sciences, Ph.D.	2005
Jennifer Adams	Civil & Environmental Engineering, Ph.D.	2003
Tim Brown	Civil & Environmental Engineering, Ph.D.	2003
Stephanie Kampf	Civil & Environmental Engineering, Ph.D.	2003
Darla Elswick	Civil Engineering, Ph.D.	1997

Other graduate student supervision:

Pamela Boyle	Visiting MSCE student (University of MD)	2001-2002

5. Research Activities

5.1. Sponsored academic research (total $7,511,137 in 67 awards 1995–2006)

Agency	Title	Total Award	Role	Funding Status	Start/End Dates

City of Seattle	Geology of the City of Seattle	$55,000	PI	Completed	1/06–12/06
King County	King County geology	$20,000	PI	Completed	1/06–12/06
US Geological Survey, National Earthquake Hazards Program	The Quaternary Geologic Framework for the Greater Seattle Area	$225,000	Lead PI	Funded, active	5/06–12/08
City of Kirkland	Geology of Kirkland	$45,000	PI	Completed	3/06–12/06
King County Department of Natural Resources	Groundwater Characterization, Issaquah and Bear Creek Valley Areas	$108,564	Co-PI	Completed	6/05–3/07
National Science Foundation	Landscape Self-Organization by Ice Sheets	$597,410	Co-PI	Completed	1/04–12/06
US Geological Survey, National Earthquake Hazards Program	The Quaternary Geologic Framework for the City of Seattle	$75,000	Co-PI	Completed	1/05–12/05
City of Mercer Island	Geology of Mercer Island	$50,000	PI	Completed	5/04–12/04
City of Bainbridge Island	Geology of Bainbridge Island	$76,000	PI	Completed	4/04–12/04
King County Department of Natural Resources	Groundwater characterization of Vashon-Maury Island	$75,000	PI	Completed	4/04–12/04
King County	Geologic Database and Interpretations for Regional Wastewater Planning—Phase III	$100,000	PI	Completed	1/04–12/04
King Co., Snohomish Co., Pierce Co., Spokane Co., Kitsap Co., Pierce County; cities of Olympia, Seattle, Everett	PI Support, Center for Water and Watershed Studies	$45,000	PI	Completed	1/04–12/04
US Geological Survey, National Earthquake Hazards Program	The Quaternary Geologic Framework for the City of Seattle	$100,000	PI	Completed	1/04–12/04
U.S. Geological Survey	Web-Site Development, USGS Central/Eastern US Earthquake Hazard Program	$10,433	PI	Completed	10/03–12/03
Seattle Monorail Project	Geologic Support, Seattle Monorail Project	$63,000	PI	Completed	7/03–6/04
U. S. Geological Survey	Geologic Mapping of the Tahuya Peninsula,	$13,050	PI	Completed	4/03–3/04

	WA				
US Geological Survey, National Earthquake Hazards Program	The Quaternary Geologic Framework for the City of Seattle	$125,000	PI	Completed	1/03–12/03
King Co., Snohomish Co., Pierce Co., Spokane Co., Kitsap Co., Pierce County; cities of Olympia, Seattle, Everett	PI Support, Center for Water and Watershed Studies	$50,000	PI	Completed	1/03–12/03
Russell Foundation, Washington State University	Low-Impact Development Monitoring	$23,000	PI	Completed	9/02–8/03
City of Seattle, Landau Associates	Cedar Moraine Studies for City of Seattle	$7,000	PI	Completed	12/02–12/03
City of Seattle	High Point Flow and Water Quality Monitoring (Phase 1)	$125,968	Co-PI	Completed	9/02–8/04
King County	Scientific Review Panel, Normative Flow	$142,000	PI	Completed	1/02–12/04
City of Bothell	Critical Areas mapping, City of Bothell	$16,000	PI	Completed	1/02–12/02
King Co., Snohomish Co., Spokane Co., Kitsap Co., Pierce County; city of Olympia	PI Support, Center for Urban Water Resources Management	$30,000	PI	Completed	1/02–12/02
King County	Geologic Database and Interpretations for Regional Wastewater Planning—Phase II	$676,000	PI	Completed	8/01–12/03
USEPA, Puget Sound Water Quality Action Team	Alternative Futures Analysis for Watershed Protection	$60,000	PI	Completed	5/01–6/04
US Geological Survey, National Earthquake Hazards Program	The Quaternary Geologic Framework for the City of Seattle	$340,000	PI	Completed	1/01–12/02
US Environmental Protection Agency	Application of Remotely-Sensed Data to Regional Analysis and Assessment of Stream Temperature	$998,395	Co-PI	Completed	4/00–3/03
National Science	The Impact of Urban	$424,970	Co-PI	Completed	9/99–3/03

Foundation	Patterns on Ecosystem Dynamics				
City of Seattle Public Utilities	Instream gravel management of Seattle's urban creeks	$103,880	Lead PI	Completed	6/00–6/02
King County	Geologic Database and Interpretations for Regional Wastewater Planning—Phase I	$75,000	PI	Completed	5/01–12/01
King Co., Snohomish Co., Spokane Co., Kitsap Co., Pierce County; cities of Olympia, Kent, Issaquah, Seattle	PI Support, Center for Urban Water Resources Management	$35,000	PI	Completed	1/01–12/01
Department of Ecology	Land-Cover Change Analysis for the Puget Lowland	$30,000	Co-PI	Completed	4/01–12/01
Department of Ecology	Monitoring Elements for Phase I Municipal Stormwater General Permits	$8,500	Co-PI	Completed	5/01–6/01
King Co., Snohomish Co., Spokane Co., Kitsap Co., Pierce County; cities of Kent, Issaquah, Seattle	PI Support, Center for Urban Water Resources Management	$49,000	PI	Completed	1/00–12/00
City of Seattle	Evaluation of Ultra-Urban Stormwater Management Strategies	$70,000	Co-PI	Completed	8/99–7/00
King Co., Snohomish Co., Spokane Co., Kitsap Co., Pierce County; cities of Olympia, Kent, Issaquah, Seattle	PI Support, Center for Urban Water Resources Management	$35,000	PI	Completed	1/99–12/99
U. S. Geological Survey	Puget Lowland Urban Corridor Geology	$45,000	PI	Completed	12/98–9/00
City of Seattle	Geology of the City of Seattle	$330,000	PI	Completed	8/99–12/03
US Geological Survey, National Earthquake Hazards Program	The Quaternary Geologic Framework for the City of Seattle	$140,000	PI	Completed	11/98–10/99
King Co. Water and Land Re-sources Division	Stream Monitoring, Urban Planned Developments	$390,000	PI	Completed	1/98–12/01
University of Washington—	Automated Land-Cover Classification	$9,284	Lead PI	Completed	8/98–6/99

PRISM	from LANDSAT Imagery				
City of Bellevue	Urban Stream Monitoring	$10,000	PI	Completed	8/98–12/98
USEPA, Office of Water	Conducting watershed mgmt. training—the "Watershed Academy"	$120,000	Lead PI	Completed	4/98–9/00
King Co., Snohomish Co., Spokane Co., Kitsap Co.; cities of Olympia, Kent, Issaquah	PI Support, Center for Urban Water Resources Management	$36,000	PI	Completed	1/98–12/98
King Co. Water and Land Re-sources Division	Stormwater Management Facilities Evaluation	$54,000	PI	Completed	9/96–8/98
City of Issaquah; King Co.	Issaquah Creek Sediment Budget	$35,000	PI	Completed	9/97–6/99
U. S. Geological Survey—EDMAP	Central Pierce County Geologic Mapping	$17,500	PI	Completed	9/97–9/98
U. S. Geological Survey	Puget Lowland Urban Corridor Geology and Geologic Hazards	$20,000	PI	Completed	6/96–9/98
USEPA	Rehabilitation of Urban Streams	$663,000	Co-PI	Completed	4/97–12/00
Battelle PNW National Lab	Hydrogeology Seminar—Tacoma area	$2,600	PI	Completed	6/98–7/98
Washington HEC Board	Review of Bothell Campus stream/ wetland restoration	$3,000	Lead PI	Completed	4/98–6/98
City of Mercer Island	"Basin 6" sediment analysis	$3,000	PI	Completed	11/97–12/97
Water Environ-ment Research Foundation	Stormwater Environmental Indicators	$161,283	PI	Approved by sponsor Project lost during contract negotiations between UW and WERF	9/97–8/99
City of Seattle, King Co.	Hydrogeologic Pathways, Duwamish Corridor	$47,000	PI	Completed	3/97–7/98
Snohomish Co.	Landslide Inventory and Hazard Mapping	$2,000	PI	Completed	3/97–6/97
Snohomish Co.	Watershed Analysis and Geologic Hazard Mapping	$2,500	PI	Completed	3/97–9/97
Center for Streamside Studies, College of	Graduate Student Support (watershed-related projects)	$15,000	PI	Completed	3/97–6/97

Forest Resources, UW					
King Co., Snohomish Co., Spokane Co., Pierce Co., Kitsap Co.; cities of Olympia, Kent, Everett, Seattle	PI Support, Center for Urban Water Resources Management	$49,500	PI	Completed	1/97–12/97
Natural Resources Conservation Service (USDA)	Clackamas County Watershed Assess-ment and Environ-mental Indicators	$40,000	PI	Completed	10/96–9/97
City of Bellevue, King Co., WSDOE	Monitoring of Eastgate Detention Ponds for Phosphorus Reduction	$38,000	PI	Completed	9/96–9/97
UW Capital Facilities	Wetland and Stream-Restoration Review, UW Bothell Campus	$19,000	PI	Completed	6/96–12/97
King Co. Surface Water Manage-ment Division	King County Water-shed Support and Technical Assist.	$225,000	PI	Completed	5/96–12/01
City of Seattle	Steep Slope Tech-nical Policy Analysis	$1,800	PI	Completed	4/96–6/96
Snohomish Co., Spokane Co.	Operational Support, Center for Urban Water Resources Management	$49,500	PI	Completed	1/96–12/96
King Co.	Maintenance of Biofiltration Swales	$38,000	PI	Completed	12/95–6/97
City of Olympia, King Co., WSDOE	Infiltrative Parking Surface Demo	$35,000	PI	Completed	9/95–12/96
King Co.	Improved Maintenance of Stormwater Detention Ponds	$31,000	PI	Completed	9/95–6/96
USEPA Region X	Watershed Restoration Training	$20,000	PI	Completed	9/95–9/96

6. Documentation of Teaching Effectiveness

6.1. Courses taught

Course Number/ID	Title	Year/ Quarter taught	Credit hours	Enroll-ment
ESS 426	Fluvial Geomorphology	Sp ‘06	5	22
ESS 590D	Fluvial geomorphology reading seminar	Sp ‘04	2	3
GEOL 412	Fluvial	Sp ‘02	5	16

	Geomorphology			
GEOL 412	Fluvial Geomorphology	Sp ‘01	5	22
LARCH 523	Urban Stream Restoration (co-instructor)	Sp ’00	5	Not availa-ble
LARCH 523	Urban Stream Restoration (co-instructor)	Sp ’99	5	20
LARCH 523	Urban Stream Restoration (co-instructor)	Sp ’98	5	Not availa-ble
LARCH 523	Urban Stream Restoration (co-instructor)	Sp. ’97	5	22
GEOL 313	Environmental Geology	F ‘96	4	40 (appx.)
LARCH 523	Urban Stream Restoration (co-instructor)	Sp ’96	5	19
GEOL 313	Environmental Geology	F ‘95	4	Not availa-ble
GEOL 313	Environmental Geology	F ‘94	4	N/A
LARCH 523	Urban Stream Restoration (co-instructor)	F ’94	5	N/A
GEOL 313	Environmental Geology	F ‘93	4	N/A
GEOL 313	Environmental Geology	F ‘92	4	N/A
CIVE 499	Urban Watershed Analysis (co-instructor)	F ‘91	3	N/A
GEOL 313	Environmental Geology	F ‘91	4	N/A
GEOL 313	Environmental Geology	F ‘89	4	N/A
GEOL 412	Fluvial Geomorphology	Sp ‘89	5	N/A
GEOL 313	Environmental Geology	F ‘88	4	N/A
GEOL 313	Environmental Geology	F ‘87	4	N/A
GEOL 313	Environmental Geology	F ‘86	4	N/A
GEOL 313	Environmental Geology	F ‘85	4	N/A
GEOL 412	Fluvial Geomorphology	Sp ‘85	5	N/A
GEOL 313	Environmental Geology	F ‘84	4	N/A

Independent study	**Year/ Quarter**	**Credit**

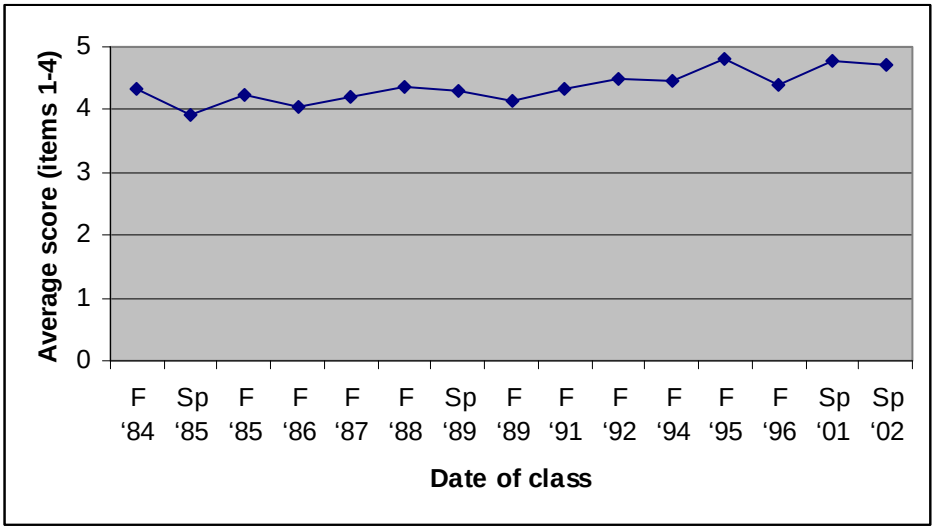
supervision (4XX = U.G., 600/700 = MS, 800 = Ph.D.)		hours
ESS 800	W ‘07	2
CEE 800, ESS 800	F ‘06	2-10
CEE 800	Sp ‘06	2
CEE 800, ESS 800	Sp ‘05	2-10
ESS 800	F ‘04	2-10
CEE 700 & 800, ESS 800	Sp ‘04	2-10
CEE 700 & 800, ESS 800	W ‘04	2-10
ESS 499 (UG indep. study)	F ‘03	3
CEE 700 & 800, ESS 800	F ‘03	2-10
CEE 700 & 800, ESS 800	Sp ‘03	2-10
CEE 700 & 800, ESS 800	W ‘03	2-10
CEE 700 & 800, ESS 800	F ‘02	2-10
CEE 700 & 800, GEOL 800	Sp ‘02	2-10
CEE 700 & 800, GEOL 800	W ‘02	2-10
CEE 700 & 800, GEOL 800	F ‘01	2-10
CEE 700 & 800, GEOL 800	Sp ‘01	2-10
CEE 700 & 800, GEOL 800	W ‘01	2-10
CEE 700 & 800, GEOL 800	F ‘00	2-10
CIVE 700 & 800	Sp ’00	2-10
CEE 700 & 800, GEOL 800	W ‘00	2-10
CIVE 700 & 800	F ’99	2-10
CEE 700 & 800, GEOL 700	Sp ’99	2-10
CEE 700 & 800, GEOL 700	W ‘99	2-10
CEE 700 & 800, GEOL 700	F ’98	2-10
CIVE 700	Su ‘98	10
CEE 700 & 800, GEOL 700	Sp ’98	2-10
CEE 700 & 800, GEOL 700	W ‘98	2-10
CEWA 600	W ‘98	3
CEE 700 & 800, GEOL 700	F ‘97	2-10
CIVE 499	W ‘97	1
CIVE 600	W ‘97	3
CIVE 600 & 700	F ‘96	2-10
CIVE 600 & 700	Sp ‘96	2-10
CIVE 499	Sp ‘96	1
CIVE 600 & 700	W ‘96	2-10
CIVE 499	W ‘96	1

6.2. Summary of all available teaching evaluations

Course Number/ID	Title	Year/ Quarter taught	Credit hours	Enroll-ment	Evaluation IAS-Report (avg. of items 1-4; 1 [low] to 5 [high])
ESS 426	Fluvial Geomorphology	Sp. ‘06	5	22	4.6
GEOL 412	Fluvial Geomorphology	Sp ‘02	5	16	4.7
GEOL 412	Fluvial Geomorphology	Sp ‘01	5	22	4.78
GEOL 313	Environmental Geology	F ‘96	4	40 (appx.)	4.4

GEOL 313	Environmental Geology	F '95	4	N/A	4.8
GEOL 313	Environmental Geology	F '94	4	N/A	4.46
GEOL 313	Environmental Geology	F '93	4	N/A	N/A (alternate form)
GEOL 313	Environmental Geology	F '92	4	N/A	4.5
GEOL 313	Environmental Geology	F '91	4	N/A	4.33
GEOL 313	Environmental Geology	F '89	4	N/A	4.14
GEOL 412	Fluvial Geomorphology	Sp '89	5	N/A	4.31
GEOL 313	Environmental Geology	F '88	4	N/A	4.36
GEOL 313	Environmental Geology	F '87	4	N/A	4.20
GEOL 313	Environmental Geology	F '86	4	N/A	4.06
GEOL 313	Environmental Geology	F '85	4	N/A	4.22
GEOL 412	Fluvial Geomorphology	Sp '85	5	N/A	3.91
GEOL 313	Environmental Geology	F '84	4	N/A	4.34

Summary trend of evaluations:



6.3. Supervision of undergraduate independent study

Jennifer Glass	internship with Snohomish Co.—General Studies 350: Earth & Space Sciences and Oceanography departments	2004
Ryan Murphy	undergraduate project, Earth & Space Sciences	2003

Brent Goehring	undergraduate project, Earth & Space Sciences	2003
Andrea Jones	undergraduate project, Space Grant program	2001
Karen DuBose	undergraduate project, STEM Internship program	2000
Sean King	undergraduate project, Space Grant program	2000
Megan Holcomb	undergraduate project, Space Grant program	1999
Nikki Burr	undergraduate project, Space Grant program	1999
Joan Blainey	undergraduate project, Geological Sciences	1997
Lisa Steubing	undergraduate project, Geological Sciences	1997
William Sullivan	undergraduate project, Geological Sciences	1996

6.4. Other teaching experience

American Fisheries Society, Western Division meeting, workshop on Stream Restoration: Integrating Practical Approaches, invited speaker, *Rehabilitation of urban streams—philosophy and approaches*, Portland, OR, May 8, 2008.

Stormcom Workshop and Exposition, regional conference, co-instructor for *Monitoring* and *Flow Control* tracks, SeaTac, WA, December 1, 2006.

The Center for Watershed Protection, *Watershed Protection Institute*, co-lead organizer and instructor, Bainbridge Island, WA, September 13-17, 2004.

The Ohio State University, STREAMS Channel Protection and Restoration Conference, *Understanding and preventing urbanization impacts of stream health*, October 6, 2003.

The Center for Watershed Protection, *Watershed Protection Institute*, invited guest instructor, Baltimore, MD, September 22-25, 2003.

U. S. Environmental Protection Agency, short course on *Fluvial Geomorphology,* co-lead instructor, June 11–14, 2001, Seattle, WA.

U. S. Environmental Protection Agency, The Watershed Academy: *Working at a Watershed Level*: Co-Lead Instructor, September 20–24, 1999, University of Washington campus.

Co-Convener, *Seattle Urban Geologic Hazards Workshop*: sponsored by U. S. Geological Survey and Center for Urban Water Resources Management, University of Washington campus, February 23–25, 1999.

U. S. Environmental Protection Agency, The Watershed Academy: *Working at a Watershed Level*: Co-Lead Instructor, September 21–25, 1998, University of Washington campus.

University of Washington—Center for Urban Horticulture, Continuing Education:

Managing for Slope Stability: Geology and Hydrology Review (1.5-hour lectures) Jan. ‘96, Mar. ‘98

University of Washington-Engineering Professional Programs (12-hour courses):

Engineering and Quaternary Geology of the Puget Lowland (Co-Instructor of 2), April ’99, Sept. ’00, May ’03.

Alternative On-site Stormwater Management (Co-Instructor of 3), Sept. ’97, Mar. ’99.

Geology and Geomorphology of Stream Channels (Lead Instructor), Mar. ’96, Jan. ‘97, Nov. ’98, Feb. ’00, Sept. ’01, Mar. ’03, May ‘04.
Fundamentals of Urban Surface Water Management (Co-Instructor of 2), Sept. ’95, Nov. ’96, Jan. ’98, Oct. ’99, March ’01, Sept. ‘02.

7. Service

7.1. University service

Chair, Proposal to establish a graduate degree program in River Restoration, 2005-2006.

Member, Technical Advisory Group for the Puget Sound Center for Urban Bay Studies (UW Tacoma), 2004-2006.

Chair, search committee for Research Professor and Director, Center for Water and Watershed Studies, 2004.

Reviewer, Olympic National Research Center, reviews of research proposals, 2004.

Member, Financial Desktop's PI Advisory Team, 2003-2006.

Search committee for Director, Center for Streamside Studies (Colleges of Fisheries and Forest Resources), 1997.

Research Royalty Fund, reviewer, 1997.

University of Washington Bothell Campus, Shortlist Committee for Architectural Selection, University of Washington, June 1996.

7.2. Professional society and other service

Session organizer and chair, River Restoration Northwest, *Guiding Salmon Restoration through Digital Models that Link Landscape Attributes with Salmon Populations*, Skamania, WA, February 5, 2009.

Session organizer and moderator, Southern California Wetlands Recovery Symposium, *Watershed Restoration: A Systems Perspective*, San Diego, CA, May 7, 2008.

Session moderator, Headwaters to Oceans Annual Meeting (California Coastal Coalition and the Southern California Wetlands Recovery Project), Long Beach, CA, October 23–25, 2007.

Session moderator, Northwest Geological Society 20th Anniversary Symposium, Seattle, WA, October 13, 2007.

Senior Editor, *Quaternary Research* (Elsevier Press)

General Chair, Geological Society of America Annual Meeting (7000 attendees), Seattle, WA, November 1-4, 2003.

Moderator, Instream Flow Workshop, University of Washington, May 28-29, 2003.

Session moderator, Society for Ecological Restoration, Symposium on Stream Restoration, April 5, 2001.

Member, Pacific Northwest Advance National Seismic System Advisory Committee, 2001–2002.

Session moderator, Puget Sound Research Symposium ’01, “Stormwater,” February 14, 2001.

Co-chair, 3rd Symposium on the Hydrogeology of Washington State, “Forum on the Quaternary Geology of the Puget Lowland,” October 17, 2000.

Session chair, 3rd Symposium on the Hydrogeology of Washington State, “Surface water-groundwater interactions,” October 18, 2000.

Co-field trip leader, Association of Engineering Geologists, “Geology of the Seattle-Tacoma area,” June 17–18, 2000.

Co-chair, Geological Society of America, Cordilleran Section Meeting, “Symposium on the Quaternary Geology of the Puget Lowland, April 2000.

Moderator, American Water Resources Association, Annual Meeting, plenary session on “Implementing Regional Endangered Species Act Programs—What’s Worked and What Hasn’t,” Seattle, WA, December 8, 1999.

Co-field trip leader, American Water Resources Association, Annual Meeting, Stormwater Management Facilities and Stream Rehabilitation Projects, Seattle area, WA, December 5, 1999.

Moderator, “Soils for Salmon” conferences: March 31, 1999 (Mt. Vernon); October 6, 1999 (Seattle); February 29, 2000 (Vancouver, WA).

Co-field trip leader, Northwest Geology Society, “Geology of the Seattle-Tacoma area,” June 26–27, 1999.

Co-chair, Field trip leader, 2nd Symposium on the Hydrogeology of Washington State, “Tacoma-area hydrogeology and stratigraphy”, sponsored by the Washington State Department of Ecology, August 25–27, 1997.

