WASHINGTON STATE UNIVERSITY

THE WILLIAM D. RUCKELSHAUS CENTER

UNIVERSITY OF WASHINGTON

Dear Interested Party,

Attached please find a draft report on the impacts of flooding in the Chehalis River Basin and potential flood mitigation alternatives. The purpose of this report is to provide the Washington State Legislature and other decision makers with information to aid decisions that will set a course for effective solutions to reduce the adverse impacts of flooding in the Basin and, at the same time, support the economic prosperity of Basin communities and the protection/restoration of fish and other natural resources. The William D. Ruckelshaus Center, a joint effort of the University of Washington and Washington State University (more information available at www.ruckelshauscenter.edu), is under contract with the Washington State Office of Financial Management (OFM) to coordinate development of the report, using technical information provided by other agencies and organizations.

Comments on the draft report are very welcome and encouraged. Please send comments to melissa.kuehne@wsu.edu or mail to Melissa Kuehne, Ruckelshaus Center, WSU West, 520 Pike Street, Suite 1101, Seattle, WA 98101 by Friday August 10, 2012. In commenting on the report, it would be helpful to have suggestions for how to improve the information it contains, as well as for what priority flood hazard mitigation projects should be considered and why. Any comments received will be taken into account as the report is finalized and included in an appendix to the final report so they become part of the record of this process. The final report is intended to be available in late August/early September.

In 2011, as part of the capital budget (ESHB 2020, Section 1033), the Washington State Legislature required OFM to prepare a report on alternative flood damage reduction projects and—in coordination with tribal governments, local governments, state and federal agencies—to recommend priority flood hazard mitigation projects for continued feasibility and design work. In response to the Legislative directive, this report compiles existing information on the potential flood mitigation projects that seem of most interest to Basin leaders and decision makers at this time. Potential flood mitigation benefits, adverse impacts, costs and implementation issues are summarized for each project. Projects addressed by this report include:

- A water retention project on the mainstem Chehalis River—a multi-purpose dam located upstream of Pe Ell;
- Improvements to the levee around the Chehalis-Centralia Airport;
- Flood walls to protect Interstate 5 in the Chehalis / Centralia Area;
- Raising/improving the US Army Corps of Engineers levee system around Centralia and Chehalis, (the “Twin Cities Project”);
- Other potential construction projects and programmatic approaches, such as land use management, flood proofing, home elevations and buyouts, and livestock evacuation and sanctuary areas.

In June 2012, local community leaders and representatives of the Confederated Tribes of the Chehalis Reservation and the Quinault Indian Nation met to discuss progress to date in flood mitigation and additional potential flood mitigation projects. One of the primary outcomes of this discussion was an overwhelming sense that policy makers and leaders are interested in a Basin-wide solution for the Chehalis. The draft report discusses potential elements of a Basin-wide solution and provides some potential project combinations to spark additional discussion. In the months to come, the Ruckelshaus Center will facilitate leaders in the Basin as they attempt to craft a comprehensive set of recommendations for Governor Gregoire's consideration and inclusion in her proposed 2013-2014 State biennial budget.

The great success pointed to by many in the Chehalis Basin is the way that neighbors and governments have pulled together to respond during the flood emergencies in 2007 and 2009, and then to cleanup and rebuild. Many now fear that the great tragedy will be if the Basin as a whole cannot identify and band together behind priority flood mitigation projects, with support from the region and state. Future floods will come; based on their history, the residents of the Basin will pull together to respond as they always have. The question people in the Basin are asking now is whether they and their leaders also can pull together to make difficult decisions about how best to invest in Basin-wide flood mitigation for a better future.

I hope you will take the time to comment on the draft report and I very much look forward to your thoughts. Please note that we also are interested in gathering additional personal perspectives on the flooding and the Basin; more stories like the ones in the draft Appendix B would be greatly appreciated.

Respectfully,

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Enc.

Chehalis Basin Flood Mitigation Alternatives Report

*July 16, 2012 — **DRAFT***

Chehalis Basin Flood Mitigation Alternatives Report

JULY 16, 2012 — DRAFT

Unless otherwise noted, all photos in this report are courtesy of *The Chronicle*, Centralia, Washington.

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Executive Summary

Flooding is a common occurrence in the Chehalis River Basin, in southwest Washington. In 2007 and 2009, the Basin suffered two catastrophic floods approximately 18 months apart. Monetary damages from the 2007 flood alone topped $500 million, and the flooding extracted an incalculable physical and psychological toll on the Basin's residents. Flooding is a natural occurrence and supports significant ecological functions that benefit people, fish, wildlife, fish and the ecosystem as a whole. Flooding also can cause disastrous damage to human communities and infrastructure. It is not possible to stop flooding, but it is possible to reduce the negative impacts to human communities.

In 2011, as part of the capital budget (ESHB 2020, Section 1033) the Washington State Legislature required the Office of Financial Management (OFM) to prepare a report on alternative flood damage reduction projects and — in coordination with tribal governments, local governments, state and federal agencies — to recommend priority flood hazard mitigation projects in the Chehalis River Basin for continued feasibility and design work. The purpose of this report is to provide the Washington State Legislature and other decision makers with information to aid their decisions which will set the course for effective solutions to reduce the adverse impacts of flooding in the Basin and, at the same time, support the economic prosperity of communities in the Basin and protection/restoration of fish and other natural resources.

The William D. Ruckelshaus Center, a joint effort of the University of Washington and Washington State University (more information available at www.ruckelshauscenter.edu), is under contract with OFM to coordinate development of the report using technical information provided by other agencies and organizations.

Contents of This Report

In response to the Legislative directive, this report describes the Chehalis Basin, the flooding it has experienced, and work already underway to address flooding impacts, including creation of a hydraulic model for the Chehalis Mainstem, land management activities to control building and new fill in the floodplain, flood proofing, home elevation, and buyout programs, livestock and farm evacuation and sanctuary areas, and the early flood warning program.

Over the years many different flood hazard mitigation approaches have been suggested and studied, and individuals in the Basin have developed perspectives about which projects might be the most effective, based both on studies and their personal experiences with flooding. The potential flood hazard mitigation projects summarized in this report were included based on the Legislative requirements and the current focus of interested parties in the Basin. They are predominately oriented around the Twin Cities area because of the extensive work there by the Corps and state and local governments over the past several decades. Other areas of the Basin have not been analyzed in detail wit h respect to flood relief, such as the areas downstream of the Twin Cities and upstream on the mainstem, South Fork, Bucoda and Napavine.

The report compiles existing information on the potential flood mitigation projects that are being discussed by Basin leaders and decision makers at this time. Potential flood mitigation benefits, adverse impacts, costs and implementation issues are summarized for each project. Projects addressed by this report include:

- A water retention project on the mainstem — multi-purpose dam located upstream of Pe Ell;
- Flood walls to protect Interstate 5 in the Chehalis-Centralia Area and improvements to the levee around the Chehalis-Centralia Municipal Airport;
- Raising/improving the US Army Corps of Engineers levee system around Centralia and Chehalis, the "Twin Cities Project;"
- Numerous other potential construction projects and programmatic approaches such as land use planning, flood proofing, home elevations and buyouts, and livestock evacuation and sanctuary areas.

Projects (and benefit/cost information) are described in Section 3 of the report and, in detail, in the appendices.

There are many projects which do not have cost estimates. These include the floodwater bypasses, Skookumchuck levees, and the Bucoda levee. Projects that currently do not have cost estimates need more analysis of both project scope and impacts and costs. It will be possible to have additional cost information on some of the projects in the next few months.

Chehalis River Basin

Water Retention Project on the Mainstem

A number of potential locations were considered in the early analysis of potential water retention facilities. Although some residents, especially in the Boistfort valley, would still like to see a water retention project on the South Fork, the flood retention project site still under consideration in the Basin is a multi-purpose dam upstream of Pe Ell, on the Upper Chehalis River. The structure would have 80,000 ac-ft of dedicated flood control storage, a structural height of 288 feet, and flow augmentation/ hydropower storage capacity of 65,000 ac-ft. In events such as the December 2007 flood, the dam currently under consideration is predicted to lower flood elevations in the upper watershed by 6-12 feet, by 3-4 feet in the Twin Cities, by 2-3 feet on the Chehalis Mainstem downstream of the Twin Cities, and by almost 2 feet at Montesano.

According to the Anchor QEA Fish Impact Study, a dam could provide flow augmentation during summer months which may increase the number of spring Chinook salmon spawning in the upper mainstem of the river by22%-46%; however, there is not agreement among technical experts about the certainty or extent of these potential benefits. The Anchor QEA Fish Impact study predicts reductions in winter Steelhead populations to be 32%-81%, and reductions in Coho salmon populations are predicted to be 28%-67%, for those fish that spawn in the upper mainstem of the river. These reductions would be largely due to a decreased quantity of habitat and increased percentage of fine sediments downstream of the dam. People who support water retention recommend implementing fish restoration projects like side channel restoration and removal of passage barriers to mitigate these effects. There are significant opportunities to improve fish habitat identified in the Anchor QEA Fish Enhancement Report and the Chehalis Basin Watershed Management Plan. It is not clear how the implementation of restoration projects would fully mitigate and enhance fisheries in the Basin with the impacts of the dam.

Even though the dam would reduce flood elevations, it would not fully protect Interstate 5 under all flood events considered. In events such as the December 2007 flood, the Interstate might still be impacted by minor flooding near the Salzer Creek and Dillenbaugh Creek crossings. Flooding at these locations could be several inches above the low point on the road surface. The on-ramp to Interstate 5 from State Route (SR) 6 would also be flooded to a depth of several feet deep. In an event like the January 2009 flood, which was more significant on the Newaukum/Dillenbaugh system and less so on the mainstem Chehalis River the freeway would still experience flooding at one location on the west side of I-5 north of the 13th Street interchange. In several other locations the floodwaters would be within several inches of the road surface. All of these results assume that in addition to the dam the airport levee is also raised to prevent flooding of the airport area, which would also prevent flooding of the low lying section of I-5 west of the airport. If the airport levee is not raised other measures would be required in this area to prevent flooding of I-5, even with the dam in place.