American Geophysical Union:
Co-chair, American Geophysical Union Annual Meeting Special Sessions:
- “Impacts of Urbanization on Hydrologic Processes and Regional Climate,” December 2007
- “Scientific Basis for Stream Restoration,” May 2000
- “Fluvial and Hillslope Geomorphology,” December 2000
- “Fluvial and Hillslope Geomorphology,” December 1999
- “Watershed Restoration,” May 1997

Policy Science Committee member, 1992–1996

American Society of Civil Engineers, symposium co-chair, “Urban Water Resources Management,” Water Resources and Management Division annual meeting, August 1999, Seattle WA.

Society for Ecological Restoration, symposium chair, “Urban Watershed Restoration,” annual meeting, September 29–October 1, 1998, Tukwila, Washington.

7.3. Community Service

Member, expert panel on “Impacts from urban growth—hydromodification design of new development,” Santa Barbara County, Project Clean Water, January 15th, 2009.

Member, expert panel to develop guidance protection of marine shorelines, Washington SeaGrant, University of Washington, Seattle, November 19, 2008.

Invited speaker, Ventura County Wetlands Recovery Task Force, Ventura, CA, “Tectonic uplift, hillslope erosion, and the impacts of fire in the Santa Paula & Sespe watersheds,” November 13, 2008.

Invited speaker, Kirkland Kiwanis club, monthly speaker, “The Landscape and Geology of the Puget Lowland,” February 1, 2007.

Invited speaker, East Baton Rouge Urban Watershed Protection Workshop, “Watershed Protection Principles—Suggestions and Caveats from the Pacific Northwest,” March 9, 2006.

Invited speaker, Magnolia Community Club, “Geology and Geologic Hazards of Magnolia,” February 9, 2006.

Chair, independent science panel review team of the Puget Sound Shared Strategy’s pilot project to evaluate instream flows and their consequences for endangered salmon, 2005.

Consultant, Washington Department of Transportation, Value engineering reviewer for stormwater management on the I-405 corridor, 2004.

Invited speaker, Association of Engineering Geologists, Washington Chapter, “New Findings on the Geology of the Puget Lowland,” May 20, 2004.

Member, Puget Sound Action Team, Low Impact Development Guidance Manual Advisory Committee, 2003-2004.

Invited speaker, Seattle Aquarium Beach Naturalist Program, “Shoreline Geology and Puget Sound Landscapes,” Seattle, WA, May 4, 2004.

Invited reviewer, Washington State Department of Transportation Environmental Mitigation Program, May 2003.

Invited panel member, Governor’s Independent Science Panel review of WADOE’s draft Stormwater Manual, February 2003.

Invited speaker, Low-Impact Development workshop, Puget Sound Water Quality Action Team, Port Townsend, WA, November 20, 2002.

Invited speaker, Seattle Aquarium Beach Naturalist Program, “Puget Sound Geology,” Seattle, WA, May 7, 2002.

Chair, King County Science Review Team for normative flows to protect endangered species, 2002–2004.

City of Bellevue, Geomorphic and hydrologic assessment and management alternatives for Kelsey Creek, 2002–2003.

Member, City of Portland, Independent Science Team for Endangered Species Act guidance, 2001–2003.

Invited speaker, Stilly-Snohomish Task Force, “Geology and Salmon,” Everett, WA, October 11, 2000.

Invited panelist, NMFS Tri-County workshop on land-use controls and endangered species act criteria, Seattle, September 28, 2000.

Invited speaker, NW Ecobuilding Guild, “Urban stormwater and permeable pavement,” Seattle, June 29, 2000

Member, Governor’s State Salmon Team, Urban Stormwater Group, 1998–2001.

Member and elected co-chairman, Citizens Advisory Panel on Creeks, Drainage, and Wastewater: City of Seattle, Public Utilities Department, 1998–2000

Member, Washington State Geological Mapping Advisory Commission (Department of Natural Resources), 1995–2002.

Invited speaker, City of Bothell Planning Commission, Critical Areas regulations revisions, Bothell, WA, July 22, 1998.

Invited reviewer, King County Department of Natural Resources and City of Carnation, Tolt River levee modifications, July 1998.

Invited speaker and panelist, City of Seattle Department of Public Utilities, Staff and public workshop on “Landslides in Seattle,” Seattle, WA, December 5, 1997.

Invited speaker and panelist, Henderson Inlet Watershed Council, Rehabilitation potential of Woodland Creek, Lacey, Washington, November 12, 1997.

Consultant, Muckleshoot Indian Tribe, evaluation of potential development impacts to Crisp Creek watershed, 1997.

Consultant, U.S. Geological Survey, miscellaneous geological investigations, 1996–1997.

Consultant, City of Seattle, Critical Areas designation and criteria for steep-slope areas, 1996.

Featured speaker: *Factors affecting flooding—urban development*: Lewis County, Community Meeting on Flood Issues in the Chehalis River Basin, Centrailia College, Centrailia, Washington, May 1, 1996.

Consultant, City of Tacoma, Flood causes on Leach Creek, 1993, 1996–1997.

7.4. National service

External review panel member, University of Maryland Baltimore County, graduate program in "Water in the Urban Environment" (2009).

National Research Council, National Academies, committee member, "Urban Stormwater Management in the United States" (2007-2008).

National Science and Engineering Research Council (Canada), mail reviewer.

National Science Foundation, Division of Earth Science, Mail Review Panelist.

National Science Foundation –Environmental Protection Agency NCERQA "Waters and Watersheds" program, mail reviewer.

Swiss National Science Foundation, mail reviewer.

U. S. General Accounting Office, Evaluation of National Water-Quality Policy, Delphi review panelist, 2001.

U.S. Geological Survey, National Educational Mapping Program, Panel member 1997–2000.

U.S. Geological Survey, National Earthquake Hazard Reduction Program 1992, 1993, 1996.

7.5. All other service

Faculty sponsor, Student Chapter of the American Water Resources Association, 1997–2004 (national award, AWRA Outstanding Student Chapter for 2001)

Cynthia Carlstad, LHG

Senior Scientist

Cynthia Carlstad is a hydrogeologist with over 20 years of professional experience in flood hazard, stormwater and watershed management, and in assisting clients develop strategies to meet their regulatory obligations. She has been involved in multidisciplinary watershed planning for most of her career, including those driven by the Watershed Management Act, water quantity issues; flood control; water quality, including control of non-point source pollution; water supply; forestland management; and superfund remediation issues. All of these have entailed facilitating committee-based planning, working with diverse interest groups, and balancing the needs of all stakeholders.

She has worked with numerous communities in implementing stormwater programs. Her involvement has included conducting stormwater program evaluations, drafting stormwater ordinances, developing technical manuals, preparing policies for acceptable stormwater quality control measures, and managing stormwater sampling programs.

Cynthia is experienced in the area of public education and participation. In addition to her background teaching hydrology and environmental science at the college level, she has conducted training sessions for clients on stormwater sampling and been involved with many citizen action committees throughout watershed planning programs.

EXPERIENCE

Flood Hazard Management

Comprehensive Flood Hazard Management Plan, Skagit County, WA, 2009
Skagit County
Project Manager. Developing County-wide flood hazard reduction plan in coordination with North Cascades National Park, U.S. Army Corps of Engineers, three tribes, two major hydropower project owners, salmon recovery and farmland preservation interests, and County and City staff. Facilitating interagency Advisory Committee and coordinating with three Technical Committees to ensure broad public and intergovernmental support.

Comprehensive Flood Hazard Management Plan and Channel Migration Zone Study, Yakima County, WA, 2000
Yakima County
Developed solutions for flood hazard issues along a 13-mile reach of the lower Naches River above the City of Yakima. Specific issues include delineating channel migration zones along this very actively migrating river channel, addressing affects of upstream reservoir management on the geomorphic and sediment transport function of the river system, application of emerging geocomputation technologies in developing predictive tools for watershed management, coordination of a citizen's advisory committee, and coordination/collaboration with related studies underway by the U.S. Bureau of Reclamation, Yakama Indian Nation, Central Washington University, and the U.S. Army Corps of Engineers.

Comprehensive Flood Hazard Management Plan, Yelm, WA, 2000
City of Yelm
Managed development of Plan to direct flood hazard mitigation projects for Yelm Creek, which flows through the middle of the City of Yelm. Major issues

Project Role:
Hydrogeologist

Education:
M.S., Geology, Western Washington University, 1992

B.S., Geology, Western Washington University, 1983

Registration/Certification:
Licensed Hydrogeologist, Certification No. 1890

Professional Affiliations:
American Water Resources Association

Water Environment Federation

Northwest Geological Society

Washington Hydrologic Society

Office:
Seattle, Washington

Years of Experience:
20

Years with Tetra Tech:
Twelve

Areas of Experience:
Flood Hazard Management

Watershed and Stormwater Management

Regulatory Strategy and Compliance

included balancing the needs of flood mitigation with salmon recovery efforts, addressing low summer baseflows in the stream, sensitivity to property rights, limitations of the small city government's ability to fund large capital improvement projects, and protection of the shallow groundwater aquifer. Recommendations focused on multi-objective management tools that allow the City to access nontraditional flood control funding sources.

Channel Modification Feasibility Study, Puyallup, WA
City of Puyallup
Conducted a feasibility study of the effectiveness of channel enlargement on alleviating flooding from a tributary stream to the Puyallup River. The study employed HEC-RAS modeling to predict flood levels under several channel modification scenarios. A discussion about the regulatory process, project design and construction issues, and preliminary cost estimates was also provided.

Flood Control Assistance Account Applications, Yakima County, WA
Yakima County
Under the Washington Department of Ecology grant program for flood projects, prepared five separate grant applications for flood hazard projects in Yakima County. The scope of these projects included three Comprehensive Flood Hazard Management Plans, a flood warning system for river sections below the Bumping Lake Dam, and construction of a barb in the Naches River to protect a section of levee and irrigation diversion intake. In a very competitive application process, two applications were funded, and two were listed for "award if additional funding comes available".

Comprehensive Flood Hazard Management Plan, Benton County, WA, 2000
Benton County
Prepared "existing conditions" report for this flood hazard planning effort. Researched and documented sources and effects of historical flooding; previous investigations related to flooding; and local, state and federal regulations that pertain to flooding in Benton County; and identified flood problem areas. The "existing conditions" report will provide the basis for developing solutions for flood hazard management in Benton County.

Comprehensive Flood Hazard Management Plan, Mason County, WA, 1995
Mason County
Conducted technical analysis supporting flood hazard reduction planning for the Skokomish River basin. The success of flood hazard reduction strategies in this basin required the cooperation of diverse interest groups, including federal, state, and local residents. These groups were brought together to actively participate in plan development. Technical analyses included the evaluation of historical forest management, land-use conversions in the floodplain, effects of sea-level changes and land subsidence on the river delta, and geomorphological and sediment transport changes within the river system.

Comprehensive Flood Hazard Management Plan, Lewis County, WA, 1994
Lewis County, Public Services Department
Developed flood hazard management plan through the Washington Department of Ecology Flood Control Assistance Account Program (FCAAP). Work included identification of regional drainage basins, development of goals and objectives for flood control work, evaluation of instream and alternative nonstructural flood control measures, assessment of environmental impacts, prioritization of alternative solutions, and preparation of recommendations for the implementation plan. The 1994 CFHMP was comprehensive, but following the standards of that time, was very descriptive in nature.

Stormwater Management

Comprehensive Stormwater Plan, Snoqualmie, WA, current (2009).
City of Snoqualmie
Conducting NPDES Phase II Gap Analysis for Snoqualmie, a rapidly growing city likely to enter the NPDES Phase II permit program in 2012. Evaluated existing municipal code and provided recommended modifications for compliance with permit requirements. Audited existing City programs for compliance with NPDES Phase II required program elements: Stormwater Management Plan, Public Education and Outreach, Public Involvement, Illicit Discharge Detection and Elimination, Runoff Control for New Development, Redevelopment, and Construction Sites, Municipal Pollution Prevention, and Operation and Maintenance. Prioritized and conducted

stormwater system inventory to provide necessary system data for City while proactively meeting NPDES Phase II permit requirement.

Glenrose Basin Design Engineering Services, Spokane County, WA, current
Spokane County
Project Manager. The Glenrose Basin Project includes two phases of work. Phase One focuses on the Browne's Mountain sub-basin. The work provides for the construction of a regional stormwater facility, including a 0.4-acre sedimentation pond, a 1.9-acre infiltration pond, two concrete spillway weirs, two 72-inch-diameter Type 2 catch basin flow control structures, 590-LF of-8 inch PVC gravity sanitary sewer pipe, two sanitary sewer manholes, appurtenances, general site grading, landscaping, and site amenities. Depending upon the outcome of the Phase One efforts, it is anticipated that Phase Two will refine the location of the proposed facility sites and recommended stormwater facilities throughout the Glenrose Basin. The work in both phases includes developing and implementing a public involvement strategy to ensure that ideas from stakeholders and interested agencies are integrated into the final engineering/landscape designs.

NPDES Phase II Gap Analysis
City of Snoqualmie
Conducted review of city's NPDES Phase II status, and partial gap analysis for NPDES Phase II requirements as part of stormwater comprehensive plan. The City is currently not covered under NPDES Phase II, but is growing rapidly through planned unit developments, creating "old city-new city" challenges for city staff in providing infrastructure and regulatory oversight. Gap analysis included review of existing city code; storm system mapping and inventory; public education; and operations and maintenance programs; and identification of needed updates to be compliant with NPDES Phase II permit.

Stormwater Standards Manual Development, Juneau, AK, current (2009)
City and Borough of Juneau
Developed Juneau's first stormwater management manual for post–construction runoff from new development and redevelopment. Includes development of design storm for BMP/conveyance system sizing and identification/customization of BMPs suitable for use in Juneau's extreme climate. Assistance with process/procedures for implementation into regulation and municipal code. Manual development includes working through interdepartmental work group and presentation of draft standards at public meeting.

Stormwater Management Manual and Ordinance Development, Federal Way, WA, 1997
City of Federal Way
Prior to NPDES Phase II, all Puget Sound cities were required to develop stormwater programs with elements similar to NPDES Phase II. The core of these programs was development of a stormwater manual and adoption of a set of stormwater ordinances, encompassing stormwater management, operations and maintenance, and water quality. The ordinances must contain minimum requirements for development and redevelopment that are equivalent to those contained in the Washington Department of Ecology's model ordinances. A manual and set of three ordinances were developed, approved for equivalency with State requirements, and adopted by the City.

NPDES Phase II Gap Analysis
City of Oak Harbor
Completed gap analysis for NPDES Phase II requirements as part of stormwater comprehensive plan. Gap analysis included review of existing city code; storm system mapping and inventory; public education; and operations and maintenance programs; and identification of needed updates to be compliant with NPDES Phase II permit.

Stormwater Program Evaluation, Shoreline, WA
City of Shoreline
The Puget Sound Water Quality Management Plan required all local governments in the Puget Sound region to implement stormwater programs. These programs must be approved by Ecology. A set of tables was developed for Shoreline that compares Ecology-required elements of stormwater programs to the current status of those elements in Shoreline. This stormwater program evaluation fulfilled two Ecology requirements, the requirement for an equivalency review and the requirement for an implementation schedule for Shoreline's stormwater program.

Stormwater Program Evaluation (Update), Auburn, WA 2002
City of Auburn
Prior to NPDES Phase II, all local governments in the Puget Sound region were required to implement stormwater programs under the Puget Sound Water Quality Management Plan. This review addressed the adequacy of the City's stormwater program as measured against requirements under the Puget Sound Water Quality Management Plan, the 2001 Ecology Stormwater Technical Manual, and the Tri-County Endangered Species Act proposal. Current Auburn city code and program elements were evaluated against Ecology's requirements to determine areas where Auburn's current program is adequate and areas where additional program development is necessary. The results of this evaluation fulfilled Ecology's requirements for both an equivalency review of Auburn's stormwater program and development of an implementation schedule.

Surface Water Drainage Manual, Federal Way, WA,
City of Federal Way
Assisted the City of Federal Way in customizing the newly adopted King County Surface Water Design Manual for use in Federal Way. Facilitated the discussions of an interdepartmental group consisting of Federal Way Surface Water Management, Development Services, and Environmental Review staff in their review of the King County Manual. Based on the input from this group, an addendum to the manual was developed that describes deviations from the King County manual for development and redevelopment activities in Federal Way.

Review of Best Management Practices for Stormwater, Auburn, WA
City of Auburn
Prepared an assessment of the effectiveness of Best Management Practices (BMPs) available for use in an urban redevelopment setting. This assessment included a review of the latest experimental BMPs and recommendations for the appropriate use of specific BMPs in Auburn's downtown area.

Stormwater Program Evaluation, Mukilteo, WA
City of Mukilteo
Local governments in the Puget Sound region are required to implement basic and comprehensive stormwater programs. Conducted an evaluation of the adequacy of each of the required stormwater program components in Mukilteo and provided an action plan for improving areas that are currently inadequate. This program evaluation was integrated with development of a Comprehensive Surface Water Management Plan for Mukilteo, providing a coordinated set of recommendations for Mukilteo's stormwater needs.

Stormwater Program Evaluation, Auburn, WA
City of Auburn
Under the Puget Sound Water Quality Management Plan, all local governments in the Puget Sound region are required to implement basic and comprehensive stormwater programs. Current Auburn regulations and programs were evaluated against Ecology's requirements to determine areas where Auburn's current program is adequate and areas where additional program development is necessary. Equivalency tables were provided that summarized the results of the stormwater program evaluation; a prioritized action plan for stormwater program items found to be deficient was also prepared. The results of this evaluation fulfilled Ecology's requirements for both an equivalency review of Auburn's stormwater program and development of an implementation schedule.

Stormwater Sampling Program, Fort Lewis, Washington
U.S. Army
Designed and managed a stormwater sampling program to fulfill Fort Lewis's NPDES requirements for its permitted stormwater outfalls. The sampling program included preparation of a sampling plan detailing sample locations, techniques, sample analytes, and laboratory methods. Sample collection was accomplished by a rapidly-mobilized field team, and consisted of first-flush and flow-weighted composite samples for five stormwater outfalls.

Stormwater Pollution Prevention Plan, Goldsborough Dam, WA, 2000
US Army Corps of Engineers, Seattle District
Prepared a Stormwater Pollution Prevention Plan for construction activities associated with removing Goldsborough Dam. The Plan provided information related to stormwater management at the site during construction, including general policies, site layout, erosion and sediment control measures, mitigation of specific erosion problem areas, and control of non-sediment pollutants.

Stormwater Pollution Prevention Plans, Longview, WA
Port of Longview
Managed development of Stormwater Pollution Prevention Plans for the Port of Longview and four tenants. Scope of plans included drainage mapping, identification of potential pollution sources, and recommendations for Best Management Practices (BMPs) to address stormwater contamination.

Stormwater Pollution Prevention Plan, Tacoma, WA
Plum Creek Timber Company
Managed development of Stormwater Pollution Prevention Plan for a log sort yard on a site leased from the Port of Tacoma. Scope of plan included drainage mapping, identification of potential pollution sources, and recommendations for Best Management Practices (BMPs) to address stormwater contamination.

Stormwater Funding Evaluation, Hoquiam, WA
City of Hoquiam
Prepared an evaluation of the current surface water utility revenues in Hoquiam and the adequacy of those revenues in meeting surface water program needs. Provided a description of alternative funding structures.

Stormwater Funding Alternatives, Pacific County, WA
Prepared a summary of alternative methods for funding stormwater projects and programs. For each funding mechanism, this summary provided a description, steps needed to implement, types of projects that could be funded, and limitations.

Stormwater Monitoring Program, San Diego, CA
Solar Turbins, Inc.
Managed preparation and implementation of stormwater monitoring program, required by the State of California NPDES program, for three industrial facilities.

Watershed Management

Lower Spokane Watershed Planning (WRIA 54), Spokane County, WA, current
Spokane County
Project Manager. Assisting the Watershed Planning Unit (WRIA 54) on the Lower Spokane in development of its Watershed Management Plan. Five discrete tasks comprise this effort:

Phase 2, Level 1 Data Compilation and Assessment (completed in November 2006) **–** The assessment summarized water use and water rights data, watershed characteristics, hydrology and hydrogeology of the watershed, water quality data, and presented a generalized water balance. The Tetra Tech team delivered the draft and final Level 1 Technical Assessment within a 11-month timeframe – ten months earlier than the specified grant deadline.
Instream Flow Studies for WRIA 54 and Lower WRIA 57 (completed in June 2007) – This three-step task included facilitated Instream Flow Technical Team workshops and stakeholder interviews, a field and modeling study to collect field data and model preferred streamflows for fish habitat, and two facilitated workshops to initiate a process for developing integrated instream flow recommendations for the entire Spokane River system.
Multipurpose Water Storage Study (draft report completed in May 2007) –Tetra Tech team conducted an assessment of water storage needs and opportunities in WRIA 54. This study included a WRIA-wide screening to identify potential water storage projects, and a detailed focus on two study areas within WRIA 54 where water needs are expected to increase significantly due to population growth.
Water Quality Study (ongoing) – This study supplements the Phase 2, Level 1 with a more detailed assessment of water quality conditions and issues followed by a water quality workshop in August 2007 with the Watershed Planning Unit to assist in prioritizing water quality issues and monitoring needs. The next phase of this work will be to develop sampling and analysis plans to evaluate non-point source pollution impacts within two separate study areas within WRIA 54.
WRIA 54 Watershed Management Plan (initiated in August 2007) – Tetra Tech is assisting in developing the Watershed Management Plan primarily through a process of facilitated Watershed Planning Unit and technical work group efforts. Initially conducted two issues identification and prioritization workshops. Then led six technical work groups to develop Watershed Management Plan modules that document background information, alternatives analysis, recommendations and implementation plan. Each work group will ultimately present and discuss its

recommended Watershed Management Plan module with the entire Watershed Planning Unit for discussion and approval. Tetra Tech has designed a schedule for this process that will allow completion of the draft Watershed Management Plan by September 2008, a full year prior to the State deadline.

South Fork Tolt Watershed Plan, Seattle Public Utilities, WA, current
Project Manager. Developed land management plan for the City's municipal watershed. Facilitated eight technical work groups, and a steering committee to develop a Plan that captured state-of-the science analysis of carbon sequestration, forest, aquatic, and wildlife restoration, invasive species management, and watershed and cultural resource protection, but can also be easily communicated to policy-makers. Planning process included a stakeholder involvement program.

Chehalis Watershed Plan, WA, 2004
Chehalis Basin Partnership; Grays Harbor County, Thurston County, Corps of Engineers
As Project Manager, facilitated this intergovernmental group in developing a watershed plan, under the ESHB 2514 planning process, for the entire Chehalis River watershed (WRIA 22 and 23). This was a large and complex planning process, with over 40 diverse entities participating, including over ten cities, four counties, two tribes, several state and federal agencies, and numerous special interest groups. Successfully mediated development of recommendations for controversial issues such as water rights adjudication, instream flow recommendations, and implementation of a coordinated water quality monitoring program. Managed several technical studies in conjunction with Watershed Plan, including an Instream Flow Study (stream gauging), Water Quantity Evaluation, and Multipurpose Water Storage Feasibility Assessment.

Cynthia worked with the Chehalis Basin Partnership on development of the **Chehalis Watershed Plan, under the 2514 Watershed Management Act**, which was approved by the Planning Unit in April 2004. Cynthia assisted in (1) developing an outline for the watershed management plan; (2) developing a strategy for tackling the diverse issues and interests within the watershed; (3) preparation of a detailed summary of technical watershed data to set the stage for management recommendations; (4) scoping and prioritizing technical studies; (5) conducting stakeholder workshops throughout the watershed; (6) managing an Instream Flow Study, including establishing stream gauging stations, collecting flow data, analysis of flow data, and development of flow exceedance curves; (7) managing a Water Quantity Evaluation Study that includes a water balance and detailed analysis of water rights and consumptive water use for a portion of the watershed; (8) managing development of a water quality monitoring program for the entire watershed; (9) managing a multipurpose water storage study; and (10) writing major portions of the Watershed Plan. Through the course of this project, Cynthia also gave numerous presentations to the Planning Unit and subcommittees, providing information and education material about each of the technical topics and recommendations included in the Watershed Plan.

WRIA 19 (Hoko-Lyre) Planning Unit, Clallam County, WA, 2004
Clallam County
Project Manager. Facilitated Olympic National Park, two tribes, and numerous state and local agencies, managed technical watershed analyses and development of watershed management plan. Technical studies included instream flow study; multipurpose water storage assessment; and a surface water monitoring plan for nine rivers. The watershed plan lays forth a comprehensive strategy for managing consumptive and instream water needs, water quality and habitat.

Chambers-Clover Planning Unit (WRIA 12), Pierce County, WA, 2004
Tacoma-Pierce County Health District
Cynthia is also currently assisting the Chambers-Clover Planning Unit (WRIA 12) in finalizing its Watershed Plan under the Watershed Management Act. For this group, she has provided service through a work-order-based contract, functioning as part of the technical analysis, writing and presentation team, along with Planning Unit Technical Committee members. Her role included summarizing and formatting the technical basis for the Plan, developing and formatting recommendations and an action plan for identified high priority issues, developing "early action" projects to speed implementation of the Plan, and presentation/technical advisement on the draft Watershed Plan. Cynthia also managed development of a coordinated monitoring program designed to evaluate the effectiveness of actions recommended by the Watershed Plan.

Seattle Public Utilities, Sewer & Drainage On-Call, Road Abandonment Planning, Seattle, WA, 2005

Seattle Public Utilities
Project Manager. Targeted wetland mapping, drainage survey, road survey, habitat assessment, channel morphology survey, topographic survey, and hydrologic estimates to support forest road abandonment/improvement decisions. Developed concise road abandonment plans for each road segment, including relocation and restoration of a 1,000 foot stream segment, pre-application site visit with natural resource agency staff, and developed preliminary design drawings.

Clover Creek Watershed Plan, Pierce County, WA, 2000
Pierce County Water Programs
Cynthia assisted in developing alternative solutions to surface water problems identified in the Clover Creek Basin Characterization Project. This plan identifies problems in the basin related to water quality, flooding due to excess runoff, habitat degradation and groundwater flooding. The assessment includes a habitat survey of the basin, collection of stream flow data, collection of water quality data, collection of groundwater data and performing a rapid bio-assessment of the basin.

Baseflow Restoration Feasibility Study, Fort Lewis, WA
U.S. Army
Conducted a feasibility study on restoring baseflow to a stream on Fort Lewis that has experienced periodic loss of baseflow caused by large groundwater withdrawals and urbanization within its watershed. The study evaluated the likely success, implementation approach and obstacles, and costs of five alternatives to augment streamflow during dry periods.

Temporary Stream Bypass Guidance Manual, King County, WA
King County
Prepared guidance document for culvert replacement projects that require a temporary stream bypass during construction. This manual is used by King County to establish design requirements when a stream bypass is necessary, and to substantiate the County's requirements when applying for permits for culvert replacement projects. It was also incorporated into Corps of Engineers Endangered Species Act guidance documents.

Surface Water and Sediment Quality Monitoring Program, Fort Lewis, WA
U.S. Army
Managed water and sediment quality characterization program for large military installation. Program included the following four elements:

- Baseline surface water and sediment quality sampling at 26 sites throughout the course of three years.
- NPDES Stormwater Pollution Prevention Plan which included compilation of potential pollution sources, inventory of materials at industrial sites, identification of non-stormwater discharges, coordination with existing environmental management plans, and recommendations for Best Management Practices to prevent stormwater contamination.
- Non-point source pollution assessment evaluating potential pollution from different land uses on base.
- Design and maintenance of computerized data management system for tracking water and sediment quality data.

Federal Clean Water Act, Section 319 for Nonpoint Source Pollution Implementation Projects, Yakima River Basin, WA
Developed nonpoint source pollution reduction implementation projects assessing and mitigating water quality impacts from timber management and on-farm irrigation water management.

Yakima Valley Conference of Governments - Water Quality Management Plan, Yakima River Basin, WA
Provided technical expertise and guidance to regional planning effort. The purpose of this plan was to prioritize and devise management strategies to address water quality issues in the Yakima Basin. Community advisory teams from each region within the basin, and technical advisory teams for each beneficial water use (fisheries, drinking water, agricultural, industrial, etc.) were set up to actually formulate the plan.

Upper Yakima Resource Management Plan, Yakima River, WA

Developed management plan assessing and mitigating water quality cumulative effects from forest practices. Used computer modeling tools of risk assessment and field monitoring to address channel characteristics affecting fish habitat (fine sediment content of channel bed and pool/riffle frequency), suspended sediment, and temperature.

Milltown Reservoir and Clark Fork River Remedial Investigation/Feasibility Study, MT
Under CERCLA, analyzed surface water hydrology, water quality, and sediment transport to characterize the surface water regime for development of remedial alternatives and risk assessment to eliminate impacts of contaminated sediments deposited in Milltown Reservoir. Sediment transport through the reservoir was modeled using HEC-6, a one-dimensional numerical model. Historical sediment transport was analyzed and future sediment transport impacts were predicted. Project included water and sediment sampling.

Riparian Area Assessment, Yakima Training Center, WA
U.S. Army
Conducted hydrologic survey of springs on the U.S. Army Yakima Training Center. Project was an interdisciplinary assessment of the riparian potential of surrounding springs in the interest of wildlife habitat enhancement. Hydrologic survey focused on geologic origin and reliability of springs, and included a survey of groundwater resource records for the region.

Timber/Fish/Wildlife (TFW) Program Management, Central WA
Washington Department of Ecology, TFW
The TFW program is an interdisciplinary effort to regulate forest practices in Washington State. Managed the TFW program for the WA Department of Ecology in Central WA, including the east slope of the Cascade Mountains. Conducted technical investigations on the potential impacts of slope stability and water quality from forest practices applications for timber harvest, road construction, and chemical application. Investigations included field mapping and inventories and air photo interpretation, and required cooperation between the WA State Departments of Natural Resources, Fisheries, Wildlife, and Ecology, the U.S. Forest Service, Indian tribes, and private landowners.

Water Rights Investigations, Miscellaneous Water Right Applications
Conducted technical investigations supporting water right permit decisions for surface and groundwater appropriations. The first component of these investigations addressed the technical complexities of ground/surface water interaction, the effects of cumulative groundwater withdrawals, and surface water runoff timing and yield. The other component of these investigations requires an evaluation of water law policy issues such as the justification for beneficial use of water and the protection of minimum instream flows. Final permit decisions resulted from a workable integration of the technical water availability questions with the challenging policy questions.

Stillaguamish River Channel Migration, WA
Analyzed historical channel migration to determine origin of channel features. Employed map and aerial photograph interpretation as major tool.

Skagit River Channel Migration, WA
Analyzed historical channel migration which impacted land ownership adjacent to channel. Employed map and aerial photograph interpretation as analysis tool.

Debris Torrent Investigations, Whatcom and Skagit Counties, WA
Analyzed causative factors that initiated destructive channelized debris flows. Evaluation included map and aerial photograph interpretation, geologic mapping and surveying, and analysis of precipitation data.

Hydrology/Geology Instruction, Bellingham, WA
Western Washington University
Taught graduate courses in Surface Water Hydrology, Groundwater Hydrology, and Environmental/ Engineering Geology.

Tenaska Cogeneration Facility, Whatcom County, WA
Established the regulatory setting affecting the application process for water rights, the state review process, conditions for water allocation, and responsibilities of water rights holders to protect their water rights. In association with this work, an inventory of water rights holders in the region was conducted and various strategies were proposed for obtaining water via a new water right application or water right transfers.

AES Cogeneration Site, Grays Harbor County, WA
Conducted an extensive inventory of water rights holders for surface water and groundwater withdrawals in the region. Work included establishing the regulatory setting governing water rights in the state and providing recommendations to obtain water rights for the volume of water required to operate the proposed cogeneration facility

Regulatory Strategy and Compliance

Programmatic Biological Assessment for Stream Restoration Projects, King County, WA
King County, Roads Division
Assisted King County Roads Division develop a strategy for streamlining Endangered Species Act permitting responsibilities for stream restoration projects. Developed a programmatic approach for Road's Division activities and collaborated with Corps of Engineers in developing a checklist-style approval process for County projects.

NPDES Stormwater Characterization, Blaine, WA
Arco Products Company
Managed stormwater characterization of refinery site. Program included development of sampling and analysis plan including drainage basin delineation, justification for characteristic storm criteria, and establishment of sampling sites, methodologies, and sample parameters. Stormwater samples were collected and analyzed from five representative outfalls. Results from these samples were presented in a characterization report submitted to the Washington Department of Ecology. Application forms and support materials were prepared to add stormwater outfalls to Arco's NPDES permit.

NPDES Sediment Study, Bellingham, WA
Georgia Pacific
Prepared baseline sediment quality report for marine sediments in the vicinity of industrial outfall. Report detailed physical, chemical and biological test results, and included interpretations of test results as they related to Georgia Pacific's wastewater discharge.

Upper Meridian Valley Creek Improvements, Kent, WA
City of Kent
Responsible for the environmental permit development for this sensitive project. The project included creek restoration and culvert replacements in the upper reaches of the Upper Meridian Valley Creek located in the City of Kent. The existing culverts are restrictive in both flow capacity and ability to provide adequate passage of salmonids. Cynthia was responsible for permit application, including JARPA, and the Biological Assessment (BA) and Biological Evaluation (BE).

Wastewater Land Treatment System, Yakima, WA
Assisted in the design of a wastewater land treatment system for food processing industry, reviewed and recommended monitoring plans including a monitoring well network and management procedures, and conducted compliance monitoring. Monitoring and analysis included evaluating the regional and groundwater flow system and determining potential chemical impacts to the groundwater system from wastewater contamination.

Wastewater Land Treatment System, Prosser, WA
Food processing industry wastewater land treatment project included agency negotiation and review for 1) wastewater pipeline crossing on the Yakima River, 2) design and operation plans for a land treatment system, 3) monitoring plans and management procedures for preventing and assessing groundwater impacts, and 4) coordination of State Environmental Policy Act (SEPA) requirements.

Wastewater Land Treatment System, Wenatchee, WA
Recommended land treatment system design and monitoring for fruit processing industry. Monitoring program was implemented to assess impacts from wastewater treatment on groundwater and unsaturated soil.

Wastewater Treatment, Metal-Plating Facility, Yakima, WA
Assisted metal-plating facility in upgrading their on-site waste disposal system. Coordinated requirements of CERCLA, MTCA, and the Clean Water Act in negotiating wastewater disposal options.

Biomonitoring Studies, Blaine, WA
ARCO Products Company
Managed acute biologic toxicity testing program required for compliance under refinery NPDES permit. Project included coordinating quarterly collection of wastewater samples, acute bioassay tests on three organisms, and preparation of report for submittal to the Washington Department of Ecology.

Biomonitoring Studies, Newport, TN
SONOCO Products Company
Managed acute biologic toxicity testing program required for compliance under NPDES permit. Project included coordinating bi-monthly collection of wastewater samples, acute bioassay tests on two organisms, and preparation of report for submittal to the Tennessee Department of Environment and Conservation.

NPDES and State Waste Discharge Permit Investigations, Miscellaneous Industrial and Municipal Discharges, Central WA
Provided review and recommendations for environmental impact statements, waste discharge permits, engineering design reports, and monitoring plans for wastewater treatment facilities. Conducted compliance monitoring for these facilities, and initiated and carried out enforcement actions related to water pollution control violations.

Groundwater Resource Evaluation

Groundwater Resource Evaluation, Methow Basin, WA
Designed and conducted monitoring program to evaluate the groundwater resource and ground/surface water interaction. Project was initiated to support large water supply development application for proposed multi-season resort.

Aquifer Test, Oroville, WA
Designed, conducted, and analyzed aquifer pump test in support of water right application for housing subdivision. An aquifer test was required to determine the availability of water and the impact of a new water withdrawal on heavily regulated surface water bodies.

Aquifer Test, Tonasket, WA
Designed, conducted, and analyzed results from aquifer test in support of water right application. An aquifer test was necessary to adequately define aquifer parameters, delineate a complex aquifer system, and define impact of a new groundwater withdrawal on existing wells in the vicinity. Analysis included evaluating the hydraulic continuity between the new well and the Okanogan River.

Groundwater Resource Evaluation, Black Rock Valley, WA
Analyzed groundwater level and well construction records in technical support of water right applications. This is a basalt aquifer region; the purpose of the investigation was to delineate aquifer zones, identify well construction deficiencies that may be impacting the groundwater resource, and evaluate which aquifers were fully appropriated based on groundwater level trends over a ten-year period.

Aquifer Test, Zillah, WA
Conducted aquifer pump test in basalt aquifer system to determine impact of a new pumping well on existing wells in the area. The purpose for the aquifer test and analysis was to provide technical support for a water right application decision and identify well construction deficiencies.

Well Construction Regulation, Central WA
Evaluated water well drillers in central Washington for compliance with Washington State well construction standards. Methods employed in evaluating compliance included videoscan interpretation, temperature probe analysis, and visual inspection.

Groundwater Resource Evaluation, Central WA
Designed and implemented a groundwater resource evaluation monitoring program for Central Washington. The purpose of the monitoring program was to provide long-term data on the groundwater resource in technical support for water right applications. The program was designed to provide data on the impact of seasonal and long-term groundwater use and on the recharge systems for the monitored aquifers.

Site Evaluation, Blaine, WA
ARCO Products Company
Conducted site evaluation to assess subsurface contamination potential from oil refinery. Evaluation included interpretation of geologic structure surrounding the site with the aid of subsurface boring and geologic mapping.

Nor'west Concrete, Sedro Woolley, WA
Conducted site evaluation to assess potential for contamination of shallow alluvial aquifer from gravel mining operation.

Surficial Geologic Mapping - Puget Sound Basin, WA
Conducted extensive geologic mapping and interpretation of Pleistocene glacial stratigraphy for numerous research projects.

Publications

Carlstad, C, Lackey, B, and Kern, M. 2009. Adopting the Stepchild: Ecosystem Planning In Seattle's "Other" Municipal Watershed"; AWRA Annual Conference, Seattle.

Wheeler, B, and C. Carlstad. 2004. Observations on the State of Washington's Watershed Planning Process; AWRA Annual Conference, Seattle.

Easterbrook, D.J., and C.A. McCarten (Carlstad). 1988. Causes of debris torrents in the Pacific Northwest; Geological Society of America Abstracts, Cordilleran Section.

McCarten (Carlstad), C.A. 1987. Lat Pleistocene deglaciation features at Partridge Point, Whidbey Island, Washington: Geological Society of America Abstracts, Cordilleran Section.

Syverson, T., D.J. Easterbrook, and C.A. McCarten (Carlstad). 1985. Cause of debris torrents in the Cascade Foothills of Washington: Geological Society of America Abstracts, Cordilleran Section.

Employment History:

1998-current — Tetra Tech, Seattle

1990-1998 – ENSR Consulting and Engineering, Redmond

1987-1990 – Washington Department of Ecology, Yakima

Gregory R. Fischer, PhD, PE | Senior Vice President

GEOTECHNICAL ENGINEER

EDUCATION

PhD, Civil Engineering, University of Washington, 1994
MS, Civil Engineering, University of Illinois, 1986
BS, Civil Engineering, University of Illinois, 1984

REGISTRATIONS AND CERTIFICATIONS

Professional Engineer 22 states (AZ, CO, FL, IL, IA, KS, LA, MD, MN, MT, NE, NV, NM, NC, ND, OK, SD, TX, UT, WA, WI, WY)
Post-earthquake Structure Evaluation (ATC-20)

PROFESSIONAL SUMMARY

A Dr. Greg Fischer has over 23 years of geotechnical and civil engineering experience related to dams, levees and other water resources projects. He has been responsible for estimating budgets and cost management, developing subsurface exploration and laboratory testing programs, managing field and laboratory work, completing analyses for design, managing staff engineers in the analyses and report preparation portions of projects, developing and/or reviewing plans and specifications, and managing construction monitoring activities. Greg has designed new dams, completed safety inspections of existing dams and levees, and provided recommendations for dam and levee rehabilitation. His experience includes subgrade evaluation, earthquake engineering analysis/design, slope stability evaluation, settlement studies, seepage analyses, and slope protection. He also designed both hard armor and soft armor systems along rivers. Representative projects illustrating his experience are provided below.

RELEVANT EXPERIENCE

1 ***Green River Levee Raise Evaluation, King County, Washington.*** Greg is the lead investigator for an evaluation of methods to raise the levees along the Green River in anticipation of significant flow increases over the next five years. The work consisted of a comparison of the advantages and disadvantages of methods to raise the levees, followed by probabilistic and deterministic stability analyses to evaluate the stability of the slopes following a raise.

2 ***USACE, Independent Peer Review – Hurricane and Storm Damage Risk Reduction System, New Orleans, Louisiana.*** Greg served as an Independent Peer Reviewer (IPR) for the U.S. Army Corps of Engineers' (USACE) Backside Armoring Manual. The manual will provide guidance on backslope levee erosion for designers engaged in work for the USACE in the Greater New Orleans Area. Greg's role was to review the document, provide comments on the manual, and participate in a peer review conference. Following the conference, Greg co-authored a final report summarizing opinions and recommendations of the IPRs.

3 ***Green River Levee Risk Analysis, King County, Washington.*** Project Manager for a risk assessment study for the Green River in King County, Washington. Greg led a risk-based analysis of potential flooding-related damage that could occur along the Green River. The study developed an estimate of the expected annual damage considering river discharge

probabilities; the probability of failure of flood damage reduction structures (levees); and probable damage to land, structures, and other property and goods. The results of the study allowed King County to understand the risk and consequences of flooding in a highly urban area and consider taxing/assessment options to landowners who were provided protection by the levee system.

4 ***Green River Levee Stability and Seepage and Stability Study, King County, Washington.*** Greg was the Project Manager for the study of flood hazards along a 2,000-foot-long stretch of the Green River in King County, Washington. The purpose was to determine the rate of seepage through and beneath the levee to allow King County Surface Water Management Division (SWM) to design a collection and pumping system. In addition, an evaluation of the stability of the levee was required to assist SWM in designing remedial measures for the levee. The study included geotechnical explorations, in situ field permeability testing, and laboratory testing. Analyses were performed for underseepage and dike stability during various river stages and under rapid drawdown conditions. The results of the studies indicated the presence of confined horizontal clean sand layers. These layers had the potential to transmit the full head of the river to the landside toe of the levee. Finite element and flow net analyses indicated that high uplift pressures could exist beneath the toe of the levee. Under flood conditions, the analyses suggested factors of safety approaching 1.0. Stability analyses also suggested the potential for rapid drawdown failures on the riverward side of the levee. Recommendations were provided for rebuilding the riverward side of the levee to increase stability during rapid drawdown conditions and installing a berm and relief wells along the landside toe of the levee to relief and resist high uplift pressures. Before the recommendations could be implemented, 1995 floods resulted in the occurrence of sand boils behind the levee. As an emergency measure during flood fighting, on-site observations were made and recommendations were provided to SWM to strengthen the levee until the long-term recommendations could be implemented.

5 ***Raw Water Assessment Program, Colorado Springs Utilities, Colorado.*** Greg is the project manager for CSU's systematic evaluation and assessment of its raw water system. This five-year project includes an evaluation of the entire raw water system for CSU. Shannon & Wilson's role includes assessing the condition of dams, tunnels and pipeline corridors associated with the Blue River, South Slope, Ruxton, North Slope, Northfield, Penrose, North and South Cheyenne, Manitou, Rosemont, Pikeview, and 33rd Street Systems. This has included the assessment of approximately 32 dams and sedimentation ponds, nine tunnels, over 250 miles of pipeline, and eight pump stations.

6 ***USACE Flood Control Alternatives Evaluation Study, Grand Forks, North Dakota.*** Greg was the project manager for the review and alternatives evaluation of a USACE-proposed flood control system. To prevent future flooding in the City, the USACE proposed to build a much needed levee system. Because of the presence of deep deposits of weak soils, the levees were to be set back from the riverside by several hundred feet; requiring the abandonment of hundreds of residential homes and businesses. Shannon & Wilson was retained by the City to review the USACE methodologies and results and determine if there were alternatives to the setback levee system. Greg organized a one-day brainstorming session in Seattle with the USACE, City, and expert consultants from around the country. Following this meeting, Greg directed the efforts of Shannon & Wilson in preparing a Summary Report in just two weeks. This report indicated that potential alternatives existed. Following this report, Greg led Shannon & Wilson's effort in completing detailed slope stability analyses and finite difference modeling and determined that a deep secant pile wall

system and soil mixing walls were economical alternatives to the taking of homes in the Grand Forks area.

7 ***King County, Hidden Lake Restoration Project, King County, Washington.*** Project Manager for the Hidden Lake restoration project in King County, Washington. The project involved the design of an earth dam to restore a lake that had been drained by a dam failure in the 1970s. Because of low inflow into the lake during the drier months, project criteria required that the quantity of seepage be less than 0.5 cubic feet per second (cfs). A field investigation consisting of borings and in situ field permeability testing was completed revealing the presence of a thick, permeable alluvial deposit beneath the proposed embankment location. The presence of the alluvium indicated that seepage quantities would likely be higher than desired, that liquefaction of the alluvium was possible, and that piping was possible if the material was not properly filtered. Further explorations revealed the presence of landslide debris on the right abutment. After recognizing these deficiencies, additional explorations were completed at a downstream location, indicating the presence of a hard silt layer in the valley floor, and it was recommended to move the berm to this downstream location. Recommendations were provided for zoning of the earthen dam, foundation preparation, outlet pipes and control structures, spillway design, slope treatment, and reservoir rim stability.

8 ***King County, Levee Stability Study, Tukwila, Washington.*** Greg studied the stability of a levee along the Green River near Interstate 5 in Tukwila, Washington. As part of interstate widening, this 1,000-foot-long stretch of levee was evaluated to determine its strength and stability to resist scour caused by high river events. At the outside end of a 90-degree bend, the existing bank was being eroded by current river flows. Provided recommendations to WSDOT to enhance bank stability.

9 ***Raging River Levee, Fall City, Washington.*** Project Manager. Provided geotechnical studies associated with raising a 500-foot-long stretch of the river. King County SWM determined that this stretch of levee had to be raised by up to 4 feet to provide 100-year flood protection with adequate freeboard. Because of constraints associated with placing fill in to the river (zero-rise floodway criterion), there was not an option to place fill on the riverward side of the levee. In this reach, several trailers abutted the landward side of the levee. As such, it was not possible to raise the levee by traditional landward side fill placement. Presented several alternatives to levee raising, including flood wall, gabion baskets, and reinforced soil walls. King County chose reinforced soil walls on both sides of the levee crest. Provided design details for the project and provided part-time construction monitoring services in the field.

10 ***South Fork Skykomish River near Baring, Washington.*** Project Manager. Geotechnical Engineer for the riverbank stabilization of a parcel of land along the South Fork Skykomish River. The property was sited at the outside, downstream end of a channel bend. During the 1996 floods, significant bank failure occurred, threatening a structure on the property. Average river velocities of about 15 feet per second were estimated during the 100-year flows. Completed a site visit, hand surveying, and preliminary hydrologic and hydraulic studies. Provided recommendations for a riprap revetment at the property, including riprap size and quality; rock gradation; revetment thickness, depth, and inclination. Also provided recommendations for protection of the ends of the revetment to prevent the river from eroding behind the revetment.

11 ***Issaquah Creek in Issaquah, Washington.*** Geotechnical Engineer. Provided improvements to a 6,600-foot-long reach of Issaquah Creek in Issaquah, Washington. The project included widening of the existing channel at some sections and construction of overflow channels at other sections to provide additional storage capacity. Provided recommendations to protect channel areas with the greatest potential for erosion and scour by designing a riprap revetment. Guidelines provided for riprap shape, size, thickness, inclination, embedment and filter criteria.

12 ***South Fork Nooksack River Bridge, Skagit County, Washington.*** Project Manager for emergency evaluation of undermining of the north abutment of the South Fork Nooksack River Bridge in Skagit County, Washington. As a result of high river flows and scour in 1996, 50 percent of the footing was unsupported. It was estimated that local velocities may approach 26 feet per second in this area. Made a site visit to evaluate conditions and provided recommendations for foundation support, including pin pile support. Also provided recommendations for future riprap protection and the use of spur dikes and guide walls to improve local river hydraulics.