In summary, based on the studies to date and a technical workshop held May 21 and 24, 2012, a dam on the mainstem would have the greatest reduction of flooding Basin-wide of any project and it also has the highest risk for damage to ecological functions. The monetary calculation of benefits and costs for a dam may change significantly as additional information is developed resulting in either an increase or decrease in the benefit-cost ratio.

Protection of I-5 and the Chehalis-Centralia Municipal Airport

Consistent with the Legislative requirements, WSDOT evaluated a number of projects to provide protection of Interstate 5 and the Chehalis-Centralia municipal airport. These included: raising I-5 using fill material, raising I-5 using a viaduct, relocating I-5 outside the flood area, and protecting I-5 with walls and levees. The fill, viaduct, and relocation projects had cost estimates ranging from $350 million - $2 billion. The I-5 protection option summarized below would use walls and levees to protect the Interstate. It would involve building earthen levees and structural walls, replacing bridges with bottomless arches at Dillenbaugh and Salzer Creek, and providing stormwater treatment systems and has a projected cost of $80-100 million. It would reduce flooding for some homes and businesses and increase it for others.

The airport levee part of the project would raise the existing 2.3 miles of earthen levee to an elevation three feet above the 100 year flood level as recently identified by FEMA. This is accomplished by widening the base of the levee and constructing it higher in a way that maintains existing side slopes. In addition to the improvements to the existing levee, the project would elevate Airport Road along the south side of the Airport and replace all

utility infrastructure. The cost estimate for this project is approximately $3.2 million, with the roadway improvements responsible for the majority of the cost.

Protection of I-5 and the airport provides collateral flood hazard mitigation to homes and businesses in some parts of the Twin Cities and increases flood elevations in some other parts. Based on a preliminary analysis[1], in events such as the 2007 flood, it would completely protect (i.e., make dry) 470 residences and 150 commercial structures and lower flood elevations at 290 more residences and 130 more commercial structures. It would raise flood elevations by 0-1 feet at the Newaukum confluence, Dillenbaugh Creek, and Mellen Street and 1-2 feet along the Airport levee, which would raise flood levels at a total of 120 residences and 30 commercial structures. Flood elevations downstream are predicted to increase by up to 0.1 feet (2007 and 100-year event) and 0.1 to 0.2 feet (1996 event). Increases in flood elevation that would be caused by the I-5/airport project would need to be addressed through mitigation measures such as raising buildings, moving buildings, buyouts, and other measures. Impacts to fish and other natural resources have not been fully assessed and will need to be analyzed in more detail.

US Army Corps of Engineers Levee System around Centralia and Chehalis

In the 1980s, the US Army Corps of Engineers began to evaluate a plan to build 11 miles of new levees in the Chehalis River floodplain through Chehalis and Centralia. The basic plan was authorized for further analysis by Congress as the Centralia Flood Damage Reduction Project ("Twin Cities project"), but not funded for construction. The project evaluated by the Corps included levees on the Chehalis River, the lower 2 miles of Dillenbaugh and Salzer Creeks, and the lower Skookumchuck River.

Work on the Twin Cities project was largely stopped by the Corps in 2011 after it was determined that the proposed project would not have protected Interstate 5 during a 100 year flood event, would have increased flooding upstream and downstream of the Twin Cities and, at a cost of $205 million, would not pass the Corps cost-benefit test. However, there is still interest among some parties in the Basin in reconfiguring and building some of the levees along the Skookumchuck. These levees would decrease flooding in Centralia from the Skookumchuck River that is not solved by other flood projects. The Corps has issued a draft close-out report for the project that has four options for how to proceed. The options include:

- Terminate the project; flood mitigation might be pursued under the Chehalis Basin General Investigation (which would require a local sponsor) or as smaller components under the Continuing Authorities Program (CAP) authority.
- Fully reformulate the project under a General Reevaluation Report.
- Conduct a limited Post Authorization Change Report and remove unjustified separable elements or modify separable elements to a level where they are justified.
- Move forward with a Post Authorization Change Report concurrently with a Basin wide flood risk management study under the Chehalis Basin General Investigation.

[1]WSDOT was asked to provide an estimate of the number of residences and commercial structures that would be affected by different flood mitigation projects in the Twin Cities area. WSDOT is currently in the process of expanding this analysis upstream in the mainstem and may make revisions based on additional hydraulic model runs.

Decisions on how the State of Washington will respond to the Corps close out report will be made as part of the development of recommendations for priority flood hazard mitigation projects in the Basin.

Other Flood Hazard Mitigation Alternatives

In addition to water retention, the Corps levee project, and alternatives to protect Interstate 5 and the municipal airport, there are numerous other alternatives under discussion that could provide flood relief and protection in the Chehalis Basin. These include additional capital/construction projects, such as building floodwater bypasses at Mellen Street and near Scheuber Road, numerous programmatic alternatives such as land use regulation, home elevation, flood proofing and buyout programs, and projects to increase the "natural capital" of the area through improvements to riparian buffers and floodplain function and storage. These projects are described in Appendix A, including, to the extent information is available, descriptions of their potential benefits, adverse impacts, costs and implementation issues.

Potential Flood Mitigation Project Combinations: Large Capital Projects

Because of the complex hydrology and diverse geography and human communities in the Chehalis Basin, no single project can completely alleviate the adverse impacts of flooding. It is likely a combination of projects will be needed to maximize the benefits, address concerns, and resolve implementation issues. Even with combinations of projects, flooding will continue to impact people and property in the Basin. As an example, the proposed dam on the upper mainstem of the Chehalis, while reducing flood scope (the "inundation area") and depth throughout the Basin, would not completely dry up the upper watershed, or reduce flooding enough to reliably prevent overtopping of Interstate 5. Some projects decrease flood elevations in some places, but increase them in others. Some projects cause natural resource or other impacts.

To spark conversation, this report provides an initial set of three example project combinations. The purpose of these project combinations is to show how potential flood mitigation benefits would change if various projects were combined. They are not presented as preferred or recommended options, only as examples; many other possible combinations exist. Each provides a different mix of potential flood mitigation benefits and potential natural resource risks and impacts, and costs.

Combination 1 is made up of the WSDOT floodwalls and berms to protect Interstate 5, the Airport levee improvements, and the Mellen Street and Scheuber Road floodwater bypasses. It also includes a modified concept for Skookumchuck Levees from the Corps Twin Cities project, and modification of the Sickman Ford and Wakefield Road (South Elma) bridges. Combination 1 would reliably protect Interstate 5 and provide some significant collateral flood mitigation benefits in the Twin Cities -- completely drying 680 residences and 230 commercial structures. The targeted bridge modifications and Skookumchuck levee work would provide additional localized flood mitigation benefits in those areas. Combination 1 does not provide flood mitigation in the upper watershed or in the Newaukum, or in the lower watershed or Grays Harbor. The costs for the Skookumchuck levees, bypasses and improvements to Wakefield road/bridge are unknown. The hydraulic model predicts downstream increases of up to 0.5 feet (near Porter Creek Road in the 100-year event) and a range of smaller increases depending on which event and location are looked at. It also predicts reductions of 1 foot or more at some locations (near the downstream bridge replacement projects).

Combination 2 is made up of a dam on the Chehalis Mainstem, the Airport levee improvements, and a small floodwall along I-5 near Dillenbaugh Creek (instead of the I-5 floodwalls and berms), improvements to the Skookumchuck Levees, and modification of the Sickman-Ford and Wakefield Road (South Elma) bridges . Like Combination 1 it also includes improvements to the Skookumchuck Levees, and modification of the Sickman Ford and Wakefield Road (South Elma) bridges. Also, like Combination 1 it does not provide flood mitigation for the Newaukum area, or upstream in the Chehalis River tributaries such as flooding from the Skookumchuck River in Bucoda. Combination 2 is predicted to protect Interstate 5; however, this protection is less certain that that provided by Combination 1 or Combination 3 because floodwaters in a 2007-like event would be within several inches of the road surface.

Because of the dam, Combination 2 would provide significant flood mitigation benefits in the South Fork Chehalis and throughout the mainstem Chehalis including in the Twin Cities where it is predicted to completely dry 700 residences and 210 commercial structures. In a flood such as the December 2007 event, it is predicted to reduce flood levels from 2.7 to 3.4 feet at the Skookumchuck Confluence and upstream of Galvin Road, and from .7 to 3.4 feet from Anderson Road to Wakefield Road.

Combination 3 is made up of a dam on the Chehalis Mainstem, the Airport levee improvements, and flood walls and berms to provide additional certainty about protection of Interstate 5. As with the other example project combinations, improvements to the Skookumchuck Levees, and modification of the Sickman-Ford and Wakefield Road (South Elma) bridges are also included. Combination 3 would provide the most robust flood mitigation of any of the project combinations – providing flood mitigation throughout the mainstem Chehalis including in the Twin Cities from the dam and protecting Interstate 5 with floodwalls and berms. It also is expected to be one of the most costly of the project combinations if the bypasses cost less than the $245 million estimate for the dam.

Outside of the Twin Cities area Combinations 2 and 3 would have very similar benefits to each other, with substantial water surface elevation reductions in most locations. Within the Twin Cities there would be some differences as the I-5 flood walls and levees would cut off some flow paths leaving areas downstream of these protected and areas upstream with slightly higher water levels then if the flood walls were not present. This increases the certainty of protection for I-5 and likely would provide some additional flood mitigation benefits in the Twin Cities areas. These benefits have not yet been quantified. As in project combinations 1 and 2, targeted bridge modifications and Skookumchuck levee work would provide additional localized flood mitigation benefits in those areas.

Considering Trade-Offs between Potential Projects

One of the purposes of the project combinations is to begin to illustrate where large construction projects have the potential to provide flood mitigation benefits and where they, as currently framed, do not, and to spark conversation and comparison about trade-offs between potential projects and combinations.