13 ***Levee Failure Evaluation, Kittitas County, Washington.*** Project Manager for the evaluation of a levee failure along the Yakima River in Kittitas County, Washington. In early 1996, a 600-foot-long stretch of levee failed at a sharp bend in the river. As a result of this failure, the intakes to two irrigation districts was threatened. Attended a one-day workshop with irrigation districts, County, Fisheries, tribes owners and the design team to discuss alternatives. Alternatives included replacement of levee, construction of overflow levee, moving intake structures, and improving other outdated or inadequate irrigation channels. Provided a feasibility study for improving one channel.

14 ***Flood Hazard Study, King County, Washington.*** Project Manager for the study of flood hazards along stretches of the Tolt and South Fork Snoqualmie Rivers in King County, Washington. Serious flooding had occurred along these rivers during record floods in 1990. As such, they were identified by King County as top priorities in a new flood hazard program. The study included a survey of site conditions, hydrologic and hydraulic analyses, and a geotechnical evaluation of alternatives to reduce the risk of flooding. A comprehensive feasibility report was developed for each river, which included alternatives to improve levee stability and reduce the risk of flood damage.

15 ***Hoquiam Levee Survey, Hoquiam, Washington***. Greg was the Project Manager for a condition survey of levees along the Hoquiam River for the City of Hoquiam. Conducted a detailed reconnaissance of the levee system and provided recommendations for maintenance, rehabilitation, and monitoring.

16 ***Dam Design, Cowlitz County, Washington.*** Greg was the lead designer for the design of a 700-foot-long, 20-foot-high, zoned earth retention dam, in Cowlitz County, Washington. Foundation investigation revealed that the dam was constructed over 80 feet of soft, compressible soils with permeable horizontal layers of coarse sand and gravel. Analyses indicated that stability of the embankment would be inadequate immediately following construction, necessitating the recommendation for flat side slopes. The proximity of an existing housing development located just downstream of the dam made it necessary to minimize seepage through and beneath the structure. To achieve the level of seepage required for the project, a slurry trench cutoff wall was designed. Special considerations were necessary at the contact between the slurry trench and the overlying embankment to reduce

the potential for cracking at this contact. Following design, Greg provided on-site engineering services for the County during construction.

17 ***State Route-18 (SR-18) Ponds and Embankments, King County, Washington.*** Greg was the Project Manager for the evaluation of slope stability of several pond embankments and a roadway embankment along SR-18 in King County, Washington. Shannon & Wilson was retained to evaluate the slope stability of several proposed detention pond embankments and a 60-foot-high roadway embankment. The slope stability analysis included analyzing the factor-of-safety against instability for various water levels in the ponds and providing alternatives for increasing the embankment stability, such as overexcavation and toe buttressing. Dr. Fischer assisted in a finite-element study using the computer program FastSEEP to evaluate the phreatic surfaces within the embankments due to pond filling for the slope stability analyses. The numerical studies also evaluated the groundwater mounding effects below the detention ponds due to a 100-year storm event.

18 ***Harbour Pointe Dam, Mukilteo, WA.*** Greg was the Project Engineer responsible for the design review of a 35-foot-high zoned earth detention dam in Mukilteo, Washington. The fast-track nature of the project required a review of the plans and specifications approximately one week before being sent out to bid. Because no explorations had been completed, three borings were drilled and several test pits were excavated. These explorations revealed that foundation conditions consisted of permeable sand layers requiring detailed filter placement and an upstream impermeable zone. The numerous changes required in the plans and specifications based on the review meant that many could not be implemented in time for bidding. Supervised Shannon & Wilson, Inc. construction monitoring personnel during construction. This monitoring included a number of field modifications as conditions were exposed to successfully complete the project.

19 ***Confidential Water Storage Project, Western Slope, Colorado.*** Greg was the Principal-in-Charge for a water storage project on the Western Slope for a confidential client. The project involved looking at the feasibility of constructing one or more dams to retain up to 60,000 acre feet of water.

20 ***St. Joe Dam, Flat River, Missouri.*** Greg was the Project Engineer for the rehabilitation of a 4,000-foot-long, 130-foot-high tailings dam in Flat River, Missouri. The dam was built by hydraulic filling of loose sands/silts, and as a consequence had a low seismic stability factor of safety. A complete geotechnical, hydrologic, and hydraulic analysis was provided, including detailed seismic analyses to evaluate the potential for liquefaction and lateral deformations during ground shaking. Recommendations were provided for improving the stability to pass major seismic events generated by the New Madrid fault zone. The recommendations included several remedial alternatives that provided varying levels of post-remediation factor of safety with relative degrees of risk and cost.

21 ***Tywappity Dam, Scott County, Missouri.*** Project Engineer responsible for a liquefaction analysis of the Tywappity Dam in Scott County, Missouri. The study indicated that liquefaction was possible under the design earthquake event and recommendations were provided to either decrease the probability of occurrence for liquefaction or increase the stability of the dam following a liquefaction event.

22 ***Roy Safety Inspections, State of Alaska.*** Greg was the Project Engineer for Phase I periodic safety inspection of 22 earthfill, rockfill, timber, and sheetpile cutoff dams throughout the

State of Alaska. Co-authored safety inspection reports as required by the Alaska Department of Natural Resources to evaluate stability and safety of existing dams.

23 ***al Orchard Drainage Study, Royal City, Washington.*** Greg was the lead geotechnical engineer for the study of high groundwater conditions for an 80-acre orchard in Royal City, Washington. The high groundwater conditions that damaged the orchard were determined to be a direct result of leakage from an irrigation canal. By detailed foundation exploration and site investigation, it was determined that over time, canal maintenance had resulted in the removal of a soil liner causing the observed leakage. Groundwater modeling was used to back-calculate the magnitude and time history of leaking which was correlated to the rise in observation wells that had been installed around the site.

PROFESSIONAL ASSOCIATIONS

American Council of Engineering Companies
American Society of Civil Engineers
American Public Work Association
Structural Engineers Association of Colorado
ASTM International, Permeability and Filtration Subcommittee to Committee D35 (Geosynthetics)
International Geotextile Society
North American Geosynthetic Society
Society of American Military Engineers
American Society of Foundation Engineers
Association of State Dam Safety Officials

PUBLICATIONS

1 Author of a research report for the Waterways Experiment Station titled, "The Incorporation of Wall Movement and Vertical Wall Friction in the Analysis of Rigid Concrete Structures on Rock Foundations." The purpose of the study was to review the overturning stability method used by the U.S. Army Corps of Engineers, to find deficiencies in the method, and suggest new analytical techniques to analyze sliding stability of concrete structures. The results of the study recommended incorporating strain compatibility and wall friction into the methodology currently used by the Corps.

2 "Filter Criteria Based on Pore Size Distribution," by G.R. Fischer, B.R. Christopher, and R.D. Holtz, Proceedings, 4th International Conference on Geotextiles, Geomembranes and Related Products, The Hague, Netherlands, 1990, Vol. 1, p. 289-294.

3 "Geotextile Filtration Principles, Practices and Problems," by B.R. Christopher and G.R. Fischer, Geotextiles and Geomembranes, Vol. 11, No. 4-6, Elsevier Science Publishers, Ltd., 1991, p. 337-353.

4 "Comparative Studies of Different Parametry Determination Methods for Geotextiles," by G.R. Fischer and R.D. Holtz, Geotextiles and Geomembranes, Vol. 10, 1991, p. 379-381.

5 "A Critical Review of Geotextile Pore Size Measurement Methods," by G.R. Fischer, R.D. Holtz, and B.R. Christopher, Filters in Geotechnical and Hydraulic Engineering, J. Braun, M. Heibaum, and U. Schuler, eds., A.A. Balkema, 1993, p. 83-90.

6 "Research Needs in Geotextile Filter Design," by R.D. Holtz, B.R. Christopher, and G.R. Fischer, Filters in Geotechnical and Hydraulic Engineering, J. Braun, M. Heibaum, and U. Schuler, eds., A.A. Balkema, 1993, p. 18-26.

7 "Incorporation of Wall Movement and Vertical Wall Friction in the Analysis of Bridges Concrete Structures on Rock Foundations," by G.R. Fischer, C.B. Groves, and J.R. Salley, *REMR-GT-21*, U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, Mississippi, 1993.

8 The Influence of Fabric Pore Structure on the Behavior of Geotextile Filters, by G.R. Fischer, Ph.D. dissertation, University of Washington, Seattle, Washington, 1994, 502 p.

9 "Filtration Behavior of Broadly Graded Cohesionless Tills," by G.R. Fischer, R.D. Holtz, and B.R. Christopher, Proceedings, 5th International Conference on Geotextiles, Geomembranes and Related Products, Singapore, 1994, p. 659-662.

10 "Potrzeba Badan W Projektowaniu Filtrów Z Geotekstyliów," by B.R. Christopher, R.D. Holtz, and G.R. Fischer, Proceedings, Geotechniczne Aspelity Skladowania Odfpadow, Ton 1, 1994, p. 245-252.

11 "Construction of Log Storage Facility Over Dredged Organic Soils," by G.R. Fischer, M.G. Vitale, D.R. Johnston, and B.C. Dorwart, Proceedings, Geosynthetics '95, Nashville, 1995, p. 377-390.

12 "Design and Construction of a Log Storage Facility Over Dredged Organic Soils," by G.R. Fischer, S. Puri, and D.R. Johnston, paper submitted to Geosynthetics Case Studies Book for North America, Draft 2.

13 "Evaluating Geotextile Pore Structure," by G.R. Fischer, R.D. Holtz, and B.R. Christopher, Recent Developments in Geotextile Filters and Prefabricated Drainage Geocomposites, ASTM STP 1281, S.K. Bhatia and L.D. Suits, eds., American Society for Testing and Materials, 1996.

14 "Evaluating Geotextile Flow Reduction Potential Using Pore Site Distribution," by G.R. Fischer, R.D. Holtz, and B.R. Christopher, Proceedings, Geofilters '96, p. 247-256.

15 "A Critical Review of Granular Soil Filter Retention Criteria," by G.R. Fischer and R.D. Holtz, Proceedings, Geofilters '96, p. 409-419.

16 "Influence of Procedural Variables on the Gradient Ratio Test," by G.R. Fischer, A.D. Mare, and R.D. Holtz, Geotechnical Testing Journal, Vol. 22, No. 1, March, 1999, p. 22-31.

17 "Analysis of Low Frequency Vibrations From an Underground Light Rail Transit System," by H.L. Ellis, R.A. Mikhail, G.R. Fischer, and P.M. Godlewski, Proceedings, North American Tunneling 2000, Underground Construction: "The Revolution Continues," A.A. Balkema, Rotterdam, 2000, p. 403-410.

18 "Models for Predicting Surface Settlements Due to Soft Ground Tunneling," by Z.W. Wang, K.L. Sampaco, G.R. Fischer, M.S. Kucker, P.M. Godlewski, and R.A. Robinson, Proceedings,

North American Tunneling 2000, Underground Construction: "The Revolution Continues," A.A. Balkema, Rotterdam, 2000, p. 645-652.

19 "Earth Pressures on Deep Shafts," by R.A. Mikhail, M.S. Kucker, G.R. Fischer, R.A. Robinson, and P.M. Godlewski, Proceedings, North American Tunneling 2000, Underground Construction: "The Revolution Continues," A.A. Balkema, Rotterdam, 2000, p. 563-571.

20 "Database Management of a Large, Fast-Track Field Exploration Program," by D.C. Ward, P.M. Godlewski, G.R. Fischer, and R.A. Robinson, Proceedings, 10th International Association for Computer Methods and Advances in Geomechanics, Tucson, Ariz., 2001.

21 "Design-Build of the New Mississippi Outfall Tunnel at I25 for TREX – Geotechnical Challenges," by A. Stirbys, J. Kaneshiro, A. Foung, L. Piek, and G. Fischer, American Society of Civil Engineers (ASCE), Colorado Section Geotechnical Seminar, 2002.

22 "Deep Caisson Sinking in Soft Soils, Grand Forks, North Dakota," by G.R. Fischer, F.J. Barchok, M.K. Yavarow, and W.L. Gerszewski, Proceedings of the International Conference on Case Histories in Geotechnical Engineering, New York, 2004.

23 "Directionally Drilled Raw Water Intakes, Grand Forks, North Dakota," by B.C. Dorwart, G.R. Fischer, F.J. Barchok, M.K. Yavarow, and W.L. Gerszewski, Proceedings, International Conference on Case Histories in Geotechnical Engineering, New York, 2004.

24 "Earth Pressure Balance Tunnelling for Two Short Drives for the New Mississippi Outfall, Denver, Coloardo," by J.Y. Kaneshiro, A.F. Stirbys, and G.R. Fischer, Proceedings, ITA, 2005.

25 "Risk-Based Design Procedures for Directionally Drilled Raw Water Intakes, Grand Forks, North Dakota," by B. Dorwart, G. Fischer, W. Gerszewski, and M. Yavarow, Proceedings, North American Society for Trenchless Technology NO-DIG 2004.

26 "A Geotechnical Solution to Setback Flood Control Systems," by G.R. Fischer and K.A. Kershaw, Geotechnical Practice Publication No. 2, H2GEO Geotechnical Engineering for Water Resources, Wiltshire, R.L., Goss, C.M., and Olsen, H.W. eds., Denver, 2004, p. 101-122.

27 "Rehabilitation of the St. John's Tunnel," by G.R. Fischer, M.E. Levin, and D.A. Garcia, Geotechnical Practice Publication No. 2, H2GEO Geotechnical Engineering for Water Resources, Denver, 2004, p. 123-135.

28 "Rapid Levee Assessment for Reliability and Risk Analysis," by Hollie Ellis, Christopher Groves, and Gregory Fisher, for Geocongress 2008.

Rob Flaner, CFM

Project Manager/Lead Planner

Rob Flaner developed a comprehensive background in all aspects of floodplain management while administering the Community Rating System (CRS) under contract with the Federal Emergency Management Agency (FEMA). The CRS is a FEMA program that provides incentive to communities to exceed the minimum requirements of the National Flood Insurance Program. The CRS program recognizes a comprehensive range of non-structural flood hazard mitigation activities that include: public information, mapping and regulations, flood damage reduction, planning and flood warning. Rob was responsible for coordinating all CRS objectives between State, Local, and Federal entities in a 9-state territory that spanned three FEMA Regions. During his tenure with the CRS program, Rob was able to develop strong working relationships with his Federal, State, and Local partners. The CRS since its inception has developed into a template for sustainable floodplain management that can be used at the local level to give their programs direction. Rob's detailed understanding of the CRS program and floodplain management helped him to develop a diverse floodplain management background that has been utilized by FEMA as a Disaster Assistance Employee.

Rob has taken this diverse experience in floodplain management and expanded it into planning and preparing for the impacts of all natural hazards through coordinated planning efforts pursuant to the Disaster Mitigation Act of 2000 Utilizing planning tools such as HAZUS-MH and the CRS 10-step planning template, Rob has facilitated over 5 successful planning efforts for single entities and multi-jurisdictional efforts. Projects that Rob has managed during his tenure with Tetra Tech include:

Project Role:

Risk Mitigation

Education:

B.S., Biological Sciences, University of California at Davis, 1984

Total Years of Experience:

20

Office

Eagle, Idaho

Professional Registrations and Licenses:

Certified Floodplain Manager, 2000

ASFPM US-00-00143

EXPERIENCE

On Call Contract, Floodplain Management /Planning Services, King County, Washington, 2005 to present
King County, Steve Bleifuhs, (206) 296-8011

Tetra Tech was awarded this contract in 2005 and has provided the following services under a work-order/task order basis:

- Establishing a training curriculum on proper completion and maintenance of the FEMA elevation certificate. This training was provided to key personnel from The Department of Development and Environmental Services (DDES) as part of a memorandum of understanding between DDES and the Flood Hazard Reduction Services Section
- Planning assistance was provided by facilitating the development of a Flood Hazard Identification and Vulnerability Analysis (HIVA) to be included in the2006 King County Flood Hazard Management Plan. This HIVA modeled outputs from the FEMA HAZUS-MH program and seeks to create a bridge between the FHRP and the County's Regional Hazard Mitigation Plan, prepared pursuant to the Disaster Mitigation Act
- Prepare and analysis for the Green River Flood Control Zone District (GRFCZD) on possible benefits/impacts of CRS in the region due to potential mapping change scenarios

- Provide FEMA grant application technical support in that includes: benefit/cost analysis of the prospective project, e-grant support, and grant writing
- Tetra Tech has performed over 50 benefit-cost analyses for King County since 2005 that has resulted in the County securing over $8 million grant funding under FEMA Hazard Mitigation Grant programs
- Prepare the County's 2006 application for re-verification under the CRS program. This application included a comprehensive review and evaluation of the County's entire floodplain management program as it attempts to be come the nations 2nd highest ranked community under the CRS program. This review included all of the County's outreach, mapping, regulatory, planning and Flood warning programs

Floodplain Management / Hazard Mitigation Services and Training, Pierce County, Washington 2006-present, Pierce County Water Programs, Hans Hunger, (253) 798-6162

Tetra Tech provides technical assistance under its Stormwater on-call contract with Pierce County to provide floodplain management services and training that addressed the following objectives:

- Comprehensive review of City's floodplain management program to provide recommendations for program enhancement
- Evaluation of the County's Flood Threat recognition system and Flood Warning Program for CRS credit application
- Prepare the County's application for re-verification to the Community Rating System (CRS).
- Provide interdepartmental training to County Staff on proper completion of the FEMA Elevation Certificate and maintaining compliance with the National Flood Insurance Program
- Create a county-wide Food Hazard risk Assessment that would augment the County's existing Basin Planning program, and thus qualify that program for CRS credit, and thus meeting CRS classification prerequisites
- Provide FEMA grant application technical support in that includes: benefit/cost analysis of the prospective project, e-grant support, and grant writing
- Tetra Tech has performed over 30 benefit-cost analyses for Pierce County since 2006 that have resulted in the County securing over $6 million grant funding under FEMA Hazard Mitigation Grant programs

Floodplain Management Services and Training, Snohomish County, Washington, 2005-present Snohomish County DPW, Mary Hurner (425) 388-6401

Tetra Tech provides annual technical assistance on a "work-order" basis under its Stormwater on-call contract with Snohomish County to provide floodplain management services and training that addressed the following objectives:

- Prepare the County's application to the Community Rating System (CRS)
- Evaluation of the County's Flood Threat recognition system and Flood Warning Program for CRS credit application
- Review and provide recommended changes to the County's Critical Areas Regulations as they pertained to floodplain management
- Provide interdepartmental training to County Staff on proper completion of the FEMA Elevation Certificate and maintaining compliance with the National Flood Insurance Program
- Provide technical assistance in the annual implementation and progress reporting of the Snohomish County Natural Hazards Mitigation Plan
- Provide FEMA grant application technical support in that includes: benefit/cost analysis of the prospective project, e-grant support, and grant writing

Community Rating System / Hazard Mitigation Program Assistance, City of Roseville, California 2005-Present, Department of Public Works, Engineering Services, (916) 774-5343

Tetra Tech provides services to the City of Roseville via an annual "on-call" contract to support the City's nationally acclaimed CRS and Hazard Mitigation programs. As the nation's first and only CRS class 1 community, Roseville

has become the national role model for pro-active floodplain management and hazard mitigation. Tetra Tech has been the city's principle support contractor for these programs since 2005 and provides services that include:

- Management of all facets of the City's CRS program including annual recertification and re-verification of its classification during its review cycle.
- Evaluation of the City's Flood Threat recognition system and Flood Warning Program for CRS credit application.
- Hazard Mitigation program support that includes application preparation and benefit-cost analyses.
- Tetra Tech has aided the City of Roseville in securing over $1.5 million in grant funding under FEMA Hazard Mitigation grant programs since 2005.
- Completion of the annual progress report for accomplishments of the Roseville Hazard Mitigation Plan.

Multi-Jurisdictional Natural Hazards Mitigation Plan, Humboldt County, California, 2006-2007
Humboldt County, CA, Cybelle Immett (707) 268-3736

A planning partnership of 26 eligible local governments within Humboldt County joined forces in the development of a Multi-Hazard Mitigation Plan pursuant to the requirements of the Disaster Mitigation Act of 2000. As a sub-consultant to Winzler-Kelley Consulting Engineers, Rob facilitated this planning process to assure DMA compliance and recognition under the CRS. The CRS planning guidance was followed in the development of this plan to assure compliance with both the DMA as well as the program requirements of the Flood Mitigation Assistance Grant program. A detailed risk assessment of the impact of 9 natural hazards was performed by using risk assessment tools such as HAZUS and HAZUS-MH. During this project, the Tetra tech planning team was able to retrofit the HAZUS-MH model to analyze risk from the Tsunami hazard. The Humboldt County Operational Area Hazard Mitigation Plan was formally approved for DMA compliance by FEMA region IX in January of 2008.

Hazard Mitigation Program Assistance, the City of Snoqualmie, WA, January 2008 – Present
The City of Snoqualmie, Planning Dept., Lauren Hollenbeck (425) 888-5435

The City of Snoqualmie, WA is the "poster child" for flood risk exposure in FEMA Region X. Severally impacted by 3 presidentially declared flood events in a 2-year period, The City of Snoqualmie retained Tetra Tech to provide hazard mitigation support services, including:

- Grant application assistance for FEMA hazard mitigation grant programs.
- Benefit-cost analyses for over 50 flood damaged structures
- Construction of a detailed level-2 HAZUS-MH flood model utilizing property specific data (FEMA Elevation Certificates) to establish/validate damage functions
- Public education on FEMA grants programs and their eligibility requirements
- Mediator between the State, FEMA and the City on technical and programmatic issues
- NFIP compliance
- Initiation of the 5-year update to the City's hazard mitigation plan

Hazard Mitigation Program Assistance, Idaho Bureau of Homeland Security, June –December 2008
The Idaho Bureau of Homeland Security, Dave Jackson (208) 422-3047

Under this project, Tetra Tech provided on-call hazard mitigation program technical assistance to the State of Idaho and its local governments during the FY-2009 Hazard Mitigation Assistance (HMA) grant application cycle. This technical assistance included:

- Participation in weekly conference calls between the IBHS and any local government wishing to prepare and HMA application for FY-2009
- Cost-effectiveness review utilizing FEMA's BCAR methodology
- FEMA "e-grants" technical assistance
- Grant application QA/QC

Hazard Mitigation Program Assistance, Federal Emergency Management Agency June–December 2008
FEMA, Jody Springer (202) 646-3389

Under this volunteer project, Tetra Tech served FEMA as a registered "beta" tester for the benefit-cost Analysis Re-engineering (BCAR) platform. During this beta test phase Tetra Tech performed the following tasks:

- Performed over 50 benefit-cost analyses for existing Tetra Tech clients utilizing both the new BCAR methodology and the older FEMA BCA toolkit to compare results
- Provided feedback to FEMA staff on observations and findings during testing phase
- Supported FEMA staff on trouble-shooting software application problems
- Validation of damage functions
- Utilized BCAR methodology for actual FY-2009 HMA applications

Floodplain Management Training and Technical Services, The State of Idaho, 2008
The Idaho Department of Water Resources (IDWR), Mary McGown (208) 287-4928

Under this project , Tetra Tech provided technical assistance to the State of Idaho in the implementation and management of the State Floodplain Management Program established pursuant to the National Flood Insurance Program. This assistance included the following tasks:

- Training of new personnel hired by the state to manage its floodplain management program
- Training to the local communities and the state and federal requirements established pursuant to the National Flood Insurance Program
- Training of local Building Officials on proper documentation of Building Compliance and the FEMA Elevation Certificate
- Development of training modules to be utilized by state personnel for future training and possible deployment via other mediums such as the internet

Floodplain Management Training and Technical Services, the State of Montana, Montana, 2006-2007
The Department of Natural Resources and Conservation (DNRC)

Under this project, Tetra Tech provided technical assistance to the State of Montana in the implementation and management of the State Floodplain Management Program established pursuant to the National Flood Insurance Program. This assistance included the following tasks:

- Performance of community compliance reviews (Community Assistance Visits) on behalf of the State of Montana
- Training of new personnel hired by the state to manage its floodplain management program.
- Training to the local communities and the state and federal requirements established pursuant to the National Flood Insurance Program
- Development of training modules to be utilized by state personnel for future training and possible deployment via other mediums such as the internet

TETRA TECH

Michael D. Harvey, PG
Geomorphologist

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Dr. Harvey has 35 years of experience in the application of geomorphology to river engineering, slope stability and river and habitat restoration. His broad-based academic background in soil and water engineering, soils, hydrology, and fluvial geomorphology enable him to place specific problems within a system-wide perspective. He has successfully applied the tools of engineering geomorphology to a wide range of projects for Federal, State and Local agencies as well as private sector clients throughout the U.S. and Internationally. His project experience includes the full range of stream types from lowland sand-bed rivers to steepland, gravel-bed systems. Dr. Harvey has been retained by the Office of Surface Mining, the Natural Resource Conservation Service, Corps of Engineers Hydrologic Engineering Center, ERDC, California Department of Water Resources and Albuquerque Metropolitan Arroyo Flood Control Authority to lecture on the use of engineering geomorphology in channel restoration and design.

Dr. Harvey has extensive experience with the complex issues associated with in-channel and channel-margin sand and gravel mining. These include investigations of the impacts of sand and gravel mining on channel destabilization and infrastructure damage on the San Joaquin River, San Benito River, Russian River, Cache Creek, and Dry Creek, CA, Salt River, AZ. And Cache La Poudre River and Fountain Creek, CO He has conducted assessments of the effects of sand and gravel mining on in-stream habitat, upstream fish passage and spawning gravel availability on the Gualala, Santa Clara, Santa Ynez and San Joaquin Rivers as well as Deer Creek, CA. Dr. Harvey was retained by the Government of Jamaica to develop sand and gravel management plans for the Yallahs and Wagwater Rivers to balance sediment supply, channel stability, flood conveyance capacity and aggregate extraction. The Canterbury Regional Council, New Zealand, retained him as a technical reviewer for their long-term gravel management plan for the Waimakariri River that was intended to balance flood management, gravel extraction and channel stability in the lower, tidally-influenced reaches.

Dr. Harvey has authored and co-authored more than 150 papers and reports and 3 books on various aspects of fluvial system behavior. He is co-author of the Engineering Geomorphology Chapter in the recently released Sedimentation Engineering Manual (#110) published by the American Society of Civil Engineers. Dr. Harvey is a former member of the Earth Surface Processes Panel of the National Academy of Sciences and a member of the American Society of Civil Engineers Task Committee on River Bank Erosion. He has extensive litigation support experience and has been qualified as an expert witness in both Federal and State courts. Dr. Harvey has testified in cases involving channel maintenance flows and reserved water rights, landslides, mined land reclamation, levee failure, riparian property boundaries, flooding, channel erosion, sand-and-gravel mining impacts, and ordinary high-water mark determination.

REPRESENTATIVE EXPERIENCE

Geomorphic and Physical Process Studies, San Joaquin River, Friant Dam to the Merced River, CA Ongoing
Project Manager and Geomorphologist for a multi-year investigation of the 150-mile reach of the San Joaquin River between Friant Dam and the Merced River

Project Role:
Geomorphologist

Education:
Ph.D., Fluvial Geomorphology, Sedimentology, Colorado State University, 1980

M.S.Soils, Geomorphology, Hydrology, University of New Zealand, 1973

B.S., Soil and Water Engineering, University of Canterbury, New Zealand, 1969

Registration/Certification:

Professional Geologist Wyoming

Professional Affiliations:
Geological Society of America (Fellow)
American Geophysical Union

Office:
Ft. Collins,CO

Years of Experience:
35

Years with Tetra Tech:
15

Areas of Experience:
Fluvial geomorphology

Sediment and erosion design

River behavior analysis

Stream mechanics

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to determine the potential for restoration of riparian and salmonid fishery habitat in a river that has been extensively modified by sand and gravel mining, flood control levees, upstream dam construction and flow diversions.. Project responsibilities included topographic surveys, sediment sampling, extensive geomorphic, hydrologic, hydraulic and sediment transport analyses, fish barrier investigations and interaction with diverse interest groups to meet and communicate project objectives and alternatives. Work conducted for California Department of Water Resources and Bureau of Reclamation.

Evaluation of Sand and Gravel Mining Impacts on the Lower Gualala River, Mendocino County CA, 2000
Project Manager and Geomorphologist for a study to evaluate whether commercial sand and gravel mining on the lower Gualala River was compatible with flood management and anadromous fish passage and spawning. Conducted hydrologic (HEC-FFA), hydraulic (HEC-RAS) and sediment continuity modeling to develop a sediment monitoring and management plan that was adopted to manage annual, post-winter flow mining. Fish passage was maintained by only permitting gravel bar scalping, and the annual volume of material extracted was determined by the monitoring program. The work was conducted for Mendocino County and Bedrock, Inc.

Analysis of Sand and Gravel Mining Impacts on the San Benito River, Hollister, CA, 2002
Project Manager and Geomorphologist for a study to assess historic and existing conditions in the San Benito River to determine the impacts of flood control levees and in-channel and channel-margin sand and gravel mining on the vertical and lateral instability of the river that resulted in the loss of bridges, water and sewer pipeline crossings and in-channel habitat. Responsible for acquiring historical surveys, field surveys, hydrologic analysis and hydraulic (HEC-RAS) and sediment transport (HEC-6) modeling. Developed a sediment management plan that would tie allowable mining volumes to annual sediment supply. The work was conducted for the Public Works and Planning Departments of San Benito County and the City of Hollister.

Upper Yuba Studies Program: Flood Risk Management Baseline Sediment Transport and Hydraulic Analysis, CA, 2006
Project Manager and Geomorphologist for a study to analyze the risk of downstream flooding along the Yuba and Feather Rivers as far as the Bear River confluence from a proposed modification of Englebright Dam on the Yuba River that would release sediment from behind the dam. Conducted field analyses and sampling, hydrologic analysis, hydraulic modeling (HEC-RAS) and sediment transport modeling (HEC-6T) with a modified version that incorporated the Wilcock-Crowe formulation to handle the wide range of grain sizes in the existing river and with release of the dam-retained sediments. The work was conducted for CALFED and the California Department of Water Resources.

Santa Clara River Sediment Transport and Fish Passage Investigation, CA, 2009
Project Manager and Geomorphologist for a study evaluate the impacts of historic in-channel sand and gravel mining, flow diversions for aquifer recharge and the Freeman Diversion Structure and fish ladder on upstream and downstream passage of adult and juvenile steelhead. Responsible for geomorphic assessment of channel conditions, analysis of surface water-groundwater interactions, hydraulic modeling and sediment continuity analysis. The work was conducted for the United Water Conservation District.

Lower Deer Creek Restoration and Flood Management Feasibility Study, Tehama County, CA, 2008
Project Manager and Geomorphologist for a feasibility study for combining channel restoration, in-channel and overbank habitat improvements for Fall and Spring-run chinook salmon and flood management following channelization, levee construction and in-channel sand and gravel mining to preserve hydraulic capacity of the existing flood control project that was implemented in the late 1940's. Responsible for geomorphic, hydrologic (HEC-FFA), hydraulic (HEC-RAS) and sediment transport modeling to characterize existing baseline conditions and to identify and assess alternatives. Work was conducted for Deer Creek Watershed Conservancy and California Dept. of Fish and Game.

Sediment Management Alternatives for the Yallahs and Wagwater Rivers, Jamaica, 1997
Project Manager and Geomorphologist for a study to develop sand and gravel management plans for the lower reaches of the Yallahs and Wagwater Rivers that drain the Blue Mountains. Hurricane-induced landslides and high magnitude floods episodically supply large volumes of sediment to the lower reaches of the river where the transport capacity is exceeded and aggradation that induces local flooding occurs frequently. Responsible for conducting geomorphic, hydrologic, hydraulic and sediment transport analyses and for developing mining strategies to meet

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flood control, aggregate demand and channel stability requirements. Work was conducted for the Government of Jamaica and the Jamaica Banana Producers Association.

Review of Long-term Management Plan for the Lower Waimakariri River, Canterbury, New Zealand, 2005
Retained by the Canterbury Regional Council to review the long-term management plan for the lower, tidally influenced gravel-bed Waimakariri River that is leveed to protect the City of Christchurch from flooding and channel avulsion into the City. Conducted a field inspection and reviewed hydraulic and sediment transport modeling that was used to support the management plan that included gravel extraction to maintain conveyance capacity following bed aggradation, but also included protection for anadromous fish species and local infrastructure. Work was conducted for the Canterbury Regional Council.

Cache Creek Erosion Mitigation Alternatives, Cache Creek Basin Project, Yolo County, CA, 1998
Project Manager and Geomorphologist for a study to evaluate sediment sources and supply to Cache Creek that had incised significantly as a result of uncontrolled sand and gravel mining. Responsible for geomorphic, hydrologic, hydraulic and sediment transport analyses that were used to develop "red line" limits to control mining depths in the lower reaches of the creek. Work was conducted for the Sacramento District Corps of Engineers.

PUBLICATIONS

Harvey, M.D. and Mussetter, R.A., 2009. Modeling of Fine and Coarse Sediment Dynamics in the Upper Colorado River: Implications for Biological Productivity. Proceedings 7th International Symposium on Ecohydraulics, Concepcion, Chile, January 12-16.

Mussetter, R.A., Harvey, M.D. and Harner, R.F., 2009. Relationship between Physical Characteristics, Flow Regime and Riparian Vegetation in Coarse-grained Streams. Proceedings,7th International Symposium on Ecohydraulics, Concepcion, Chile, January 12-16.

Schumm, S.A. and Harvey, M.D., 2008. Engineering Geomorphology. In Sedimentation Engineering: Processes, Measurements, Modeling and Practice, ASCE Manuals and Reports on Engineering Practice, Manual No. 110, H.H. Garcia (Ed), American Society of Civil Engineers, Reston, VA.

Harvey, M.D., Trabant, S.C., and Levitt, J.E., 2008. Modeling Sedimentation Rates at Proposed Lake Ralph Hall, North Sulphur River, Texas. Proceedings of the 50 Years of Soil and Water Research in a Changing Agricultural Environment Conference, National Sedimentation Laboratory, September 3-5, Oxford, Mississippi.

Harvey, M.D. and Mussetter, R.A., 2008. Geomorphic, Hydraulic and Sediment Transport Challenges Facing Restoration of the Upper San Joaquin River from Friant Dam to the Merced River, CA. Proceedings of the 50 Years of Soil and Water Research in a Changing Agricultural Environment Conference, National Sedimentation Laboratory, September 3-5, Oxford, Mississippi.

Harvey, M.D., Trabant, S.C., and Levitt, J.E., 2007. Predicted Sedimentation Rates at Proposed Lake Ralph Hall, North Sulphur River, Texas. Presented at the Texas Water 2007 Conference by the Texas Section of the American Water Works Association (TAWWA) and the Water Environment Association of Texas (WEAT), Fort Worth, Texas, April 10-13.

Mussetter, R.A., Harvey, M.D., and Parkinson, S., 2007. Boat Wake Erosion of Sand Bars in Hells Canyon of the Snake River, Idaho and Oregon. World Environmental and Water Resources Congress 2007, ASCE, Tampa, Florida, May.

Harvey, M.D., Sanborn, S.C., Llewellyn, D.K., and Medley, N.M., 2007. Habitat restoration in the Albuquerque Reach of the Middle Rio Grande: Basis of Design. Proc., AWRA 2007 National Conference, Albuquerque, New Mexico.

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Harvey, M.D. and Trabant, S.C., 2006. Evaluation of Bar Morphology, Distribution, and Dynamics as Indices of Fluvial Processes in the Middle Rio Grande. Abstract for Middle Rio Grande Endangered Species Collaborative Program, First Annual Symposium, Albuquerque, New Mexico, April.

Mussetter, R.A., Harvey, M.D., and Harner, R.F., 2005. Physical characteristics, flow regime and riparian vegetation in coarse-grained streams, Idaho Batholith, USA. Poster presented at the Sixth Gravel-bed Rivers Conference, Austria, September 5-9.

Mussetter, R.A. and Harvey, M.D., 2005. Design Discharges for Arroyos in an Urban Setting. Proceedings of the EWRI 2005 World Water and Environmental Resources Congress, Anchorage, ASCE, Alaska, May 15-19.

Harvey, M.D. and Mussetter, R.A., 2005. Difficulties of Identifying Design Discharges in Steep, Coarse-Grained Channels in the Arid Southwestern US. Proceedings of the EWRI 2005 World Water and Environmental Resources Congress, Anchorage, Alaska, May 15-19.

Armstrong, S., Miller, W., Mussetter, R.A., Harvey, M.D., and Thomas, D.B., 2004. Aquatic Habitat and Hydraulic Modeling Study, Rio Grande at Bosque del Apache National Wildlife Refuge. Poster session for the 2004 Festival of Cranes, San Antonio, New Mexico, November.

Harvey, M.D., Trabant, S.C., Lunger, J.R., and Llewellyn, D., 2004. Bar Dynamics in the Bosque del Apache National Wildlife Refuge. Poster session for the 2004 Festival of Cranes, San Antonio, New Mexico, November.

Mussetter, R.A. and Harvey, M.D., 2004. Geomorphic, Hydrologic, Hydraulic and Sediment Transport Analyses: Tools for Evaluating In-channel and Channel-margin Habitat Dynamics. Proceedings of the 3rd Missouri River and North American Piping Plover and Least Tern Workshop, Sioux City, Iowa, April 12-14.

Harvey, M.D. and Mussetter, R.A., 2004. Fine Sediment Dynamics in Coarse-Grained Streams; Implications for Biological Productivity in Urbanized Western Streams. Proceedings of the EWRI Environmental Resources Congress 2004, Salt Lake City, Utah, June.

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Harvey, M.D., Mussetter, R.A., Morris, C.E., 2003. Fine Sediment in the Upper Colorado River During Spring Runoff and Summer Baseflows: Implications for Flow Recommendations and Biological Productivity. Abstract: Proceedings of Hydrology Days 2003, American Geophysical Union, Fort Collins, Colorado.

Harvey, M.D., Mussetter, R.A., Morris, C.E., 2003. Fine Sediment Dynamics in the Upper Colorado River During Spring and Summer Baseflows. Presented to the Upper Colorado River Basin Researcher's Annual Meeting, Grand Junction, Colorado, January 16.

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Harvey, M.D. ,2001. Napias Creek Falls, Idaho: A natural or man-made barrier for endangered chinook salmon. In *Applying Geomorphology to Environmental Management*, Anthony, D.J., Harvey, M.D., Laronne, J.B., and Mosley, M.P. (eds), Water Resource Publications, Englewood, Colorado, pp 291-307.

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Harvey, M.D. and Schneck, T., 1994. Straight Creek sedimentation investigation, Summit County, Colorado, Report to Summit County Water Quality Committee, February, 58p. and Appendices.

Harvey, M.D. and Spitz, W.J., 1994. Geomorphological assessment of North Fork Feather River from Rock Creek Reservoir to Lake Oroville, California, Report to Pacific Gas and Electric Company, San Francisco, 89p.

Mussetter, R.A. and Harvey, M.D., 1994. Bar dynamics assessment, RM 17.7 to RM 18.2, North Fork Feather River, California, Report to Pacific Gas and Electric Co., San Francisco, 30p.

Mussetter, R.A. and Harvey, M.D., 1994. Geomorphic, hydraulic and lateral migration characteristics of the Colorado River Moab, Utah, Report to Canonie Environmental and Atlas Corporation, 45p.

Harvey, M.D., 1993. Review of Natural Resource Agency comments on Echo Bay's Section 10 and 404 Permit Applications (Gastineau Channel 420), Report to Echo Bay Alaska, Inc., 27 p.

Harvey, M.D. and Mussetter, R.A., 1993. Yuba River Basin, California Project, Geomorphic, Sediment Engineering, and Channel Stability Analysis, Report to U.S. Army Corps of Engineers, Sacramento District, Contract No. DACW05-92-C-0077, March, 133p.

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Harvey, M.D. and Mussetter, R.A., 1993. American and Sacramento Rivers, California Project, Geomorphic, Sediment Engineering, and Channel Stability Analysis, Report to U.S. Army Corps of Engineers, Sacramento District, Contract No. DACW05-93-C-0045, November, 175p.

Mussetter, R.A. and Harvey, M.D., 1993. Evaluation of Channel Maintenance Flows on North Boulder Creek, Report to Engineering-Science, Inc., November, 35p.

Peterson, M.R. and Harvey, M.D., 1993. Configuration Data Report, Riverbed Gradient Restoration, Glenn Colusa Irrigation District, Report to U.S. Army Corps of Engineers, Sacramento District, Contract No. DACW05-90-C-0168, September, 15p. Appendices.

Harvey, M.D. and Spitz, W.J., 1993. Panhandle Creek Sediment Yield Study, report to Crystal Lakes Water and Sewer Association, Red Feather Lakes, CO, 10p.

Mussetter, R.A. and Harvey, M.D., 1993. Yampa River Endangered Fish Species Habitat Investigations, Report to Colorado River Water Conservation District, December, 38p.

Harvey, M.D., 1992. Kensington Gold Venture, Review and Redesign of Tailings Impoundment Reclamation, Report to Echo Bay, Alaska, Inc., 8p.

MacArthur, R.C. and Harvey, M.D., 1992. Nonpoint source sediment pollution investigation of the Pearl Harbor Drainage Basin, Hawaii, Report to the Pearl Harbor Estuary Program, Interagency Committee, Dept. of Health, Honolulu, HI, 32p.

MacArthur, R.C. and Harvey, M.D., 1991. Urban Flooding and Debris Flow Analysis for Niu, Aina Haina and Kuliouou Valleys, Report to U.S. Army Corps of Engineers, Pacific Ocean Division, Honolulu, Hawaii, Contract No. DACW83-91-P0055, May, 50p.

Harvey, M.D., 1991. Caliente Creek, California project: Field Circumstantiation of Sediment Engineering Investigation. Report to U.S. Army Corps of Engineers, Sacramento District, Contract No. DACW05-88-D-0044, March, 18p.

Harvey, M.D. and Mussetter, R.A., 1991. Geomorphic, Hydraulic and Channel Stability Analyses of Whitewood Creek, South Dakota, Report prepared for Homestake Mining Company, Lead, South Dakota, June, 96p.

Fischer, K.J., Harvey, M.D. and Spitz, W.J., 1991. Geomorphic Analysis and Bank Protection Analysis for Sacramento River (RM 0-78), Feather River (RM 28-61), Yuba River (RM 0-11), Bear River (RM 0-17), American River (RM 0-23) and portions of Three Mile, Steamboat, Sutter, Miner, Georgiana, Elk and Cache Sloughs. Report to U.S. Army Corps of Engineers, Sacramento District, Contract No. DACW05-88-D-0044, June, 334p.

Fischer, K.J. and Harvey, M.D., 1991. Reconnaissance geomorphic investigation of Truckee River from Vista to Pyramid Lake, Nevada, Report to U.S. Army Corps of Engineers, Sacramento District, Contract No. DACW05-91-P-1543, 106p.

Fischer, K.J. and Harvey, M.D., 1990. Geomorphic analysis of Truckee River from RM 56 to RM 43, Report to U.S. Army Corps of Engineers, Sacramento District, Contract No. DACW05-88-D-0044, October, 99p.

Harvey, M.D., 1990. Geomorphic Analysis of the Caliente Creek Basin, California. Report to U.S. Army Corps of Engineers, Sacramento District, Contract No. DACW05-88-D-0044, October, 58p.

Fischer, K.J. and Harvey, M.D., 1989, Field investigation and geomorphic analysis of Abiaca Creek Watershed. Report to U.S. Army Corps of Engineers, Vicksburg District, Contract No. DACW38-88-D-0099, 128p.

Harvey, M.D., Fischer, K.J. and Thaemert, R.L., 1989, Cache Creek Basin (Outlet Channel) project: Cache Creek Erosion Mitigation Alternatives, Report to U.S. Army Corps of Engineers, Sacramento District Contract No. DACW05-88-D-0044, 142p.

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Harvey, M.D. and Watson, C.C., 1989. Systems Approach to Watershed Analysis. Report to U.S. Army Corps of Engineers, Vicksburg District, Contract No. DACW38-88-D-0099, 151p.

Harvey, M.D., 1989. Assessment of effects of sand and gravel mining on Wagwater River, Jamaica. Report to Jamaica Banana Producers Association, August, 75p.

Fischer, K.J., Gregory, D.I. and Harvey, M.D., 1989. Geologic analysis of site contamination at American Wyott Corporation, Cheyenne, Wyoming. Report to Stewart Environmental Consultants, Fort Collins, Colorado, 42p.

Harvey, M.D., 1989. Analysis of geomorphic behavior of Arkansas River from Fort Smith to Lock and Dam, No. 13, Sebastian and Crawford Counties, Arkansas. Report to U.S. Department of Justice, Land and Resources Division, Washington, D.C., February, 27p.

Schug, J.D. and Harvey, M.D., 1989. Sedimentation surveys of Big Caney, Middle Caney, Lost Creek and Spring Creek reservoirs, Kansas. Reports (4) to U.S.D.A. Soil Conservation Service, Salina, KS, Contract No. 53-6215-9-1, April.

Harvey, M.D. and Fischer, K.J., 1989. Sediment Impact Analysis: Phase I Napa River Sediment Engineering Analysis. Report to U.S. Army Corps of Engineers, Sacramento District, Contract No. DACW05-88-D-0044, 67p.

Harvey, M.D., Watson, C.C., and Schumm, S.A., 1988. Geomorphic analysis of Sacramento River, Phase II Report. Geomorphology of Sacramento River from Colusa to Red Bluff. Report to U.S. Army Corps of Engineers, Sacramento District, Contract No. DACW05-87-C-0094, 343p.

Peterson, M.R., Watson, C.C., and Harvey, M.D., 1988. Performance evaluation of channels stabilized with ARS-Type low-drop structures. Report to Waterways Expt. Station, U.S. Army Corps of Engineers, Vicksburg, MS. Contract No. DACW39-87-CO9921, 114p.

Harvey, M.D., Peterson, M.R. and Watson, C.C., 1988. Geomorphic and hydraulic engineering study of Sacramento River from Hamilton City to Woodson Bridge. Report to California Dept. Fish and Game and Glenn-Colusa Irrigation District, 174p.

Anthony, D.J. and Harvey, M.D., 1988. Report for the 1987 field season, Fall River Research, Rocky Mountain National Park. Report to USDI, National Park Service, June, 50p.

Harvey, M.D. and Fisher, K.J., 1988. Geomorphological and sedimentological characteristics of Sink Valley, Kane County, Utah. Report to Nevada Electric Investment Company, August, 86p.

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Harvey, M.D., 1987. Gravel Management Plans for the Yallahs and Wagwater Rivers, Jamaica, West Indies. Prepared for Department of Public Works, Kingston, Jamaica, June.

Harvey, M.D., 1987. Observations on the status of the tributaries to Dry Creek, Sonoma County, California, from Warm Springs Dam to Russian River Confluence. Report to USACE, Sacramento District, Contract No. DACW05-86-P-2744, February, 34p.

Harvey, M.D. and Schumm, S.A., 1987. Geomorphology and sedimentology of Sink Valley, Alton, Utah. Report to BHP-Utah International Inc., Alton Coal Project, June, 33p.

Harvey, M.D., Watson, C.C. and Peterson, M.R., 1987. Recommended Improvements for Stabilization of Hotopha Creek Watershed, Mississippi: Report to U.S. Army Corps of Engineers, Vicksburg District, Contract No. DACW38-86-D-0062/3, April, 97p.

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Pitlick, J.C. and Harvey, M.D., 1986. A summary of 1985 channel changes and sediment transport on Fall River, Rocky Mountain National Park. Report to National Park Service, March, 38p.

Schumm, S.A. and Harvey, M.D., 1986. Preliminary geomorphic evaluation of the Sacramento River, Red Bluff to Butte Basin. Report to U.S. Army Corps of Engineers, Sacramento District, Contract NO. DACW05-86-P-0293. 45p.

Watson, C.C., Harvey, M.D., Gregory, D.I., 1986. Investigation of hydrologic, geomorphic and sedimentologic characteristics of the Lower Alabama River. Report to U.S. Army Corps of Engineers Mobile District, Contract NO. DACW01-85-D-0018. 196p.