A dam on the Chehalis Mainstem provides the most flood mitigation throughout the mainstem Chehalis; it also presents the most uncertainty and potential risk to natural resources particularly salmon and steelhead and has the highest cost of those projects that have been estimated. Floodwater bypasses such as at Mellen and Scheuber roads also could provide flood mitigation in the Twin Cities; however they do not provide as much as a dam and they do not address flooding in other areas of the Chehalis mainstem. And, they raise significant questions about impacts to aquatic resources, which would need to be mitigated.

Improvements to the Airport levee and at least some floodwalls will be needed to protect the airport and Interstate 5. This infrastructure is not completely protected by a dam on the Chehalis Mainstem in all storm events considered. Additional certainty for I-5 protection is provided by floodwalls and levees, however these structures raise aesthetic and natural resource concerns.

Local Projects & Programmatic Approaches: Another Way

None of the large construction alternatives currently under discussion address flooding on the Newaukum, or upstream in the Chehalis Tributaries such as flooding from the Skookumchuck River in Bucoda. Flooding in those areas would need to be addressed through identification of local projects and through programmatic efforts such as additional home elevations or buy-outs in the flood plain, flood proofing, livestock and farm pads, and land use management approaches and restoration projects to protect and where possible improve floodplain function and storage. Local projects and programmatic approaches also might be used to amplify the protection provided by large construction projects in Twin Cities and, in the case of a dam, on the Chehalis Mainstem. Policy-makers in the Basin favor continuation and expansion of programmatic approaches as part of a Basin-wide solution.

A very different approach than reliance on major construction projects such as in the three project combinations described above would be to leverage local projects to remove key obstructions in the floodplain and use programmatic changes to address the flood damage. Such an approach could include widening of culverts, bridges, and dikes and levees that cause localized flooding, prohibiting any new development in the flood plain, raising or buying out structures already in the flood plain, improving other land use management practices, and improving forest practices to incentivize longer logging rotations, completing smaller construction projects in localized areas such as the Bucoda levee, and the Centralia-Chehalis airport levee, protecting livestock and farm investment with farm/critter pads, and ensuring effective detour routes around Interstate 5 to accommodate periodic closures during flooding.

This kind of approach would be the less expensive to implement; however the risk of flood damage to existing development in the floodplain would remain. The environmental risks of this approach are relatively low when compared to major construction projects.

Looking Forward

There is a long history of floods and studies in the Chehalis Basin. People in the Basin along with local, state, federal and tribal governments have been very successful in the immediate response and clean up of floods, and have initiated a number of actions to reduce flood damages in the future. There have been significant improvements in the flood warning system and understanding of how different storms affect flooding in the Basin as well as what different projects and programs can do to reduce flood damage. Local actions such as elevating homes, improving land use management and creating evacuation routes for livestock have been taken and continue. Community leaders and other interested parties see that now is the time to make decisions on next steps for the major structural flood mitigation projects and any significant changes to programs that would more dramatically reduce future flood damage. They hope the 2013 Legislature will make decisions on funding for priority projects and programs that build on local actions.

In June 2012, local community leaders and representatives of the Confederated Tribes of the Chehalis Reservation and the Quinault Indian Nation met to discuss progress to date in flood mitigation and additional

potential flood mitigation projects. One of the primary outcomes of this discussion was an overwhelming sense that policy makers and leaders are interested in a Basin-wide solution for the Chehalis. Hallmarks of a Basin-wide solution include:

- Maximize benefits from flood damage reduction projects and minimize negative impacts throughout the Basin;
- Work for everyone in the Basin and not shift impacts from one community to another;
- Include a combination and sequence of projects in different places to address different aspects of the flooding; there are different perspectives on what combinations and sequences of projects are most appropriate.
- Include continued progress on many of the programmatic actions such as land use management.
- Protect and where possible restore floodplain function while acknowledging and working with historical development within the floodplain.
- Do more than simply protect Interstate 5; communities and people beyond the Interstate must be helped too.

The policy-level conversations that took place in June create a starting place for the types of conversations and mutual commitment that will be needed if leaders in the Chehalis Basin are going to successfully come together to take the next steps in significantly reducing damage from floods. During the next four months, the Ruckelshaus Center has been asked by the Governor's Office to continue working with leaders in the Basin to develop a recommended set of priority projects and programs to reduce flood damage. The Governor's office will consider public comments, the final Report and recommendations from Basin leaders to make recommendations for priority flood mitigation projects as part of her biennial budget proposal for 2013/2015. The Governor's budget will be transmitted to the Legislature by the end of 2012.

Comments on the draft report are very welcome and encouraged. ***Please submit comments to melissa.kuehne@wsu.edu or mail to Melissa Kuehne, Ruckelshaus Center, WSU West, 520 Pike Street, Suite 1101, Seattle, WA 98101 by Friday August 10, 2012***. In commenting on the report, it would be helpful to have suggestions for how to improve the information it contains, as well as for what priority projects should be considered and why. Any comments received will be considered as the report is finalized, and included in an appendix in the final report, to become part of the record of this process. The final report will be available in late August/early September.

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Introduction

Flooding is a common occurrence throughout the Chehalis River Basin. Accounts of flooding along the Chehalis, Newaukum, and Skookumchuck rivers, from Pe Ell and Boistfort to Centralia, Elma, Montesano, and Aberdeen have been documented since the time pioneers first settled in Lewis County, and before that by the area's indigenous tribes and nations. Basin residents are practiced at living with flooding and, in many ways, have done so successfully for many years.

"Since the 2007 flood our community in the upper watershed has not been the same, there is a sense of fear that it would happen again. Every time it rains hard, the fear comes back."

Basin resident

According to accounts since the 1930's, minor flooding generally occurs every 2 to 5 years, and major flooding roughly every 10 years. Yet, in 2007 and 2009 the Chehalis Basin was hit with two catastrophic floods approximately 18 months apart. The 2007 and 2009 floods affected all areas of the Basin, destroying homes and farms, killing livestock, and inundating businesses and infrastructure. Families took refuge on rooftops to await rescue. Interstate 5 was closed for days. Damages from the 2007 flood alone topped $500 million.

And, beyond the financial costs, the flooding extracted a physical and psychological toll on residents that is impossible to measure. As one long term resident said, "Since the 2007 flood our community in the upper watershed has not been the same, there is a sense of fear that it would happen again. Every time it rains hard, the fear comes back."

It is clear that actions are needed to better protect people and their livelihoods in the Basin. Many people in the Basin have expressed the need to break the cycle of flood, study, inaction, flood again. They want durable action, and they want it soon. As one resident expressed, "Do something, do it soon, and do it well."

The great success pointed to by many in the Chehalis Basin is the way that neighbors and governments have pulled together to respond during the flood emergencies in 2007 and 2009, and then to cleanup and rebuild. Many now fear that the great tragedy will be if the Basin as a whole cannot identify and band together behind priority flood mitigation projects, with support from the region and state.
Future floods will come; based on their history, the residents of the Basin will pull together to respond as they always have. The question people in the Basin are asking now is whether they and their leaders also can pull together to make difficult decisions about how best to invest in Basin-wide flood mitigation for a better future.

"The extraordinary outpouring [in 2007] of money, time and support from total strangers still chokes me up. I think they and the community fed off each other. We kept working because they were helping and they kept coming because I think they knew they were making a real difference in helping people help themselves."

Dave Fenn, Boistfort Valley Farmer

Goals for This Report

In 2011, as part of the capital budget (ESHB 2020, Section 1033) the Washington State Legislature required the Washington State Office of Financial Management (OFM) to prepare a report on alternative flood damage reduction projects and – in coordination with tribal governments, local governments, state and federal agencies – to recommend priority flood hazard mitigation projects for continued feasibility and design work.

The William D. Ruckelshaus Center, a joint effort of the University of Washington and Washington State University (more information available at www.ruckelshauscenter.edu), is under contract with the OFM to develop the report. The Ruckelshaus Center compiled and synthesized the available information on flooding and flood hazard mitigation alternatives in the Chehalis River Basin for this report; it did not provide additional technical evaluation or information.

In response to the charge from the Legislature, this report will:

- Address the potential for flood mitigation through upstream water retention facilities, including benefits and impacts to fish and potential mitigation of impacts;
- Describe the current alignment and design of federal flood levees proposed at Centralia and Chehalis, including the extent of protection provided to these communities, and any upstream or downstream effects of the levees;
- Evaluate alternative projects that could protect the interstate highway and the municipal airport at Centralia and Chehalis, and ensure access to medical and other critical community facilities during flood events;
- Discuss other alternatives that could provide flood relief and protection in the Basin, such as replacement of highway bridges that constrain floodwaters, flood easements on agricultural lands,

livestock evacuation facilities and routes, small-scale water diversion and retention, use of riparian habitat and environmental restoration projects to mitigate damage from floodwaters, and other projects or programs;

- Summarize the benefits and costs of recommended projects, using available information and accepted benefit/cost methods; and,
- Identify the responsible parties and procedures for making final decisions on funding, construction, and governance of recommended flood projects, any related and necessary government agreements, and a schedule for these decisions.

In response to the Legislative direction, this report is focused mostly on capital projects that can reduce flood damage. There is more information about projects in the Twin Cities area due to the intensive study of flooding in that area over the past several decades; however, there are flooding issues throughout the Basin. In addition fulfilling the Legislative requirements the report is intended to provide the "human face" of the flooding story – and to reflect the sense of history and place of the Chehalis River Basin.

"The visual is nothing like I've ever seen other than my recollection of Mount St. Helens"

Governor Christine Gregoire

The purpose of this report is to provide the Legislature and other decision makers with information to make decisions that set a course for effective solutions to reduce the adverse impacts of flooding and, at the same time, support the economic prosperity of the communities in the Basin, fish, and other natural resources. This report provides current information on the potential flood hazard mitigation projects that are of most interest in the Basin and in support of the requirements from the Legislature. It does not recommend priority flood hazard mitigation projects for continued feasibility and design work. Recommendations for priority projects will be developed in coordination with tribal governments, local governments, state agencies and other interested parties later in the summer and fall of 2012.

Governor Chris Gregoire speaks with Kathy Roberts after the flood of 2007 forced Ms. Roberts to leave her home for the shelter.

Report Review

Comments on this report are encouraged. The deadline for comments is ***Friday, August 10, 2012***. ***Please submit comments to melissa.kuehne@wsu.edu or mail to Melissa Kuehne, Ruckelshaus Center, WSU West, 520 Pike Street, Suite 1101, Seattle, WA 98101 by Friday August 10, 2012.*** Any comments received will be taken into account as the report is finalized and included in an appendix to the final report so they become part of the record of this process. The final report is intended to be available in late August/early September. In

commenting on the report, it would be helpful to have suggestions for how to improve the content of the information, and what priority projects should be considered. More stories, like the ones in the report and in Appendix B, would be greatly appreciated.

In months to come the Ruckelshaus Center will facilitate leaders in the Basin as they attempt to craft a comprehensive set of recommendations for the Governor's consideration and inclusion in the 2013-2014 State biennium budget.

February 1996 Flood Event

The February 1996 flood was the result of a large frontal storm with very broad rainfall from north of Seattle to southern Oregon. It had been extremely cold in the month prior to the storm, and there may have been some low-elevation snow accumulations. The 24-hour rainfall totals ranged from the 10+ year to 100+ year recurrence. At the time, it was the highest flood discharge for all major drainages in the Centralia/Chehalis valley, until the 2007 flood event.

The resulting flood was:

- **Largest observed in the historic record on the Skookumchuck River (71 years) and Newaukum River (71 years)**
- **Second largest observed in the historic record at Grand Mound (82 years), Porter (63 years), and Doty (71 years)**
- **Fourth largest observed in the historic record on the South Fork Chehalis (71 years)**

The total damage costs associated with the February 1996 event are up to $100 million:

- **Major flooding occurred in Grays Harbor, Lewis, and Thurston Counties**
- **Within the Urban Growth Areas of Centralia and Chehalis, 4,855 acres (or 33%) were inundated**
- **Interstate 5 was flooded and closed for four days**
- **75% of the Chehalis Reservation was covered in water, with measured flood depths up to 10'. Access routes including Howanut Road, Anderson Road, and Moon Road were under 1'-4' of fast-moving water, and U.S. Highway 12 was flooded.**

Navigating the Report

The rest of this report is divided into four sections. Section 1 gives a brief overview of the history of flooding in the Chehalis Basin, the different types of floods that are experienced, and types of flood damages. Section 2 describes the Basin. Section 3 describes current and potential future projects and programs to respond to flooding, flood mitigation alternatives, and detailed responses to the six elements required by the Legislature. Section 4 describes conclusions and next steps.

Appendix A provides details of the potential flood mitigation benefits, adverse impacts, and implementation considerations for each flood mitigation alternative under consideration. Appendix B is a compilation of individual stories and reflections on flooding and flood impacts shared by residents of the Basin; we welcome

additional stories for inclusion in the final report. Appendix C is a draft report from the Washington Department of Natural Resources (DNR) on forest practices in the Chehalis Basin, comments on the report, and information about the ongoing scientific debate about the contribution (if any) of forest practices to flooding. Appendix D is a report from the University of Washington Benefit-Cost Analysis Center, evaluating the benefit/cost information available for potential flood mitigation projects in the Chehalis Basin. Appendix E summarizes information provided by Washington State Department of Fish and Wildlife on salmon returns in the Chehalis Basin. Appendix F is a draft report from WATERSHED Science & Engineering (WSE) on the Chehalis Basin Hydraulic Model. Appendix G is a bibliography of the information sources used in preparation of this Report.

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Section 1: The Problem

FLOOD STORY:
Dave Fenn - Boistfort Valley Farmer

My point is there was, and continues to this day, an extraordinary sense of community here. That was proven by the events following the flood and was true also in the Pe Ell, Doty area. By the way, "the flood" now means 2007. There was a community plan in place to respond to an emergency and it worked. The mobilizing of people to help each other was amazing. And then the outside help that arrived kept the locals going through to the end. An example of spontaneous help involved my daughter's family. They live on Ceres Hill Rd. near the confluence of the two forks. I called at daylight to tell them it looked as though the River would be higher than it had ever been and they needed to take their cars and tractor to the hill. They only had time to get to the car, stop and get the 80 something neighbor lady and drive up the hill. A neighbor on the hill took them in for several days, until they were able to clean the house enough to move back in the upstairs.

Dave Fenn (left) buys strawberries from his neighbor, farmer Mike Peroni. Photo by Joshua McNichols.

Then the outside help started arriving. Through donations and locals that had not been flooded, the Grange fed helpers and affected people for months. The Mormon Church sent hundreds, if not thousands, to the area to do the initial cleanup. Then churches and other organizations came for months to assist. The Mennonites had members come from as far as Vanderhoff, B.C. and New York state There were donations from everywhere to help rebuild. I had a church member from Tacoma tell of going to New Orleans to help rebuild and he was stunned by the difference between here and there. In New Orleans they were sitting and waiting for help. Here, everyone immediately had started helping each other begin the rebuilding process.

Even though there is a great sense of community and self reliance here and a heartwarming reaffirmation of the basic sense of human decency from the volunteer help, the flood has had serious consequences on the psyche and economics of the area. Several homes were removed, not to be rebuilt. Some good families moved away. There are potential serious restrictions on a number of homes and farms that may have long term effects on their use and value. Besides the money, people have spent untold hours dealing with cleanup and plans for the future. Flooding is a weight on the shoulders of the community.

1: The Problem

Floods are the most destructive natural hazard in the US, causing more deaths and financial loss in the 20th century than any other natural disaster. In the past 30 years, major flood events have occurred on the Chehalis River and its tributaries in Lewis, Thurston, and Grays Harbor Counties, and in the Chehalis Reservation, in 1972, 1975, 1986, 1990, 1996, 2007, and 2009. The recent 1996, 2007, and 2009 floods caused extensive damage to private property, public buildings, roads, and bridges. Each of the recent floods closed Interstate 5 for days.

"We're very interested in moving ahead. There are a lot of people hurting. We have studied the issue to death."

Ron Averill, Lewis County Commissioner

Flooding in the Chehalis typically occurs during the fall and early winter months, with recent major flooding occurring in February 1996, December 2007, and January 2009. These three floods were among the largest on record, with peak annual flows that rank in the top five at U.S. Geological Survey (USGS) stream gages at the Chehalis River near Grand Mound, Newaukum River near Chehalis, and South Fork of the Chehalis. The gage on the Chehalis River near Grand Mound shows that the five largest peak flows in the past 85 years, all of which exceeded 50,000 cubic feet per second (cfs), have occurred since 1986 (December 2007, February 1996, January 1990, November 1986, January 2009). Significant widespread flooding and damage was associated with each of these events. These data support the perception that flooding has become worse in recent years. With the inclusion of the recent flood data in the historic record, the 100 year flood at the USGS gage at Grand Mound is now estimated to be 77,800 cubic feet per second (cfs). That is 39% higher than the 100 year flood estimate of 56,000 cfs calculated in 1982.

For the people and communities of the Basin, the cumulative psychological and financial impacts of flooding have been tremendous. They are eager to move beyond studies and find a long-term solution to flooding.

Flood Causes and Variability

Flooding in the Chehalis Basin is typically the result of heavy rain events, and, to a lesser degree, rain-on-snow events. The largest floods in western Washington are caused by intense precipitation due to atmospheric rivers or the so-called "Pineapple Express." Atmospheric rivers are generally characterized by relatively narrow bands of concentrated warm, low-level water vapor that produces large amounts of rain when they encounter mountain ranges.

In the Chehalis Basin, the track of an atmospheric river is an important factor in determining the extent and magnitude of floods. When storms are widespread over the Basin, they cause widespread flooding. When storms center over the Willapa Hills, they cause flooding in the upper Chehalis and, as the water moves downstream, throughout the Basin. When storms are centered over the Black Hills and Cascade foothills, they can cause flooding in the Skookumchuck and Newaukum Rivers and locally near the confluence of these rivers with the Chehalis in the Centralia/Chehalis area; however, they generally do not cause major flooding downstream on the Chehalis. Storms over the southern Olympics in the Satsop and Wynoochee Basins can cause flooding in the lower Chehalis, without having much effect in the upper Basin. And, any riverine flood event can be exacerbated by high tides and tidal storm surges at the Grays Harbor estuary, affecting the coastal cities of Aberdeen, Hoquiam, and Cosmopolis. Tidal flooding also can occur in the absence of any significant river flows.

In addition to storm intensity and location, the Chehalis River Basin Comprehensive Flood Hazard Management Plan notes multiple factors that determine the extent and severity of flood damage in the Basin. These include:

- *Time of year*: Flooding in the Basin typically occurs during the fall and early winter months, with recent major flooding occurring between November and March.
- *Flood magnitude and duration*: The severity of floods varies depending on type, spatial extent, and duration of storms. The 1996, 2007 and 2009 flood events in the upper Basin occurred in a timeframe of a week or less, and the duration of flooding will be influenced by soil saturation and other conditions prior to the storm event, as well as the length of the storm event itself.
- *Sediment transport and deposition*: Increased sediment loads due to flooding can result in deposition within active channels, and landslides that block channels and divert flow.
- *Land use/development*: Forestry operations, agriculture production, impervious surfaces, loss of vegetation, and structures and fill in the floodplain can all contribute to higher volumes and peak flows during floods.
- *Obstructions in the channel*: Obstructions include structures such as levees, bridges, and roads, as well as natural obstructions of debris formed during a particular flood event.

Forest practices in the upper portions of the watershed are perceived by some to create or exacerbate floods and flood damage. Some Basin residents speculate that short rotation times for harvest, clear cut practices, and harvest and road building on steep slopes leave an immature forest that is more susceptible to rain on snow events and landslides. These issues are addressed by the Washington State Forest Practices Act, but there is debate as to its success in addressing the issues and there is limited data on the status of the forests in the Chehalis Basin.