Laird, J.R. and Harvey, M.D., 1986. Complex response of a small chaparral vegetated basin to geomorphically-effective fire, El Oso Creek, Tonto Basin, Arizona. Report to U.S.D.A. Forest Service, Rocky Mountain Forest and Range Experiment Station, Tempe, Arizona. 192p.

Harvey, M.D., and Spitz, W.J., 1986. Investigation of the causes of timber mortality, Cooper property, Itawamba county, Mississippi. Report to U.S. Army Corps of Engineers, Mobile District, Contract No. DACW01-86-M-5018, September, 69 p.

Watson, C.C., Harvey, M.D., Schumm, S.A., and Gregory, D.I., 1986. Geomorphic study of Oaklimiter Creek, Burney Branch, and Muddy Creek, in Benton, Lafayette and Tippah Counties, Mississippi. Section 1. Simulation of Oaklimiter Creek Evolution and Alternative Designs for Flood Mitigation. Report to USDA, Soil Conservation Service, MS, Project No. SCS-54-MS-83, June, 197p.

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Harvey, M.D. and Schumm, S.A., 1985. Geomorphic analysis of Dry Creek, Sonoma County, California from Warm Springs Dam to Russian River Confluence. Report, U.S. Army Corps of Engineers, Sacramento District, Contract No. DACW-0585-P001, August, 91p.

Harvey, M.D., Watson, C.C., and Schumm, S.A., 1984. Geomorphic study of Muddy Fork, Silver Creek Watershed, Clarke, Floyd and Washington Counties, Indiana. Final Report, Project SCS-AS-80, 8/79, USDA Soil Conservation Service, June, 77p.

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Schumm, S.A., Watson, C.C., Gregory, D.I., and Harvey, M.D., 1984. Episodic behavior of sand-bed rivers. U.S. Army Research Office, Contract NO. DAA929-81-C-0037, Final Report. 61p.

Finley, J., Harvey, M.D., and Watson, C.C., 1984. Experimental studies of erosion from slopes protected by rock mulch. Final Report, U.S. Environmental Protection Agency, Contract No. 68-02-4040. 39p.

Schumm, S.A. and Harvey, M.D., 1983. Geomorphic evaluation of the Grand Junction and Rifle Uranium Mill Tailings Piles. Report to NUS Corp., Denver, CO, Water Engineering & Technology, Inc., February, 17p.

Harvey, M.D. and Schumm, S.A., 1983. Report on the alluvial valley floor mapping Coal Creek Mine, Wyoming. Report prepared for Thunder Basin Coal Company, Wright, Wyoming, February, 6p.

Harvey, M.D., and Schumm, S.A., 1983. Geomorphology of Toposhaw, Abiaca and Pelucia Creeks, Mississippi Final Report, Project 53-44423-1-221, USDA, Soil Conservation Service, 14p.

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Harvey, M.D., and Schumm, S.A., 1981. Geomorphic evaluation of the long-term stability of Atlas Minerals Uranium Mill Site, Moab, Utah. Report prepared for Woodward Clyde, Consultants, Denver, CO 28p.

Schumm, S.A. and Harvey, M.D., 1981. Report on alluvial valley floor mapping, landform identification and erosion hazards, Coal Creek Mine, Wyoming. Report prepared for ARCO Coal Company, December, 12p.

Harvey, M.D., Schumm, S.A., Buchanan, J.B., and Mizuyama, T., 1981. Geomorphic evaluation of Lower Truckee River, between Wadsworth and Marble Bluff Dam, Nevada. Report prepared for Bureau of Indian Affairs, December, 21p.

Harvey, M.D. and Schumm, S.A., 1981. The geomorphology of Oaklimiter Creek, Northern Mississippi. Report, Soil Conservation Service, Project SCS-23-MS-80. 76p.

Schumm, S.A., Harvey, M.D., and Watson, C.C., 1981. Yazoo Basin Geomorphology. Soil Conservation Service, Project SCS-23-MS-80. 483p.

Harvey, M.D., Schumm, S.A., and Watson, C.C., 1980. The geology and geomorphology of Cypress Creek Watershed, Yalobusha County, Mississippi. Report prepared for Smith and Sanders, Inc., Jackson, MS. Water Engineering and Technology, Inc., Shreveport, LA. 37p.

LITIGATION SUPPORT AND TESTIMONY

U.S. Court of Claims

J.R. Cooper vs. U.S. (Case No. 681-84L)—1986
M.A. Powers et al. vs. U.S. (Case No. 434-75)—1989
B. Bagwell et al. vs. U.S. (Case No. 439-87L)—1996
C.S. Green et al. vs. US (Case No. 00-167L)—2002
R.C. Ingram, Jr. et al. vs. US (Case No. 03-2430L)—2006

U.S. Federal Court Cheyenne, Wyoming

C.R. Hanson vs. U.S.—1981

District Court, Water Division No. 1, State of Colorado

State of Colorado vs. U.S. (Case No. W-8439-76)—1990

Superior Court of California, Yuba County

Multiple plaintiffs vs. Reclamation District 784 and the State of California (Case No. 2104)—1994

Superior Court of California, San Benito County

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Sandman, Inc. vs. County of San Benito and Board of Supervisors (Case No. 22107)—2000

Superior Court of California, San Joaquin County
Reclaimed Island Lands Company vs. State of California and RD 2107, the Dept of Water Resources of the State of California (Case No. 004313)—1999

U.S. District Court for the District of Idaho
Napias Creek (Case No. 94-0159-S-HLR)—1996

Fifth Judicial District, State of Idaho, County of Twin Falls
Snake River Basin Adjudication (Case No. 39576) (Consolidated Case No. 63-25243)—1998

Fifth Judicial District, State of Idaho, County of Twin Falls
Snake River Basin Adjudication (Case No. 39576) (Consolidated Case No. 02-10063)—2001

Superior Court of California
Sandman, Inc. vs. County of San Benito and Board of Supervisors (Case No. 22107)—2001

U.S. District Court of Kansas
Jacquline Seyler v. Burlington Northern Santa Fe Corporation and AMTRAK (Case No. 99-2342-KHV)—2002

Superior Court of California, San Benito County
Sandman, Inc. vs. County of San Benito and Board of Supervisors (Case No. 22107)—2002

Superior Court of Arizona, County of Mariposa
The Burlington Northern and Santa Fe Railway Company v. The State of Arizona et al. (Case No. CV98-14172)—2002

U.S. District Court for the Eastern District of California
California Sportfishing Protection Alliance v. Diablo Grande, Inc. (Case No. F-00-597- OWWDLB)—2001

Superior Court of California, Mono County
Louis A. deBottari v. California Department of Transportation (Case No. 12449)—2004

Superior Court of California, County of San Joaquin
Reclaimed Island Land Co. v. RD 2107 and the State of California (Case No. 0043113)—2000

District Court of El Paso County, Colorado
Speight Partnership and Greenview Trust v. City of Colorado Springs and El Paso County (Case No. 01CV1290)—2008

JON A. KUSLER
1434 Helderberg Trail ▪ Berne, NY 12023 ▪ (518) 872-1804 ▪ jon.kusler@aswm.org

Summary

- Writer, lawyer, educator and administrator with 35 years of experience working with legal/science/policy issues in water resources management and the management of water related lands.
- Published many articles, books and reports specializing in mitigation of natural hazards, wetland management, and water resources planning.
- Worked extensively as consultant to nonprofit organizations, and to state and federal agencies.
- Served on the staffs of the University of Wisconsin and the University of Massachusetts.
- Organized more than sixty workshops, training sessions, and symposia dealing with the protection and restoration of wetlands, floodplains, streams and related ecosystems.

Experience

2001 to Present — Associate Director, Association of Wetland Managers, Inc.
Director, International Institute for Wetland Science and Public Policy, Inc.

- Directing Research Projects
- Designing and Running Workshops and Symposia
- Fundraising
- Developing Publications
- Co-Planned and Co-Facilitated ASWM's National Annual Symposia from 2001 to Present
- Co-Planned and Co-Facilitated ASWM's Workshops from 2001 to Present

1984 to 2000 — Executive Director, Association of State Wetland Managers, Inc.

- Supervised the Association's Activities Including Designing and Conducting Annual Symposia and Workshops
- Supervised Association Committees
- Planned and Facilitated ASWM's National Annual Symposia From 1984-2000
- Planned and Facilitated ASWM's Workshops From 1984-2000
- Editing and Publishing Proceedings From Annual Symposia and Workshops (See Publication List Below.)
- Editing and Publishing ASWM's Quarterly Newsletter, Wetland News

Fellowships and Awards

1990 — National Wetlands Lifetime Achievement Award. The Environmental Law Institute and the U.S. Environmental Protection Agency.

1979	Gilbert White Award in Floodplain Management, Association of State Floodplain Managers.
1979 to 1978	Institute Fellow, Environmental Law Institute, Washington, D.C.
1976 to 1977	Institute Fellow, University of Massachusetts, Institute for Man in the Environment.
1973	Honorable Charles Bullard Research Fellow, Harvard University.
1976 to 1968	E.D.A. Law Fellowship, University of Wisconsin Law School.
1966	Water Resources Fellowship, University of Wisconsin Water Resources Program.
1963	Knapp Fellowship, University of Wisconsin Law School.

Education

University of Wisconsin, Madison (with work at University of Minnesota and University of San Francisco):

- Ph.D., Land and Water Use Management (an interdisciplinary degree involving law, geology, and economics), 1972
- M.S., Water Resources Management, 1967
- B.S., English and Geology, 1969
- J.D., Law, 1965

Registration Admitted, Wisconsin Bar, 1965

Consultant

Selected Activities as Water and Land Resource Consultant

1989 Maryland Department of Natural Resources, Annapolis, Maryland. Consultant to the nontidal wetland task force. Advised the task force and helped develop draft nontidal wetland legislation which was adopted by the state of Maryland.

U.S. Environmental Protection Agency, Washington, D.C. Helped put together and run two workshops concerning multiobjective management of rivers and adjacent lands held in Colorado Springs and Knoxville.

International Joint Commission (Canada/U.S.). 1989. Consultant to the Commission on flood and erosion problems, wetland protection and management. Help develop position papers, conduct a workshop.

L.R. Johnson Associates. Provided consultant advice for two studies: a study concerning dune management on Lake Ontario; a study concerning shoreline development in New York.

Federal Emergency Management Agency. Provided consultant advice concerning the liability implications of the National Flood Insurance Program.

1988 to 1989 The Conservation Foundation, Washington, D.C. Consultant to the Foundation and the National Wetland Forum. Helped develop position papers, advised Forum staff.

The Unified National Program for Floodplain Management (With L.R. Johnson Associates). 1988-1989. Consultant to a two year effort to assess the status of floodplain management in the U.S. and make recommendations for future actions.

1987 to 1988 Association of Floodplain Managers. Conducted a workshop concerning high risk flood areas in the Western U.S., edited the proceedings.

1987 Federal Emergency Management Agency. Prepared a report for FEMA concerning public liability and natural hazards.

1985 to 1987 Association of Floodplain Managers. Directed a project for the Association which involved the preparation of a handbook, published by FEMA, concerning the management of high risk flood areas.

1984 to 1987 American Bar Association, Special Committee on Housing and Urban Development. Directed a National Science Foundation Project concerning post-disaster response and mitigation of future losses; conducted an international symposium concerning this subject; edited the proceedings.

1983 Texas Department of Public Safety, Austin, Texas. Helped conduct two workshops dealing with legal issues in floodplain management.

Tennessee Valley Authority. Helped design and conduct two workshops dealing with legal issues in floodplain management; and prepared workshop materials.

North Carolina Department of Natural Resources. Helped design and conduct a workshop dealing with legal issues in floodplain management.

American Institute of Architects, Washington, D.C. Helped design and conduct two workshops dealing with architectural design in flood hazard areas. Prepared a paper dealing with public and private liability for activities in flood hazard areas.

1982 to 1983 Maryland Department of Natural Resources, Annapolis, Maryland. Assisted in the preparation of a nontidal wetland protection handbook and slide show.

Alaska Department of Environmental Conservation. Co-authored a study concerning the operation of the federal 404 program in Alaska and the feasibility of the state assuming jurisdiction over "Phase II and III" waters.

U.S. Office of Technology Assessment, Washington, D.C. Conducted research, prepared papers, and reviewed materials on legal issues associated with wetland management.

1981 to 1983	Consultant and legal advisor to the Association of State Floodplain Managers. Assisted in the preparation of a report on the strengthening of state floodplain management; symposium coordinator for two national symposia concerning floodplain management.
1980 to 1983	American Bar Association, Washington, D.C. Co-directed a project concerning legal issues in wetland and floodplain management which involved five symposia (in Chicago, Denver, Atlanta, Philadelphia and San Francisco) and the preparation of a legal casebook.
1980	Government of Argentina. Evaluated wetland and floodplain problems in Argentina. Presented a paper in a professional seminar.
1979 to 1982	Federal Insurance Administration, Washington, D.C. Designed and helped conduct a floodplain workshop for federal agency staff; reviewed training and education seminars; prepared a memo concerning coastal flooding and wetlands.
1978 to 1982	U.S. Water Resources Council, Washington, D.C. Conducted five floodplains and wetlands protection seminars; prepared a research agenda memorandum; a five month seminar series dealing with emerging issues in wetland and floodplain management; assessment of floodplain management; assessment of post-flood acquisition policies; preparation of wetland and floodplain management slide presentations and an update of Volumes I and II of Regulation of Flood Hazard Areas to Reduce Flood Losses. (See publication list.)
1978 to 1979	Anderson-Nichols, Boston, Massachusetts. Assisted in a review of FIA flood insurance study methodologies.
1978	U.S. Environmental Protection Agency. Prepared a report on the role of the states in implementation of Section 404 of the Clean Water Act of 1977.
1977 to 1979	Ralph M. Field Associates, Westport, Connecticut. Provided assistance on a HUD contract examining the potential for federal acquisition of floodplain areas.
	Conservation Foundation, Washington, D.C. Assisted in a project on management of coastal flood hazard and ecological areas. Helped design and conduct a second national wetland symposium in Buena Vista, Florida.
1977 to 1978	Urban Institute. Helped design a project examining the enforcement of state wetland and shoreland regulations.
	Intergovernmental Floodplain Management Project, University of Massachusetts, Amherst, Massachusetts. Assisted Rutherford Platt in the design and conduct of a project dealing with the regional implementation of floodplain management strategies.
1976 to 1983	Environmental Law Institute, Washington, D.C. Supervised several projects dealing with the management of sensitive lands and wetland protection. Designed and conducted the first National Wetland Protection Symposium. Founded the National Wetlands Newsletter.

1976	Environmental Law Institute. Assisted in preparation of a handbook for planners and local governmental officials in implementing regional controls for nonpoint sources of water pollution.
	U.S. Department of the Interior, Office of Water and Land Use Planning. Member of two steering committees dealing with critical area definition and data-gathering.
1975	Delaware River Basin Compact Commission, New Jersey. Spring-Summer. Prepared model floodplain regulation standards and ordinances.
1974 to 1976	U.S. Department of Housing and Urban Development, National Flood Insurance Program. With the assistance of several attorneys, prepared an inventory of local enabling authority for zoning, subdivision control and building codes in the 50 states, and identified deficiencies. Prepared legal memorandum pertaining to the scope of local powers and other materials (published as a separate document by the Department).
1974	Smithsonian Institute, Center for Natural Areas. Spring. Helped prepare a report on planning guidelines for defining areas of critical environmental concern.
1973 to 1976	U.S. Army Corps of Engineers, Floodplain Management Services. Directed a series of seminars conducted in Washington, Philadelphia, Jacksonville, Chicago, Tulsa, and San Francisco on floodplain regulations. Each seminar examined the uses of floodplain zoning, subdivision controls, building and special codes nationwide, legal and planning issues, data needs, and techniques for integrating regulatory and non-regulatory floodplain management. Prepared report.
1973	Wisconsin Department of Administration. Prepared a report concerning establishment of a state coastal zone management program, and a comprehensive state planning and critical areas protection bill.
1972	Staff Assistant to the Wisconsin Governor's Committee on Natural Resources. Assisted in preparation of a report concerning the protection of land uses of critical state concern and implementing legislation; co-author of draft bill.
	U.S. Water Resources Council, Washington, D.C. Developed and reviewed materials pertaining to floodplain management.
1972	Illinois Department of Transportation. Helped draft floodplain regulations.
1970 to 1973	Minnesota Department of Natural Resources. Assisted in the drafting of state floodplain and shoreland zoning administrative standards, model ordinances and interpretive materials. Assisted in drafting and analysis of legislation concerning surface water zoning, wetland protection and state land use planning.
1968 to 1970	Wisconsin Department of Natural Resources. Prepared reports concerning surface water zoning and control of artificial lakeland subdivision.

University Positions

1999 to 2006 State University of New York at Syracuse

- Adjunct Professor

1982 College of the Atlantic, and the University of Maine Graduate School (Summer):

- Instructor, Graduate Program
- Taught a Course in the Law of Wetlands and Floodplains

1974 to 1975 University of Massachusetts, Water Resources Center (Winter and Spring):

- Project Director and Consultant: Chairman of a series of seminars concerning lake and shoreland management.

1974 to 1975 University of Wisconsin Institute for Environmental Studies:

- Research Director: Several projects dealing with definition and standard-setting for critical environmental areas. (Funded by the University of Wisconsin Sea Grant Program).

1974 University of Maine Water Resources and Shoreland Project (Winter):

- Consultant: Reviewed project materials.

1973 Harvard University (Spring and Summer):

- Honorable Charles Bullard Research Fellow: Prepared a report investigating techniques for protecting parks from incompatible adjacent development; recommended new programs. Funding provided by U.W. Institute for Environmental Studies through a grant from the National Science Foundation.

1972 to 1973 University of Wisconsin Institute for Environmental Studies:

- Project Director: Project funded by National Science Foundation on data needs for determining and managing areas of critical environmental concern.

1972 to 1973 University of Wisconsin Institute for Environmental Studies:

- Research Director: National Science Foundation funded seminar series on land use problems. Project resulted in a seven-volume report concerning state/local planning and regulation of land resources of greater than local concern.

1972 University of Wisconsin Institute for Environmental Studies:

- Lecturer: Environmental Law. (Graduate Course)

1970 to 1973 University of Wisconsin, Inland Lake Renewal and Demonstration Project:

- Consultant and Specialist: Prepared six published reports and contributed to a seventh concerning artificial lake construction, lake rehabilitation and lake protection districts legislation, surface water zoning, domestic waste disposal regulations and the sanitary surveys.

1968 to 1971 University of Wisconsin, Center for Resource Policy Studies:

- Co-Principal Investigator: Study concerning the use of regulations to reduce flood losses, jointly funded by the U.S. Water resources Council, U.S. Army Corps of Engineers, U. S. Departments of Interior, Agriculture and Housing and Urban Development, and the Tennessee Valley Authority. Project resulted in two major published reports.

1966 to 1968 University of Wisconsin, Extension Division:

- Specialist: Helped prepare a guidebook and model ordinances to implement shoreland zoning in Wisconsin.

Commissions and Advisory Boards

1992 to 1993 Member, Office of Technology Assessment, U.S. Congress Advisory Committee, Systems at Risk From Climate Change.

1990 to 1992 Member, National Research Council, National Academy of Science, Committee on the Restoration of Aquatic Ecosystems.

1988 to 1989 Policy Advisor, National Wetland Policy Forum.

Publications (Listed by Topic)

Assessment

Kusler, Jon A. 2006. Common Questions: Wetland Assessment. Association of State Wetland Managers, Inc.

Kusler, Jon, Ph.D. 2006. Recommendation of Reconciling Wetlands Assessment Techniques. Association of State Wetland Managers, Inc.

Kusler, Jon, Ph.D. 2004. Final Report 1: Assessing Functions and Values. Association of State Wetland Managers, Inc.

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Kusler, Jon. 2006. Common Questions: Establishing Local Government Wetlands and Watershed Management Programs. Association of State Wetland Managers, Inc.

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Land Trusts

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Kusler, Jon. 2006. Common Questions: Land Trusts and the Protection/Restoration of Wetlands. Association of State Wetland Managers, Inc.

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Restoration

Kusler, Jon., Ph.D. 2006. Developing Performance Standards for the Mitigation and Restoration of Northern Forested Wetlands. Association of State Wetland Managers, Inc.

Kusler, Jon. 2006. Common Questions: A Guide for Legislators: Wetland Protection and Restoration. Association of State Wetland Managers, Inc.

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Kusler, Jon A. and Mary E. Kentula (eds.). 1990. Wetlands Creation and Restoration: The Status of the Science. 600 pp. Island Press.

Climate Change

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Floodplain and River Management

Kusler, Jon., Esq. 2007. Professional Liability for Construction in Flood Hazard Areas. Association of State Wetland Managers, Inc. Prepared for the Association of State Floodplain Managers Foundation.

Kusler, Jon and Larry Larson. 1993. "Beyond the Ark" in Environment, Vol. 35, No. 5. 9 pp.

Kusler, Jon. 1984. Regulation of Flood Hazard Areas to Reduce Flood Losses, Vol. 3. U.S. Government Printing Office, Washington, D.C.

Kusler, Jon. 1981. Floodplain Regulations and the Courts, 1970-1981 University of Colorado Natural Hazards Center, Boulder, Colorado. Special publication 5. 51 pp.

Bloomgren, Patricia and Jon Kusler. 1981. Strengthening State Floodplain Management. University of Colorado Natural Hazards Center, Boulder, Colorado. 160 pp.

Kusler, Jon. 1979. Summary: Emerging Issues in Wetland and Floodplain Management. U.S. Water Resources Council, Washington, D.C. 26 pp.

Kusler, Jon. 1976. Floodplain Regulations in Perspective. U.S. Army corps of Engineers, Floodplain Management Services, Washington, D.C. 150 pp.

Kusler, Jon, (a contributor). 1973. Basin-wide Program for Floodplain Delineation. Anderson-Nichols & Co., Inc., Boston, Massachusetts. 147 pp.

Kusler, Jon and Douglas Yanggen, et al. 1972. Vol. I & II, Regulation of Flood Hazard Areas to Reduce Flood Losses. U.S. Government Printing Office, Washington, D.C. 389 pp.

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Kusler, Jon and James Wright. 1970-1971. Floodplain Zoning Ordinances. Minnesota Department of Natural Resources.

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2. Floodplain Management Techniques.
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Lake and Shoreland Management

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Kusler, Jon (contributor and director of seminar series). 1976. Lake-Shoreland Management Programs: Selected Papers. University of Massachusetts Water Resources Center, Amherst, Massachusetts. 244 pp.

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1. What is a Wetland?
2. Why Protect Wetlands?
3. Wetland Evaluation
4. Wetland Protection Techniques

State/Local Land Use Control Legislation

Kusler, Jon and J. Christie. 2006. Common Questions: State Wetland Regulatory Programs. Association of State Wetland Managers, Inc.

Kusler, Jon, Ph.D. 2004. Addressing the Gaps: A Federal, State, Tribal and Local Partnership for Wetland Regulation. Association of State Wetland Managers, Inc.

Strauss, Eric and Jon Kusler. 1977. Statutory Land Use Control Enabling Authority in the 50 States. U.S. Department of Housing and Urban Development. 302 pp.

Kusler, Jon. 1974. "Land Use: Persuasion or Regulation" in Land Use: Persuasion or Regulation, 4 pp., (1975), Proceedings of the 29th annual meeting, Soil Conservation Society of America.

Kusler, Jon. 1972. State Land Planning and Regulatory Functions: Proposals and Programs from the Several States and a Draft Bill for Wisconsin. University of Wisconsin Institute for Environmental Studies, Madison, Wisconsin. 233 pp.

Kusler, Jon et al. 1972. Rural Land Use in Wisconsin: A Preliminary Description of Problems and Preventive Efforts. University of Wisconsin Institute for Environmental Studies, Madison, Wisconsin. 144 pp.

Park Protection

Kusler, Jon. 1974. Public/Private Parks and Management for Private Lands for Park Protection. University of Wisconsin Institute for Environmental Studies, Madison, Wisconsin. 178 pp.