Land use management by local cities and counties has been criticized for allowing more development in the floodplain, increasing the number of homes and businesses at risk and worsening the flood damage on existing

homes and businesses. Historically, many of the cities and towns as well as major infrastructure like Interstate 5 were built in the floodplain in the Chehalis, similar to other communities in the Northwest. Except for infill in the cities and towns, new development in the floodplain has largely stopped based on development records and changes to local land use regulations. Under the current regulations in counties and cities in the Basin, there is not expected to be any significant new development of homes and business in the floodplain that would create measurable increases in flood damage.

In an effort to further understand the variability of Chehalis River floods, WSE analyzed data from the top ten annual peaks at the USGS Grand Mound gage (just downstream of Centralia and Chehalis) and the corresponding peaks at major upstream USGS gages, including the South Fork of the Chehalis River at Doty, the Newaukum River, and the Skookumchuck River at Bucoda. A key finding of this analysis is that extreme flood events near Grand Mound are always accompanied by high flows in the Chehalis River headwaters above Doty.[2] WSE made the following observations:

1) A large flow on the Chehalis at Grand Mound has never been observed without a correspondingly large flow upstream on the Chehalis River at Doty.
2) A large flow at Doty is a reliable (although not perfect) indicator of a large flow downstream at Grand Mound.
3) A large flow on the Chehalis at Grand Mound can happen with or without a significant flow contribution from the Skookumchuck River. A large flow on the Skookumchuck is not a very good indicator of large flows downstream at Grand Mound.
4) Peak flows on the Newaukum River and South Fork Chehalis are similarly correlated to the downstream flows at Grand Mound, less so than the Doty flows but more so than the Skookumchuck flows.
5) Major flood events can be isolated on a single tributary or set of tributaries, and not affect the whole Basin. For example, the 1997 flood on the Satsop was the highest flood on record there, but did not cause major flooding anywhere else in the Basin.

To evaluate the efficacy of alternatives against the range of floods observed in the Chehalis Basin, the hydraulic modeling and analysis looked at four flood scenarios: the 1996 event, the 2007 event, the 2009 event, and a hypothetical 100-year flood. Each of these events was focused on a different part of the Basin, so they offer a wide range of conditions for evaluation of flood hazard mitigation alternatives.

[2] Of the top ten flood events in the past 80 years, two occurred in the 1930s when none of the other major USGS gages in the Basin were in operation.

Chehalis River Basin and Communities

December 2007 Flood Event

The December 2007 flood was the result of a classic atmospheric river (or Pineapple Express) event, characterized by heavy rainfall within a fairly narrow focus. The highest rainfall concentrations were in the Willapa Hills in the upper Chehalis Basin, which set records for 24-hour precipitation; the heaviest level of precipitation was actually concentrated in a span of 12 hours or less.

The resulting flood was:

- **Largest observed in the historic record at Grand Mound (82 years), Porter (63 years), Doty (71 years), and the South Fork Chehalis (71 years)**
- **Third largest observed in the historic record on the Newaukum River (71 years)**
- **Only the 55th largest observed in the historic record on the Skookumchuck River**

The total damage costs associated with the December 2007 event are up to $500 million:

- **Major flooding occurred in Grays Harbor, Lewis, and Thurston Counties**
- **Damage from the flood had a disproportionate effect on the upper Basin**
- **Within the Urban Growth Areas of Centralia and Chehalis, 3,708 acres (or 25%) were inundated**
- **In the unincorporated areas of Lewis County, from Pe Ell to Adna, 10,702 acres (or 47%) of the total 22,919 acres zoned agricultural were flooded**
- **Interstate 5 was covered by over 12' of water in some locations, and was closed for four days**
- **Homes in the central area of the Chehalis Reservation were inundated with up to 4' of water. At the east end of the Reservation, water overtopped Anderson Road, and up to 2' of water overtopped US Highway 12, and flowed into the Black River. At the west end of the Reservation, portions of Balch Road were damaged and the east approach to the Sickman-Ford Bridge was overtopped and damaged. Southeast of the Reservation, Independence Road was overtopped.**
- **The Skookumchuck Dam was drawn down at the time of the flood, leaving the reservoir with more available storage than it would typically have. This may have played a role in reducing flood peaks downstream.**

Flood Impacts

Flooding in the Chehalis River causes many impacts, including losses to homeowners and businesses, water pollution from storm runoff and sedimentation, agricultural losses, and damage to public infrastructure.

"You're out there with people you've worked with for 20 years, and you see their livelihood gone."

Lyle Heimbigner, USDA Grays Harbor-Lewis Farm Service Agency

PEOPLE AND HOMES

Millions of dollars in property damage has occurred due to flooding in the Chehalis Basin. Floods have caused countless residents to become trapped in their homes, destroyed sewer and drainage systems, contaminated drinking water supplies, and forced people to evacuate their homes, leaving personal belongings and sentimental possessions to be destroyed. The work needed to rebuild and treat homes damaged by flooding is costly, and the psychological damage to individuals and their families can take years to heal.

"[I remember] the longest night of one's life – working in the dark and the rain to save our animals, equipment and supplies while yelling "Get back in the house!!" to our three small children who 'wanted to help', standing knee deep in our carport, separated from us by 50 yards of rapidly rising flood water; checking the water level every 20-30 minutes until it reached its peak around 3:00 a.m. The pain and sorrow of friends and family – some who lost just a little, and some who lost almost everything, including the desire to go on. The disheartening sights and sounds – helicopters flying back and forth throughout the night rescuing those who were stranded on their rooftops; livestock and pets crying, frantically trying to escape the flood waters."

Julie Balmelli-Powe, Twin Cities resident

"There have been some where people get too hopeless and helpless and the pain of the moment overwhelms them. A lot of times, they're just fatigued, and they're so tired they can't see hope."

Tony Fielder, Red Cross Volunteer

FARMS/AGRICULTURAL LANDS/LIVESTOCK

Flooding and landslides in the Chehalis Basin have led to erosion that has damaged significant amounts of agricultural land. For example, silt and wood debris carried downstream in the 2007 flood was estimated to have affected 4,776 acres of agricultural land, with cleanup costs of over $2.3 million. Other impacts to farms and agricultural lands include lost, injured, or killed livestock, damage to fences, and damage to farm equipment such as loaders and tractors. The Lewis County Health Department counted a total of 1,600 commercial livestock, including 400 dairy cows that were lost in the 2007 flood in Lewis County. Close to $5 million of farm equipment was also damaged in the 2007 flood.

"Tragic stories still haunt us like the farmer who shot his whole bloodline of hand raised registered cattle, that after chasing them up on a hill, had followed him back to the barn where they had always felt safe - to him, shooting them was more merciful than watching them drown; sheep and cows stranded in barns, crawling on top of one another trying to stay above the water, some piles of dead animals reaching as high as the rafters, occasionally a bitter sweet ending with the animal on top surviving."

Julie Balmelli-Powe, Twin Cities resident

BUSINESS

Many businesses have suffered extensive damage to their property and equipment due to flooding, in addition to lost revenue during and after flooding. For some businesses, even if floods did not impact them directly, they may have to support employees who cannot come to work or local suppliers unable to meet their needs. More than 200 businesses were flooded in the 2007 flood. Many of these businesses were not aware of the potential severity of the 2007 flood, and did not have flood insurance, even if they had been flooded previously. The total business costs from the 2007 flood were estimated to be $45 million.

"It completely shut us down."

Darrel Sorenson, President and CEO of Sorensen's Transport Company based out of Chehalis. He estimated $1.5 million in losses from water damage due the overtopped Airport Dike in the 2007 flood, including loss of 12 tractors and a large amount of refrigerated goods.

"Well, 12 years ago we had a flood, and it was 44 inches of water. This year [2007] it's about 78 or 80 inches."

Darris McDaniel, owner of Shop 'n Kart in Chehalis.

TRANSPORTATION

Several bridges and other transportation infrastructure exist in the Chehalis Basin that have been impacted by flooding. In the upper Basin, there are at least 21 bridge crossings, and in the lower Basin, there are a similar number of crossings. The Sickman-Ford Bridge on the Chehalis Reservation and associated approaches in the Basin reduce the floodplain width, which results in a backwater condition during high flows. Road damage in the 2007 flood included $4.5 million worth to Interstate 5 and State Route (SR) 6, and an additional $1.5 million to other

Lewis County roads including SR 7 and U.S. Highway 12. The flood also damaged many logging roads, rail and air infrastructure, the Curtis Industrial Park rail line, railroad bridges, and culverts between the Port of Chehalis and Pe Ell.

INTERSTATE 5

Flooding in the Chehalis Basin has impacted access to Interstate 5 (I-5), closing it for four days in 1996, four days in 2007, and two days in 2009. The Washington Department of Transportation (WSDOT) estimated the total cost of the delays along I-5 in 2007 at $47 million. The major costs from I-5 closure are freight delays, but also include costs to private operating companies from logistical and scheduling costs, and indirect market costs.

January 2009 Flood Event

The January 2009 flood was the result of a major storm in the eastern and northern portions of the Chehalis Basin, and significant rain in the upper Chehalis. The January 2009 event also led to very high flows along the lower Basin tributaries, including the Satsop, Wynoochee, and Black Rivers. In comparison to the 2007 flood, the 2009 event appears to have been a result of more evenly-distributed precipitation.