Data Needs/Data Gathering (see also Critical Areas below)

Kusler, Jon et al. 1975. Data Needs and Data Gathering for Areas of Critical Environmental Concern. University of Wisconsin Institute for Environmental Studies, Madison, Wisconsin. This included a series of three.

Jolly, Bill and Jon Kusler, et al. 1974. Planning Considerations for Statewide Inventories of Critical Environmental Areas. Smithsonian Institute, Center for Natural Areas, Washington, D.C. 274 pp.

Kusler, Jon. 1973. Special Data Requirements for Regulating Lands of Statewide Concern. Wisconsin Critical Resource Information Program, Report 2. Brief discussion of regulatory data needs. University of Wisconsin Institute for Environmental Studies, Madison, Wisconsin. 12 pp.

Kusler, Jon and Farnum Alston. 1972. Environmental Impact Evaluation Procedures: Some Recommendations for Wisconsin. Madison. 30 pp.

Kusler, Jon, Carl Runge and Farnum Alston (eds.). 1972. Symposium: A Survey of Statewide Land Resource Data Collection Systems. Papers from a nationwide symposium concerning state geoinformation systems, University of Wisconsin Institute for Environmental Studies, Madison, Wisconsin. 174 pp.

Critical Areas (See also Data Gathering above)

Kusler, Jon. 1978. Regulating Sensitive Lands. Ballanger Publishing Company, Cambridge, Massachusetts. 248 pp.

Kusler, Jon. 1972. “Open-Space Zoning: 'Taking’ or Valid Regulation”, 57 Minnesota Law Review 1, 81 pp.

Legal Issues

Kusler, Jon, Esq., P. Parenteau, Esq., and E. A. Thomas, Esq. 2007. "Significant Nexus" and Clean Water Act Jurisdiction.

Kusler, Jon, Esq. and P. Parenteau, Esq. Discussion Paper Rapanos V. United States "Significant Nexus" and Waters Subject to the Clean Water Act Jurisdiction. Association of State Wetland Managers, Inc.

Kusler, Jon. 2006. Common Legal Questions: Landowner Liability for Draining or Filling Wetlands. Association of State Wetland Managers, Inc.

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Kusler, Jon, Esq. Draft 2001. Model State Wetland Statute to Close the Gap Created by SWANCC. Association of State Wetland Managers, Inc.

Kusler, Jon. 1993. "The Lucas Decision: Avoiding 'Taking' Problems with Wetland and Floodplain Regulations." Maryland Journal of Contemporary Legal Issues. Vol. 4, Issue 1, 73-96 pp.

Kusler, Jon. 1990. Public Liability and Natural Hazards. Report prepared for the National Science Foundation. 500 pp.

Kusler, Jon. 1988. Natural Hazards and Public Liability. Federal Emergency Management Agency, Washington, D.C. 125 pp.

Kusler, Jon (ed.). 1987. Post Disaster Response and Mitigation of Future Losses. American Bar Association, Washington, D.C. 280 pp.

Kusler, Jon (ed.). 1986. National Wetland Symposium: Mitigation of Impacts and Losses, New Orleans, Louisiana, October 8-10, 1986. 460 pp. Association of State Wetland Managers, Inc.

Kusler, Jon and Rudd Platt. 1983. The Law of Wetlands and Floodplains: A Case Book. American Bar Association, Washington, D.C.

Resume for LARRY A. LARSON, P.E., CFM
Executive Director
Association of State Floodplain Managers, Inc.

2809 Fish Hatchery Road, Suite 204
Madison, WI 53713
608-274-0123, Fax 274-0696
larry@floods.org www.floods.org

Larry Larson has forty years of experience in flood loss reduction program administration at the state and NGO levels. He has served as the Executive Director of the Association of State Floodplain Managers, Inc. (ASFPM) since 1982. The goal of ASFPM is to reduce flood losses throughout the nation, by promoting policies and programs that are workable at the local level and lead to sustainable approaches to development. Mr. Larson was instrumental in the formation and development of this national, non-profit membership association of over 13,000 professionals and 27 State Chapters. The ASFPM represents the states and 20,000 communities in the nation that are responsible for implementing flood loss reduction programs, and promotes multi-objective approaches to management of flood hazards and natural resources to achieve common goals at the local, state, and federal levels. As such, the Executive Director takes a leadership position in policy discussions with the Office of the President, the U.S. Congress and the federal agencies. Mr. Larson coordinates with numerous federal agencies, the private sector, universities, professional organizations and Congress to achieve the Association's objectives. ASFPM's special reports are developed by staff or by members or sub-consultants under Mr. Larson's direction. He is responsible for assuring that such projects accomplish the established goals.

Other ASFPM functions that are coordinated under the oversight of the Executive Director include the national professional certification program for floodplain managers, finances, membership services, project management, monthly newsletters, publications, the annual National Floodplain Management Conference for over 1,300 participants, and special issue conferences and workshops. Larson is also the Secretary-Treasurer for the ASFPM Foundation, created to further research and education to help reduce flood losses and improve the management of floodplains and watersheds throughout the nation.

Mr. Larson serves on the Intergovernmental Flood Risk Management Committee (IFRMC), composed of senior staff from FEMA and the U.S. Army Corps of Engineers and leadership from ASFPM and the National Association for Flood and Stormwater Management Agencies (NAFSMA), who discuss mutual concerns about current national policies for reducing flood risk and levee safety issues, and explore options for improvement. This effort was initiated by USACE Major General Don Riley and FEMA Assistant Director of Mitigation Directorate and Federal Insurance Administrator David Maurstad. Mr. Larson also served as a member of the Steering Committee for the first major evaluation of the National Flood Insurance Program being undertaken by the American Institute for Research, under contract with the Federal Emergency Management Agency (FEMA).

PROFESSIONAL HIGHLIGHTS

- 2000-present
  - Co-authored a new approach to community development – No Adverse Impact (NAI). This is an approach to sustainable development that provides communities with information they need to avoid increases in future flood elevations and flood damages. Communities throughout the nation are adopting this NAI approach.
  - Prepared a publication and training courses for community, state, federal officials and other private and NGO professionals to understand how to implement No Adverse Impact approaches throughout the nation

- Initiated formation of broad based coalition to support improved flood maps in the nation in order to provide communities realtors, insurance agents, lenders and community land use mangers the updated maps they need to effectively reduce flood damages in the nation

- 1993-1994. Organized meetings and forums for the Association of State Floodplain Managers with the President's office and federal and state agencies, as well as locals and all involved interest groups. The objective was to review the causes of the 1993 Great Midwest floods (the nation's most costly), and recommend changes in management and mitigation of the nations flooding. From this effort came many policy and legislative changes.
- 1992, 1995, 1998 and 2003. Led survey of state activities related to reducing flood losses, compiling reports that analyze and summarize the effort. In 2003 this included a report which outlines what constitutes an effective state floodplain management program.
- Late 1980s into 1990s. Fomented the formation of State and Regional Chapters of professionals working to reduce flood damages and provide the wise use of the nation's floodplains. This allows peer exchange of local land use managers who work under the same institutional framework
- 1986. Led initiative to revise Wisconsin's FPM Administrative Code NR 116 to incorporate innovative technical and planning concepts into requirements for local floodplain ordinances, including innovative levee and dam safety measures
- 1980. Responsible for developing the statewide wetland protection program that utilizes state oversight of mapping and monitoring local regulations
- 1977-1982. Played the lead role in the formation of the Association of State Floodplain Managers, Inc. (ASFPM) to improve national and state flood policies
- Mid 1970s. Built Wisconsin's floodplain management program into a national model
- Late 1960s. Represented Wisconsin on multi-agency federal and five-state team to develop management alternatives for upper Mississippi River, led to major federal legislation

PUBLICATIONS AND PROJECTS

- **Floodplain Management 2050, 2008.** Report of the 2007 2nd Assembly of the Gilbert F. White National Flood Policy Forum, an ASFPM Foundation initiative.
- **National Flood Policies and Programs in Review 2007**. Led small group of experts in producing this publication for ASFPM, a review and analysis of national flood policy, with 280 recommendations for necessary changes in national policy. Available on ASFPM web site www.floods.org
- **Reducing Flood Losses: Is the 1% Chance Flood Standard Sufficient?** and **Actions Needed to Reduce Flood Losses in the U.S., 2004.** Reports of the 2004 Assembly of the Gilbert F. White National Flood Policy Forum, an ASFPM Foundation initiative.
- **No Adverse Impact (NAI) Toolkit, 2003.** Developed for community implementation in their efforts to reduce flood impacts and to prevent increases in flood losses in the future.
- **No Adverse Impact: New Directions in Floodplain Management Policy**. Published in *Natural Hazards Review Nov 2001, IAAN 1527-6988.* Co-authored this policy with Doug Plasencia setting forth the approach the nation's communities must use in order to reduce flood losses.
- **Second National Assessment of Research on Natural Hazards.** Contributing author to the Second Assessment was a multi-year project sponsored by the National Science Foundation and led by the University of Colorado at Boulder. Completed in 1999. This series of research efforts provided the basis for the book "Disasters by Design" authored by Dennis Mileti, Director of the Hazards Center at Boulder---book available from the Joseph Henry Press, and imprint of the National Academy Press
- **America Under Water: Tough Lessons from Recent Floods.** *USA Today Magazine July 1994* Discusses the impacts, risks and false sense of security of levees for flood protection in the nation
- **Floodplain Management: The Gap between Policy and Implementation or Principle and Practice.** *Water Resources Winter 1993—The Universities Council on Water Resources.* This article reviews national flood policy and how that policy is actually implemented—with recommendations for improvement. (printed during 1993 Midwest flooding)
- **Beyond the Ark: A New Approach to U.S. Floodplain Management.** *Environment Magazine,* June 1993 by Jon Kusler and Larry Larson. This article reviewed current policy and suggested

how a more integrated approach to floodplain management would provide multiple benefits to the nation.

- **Model State Legislation for Floodplain Management, Association of State Floodplain Mangers, 1982**. This presents alternative state laws for developing or improving state programs. Principal Co-author.
- **Design Guidelines for Flood Damage Reduction, American Institute of Architects, 1981**. Served as a review consultant on this document for design professionals to assist and guide them in designs that are compatible with wise floodplain management.
- **Flood Hazard Mitigation, National Science Foundation Report to Congress, 1980**. One of the principal authors of this report on flood hazard mitigation which: a) explored national policy on practices; and b) reviewed the structural/non-structural approaches and drew a series of conclusions and recommendations to Congress and Federal, State and local agencies to improve implementation of flood hazard mitigation practices.
- **Alternatives to the LaFarge Dam, 1979.** A Federal/State Task Force was appointed by the White House (President Carter) to prepare a report on non-structural alternatives to a planned Corps of Engineers dam. Principal author on the Work Group for the State of Wisconsin.

PRIOR PROFESSIONAL POSITIONS

1967 – 1997 Wisconsin Department of Natural Resources

1985-1997: Section Chief, Floodplain Management & Dam Safety Program
1975-1985: Management positions; Floodplain and Shoreland Management Programs
1967-1974: Staff Engineer, Department of Natural Resources

1962 – 1967 California Department of Water Resources

Design of Highways, dams and aqueducts

PROFESSIONAL ORGANIZATION ACTIVITIES

- Founding member of Association of State Floodplain Managers, Inc., 1977, national chair from 1979-82 and volunteer Executive Director from 1982 to 1997 (part-time paid position since February, 1997).
- Wisconsin State Engineering Association – President for two years, on Board for five years, representing over 1,000 engineers, architects and other professionals in collective bargaining with the State.

EDUCATION/REGISTRATION

University of Wisconsin – Platteville, BS in Civil Engineering, 1962
Registered Professional Engineer, Wisconsin and California
Certified Floodplain Manager (CFM) nationwide

HONORS / AWARDS

- 2006, Outstanding Service to the Industry Award, Oklahoma Floodplain Managers Association.
- 2005, John Wesley Powell Award from U.S. Geological Survey, their highest recognition to an individual not employed by the Federal government for their noteworthy contributions to the USGS objectives and mission.
- 1997, Outstanding Service award from FEMA Region V.
- 1996, Jerry Louthain Service to Members Award, ASFPM.
- 1989, Business Associate of the Year Award, Wisconsin Chapter of American Business Women's Association.
- 1985, first time recipient of the prestigious Goddard-White Award, the highest level of distinction in floodplain management, presented to an individual for exemplary contributions to flood loss reduction in the nation.
- 1983, Outstanding Public Service Award, Federal Emergency Management Agency, for promoting leadership and contributions to the advancement of floodplain management.

Tony Melone, PhD, PE, CFM

Vice President

Project Role:

Principal-in-Charge

Education:

Ph.D., Civil Engineering/ Hydrology, University of British Columbia, 1986

M.S., Civil Engineering/ Hydraulics, Colorado State University, 1975

B.S., Engineering Mechanics, University of Illinois, 1973

Registration/Certification

Professional Engineer, WA (1988); CO (1979)

Certified Floodplain Manager (CFM), 2008

Professional Affiliations:

American Society of Civil Engineers

Association of State Floodplain Managers

Northwest Floodplain Managers Association

Office

Seattle, Washington

Years of Experience

31

Years with Tetra Tech

15

Key Areas of Experience

Hydrologic & hydraulic engineering

Basin planning

Stormwater management project design

Project management of complex projects involving multidisciplinary teams

Tony Melone is the Manager of Tetra Tech's Water Resources program. He has over 30 years of professional consulting and project management experience applying his expertise in hydrologic and hydraulic engineering to basin planning and surface and storm water management projects. He has been responsible for the management and preparation of numerous stormwater, floodplain, and flood hazard management plans as well as preparation of plans, specifications and cost estimates for surface water management facilities. Much of this work has focused on meeting local, state and Federal laws related to flow control and water quality treatment. His responsibilities on these complex projects have included work plan development, staff management, client liaison, public meetings and consensus building, and oversight of project budgets and schedules to ensure timely project completion. Dr. Melone has managed complex watershed investigations involving multidisciplinary teams of engineers, geologists, geomorphologists, and scientists specializing in water quality, biology, contaminant transport, fisheries, and ecology.

EXPERIENCE

Soldiers Home Levee Setback Levee and Habitat Restoration, Pierce County, Washington
Principal-in-Charge for design of the one-mile-long Soldiers Home Setback Levee and of the raising and stabilization of another mile of existing levee on the Puyallup River. The new setback levee provides 100-year flood protection and allows approximately 70 acres of floodplain habitat to be reconnected to the main channel of the river.

Lower Puyallup River Flood Protection, Pierce County, Washington
Project Manager for a multi-disciplinary investigation to assess flooding on the Lower Puyallup River and identify measures to reduce the extent of the currently mapped FEMA floodplain, which has recently been re-mapped following decertification of levees along the river. Work included evaluation of flood hydrology, levee conditions, sediment transport, hydraulics, and the economic cost of potential flood damage. That information, along with a detailed assessment of environmental conditions along the river, will be used in subsequent phases of the investigation to represent a baseline against which potential improvements can be compared.

FEMA Floodplain Map Modernization, Washington State Department of Ecology
Project Manager for updating floodplain maps (FIRMs) and Flood Insurance Studies (FIS) for many cities and counties in Washington State, including Spokane, King, Kitsap, Spokane, Grays Harbor, Cowlitz, Clallam, and Yakima counties. Project activities include remapping of floodplains using updated topography, stream surveys, and hydrologic and hydraulic modeling. The mapping effort uses state-of-the-art GIS and FEMA modeling/mapping methods to develop Digital Flood Insurance Rate Maps (DFIRMs) and update the FIS for each County. A sampling of projects includes:

- **FEMA Floodplain Mapping, Pierce County, Washington**. Updated floodplain mapping and FIS for six creeks within Pierce County. HSPF, HEC-RAS, HEC Geo-RAS, and ArcView GIS were used as hydrologic,

hydraulic, and mapping tools to produce new floodplain maps for inclusion in a county-wide DFIRM.

- **FEMA County-wide DFIRM, Washington.** Performed floodplain refinement and redelineation on stream and rivers to produce updated county-wide DFIRMs for Kitsap, King, Spokane, Yakima, Clallam, Cowlitz and Grays Harbor Counties. DFIRM production was undertaken as part of FEMA's map modernization program, and maps were produced using FEMA DFIRM tools and uploaded to the Mapping Information Portal (MIP).

Stormwater and Floodplain Management Projects, Kitsap County, Washington
Project Manager for a series of investigations and improvement projects to manage stormwater runoff and reduce flooding along Clear Creek.

- **Comprehensive Flood Hazard Management Plan.** Conducted a basin-wide evaluation of flooding in the Clear Creek watershed and evaluated structural and nonstructural measures to manage flood hazards and reduce future flood damages. Plan recommendations guided decisions by the County for implementation of capital improvement projects to address flood problems.

- **Clear Creek / Silverdale Drainage Analysis.** Conducted hydrologic and hydraulic modeling using SWMM to analyze local stormwater runoff problems in the Silverdale area. The analysis evaluated alternatives for eliminating stormwater conveyance deficiencies. In addition, analyses on Clear Creek were conducted using HEC-HMS and HEC-RAS to establish flood elevations and floodplain inundation areas.

- **Myhre Road Culvert Replacement and Floodplain Enhancement Project.** Replaced an undersized box culvert with a bridge crossing to increase hydraulic capacity, improve fish passage, and reduce backwater effects and upstream overbank flooding. To further reduce upstream flooding, a floodplain enhancement project was undertaken to remove fill materials placed adjacent to the creek. The enhancement project increased floodplain storage, created new wetlands and provided water quality treatment for stormwater runoff.

- **Silverdale Way Culvert Replacement & Stream Restoration Project.** Replaced an arch culvert with a bridge crossing on Silverdale Way to improve fish passage and increase the hydraulic capacity of the crossing. The increased capacity of the new bridge prevents overtopping of flood flows over the roadway, and in combination with downstream enhancements, the project provides for increased flood storage and habitat enhancement.

North Creek / Little Bear Creek / City of Stanwood Drainage Needs Reports (DNR), Snohomish County, Washington
As part of a multi-firm team, served as project manager for the North Creek / Little Bear Creek / City of Stanwood Drainage Needs Reports. Work included a comprehensive inventory of stormwater conveyance and natural drainage features; hydrologic and hydraulic modeling of stormwater runoff; identification of problem areas for habitat; water quality and stormwater conveyance; development of alternative solutions to problems; and prioritizing projects for implementation in a capital improvement plan. Problem identification and recommendations from the DNRs led to design and construction of numerous capital improvement projects, including:

- 156th St Drainage System Upgrade,
- Winesap Road Ditch Regrade and Storm Drainage Replacement,
- 128th Street SW Conveyance Improvement, and
- Lowell-Larimer Road Drainage Improvement.

Lake Margaret Culvert Replacement, King County, Washington
Principal-in-Charge for replacement of the Lake Margaret Culvert. Work included preparation of plans and contract documents for replacing an existing 42-inch culvert with a 12-foot wide by 10-foot high box culvert. The embankment side slopes were approximately 24-feet high and were stabilized with geogrids and vegetation. Stream bed gravel was placed in the box culvert and large woody debris near the culvert outfall to improve stream habitat. Project was recognized for technical excellence and received the Washington State APWA Project of the Year award in 2003.

Big Gulch Stormwater Bypass Pipeline and Stream Restoration
Project Manager for design and construction of a high-flow stormwater bypass pipeline and restoration of the stream channel through Big Gulch. Work included a hydrologic analysis of the watershed using HSPF to calculate creek flows for pre-development and existing basin conditions. The 30-inch diameter HDPE stormwater bypass pipeline was designed to convey excess flows from the watershed and restore creek flows to pre-development conditions. A creek restoration effort was undertaken for over one mile to reverse the adverse impacts of recent high flows, including installation of large woody debris (LWD) to stabilize the creek bed and improve riparian and fisheries habitat.

Coal Creek Sediment Management, Bellevue, Washington
Project Manager for evaluation of sediment sources, originating from coal mine waste, and sediment transport and deposition along Coal Creek from Lake Washington upstream to approximately one mile upstream of Lakemont Boulevard. Investigations included identifying coal mine waste disposal areas, estimating the volume of deposits, evaluating the potential for sediment delivery to the creek via erosion and slope failures, and evaluating the long-term transport and deposition of sediment in the creek. Investigations led to development of a programmatic Environmental Impact Statement (EIS) for proposed sediment control measures, including bank and slope stabilization and creek bed control structures.

Comprehensive Flood Hazard Management Plan for the Lower Nooksack River, Whatcom County, Washington
Project Manager for the development of structural and nonstructural flood hazard management alternatives for the lower 37 miles of river. Work included documentation of flood problems and damages, historical gravel management practices and regulatory programs governing river management. Analysis of flood hazard management options was conducted using 2-dimensional flood plain modeling techniques as well as HEC-2. Management alternatives selection was guided by a 15 member advisory committee.

Comprehensive Stormwater Management Plan, City of Mukilteo, Washington
Project Manager for the City's Comprehensive Stormwater Management Plan. Work included hydrologic/hydraulic modeling of the stormwater conveyance and storage system using SWMM, identification of problem areas for future build-out conditions, evaluation of alternatives for mitigating flooding and water quality problems, and prioritization of improvement projects. The project included development of an operations and maintenance schedule, regulatory compliance review, facilitation of public works and maintenance involvement, and recommendation of funding and implementation strategies.

Floodplain Management Plan; 2-D Modeling for Programmatic EIS, City of Sumas, Washington
Project Manager for providing the hydraulic analysis of flood flows through the city as part of the City's floodplain management investigation. Numerous creeks, rivers, railroad and street embankments, and undulating topography complicated the modeling. Two-dimensional flow modeling was selected for this project due to the complex flow paths; the inability of conventional models, such as HEC-RAS, to represent the highly non-linear flow interactions; and the variability of flow paths depending on the boundary conditions. The model was calibrated using flood elevation data from recent flooding in the area that corresponded to about a 50-year recurrence flood event.

South 356th Regional Stormwater Detention and Water Quality Treatment Facility, City of Federal Way, Washington
Program Manager for feasibility analysis and design of a regional detention facility on a rapidly urbanizing portion of Hylebos Creek. Tetra Tech designed a 21 acre-foot detention facility with water quality features to treat runoff and reduce downstream peak flows. New storm drains upstream provided needed flow capacity. Stream restoration

measures improved channel stability and habitat along 650 feet of open channel downstream. Work included a hydrologic analysis of flood flows, hydraulic analysis of the trunk system, evaluation of stream stability, delineation of wetlands, geotechnical site evaluation, design of the facility, and construction oversight.

Comprehensive Stormwater Management Plan, City of Auburn, Washington
Project Manager for updating the City's Comprehensive Stormwater Management Plan. Work includes hydrologic/hydraulic modeling of the stormwater conveyance and storage system, identification of problem areas for future build-out conditions, evaluation of alternatives for mitigating flooding and water quality problems, and prioritization of improvement projects. The project area includes previously studied areas within the old City boundaries, recently annexed areas, and potential annexation areas.

Peters Creek Restoration, City of Redmond, Washington
Principal-in-Charge for creek restoration project. The upper reaches of Peters Creek are deeply incised and unstable due to increasing flow rates from the developing watershed. Sediment from these areas has destroyed much of the salmonid habitat within the lower reaches of this tributary to the Sammamish River. The main branch comprises 1,200 linear feet of channel within a heavily wooded ravine. Difficult access conditions required creative design and construction feasibility considerations. Specific designs were developed for stabilization of slope failure areas and head cuts; locations for structures to provide grade control, channel complexity, and habitat enhancement were identified; and plan drawings were provided for temporary erosion control, planting, and construction sequence to minimize disturbance.

Comprehensive Surface Water Management Plan, City of Federal Way, Washington
Principal-in-Charge for the Federal Way Surface Water Management Plan. Work included hydrologic and hydraulic modeling of eight trunk systems in the City using SWMM and HSPF, identification of conveyance deficiencies in the system for existing and future conditions, recommendations for eliminating capacity deficiencies and improving water quality, development of an evaluation matrix for ranking proposed system improvements, and development of a capital improvement program and schedule.