The resulting flood was:

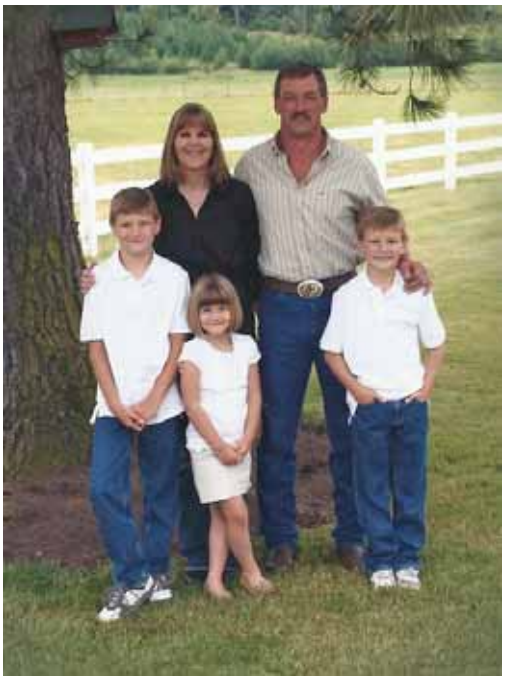
- **Second largest observed in the historic record on the South Fork Chehalis (after 2007) and Newaukum River (after 1996)**
- **Third largest observed in the historic record on the Chehalis River at Porter, Skookumchuck, and Wynoochee Rivers**
- **Fifth largest observed in the historic record at Grand Mound and on the Satsop River**

The total damage costs associated with the January 2009 event are not currently available; however Interstate 5 was flooded and closed for two days.

Section 2: The Chehalis Basin

FLOOD STORY:
Julie Balmelli-Powe – Twin Cities Resident

When I think of the major flood events, there are so many memories. The helplessness of being cut off from everyone you care about, knowing that others are in need, but there is no way to reach them. The debris – everywhere – and I mean everywhere - dead things, yards and yards of plastic, jugs of oils and chemicals, fencing, haylage bales, commercial propane tanks, coolers, childrens' toys, wheels and tires, green house supplies, lumber, trees, piles of brush and dead grass, and lots and lots of garbage and mud – everywhere. The devastation of homes, farms, and businesses—all coated with 'flood mud'. The 'flood mud', like pudding, was in and on everything – crawl spaces, mailboxes and inside homes and outbuildings. Too soft to shovel, too thick to hose out.



Julie's and her family.

During the 2007 flood, one could only imagine the tragedies happening elsewhere, though nothing you imagined was as bad as what really had. Families who the day before were secure in their homes, were now homeless with just the clothes on their backs; horses trying to swim to safety only to get caught in a fence under the water, unable to get free; having to listen to baby calves that were moved to a make-shift critter pad that never flooded before, crying in fear throughout the night, trying to escape the rising flood waters, but unable; and the rescuers who dropped everything to help those in need, only to return to the fire station to find themselves victims of the flood as the cars were now submerged

Yet through all of this, I also remember a feeling of pride and thanksgiving in our communities. The resiliency of the communities, the generosity of friends, neighbors and total strangers willing to go miles and miles out of their way to bring food and supplies to those in need - everyone pitching in, helping out, rebuilding; FEMA employees thinking they were going to be swamped with people wanting their share of government handouts, surprised by how few showed up.

2: The Chehalis Basin

The Chehalis River flows approximately 125 miles, and drains an area of approximately 2,700 square miles in eight counties, including large portions of Grays Harbor, Lewis, and Thurston counties. It is the largest river basin in square-miles contained entirely in western Washington.

The Chehalis begins in the Willapa Hills, relatively low-lying, un-glaciated foothills and low mountains. It follows a relatively low gradient. Along its length, it draws water from three additional ranges: the Black Hills, the Cascade Foothills, and the southern Olympic Mountains. It is bounded by the Pacific Ocean to the west, the Deschutes River Basin and the Cascade Foothills to the east, the Olympic Mountains to the north, and the Willapa Hills and Cowlitz River Basin to the south.

In the upper portion of the Basin, the river valley is narrower and has less natural floodplain capacity. Development and major infrastructure, both Interstate 5 and the main rail lines, cut through the middle of the valley and the river's floodplain. Much of the development has historically occurred in or near the floodplain. The lower Basin below Centralia is less populated, except for Aberdeen, Hoquiam, and Cosmopolis at the Grays Harbor estuary; where the valley is much wider and more predominantly in agriculture.

The total population in the Basin is approximately 140,000, concentrated in four major population centers: Chehalis (7,815) and Centralia (15,570) in the upper Basin, and Aberdeen (16,440) and Hoquiam (8,765) at the mouth of the Chehalis. The Confederated Tribes of the Chehalis Reservation are located near the mouth of the Black River on the mainstem of the Chehalis. The Quinault Indian Nation is located on the southwestern corner of the Olympic Peninsula, in Grays Harbor County. Both Tribes have fished and hunted in the Chehalis Basin from time immemorial.

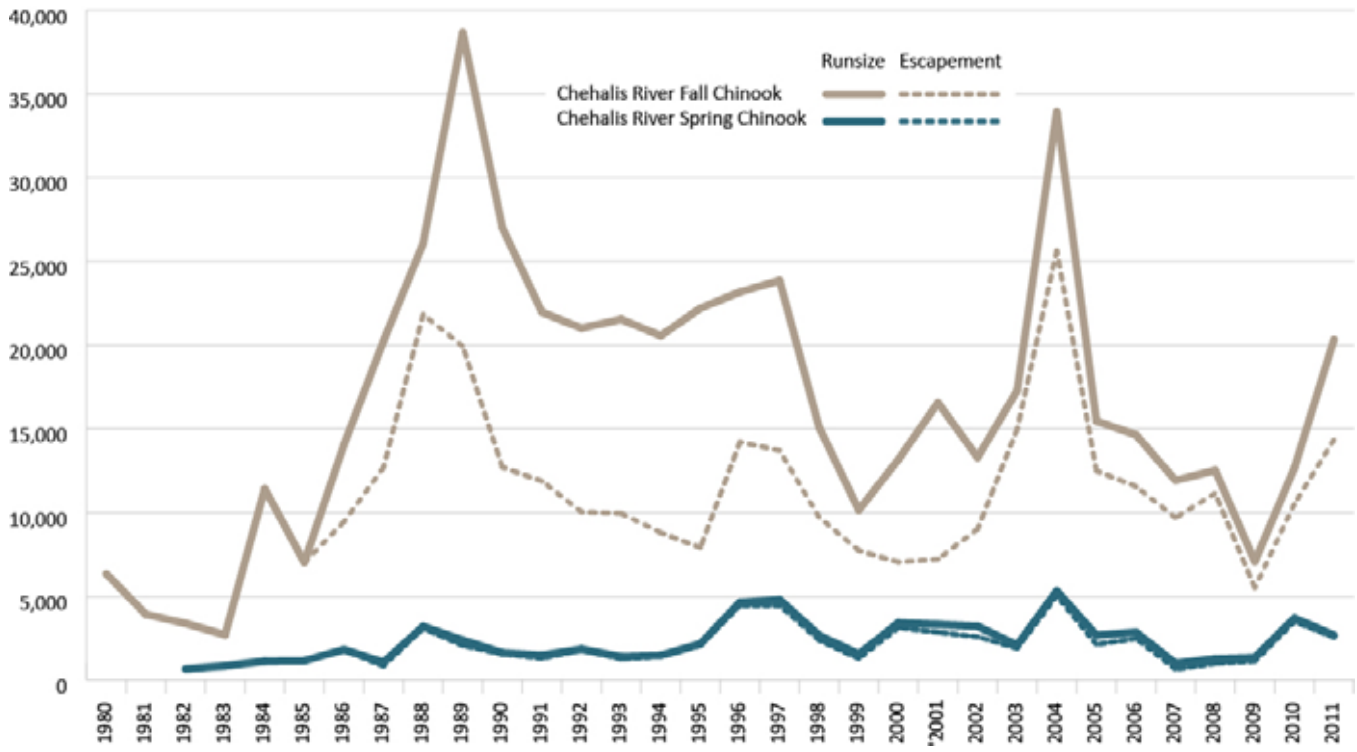
"Special for me in the lower Basin is the natural environment, the forested hills, the wildlife all surrounding and comingling with a very fertile river valley. I have found the people mostly caring and friendly and have enjoyed being accepted as an oddity, an organic direct market farmer in a more traditional livestock based area."

Steve Hallstrom, Farmer

Chehalis River Basin

The natural resources of the Chehalis Basin have supported tribes for centuries and continue to provide value to both the tribal and non-tribal people of the Basin. Farming, forestry, shellfish, and fishing continue to be core to the Chehalis River Basin economy. Salmon, in particular, play a major cultural, recreational, and economic role, and the protection and restoration of salmon habitat is a primary goal for many in the Basin. Exhibit 1 provides a summary from Washington Department of Fish and Wildlife of annual run sizes and spawning escapement numbers for Chehalis River fall and spring Chinook Salmon for the years 1980-2011. Informaiton for Coho, Chum, and Steelhead are included in Appendix E. In 2004, one of the best years for returning salmon in the last decade, tribal and non-tribal fishers in the Basin harvested over 290 spring Chinook, 3,200 Steelhead, 8,200 fall Chinook and 71,000 Coho.

Exhibit 1: Chehalis River Chinook Salmon Runsizes and Escapements, 1980 to 2011



Sub-areas

Flooding affects communities differently throughout the Basin. Factors such as the magnitude and duration of the flood, topography, historic land use patterns, population density, the presence of a major Interstate and other transportation infrastructure, and proximity to the Chehalis River and its various tributaries all play a role in how the people, property, and natural resources of the Basin live with the river and are impacted by floods. To better illustrate these differences, this report divides the Basin into six distinct sub-areas:

- Upper Mainstem
- Newaukum
- Twin Cities
- Skookumchuck
- Lower Mainstem
- Grays Harbor Cities and Tributaries

Upper Mainstem

The Chehalis River begins in the Willapa Hills, the lowest uplands in the Pacific Coast Range, upstream of Pe Ell. The Upper Mainstem area includes the mainstem of the Chehalis River and the South, East and West Forks of the River, upstream of their confluences with the Mainstem. The river begins in a relatively narrow valley, which then broadens out below the town of Pe Ell and on the South Fork at the Lewis County/Cowlitz County line.

The Upper Mainstem area includes the Boistfort Valley and the towns and communities of Pe Ell, Curtis, Adna, Dryad, and Doty. The Willapa Hills, upland reaches of the Upper Mainstem, are dominated by commercial forestry. Agriculture, both dairies and vegetable farms, dominate the fertile lowland river valleys. Agriculture is vibrant in the area, with conventional farms and the recent addition of community supported agriculture (CSA) farms serving markets as far away as Seattle and Portland. The Boistfort Valley, in particular, is home to numerous farms and dairies, several of which have been devastated by flooding.

Photo courtesy of Boistfort Valley Farm

The Upper Mainstem area is highly vulnerable to flooding. Farmers and residents throughout this area have expressed concern that flood peaks along the Chehalis River seem to be rising faster and getting bigger; they are worried that this will continue. As agriculture continues to grow in the valley, some are losing confidence in the infrastructure in place to manage flood events; concern over the ability of farms to sustain repeated losses is growing.

"At this point, you might as well laugh or you'll fall apart. It's just 40 years of your life floating by."

Cindy Dykstra. The Dykstras are dairy farmers in the Boistfort Valley near Curtis and lost their entire heard of 100 Holsteins in the 2007 flood.]

"In terms of the damage from the 2007 floods and our recovery, it's a difficult thing to talk about. We really did lose everything. Close to $80,000 in vehicles alone. Five tractors went under water. Our house was unlivable. Our cooler unit measuring 8'x28' floated away and landed on a car. My shop and tools were ruined and on and on and on."

Mike Peroni. The Peroni's farm Boistfort Valley Farm, a CSA farm in Curtis.

Newaukum

The mainstem of the Newaukum River enters the Chehalis River just south of the City of Chehalis. The headwaters of both the North and South Forks of the Newaukum begin in steep hills and narrow valleys. Flowing west and southwest, these reaches gradually approach a broad, lowland valley where they converge and meander westerly to the Chehalis.

The Newaukum area is located in eastern Lewis County, south of Chehalis and contains the City of Napavine, the third largest city in Lewis County. Napavine is the most rapidly growing city in the County in terms of new home construction and commercial economic structures, such as Love's Truck Stop and the Richie Brother Auction house. The middle and upper portion of this section of the Basin is primarily in private timber management. Agriculture is the primary land use in the broad valley of the lowlands.

"Napavine people are good, the city is well ran and it's a hometown kind of place that people love. Great school system, an in-town fire department, convenience store, barber, hair dresser, many upper end restaurants, gas stations with a brand new hotel being built with a small conference room attached, as well as additional retail space. You are never far away from a good conversation and good friends."

Lionel Pinn, Napavine City Council

Flooding is not a major problem through most of the upper reaches of the North and South Forks of the Newaukum River, but the broad valley in the lower reaches of the South Fork Newaukum River and the mainstem Newaukum River to the Chehalis River are much more susceptible to flood damages. The City of Napavine can be impacted by flooding from both the Newaukum and Chehalis Rivers. The Newaukum is the primary source of flood damage for the City, especially the Exit 72 region of I-5, which is hit the hardest by flood events. This area is home to several businesses and a key tax base for the City. When the Chehalis River reaches capacity during storm events, floodwaters push back on its creeks, streams, and into the Newaukum River, which can also affect Napavine. Local representatives are concerned that, given the right conditions, floodwaters will start to run back up river, from the north back to the south.

Twin Cities

The major population centers in the upper Chehalis River Basin are the "Twin Cities" of Chehalis and Centralia. The Twin Cities population is concentrated along the I-5 corridor in or near the floodplain. The east side of the river has been especially developed. This mostly urban area is the population center of Lewis County, the seat of government, and home to two ports, industrial parks, the first community college in Washington, a hospital, and commercial areas. It is the service center for the surrounding rural areas and a main stop on the route between Seattle and Portland. While natural resource industries used to be the dominant economic driver, communities have slowly been diversifying.

The Newaukum and Skookumchuck Rivers both join the Chehalis River at the Twin Cities. A number of major tributary streams also feed the Chehalis in this area -- Salzer, Coal, Dillenbaugh and Prairie Creeks from the east and Lincoln, Scammon, and Coal creeks from the west.

The people, businesses, farms, and roads of the greater Twin Cities experience some of the most significant flooding and flood damagein the Chehalis Basin. The Chehalis-Centralia Airport and Twin City Town Center both have been covered in water. Floodwaters pool and back up waters into China and Salzer Creek, and the Skookumchuck River, causing I-5 to close in 1996, 2007, and 2009. Other routes into and out of communities are blocked during floods as well, restricting access to the major hospital for days at a time.

"Well, 12 years ago we had a flood, and it was 44 inches of water. This year [2007] it's about 78 or 80 inches."

Darris McDaniel, owner of Shop 'n Kart in Chehalis

"[I remember] arriving home in Centralia from my job in Olympia, before I-5 closed. I remember walking to Safeway and the shelves being empty since shipments could not arrive. I remember walking on the closed freeway, and it seemed almost like a ghost road."

Edna Fund, Centralia City Council

Skookumchuck

The Skookumchuck River rises in the western region of the Mount Baker-Snoqualmie National Forest and flows northwesterly to the town of Bucoda. The mainstem Skookumchuck has a steep gradient from the headwaters to Bucoda, where the gradient lessens significantly as the Skookumchuck makes its way to the confluence with the Chehalis River at Centralia.

The Skookumchuck area is located in northern Lewis County and southern Thurston County. Forestry is the primary land use in the headwaters; agriculture is dominant in the lowland Skookumchuck River Valley.

Most residents of the area are affected by flooding. Flooding closes roads and covers the farmland in the Skookumchuck River valley upstream of Chehalis. Bucoda is periodically inundated by floodwaters from the Skookumchuck, forcing many residents to evacuate their homes and farms. When SR 107 floods, it can isolate the entire town.

The Skookumchuck Dam, which provides cooling water to the Alta Vista power plant, has at times provided limited flood storage upstream of Bloody Run Creek. In the 1996 flood, the Skookumchuck River caused significant damage. In the 2007 and 2009 flood, the pool behind the dam was not full and was able to retain flows, which likely mitigated flood impacts.

"During the 1996 flood, our entire town was almost completed isolated due to flood waters. We were worried that emergency vehicles could not get to us if there was a human tragedy."

Bucoda Mayor Alan Carr

Lower Mainstem

In the Lower Mainstem area, or middle Chehalis Basin, the Chehalis River cuts through coastal hills and its valley forms a boundary between the Willapa Hills to the south and the Black Hills to the north. The Black River meanders gradually over its lowlands before merging with the Chehalis River near Oakville. This section of the Chehalis is largely unconstrained, with limited rip-rapping, channelization, and other flow-control measures.

Located primarily within Grays Harbor and Thurston County, this section of the Basin includes the towns and cities of Grand Mound, Oakville, Porter-Malone, Elma, and Montesano. This area is also home to the Confederated Tribes of the Chehalis Reservation. Upland communities here are focused primarily on commercial forestry. Along the Chehalis River and the lower reaches of the tributaries, a diverse mix of agriculture continues to grow, ranging from dairy and beef cattle, to bulbs and flowers, to vegetables. Low density, rural residential development is scattered along the main river.

Flooding in this part of the Basin regularly affects people, farms, and property. Landslides have at times closed SR 108 and other areas south of U.S. Highways 12 and 8. Flood waters damage city water and sewer lines and other public infrastructure, have covered three-quarters of the Chehalis Reservation, and restricted vital access routes such as Howanut Road, Anderson Road, Moon Road, Highway 12, and Sickman-Ford Bridge.

"Here in the lower valley we appreciate the surrounding hills down to the valley floor; which blends into the perfect setting for industry, logging, farming, residential homes, fishing, hunting, recreation and our beautiful small cities and resourceful people. And all this is away from the hustle-bustle of the big city. Truly, this is what makes America."

Ken Estes, Mayor of Montesano

"They keep getting bigger, higher and more frequent, creating a question in the mind of 'how high will the next one be?'"

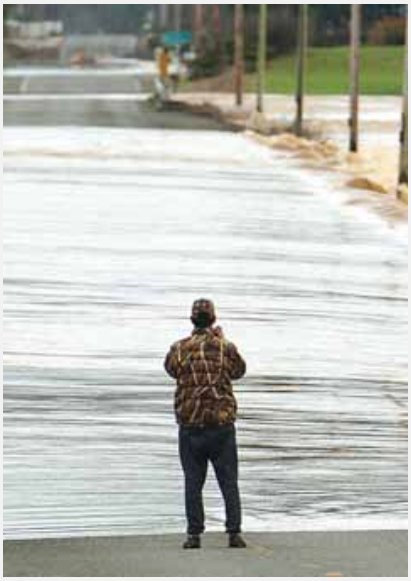
Jay Gordon, Farmer

Grays Harbor Cities and Tributaries

The Chehalis River ends its journey to the Pacific at Grays Harbor. The floodplain widens out, bounded on the north by the Olympic Mountains. This reach contains the Satsop and Wynoochee Rivers, the largest tributaries in the Basin, and other smaller rivers such as the Humptulips, Wishkah, and Hoquiam.

The land throughout this reach of the Basin is predominantly National Forest or commercial forestland. Weyerhaeuser and Cosmo Specialty Fibers are the area's largest employers. As one moves closer into the estuary and the coast, other smaller industrial, retail, tourism, transportation, and marine related jobs support the local economies. Agriculture is expanding in the rich lowland soils and timber and commercial forestry continue to dominate in the hills to the north and south. The cities in this area include Aberdeen, Hoquiam and Cosmopolis.

County officials and residents in the Grays Harbor cities are increasingly concerned about the size and frequency of floods. Past flood events have caused landslides and injuries, closed schools and businesses, virtually isolated the City of Aberdeen, put US 101 under two feet of water, and recently caused a breach in the Mill Creek Dam in Cosmopolis. The lower elevation coastal areas that lie adjacent to rivers in the Grays Harbor area, like Aberdeen and Cosmopolis, are also subject to tidal fluctuations. Storm tides and high tides regularly cause backwater flooding in rivers, and the tidal fluctuations influence river flooding upstream.