Stormwater Quality Action Plan, City of Sumner, Washington
Project Manager for a stormwater quality action plan. Work included a stormwater quality monitoring program at 14 outfall and creek locations, identification of sources of stormwater pollution, hydraulic analysis of creek flows, participation on a Planning Advisory Committee consisting of neighboring municipalities and agencies, and development of a stormwater management program to improve the water quality of stormwater runoff from the City.

Central Storm Drainage Improvements, City of Auburn, Washington
Principal-in-Charge for the preliminary design development and final design documents for storm drainage upgrades in Auburn's 444-acre Subbasin E. Storm drainage upgrades included replacing nearly two miles of 18- to 54-inch diameter pipeline and construction of water quality improvements. Construction was phased over a four-year period.

Shoreline Stormwater Study for GMA Comprehensive Plan/EIS, City of Shoreline, Washington
Principal in Charge for assessment of the drainage basins in the City with respect to the impacts under each of the three alternative development scenarios being considered. The assessment considered the implications of changing land usage, the effects of various minimum parcel sizes, the consequences of full build out conditions, and the resulting changes in imperviousness. A final section reviewed the costs associated with proposed or potential future stormwater facilities and capital improvements. This project was completed under an extremely tight schedule in order to meet the City's schedule to release the Comp Plan/EIS for public review.

Subbasin F Stormwater Plan, City of Auburn, Washington
Project Manager for a feasibility study, preliminary and final design of drainage improvements to eliminate chronic flooding and provide water quality enhancement of stormwater runoff. The project included correlation of 30 years of precipitation data and Green River flows to predict floods in the subbasin for various storm events. Results of the analysis led to recommendations for upsizing the storm drainage network and constructing a new outfall to the Green River.

Skokomish River Comprehensive Flood Hazard Management Plan, Mason County, Washington
Overbank flooding of the Skokomish River in Mason County impacts many residents of the lower valley, but many flood control solutions proposed through the years are not compatible with protection of the fisheries resource and wetlands in the area. The project approach included forming a public advisory committee to develop a flood plain management plan that was responsive to the diverse interests of affected parties in the valley. Work included developing goals and objectives for flood control work, evaluating instream and alternative nonstructural flood control measures, assessing the environmental impact of proposed measures, prioritizing alternative solutions, and preparing recommendations for their implementation.

Comprehensive Flood Hazard Management Plan, Lewis County, Washington
Three of the State's major rivers flow through the mountainous regions of Lewis County causing numerous flooding problems. Work included identifying regional drainage basins, developing goals and objectives, evaluating instream and alternative flood control measures, assessing the environmental impacts, prioritizing alternative solutions, and preparing recommendations for their implementation. A public advisory committee was formed and work proceeded with close coordination between local jurisdictions with the county as well as state and federal agencies.

Comprehensive Flood Plain Management Plan, Ellensburg, Washington
Six creeks flowing through the City form the major drainage network for floods. The capacity of each creek is affected by land use practices, urban development, irrigation practices, undersized culverts and underground channels. Work included identifying regional drainage basins, developing goals and objectives, evaluating instream and nonstructural flood control measures, conducting hydraulic analyses, assessing environmental impacts, prioritizing alternative solutions, and preparing recommendations for their implementation.

Water License Investigations, Nooksack River, Washington
Proposed developments along the Nooksack River have a need for water use in industrial processes. Water rights records were researched to document current holders of water licenses and the conditions governing withdrawal of water from the river. Water withdrawal needs were compared to minimum flow requirements established by the Department of Ecology in the Nooksack Instream Resources Protection Program. Historical streamflow data in the Nooksack River were analyzed to determine the frequency of potential flow restrictions on water license holders to satisfy instream flow requirements.

Sediment Transport Analysis, Clark Fork and Blackfoot Rivers, Montana
The Clark Fork and Blackfoot Rivers are gravel bed rivers that merge near Missoula. Historically, sands and gravels transported by these rivers have deposited near the confluence, including infilling of Milltown Reservoir. Work on this project included field investigations to document historical channel changes, modeling of sediment transport using the HEC6 computer program, prediction of sediment scour and deposition over the next 40 years, and feasibility analysis of removing sediments from deposition areas. These analyses were undertaken in coordination with input from citizens' groups and state and federal agencies.

Skagit River Flood Analysis, Skagit County
Numerous dikes, levees and other flood control structures have been constructed along the Skagit River to protect the cities of Burlington and Mt. Vernon and developments in the region from flooding of the Skagit River. A computer analysis using the 2-D FESWMS model was conducted to examine the impacts of flood control structures on flood levels in the valley.

Snohomish County Municipal NPDES Stormwater Permit
Project Manager for work undertaken to assist Snohomish County in preparation of their Municipal NPDES. Work included an inventory of all open channel and pipe drainage networks for stormwater in ten Watershed Management Areas. A stormwater quality monitoring network was established consisting of five automatic sampling stations to collect runoff samples for characterization of pollutant loadings from various land uses representative of activities in the County.

Sea-Tac Stormwater and Industrial Wastewater Control and Treatment Plan
Project Manager for work at Sea-Tac Airport to develop stormwater and industrial wastewater control plans as part of the NPDES permit requirements for existing and proposed expansion facilities. Work includes coordinating with the Department of Ecology to establish regulatory requirements, analysis of present systems for water collection and

treatment, assessment of the adequacy of existing systems, developing recommendations for upgrading treatment facilities, and design of new stormwater and industrial treatment facilities.

Flood Routing on the Capilano and Seymour Rivers
Hydrologic analysis of probable maximum precipitation, computer simulation of the probable maximum flood using the Corps of Engineers SSARR model, flood routing through water supply reservoirs, analysis of potential dam-break floods using the computer model DAMBRK, and inundation mapping for emergency planning for two dams in Vancouver, British Columbia.

Bathymetric and Sediment Isopach Mapping, Lake Mills and Lake Aldwell, Elwha River, Washington
Field investigations to map existing bed contours of two reservoirs, measure subsurface thicknesses of sediment deposited in the reservoirs using ground penetrating radar, seismic refraction, and piston coring techniques, drill through the river deltas and retrieve sediment samples, and grain size analysis of sediment samples obtained from the reservoir bed and river deltas.

Thompson River Dike and Riverbank Rehabilitation
Analysis of flood levels, flow velocities, scour potential, causes of bank erosion, and river morphology on the Thompson River in British Columbia for the development of a long-term comprehensive riverbank and flood protection design.

Racing River and MacDonald Creek Bridges
Analysis of flood water surface profiles at two bridges in British Columbia using the HEC-2 computer program, and investigation of bridge pier scour depths for the design of bridge protection works.

Migration of Borrow Pits Excavated from River Beds
Development of a computer model based on sediment transport mechanics to predict the long-term downstream migration of borrow pits excavated from the bed of the Fraser River in British Columbia.

Dinsmore Bridge
Analysis of river sounding records, flood history and development along the lower Fraser River in British Columbia to assess changes in river regime and causes of excessive local scour at the Dinsmore Bridge piers.

Stormwater Management Plan, Cogeneration Facility, Washington
Work included development of a storm water management plan for the site, computer analysis of rainfall-runoff flood hydrographs, flood routing through a drainage system, hydraulic design of a flood retention pond and biofiltration swale, and preparation of the NPDES storm water permit application.

Stormwater Runoff Study for Boise Cascade Pulp Mill
Development of a stormwater sampling and monitoring program in response to a NPDES permit compliance requirement for a pulp mill at Wallula, Washington. Work included delineation of subbasins on the site, identification of storm water runoff that is not routed to treatment facilities, assessment of industrial activities in each sub-basin, determination of monitoring requirements under the storm water regulations, and development of a storm water sampling plan.

Stormwater Runoff Study at Fairchild Air Force Base
Development of a stormwater sampling and monitoring program to characterize the quality of storm water runoff from the base and to assemble information necessary for submission of a NPDES stormwater permit application. Work included delineation of subbasins on the site, identification of industrial activities in each sub-basin, development of a monitoring network consisting of manholes in a sewer system for the base, drainage ditches into wetlands, and ditches carrying storm water from the site.

Municipal Water Supply Development and Master Drainage Plan
Hydrologic analysis of rainfall, snowpack, runoff and water budget for design of a water supply reservoir, and flood studies for layout and sizing of flood control channels in Big White Village, British Columbia.

Ashland Diesel Fuel Spill

Analysis of the hydrodynamics of flow in the affected river system, and the linking of flow dynamics to the eventual fate and transport of the spilled fuel as it was transported downriver and over a series of locks and dams near Pittsburgh, Pennsylvania.

Water Management Model, Zortman and Landusky Mines
Development of a computer model for simulating the month-by-month water budget at two gold heap leach mine sites in Montana based on the storage characteristics of heap leach pads during and after heap leach operations, climatic and hydrologic conditions, and the mine operating procedures for linking leach pads and water storage facilities for each mine.

Water Supply Development
Establishment of a hydrologic data collection network for monitoring rainfall, streamflow, suspended sediment and the water quality of surface runoff on four river systems as part of a program to develop a water supply reservoir in St. Lucia, West Indies.

Conehoma Creek Floodplain Mapping
Field program to survey creek cross-sections, hydrologic investigation of flood frequency using WRC bulletin 17B guidelines, computer simulation of flood hydrographs using the SCS-TR20 program, water surface profile analysis using the HEC-2 computer program, floodplain mapping and assessment of sediment transport processes at a site in Mississippi.

Coquitlam River Water Management Study
Field investigations and sediment sampling to identify natural and man-generated sources of sediment inflow to the Coquitlam River in British Columbia as part of a comprehensive watershed management study.

Water Supply for Bonito Mine
Analysis of climate, precipitation and surface runoff data to assess the availability of water for resource development, and an inventory of New Mexico state records to document water rights holders in the area.

Rehabilitation of Bear Creek Community Water Supply
Analysis of hydrologic data and water withdrawal techniques from wells to assess potential causes of contamination of surface and groundwater sources in the Yukon.

Wahleach Island Forest Debris Catchment Basin on Fraser River
Evaluation of alternative dike alignments, hydraulic model study of the preferred alternative, and design of a mid-channel dike network and log booms on the Fraser River in British Columbia for intercepting floating debris and diverting it into a storage area.

Wave Generation from Movement of Downie Slide
Hydraulic model study at a 1:600 scale to simulate the landslide-generated waves that would result from movement of Downie Slide into the Revelstoke Dam reservoir in British Columbia.

Arkansas Nuclear One and Vogtle Nuclear Power Stations
Hydraulic model studies at prototype scale of approach flow conditions and energy losses for the sump and intake for the Emergency Core Cooling System.

Port Development
Analysis of the characteristics of submerged marine clay deposits and hydraulic model study to simulate waves that would be generated by submarine slides in Kitimat Arm, British Columbia.

Ship Docking Facility
Hydraulic model study to optimize the orientation and size of a proposed landfill so that it effects on flow patterns and sediment transport in the Fraser River of British Columbia are minimized.

Cyprus Anvil Mine
Hydrologic analysis of the probable maximum precipitation, computer simulation of the probable maximum flood, and flood routing through the tailings pond for development of an abandonment plan for a mine in the Yukon.

Goldstream Mine

Flood frequency analysis to determine design flows and the hydraulic design of diversion structures for construction of a proposed hydroelectric station in interior British Columbia.

Real de Angeles Mine in Mexico and Arcata Mine in Peru
Hydrologic analysis of climate, rainfall, surface runoff and evaporation to establish the water balance for operation of a tailings pond.

Shaughnessy Mine Water Supply
Analysis of potential sources of surface and groundwater for development of a reliable water supply for mine operations in a semi-arid region in Alberta.

Annacis Channel Pipeline Crossing
Analysis of the river regime and potential river bed scour depths for the design of a river crossing for a municipal water supply pipeline along the Fraser River in British Columbia.

Canoe Pass Pipeline Crossing
Analysis of potential scour depths for the burial of a proposed gas pipeline along the shore of Georgia Strait on an intertidal sand bank near Vancouver, British Columbia.

Taghum Bridge
Hydraulic analysis of river water levels, velocities and approach flow patterns to calculate energy losses for alternative bridge pier designs in southeastern British Columbia.

Brownsville Wharf
Assessment of the effects on river sediment and flow patterns of replacing a pile-supported wharf along the Fraser River in British Columbia with an impervious fill structure.

Landfill Site Development
Hydrologic analysis of the month-by-month water balance at a proposed landfill site in British Columbia to address surface water handling as part of a comprehensive waste management plan.

Flat Creek Subdivision
Analysis of flood frequency, flood levels, and floodplain mapping as part of a feasibility study for a proposed subdivision in the Yukon.

Laclede Sawmill
Development of a water management plan for surface runoff to improve operating conditions in log storage areas at a sawmill in Idaho.

Suspended Sediment Modeling
Development of a computer program for the statistical analysis of historical records of suspended sediment concentrations and the generation of a regression equation which relates concentration to hydraulic parameters for a site in British Columbia.

Cewe Gravel Mine
Design of sedimentation ponds and monitoring of suspended sediment at gravel pits along the Coquitlam River near Vancouver, British Columbia.

Lime Creek Mine
Design of a series of sedimentation ponds for contaminated runoff from a coal mine in southeastern British Columbia.

Quinsam Coal Mine
Analysis of the hydraulic characteristics and flood routing capability of overflow spillway and decant structures for sedimentation ponds on Vancouver Island in British Columbia.

Poison Mountain Mine
Preliminary analysis of site hydrology for planning mine operations and an environmental impact assessment of mine development on the downstream river regime at a site near Lillooet, British Columbia.

Adanac Mine
Hydrologic analysis of rainfall, snow depths, evaporation and surface runoff to establish the water balance of a site in northern British Columbia for water supply and tailings pond development, and the hydraulic design of diversion channels for uncontaminated surface runoff.

Trout Lake Mine
Field program to establish a hydrologic data collection network for streamflow, rainfall, snow depths, wind, temperature and evaporation in interior British Columbia.

Ashlu Gold Mine
Development of a water management plan for control of surface runoff, analysis of flood hydrographs, and the design of diversion channels for uncontaminated runoff at a gold mine near Squamish, British Columbia.

Sage Creek Coal Mine
Development of a water management plan to route contaminated runoff to sedimentation ponds and intercept uncontaminated surface runoff and divert the water around a mine site in southeastern British Columbia.

Urban Flooding in North Seattle, Washington
Assessment of the causes of historical residential flooding in an area adjacent to McAleer Creek in north Seattle, Washington. Work included an analysis of the flood plain, flow paths during overbank flooding, and flood routing from the creek to individual homes.

J.K. Spruce Power Plant, China
Hydraulic model study to investigate flow conditions in the pump sump for the circulating water system, and to develop modifications to improve the hydraulic performance of the sump for a power plant in China.

Grand Rapids Combined Sewer Overflow Retention Basin
Hydraulic model study for a sewage treatment plant in Michigan to evaluate and modify the design of a circular sump containing 10 pumps, five on each side of a sump dividing wall. The sump operates during storm events to pump flood waters to a 30 million gallon flood retention tank.

Lavaca-Navidad River Authority and Formosa Plastics Water Supply
Hydraulic model study of an existing four-pump sump on Lake Texana, Texas to assess the feasibility of modifying the sump to accommodate an increase in flow at each pump from 3,100 to 11,000 gpm. The study developed sump modifications that could be retrofitted to allow the sump to be used for the increased pumping capacity.

Publications and Conference Papers

Melone, A.M. and Smelt, H. 2008. Puyallup River Flood Protection – Levee Certification Challenges. Association of State Floodplain Managers. 31st Annual Conference - New Perspectives in Floodplain Management. Reno, NV. May 2008.

Melone, A.M. 2006. Trials and Tribulations of DFIRM Production. Northwest Floodplain Managers Association. Annual Conference, October 2006. Seattle, WA.

Melone, A.M., Davidson, D. and Gaasland, G. 1998. Integrating Hydraulic Modeling with GIS for Flood Hazard Management. Association of State Floodplain Managers. 20th Annual Conference – Flood Mitigation Technology. Milwaukee, WI. May 1998.

Taylor, L.M., Carlton, D.K. and Melone, A.M. 1995. Trials and Tribulations of 2-D Modeling on the Nooksack River. International Symposium of APWA, Public Works and the Human Environment, April 1995, Seattle, WA.

Eidenberg-Noppe, P., and Melone, A. 1995. Early Flood Warning on the Nooksack River – Getting the Right Information to the Right People at the Right Time. International Symposium of APWA, Public Works and the Human Environment, April 1995, Seattle, WA.

Noppe, P.A. and Melone, A.M. 1994. Sediment Management and Regulations in Washington State. Association of State Flood Plain Managers. 18th Annual Conference, Comprehensive Watershed Management. Tulsa, OK. May 1994.

Melone, A.M. and Dube', K. 1991. Distribution and Grain Sizes of Deposited Reservoir Sediments, Seventy Years after Dam Construction. Proceedings of the International Conference of Hydropower, Waterpower '91. Denver, CO.

Melone, A.M. 1988. Canals and Waterways, Sediment Control. Volume XIV. Field and General Geology. Encyclopedia of Earth Sciences Series. Dowden, Hutchinson and Ross. Stroudsburg, PA.

Melone, A.M. and C.D. Sellars 1988. Reevaluation of Design Floods Thirty Years after Dam Construction. 16th International Congress on Large Dams (ICOLD). San Francisco, California.

Melone, A.M. 1985. Regional Analysis of the Time Distribution of Rainfall. Canadian Society for Civil Engineering. Proceedings of the Seventh Canadian Hydrotechnical Conference. Saskatoon, Saskatchewan.

Melone, A.M. 1985. Flood Producing Mechanisms in Coastal British Columbia. Journal of the Canadian Water Resources Association. Volume 10. Number 3.

Melone, A.M. and A.J. Tamburi 1979. Statistical Modeling Study of Suspended Sediment Concentrations. Canadian Society for Civil Engineering. Proceedings of the Fourth National Hydrotechnical Conference. River Basin Management. Vancouver, British Columbia.

Melone, A.M. 1977. Sediment Inflow from Runoff Through Gravel Mining Sites. Presented at the Western Canada Rivers Workshop. University of Alberta.

Melone, A.M., E.V. Richardson, and D.B. Simons 1975. Exclusion and Ejection of Sediment from Canals. U.S. Agency for International Development, Contract AIS/csd 2460.

Melone, A.M. and J.M Robinson 1973. Vertical Pipe Transport of Particles at Dilute Concentrations. Cavitation and Polyphase Flow Forum. Georgia Institute of Technology.

Employment History

Tetra Tech, Seattle, WA, Manager of Water Resources Program, Vice President, 1992-present

Engineering Hydraulics, Inc., Redmond, WA, Manager of Watershed Management Services, 1987-1992

Klohn Leonoff, Ltd., Vancouver, BC, Senior Hydraulic Engineer, 1979-1987

Western Canada Hydraulic Labs, Vancouver, B.C., Hydraulic Engineer, 1976-1979

Northwest Hydraulics Consultants, Vancouver, B.C., Hydraulic Engineer, 1975-1976

DAVID R. MONTGOMERY
Department of Earth & Space Sciences, Box 351310
University of Washington, Seattle, WA 98195
(206) 685-2560; dave@ess.washington.edu

EDUCATION
University of California, Berkeley, Dept. of Geology and Geophysics, Ph.D., 1991.
Stanford University, Department of Geology, B.S., 1984.

PROFESSIONAL EXPERIENCE

2003-2008	Director, Quaternary Research Center, Univ. of Washington.
2000-present	Professor, Dept. of Earth and Space Sciences, Univ. of Washington.
1996-1999	Associate Professor, Dept. of Geological Sciences, Univ. of Washington.
1991-1995	Research Assistant Professor, Dept. of Geological Sciences, Univ. of Washington.
1985-1986	Staff Geologist, Harlan Miller Tait Assoc., San Francisco, CA.
1984-1985	Field Geologist, J.V. Lowney & Associates, Palo Alto, CA.

AWARDS AND HONORS
MacArthur Fellow, John T. and Catherine D. MacArthur Foundation, 2008.
Washington State Book Award, for *Dirt: The Erosion of Civilizations,* 2008.
Fellow, Geological Society of America, 2007.
Fellow, American Geophysical Union, 2007.
Exceptional Reviewer, Geological Society of America Bulletin, 2007.
Kirk Bryan Award for research excellence, Geological Society of America, Quaternary Geology and Geomorphology Division, 2006.
Outstanding reviewer recognition, *Geological Society of America Bulletin*, 2006.
Washington State Book Award, for *King of Fish: The Thousand-Year Run of Salmon, 2004.*
Award for Outstanding Contribution to Washington's Water Resources, Washington Chapter of the American Water Resources Association, for *Restoration of Puget Sound Rivers*, 2004.
Foreword Magazine's Book of the Year Award, for *King of Fish: The Thousand-Year Run of Salmon,* Gold medal, Nature category, Book Expo America-Chicago, 2003.
Editors' Citation for Excellence in Refereeing, Water Resources Research, 1993, 1995.

PUBLICATIONS
Books, Authored and Edited

Trade

Montgomery, D. R., *Phantom Deluge: The Nature of Faith*, in preparation.

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Technical

Bierman, P. R., and Montgomery, D. R., *Key Concepts in Geomorphology,* W. H. Freeman, Inc., in preparation.

Montgomery, D. R., Bolton, S., Booth, D. B., and Wall, L., (editors), 2003, *Restoration of Puget Sound Rivers*, University of Washington Press, Seattle & London, 505 p.

Dorava, J., Montgomery, D. R., Fitzpatrick, F., and Palcsak, B. (editors), 2001, *Geomorphic Processes and Riverine Habitat*, Water Science and Application Monograph 4, American Geophysical Union, Washington, D.C., 253 p.

Gurnell, A. M., and Montgomery, D. R. (editors) 2000, *Hydrological Applications of GIS*, Advances in Hydrological Processes Series, John Wiley & Sons, Chichester, 176 p.

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Larson, I. J., Montgomery, D. R., and Korup, O., Limits to landslide erosion and scaling, *Nature Geoscience*, *in press*.

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Montgomery, D. R., Soil, *Nature*, v. 463, p. 31-32, 2010.

Koppes, M. N., and Montgomery, D. R., The relative efficacy of fluvial and glacial erosion over modern to orogenic time scales, *Nature Geoscience*, v. 2, p. 644-647, 2009.

Adams, J. B., Gillespie, A. R., Jackson, M. P. A., Montgomery, D. R., Dooley, T. P., Combe, J.-P., and Schreiber, B. C., Salt tectonics and collapse of Hebes Chasma, Valles Marineris, Mars, *Geology*, v. 37, p. 691-694, 2009.

Smith, M. R., Gillespie, A. R., Montgomery, D. R., and Batbaatar, J., Crater-fault interactions: A metric for dating fault zones on planetary surfaces, *Earth and Planetary Science Letters*, v. 284, p. 151-156, 2009.

Mitchell, S., Montgomery, D., and Greenberg, H., Erosional unloading, hillslope geometry, and the height of the Cascade Range, Washington State, USA, *Earth Surface Processes and Landforms*, v. 34, p. 1108-1120, 2009.

Minder, J. R., Roe, G. H., and Montgomery, D. R., Spatial patterns of rainfall and landslide hazard, *Water Resources Research,* v. 45, W04419, doi:10.1029/2008WR007027, 2009.

Montgomery, D., Peak soil, *BC Organic Grower*, v. 12, no. 3, p. 12-15, 2009.

Montgomery, D. R., Peak soil, *Ecology and Farming*, no. 44, March 2009, p. 9-11, 2009.

Montgomery, D. R., Schmidt, K. M., Dietrich, W. E., and McKean, J., Debris flow initiation during natural rainfall at CB1: Implications for modeling slope stability, *Journal of Geophysical Research - Earth Surface*, v. 114, F01031, doi:10.1029/2008JF001078, 2009.

Som, S., Montgomery, D. R., and Greenberg, H. M., Scaling relations for large Martian valleys, *Journal of Geophysical Research-Planets,* v. 114, E02005, doi:10.1029/2008JE003132, 2009.

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Diefenderfer, H. L., and Montgomery, D. R., Pool spacing, channel morphology, and the restoration of tidal forested wetlands of the Columbia River, U.S.A., *Restoration Ecology*, v. 17, p. 158-168, 2009.

Montgomery, D. R., Peak Soil, *New Internationalist*, Issue 418, December, p. 18-19, 2008.

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