"The lower Chehalis Valley is a place where most folks still know their neighbors, the valley floor is kept, tilled, tended and occupied by a small community of farmers, with a few fishermen, loggers and avid hunters. The area has had its share of economic struggles, but most farming and logging communities have, so our challenges are not all that different than other communities. The land has been in agriculture, relatively unchanged the past 50 or 60 years."

Jay Gordon, Farmer

"After catastrophic windstorms [in the December 2007 event] packing 80-plus mile per hour winds, roads in Grays Harbor County looked like they were littered with kindling as power poles, treetops, and branches slammed to the ground."

Lynn O'Conner, Emergency Operations center in Montesano

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Section 3: Responding to Flooding

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3: Responding to Flooding

This section describes the actions already underway to reduce the potential for future flood damage in the Chehalis Basin and options for future flood mitigation actions. Combined benefits of flood control in the Basin can include:

- Avoided costs for damages to residential, commercial, industrial, and agricultural property;
- Avoided emergency assistance costs for flood victims;
- Crop values for some farmers not able to replant their fields the year following a flood;
- Increased residential and commercial property values;
- Avoided infrastructure damages and costs for infrastructure improvement; and,
- Avoided impacts to fisheries habitat and water quality.

The focus of this report is mitigation of damage from major floods such as those that occurred in 1996, 2007 and 2009. There is more information about flood damage and potential flood hazard mitigation projects in the Twin Cities area because that area has been most studied. Flooding in other areas of the Basin is important, and more work is necessary to identify and describe projects needed to address flooding in these areas. A number of the projects and programs described below also could provide benefits for more frequent, smaller flood events. The **objectives for flood hazard mitigation projects, as stated by interested parties in the Basin,** include:

- Protect human health and safety, and protect livestock;
- Reduce or eliminate damage to homes, businesses, and property;
- Protect transportation routes;
- Mitigate environmental impacts;
- Increase watershed health and resiliency;
- Provide cost effective solutions; and,
- Address climate change.

People in the Chehalis River Basin have different ideas about how best to achieve these objectives. Some people are very interested in the large construction projects and the potential they have to provide flood hazard mitigation. Some people are more interested in approaches that emphasize smaller-scale more tailored solutions to local flooding problems combined with working with and improving the natural capacity of the Basin to handle floodwaters through protection and restoration of floodplain function. Some people observe that the investment that may be made in flood hazard mitigation in the Chehalis Basin presents a unique opportunity to look comprehensively across the Basin for projects that achieve multiple benefits – reducing flood hazards and improving watershed health and resiliency.

Work Already Underway

There is significant work already underway in the Basin to mitigate flood impacts, and much of this work has been initiated after the devastating floods of 2007 and 2009. Work already underway includes the following.

- **Creation of the flood authority**. The Chehalis Basin Flood Authority (Flood Authority) was created in response to the devastating flood of December 2007. The Flood Authority's stated purpose is to develop flood hazard mitigation measures throughout the Basin and to identify and implement flood control projects in the Basin.
- **Creation of a hydraulic model for the mainstem**. In the last year a hydraulic model has been created for the whole Chehalis Mainstem from Pe Ell to Aberdeen. The model allows predictions for the first time of the effects of flood mitigation projects throughout the entire Basin.
- **Identification and analysis of potential flood mitigation alternatives**. The Flood Authority has funded numerous studies throughout the Basin to understand the impacts of flooding and to explore potential alternatives to mitigate flood impacts. This includes the Chehalis River Basin Comprehensive Flood Hazard Management Plan (2010), the Earth Economics report on flood protection and ecosystem services in the Basin (2010), and various studies on potential water retention facilities (2010-2012); these recent analyses and reports have significantly narrowed the information gap about how different alternatives might perform in different parts of the Basin and about potential natural resource impacts and costs.
- **Land use and land management to control building and new fill in the floodplain**. City and county governments in the Chehalis Basin have a number of ongoing land use management actions that are intended to mitigate the negative effects of flooding. Most local governments meet or exceed the FEMA and state minimum requirements for restricting development and fill within the floodplain and for ensuring that development which does take place is appropriately flood proofed or elevated. In general, counties prohibit new lots that are wholly in the floodplain; cities allow some infill in the floodplain, but require flood proofing and new homes to be elevated. The requirements for elevation vary from one foot above the base flood elevations (100 year) to several feet above the flood of record (2007). In addition, Chehalis, Centralia, Lewis County and Thurston County participate in the Federal Emergency Management Agency (FEMA) Community Benefit Rating System and Grays Harbor County is considering applying. This voluntary, incentive-based system gives jurisdictions recognition and encourages community floodplain management activities that exceed the minimum National Flood Insurance Program requirements. As a result, flood insurance premium rates are discounted to reflect the reduced flood risks. Figures 1 and 2 summarize land use policies and regulations currently in place in the Basin.

Figure 1: Community Rating Service Scores for Chehalis Basin Communities

		LEWIS COUNTY		THURSTON COUNTY		CENTRALIA		CHEHALIS	
CRS CATEGORY	MAXIMUM POSSIBLE POINTS	POINTS EARNED	%	POINTS EARNED	%	POINTS EARNED	%	POINTS EARNED	%
310 (Elevation Certificates)	162	67	41%	147	91%	127	78%	122	75%
420 (Open Space Preservation)	900	328	36%	352	39%	160	18%	261	29%

		LEWIS COUNTY		THURSTON COUNTY		CENTRALIA		CHEHALIS	
CRS CATEGORY	MAXIMUM POSSIBLE POINTS	POINTS EARNED	%	POINTS EARNED	%	POINTS EARNED	%	POINTS EARNED	%
430 (Higher Regulatory Standards)	2740	391	14%	856	31%	519	19%	402	15%
450 (Stormwater Management)	670	374	56%	531	79%	495	74%	495	74%
520 (Acquisition and Relocation)	3200	100	3%	100	3%	105	3%	264	8%
530 (Flood Protection)	2800	42	2%	84	3%	409	15%	44	2%

Figure 2: Land Use Regulations for Chehalis Basin Communities

		GRAYS HARBOR COUNTY	LEWIS COUNTY	THURSTON COUNTY	ABERDEEN	BUCODA	CENTRALIA	CHEHALIS	MONTESANO	CHEHALIS TRIBES	NAPAVINE
Code Citation		Grays Harbor County Code 18.06	Lewis County Code 15.35	Thurston County Code 14.38	Aberdeen Municipal Code 15.52	Bucoda Municipal Code 15.24	Centralia Municipal Code 16.12	Chehalis Municipal Code 17.21	Montesano Municipal Code 17.40 Article II	Flood Damage Prevention Ordinance, Comprehensive Plan and Zoning Code	Napavine Municipal Code 15.12
Is your community's **floodway boundary definition** more restrictive than FEMA's?		No.	No.	No.	No.	No.	No.	No.	No.	No.	No.
Do you use a more restrictive **floodway development** standard than FEMA's?		No. DRAFT CODE: Yes.	Yes.	Yes.	Yes.	Yes.	Yes.	Yes.	No.	No specification in code.	Yes.
Do you use a more restrictive elevation standard for **development within a floodplain** than the FEMA standard?	*Resi-dential*	No.	Yes.	Yes.	Yes.	Yes.	Yes.	Yes.	Yes. Shoreline Management Act.	Yes.	Yes.
	Non-resi-dential	No. DRAFT CODE: Yes.	Yes.	Yes.	Yes.	No.	Yes.	Yes.	No.	Yes.	Yes.
Do you require a **set-back** from the OHWM?		Yes. Setback is per CAO and SMP.	Yes. Setback is per CAO.	Yes. Setback is per CAO.	No specification in code.	No specificatio n in code.	Yes. Setback is per CAO.	No specificatio n in code.	Yes. Shoreline Management Act.	No specification in code.	No specification in code.
Do you allow **critical facilities** within the 500-year floodplain?		No specification in code.	Yes.	Yes.	Yes.	Yes.	Yes	Yes.	No specification in code.	No specification in code.	Yes.
Do you require all new development in the floodplain to **determine the BFE** if one has not already been determined?		No specification in code.	Yes.	Yes.	No specification in code.	No specificatio n in code.	Yes.	Yes.	Yes, Shoreline certificate required.	No specification in code.	No specification in code.
Do you require new development to be elevated above the **flood of record?**		No.	Yes.	Yes.	No specification in code.	No specificatio n in code.	No specification in code.	Yes. If higher than the BFE.	No specification in code.	No specification in code.	No specification in code.
Do you require an **elevation certificate** for all new construction?		Yes.	Yes.	Yes.	Yes.	Yes.	Yes.	Yes.	Yes.	Yes.	Yes.
Do you use a more restrictive standard for "**substantial damage**" than the 50% required by FEMA?		Yes.	No.	No.	No.	No.	No.	No.	No.	No.	No.
Are there provisions for **compensatory storage** beyond basic NFIP standards?		Yes.	Yes.	No.	No.	No.	Yes.	Yes.	No.	No.	Unsure.

- ***Flood proofing, home elevation, and buyout programs for structures already in the floodplain.*** Flood proofing involves changes to a structure or property using berms, floodwalls, closures or sealants, which reduces or eliminates flood damage to buildings or property. It is used primarily for commercial structures and properties. Homes in the floodplain can be protected by home elevation, in which the structure is anchored against movement by floodwaters, and the first floor of living space, as well as all mechanical services, are at least one foot above the elevation of the 100-year flood. Buyout programs can be used by jurisdictions to acquire properties and structures in the floodplain for eventual removal. Jurisdictions in the Basin have active flood proofing and home elevation programs. For example, the City of Centralia has raised 173 homes inside the city limits and has purchased three properties in the floodplain.
- ***Livestock and farm evacuation areas ("critter pads").*** A critter pad, or livestock flood sanctuary, is an area where approved fill material is used to raise the ground above the base flood elevation to provide a safe place for animals and farm equipment during floods. When flooding occurs, farmers move their livestock onto the pads to keep the animals out of the water's reach. Critter pads generally require special permitting and must be specifically designed to ensure they have a negligible impact on the floodplain. They generally may not be built within the boundaries of a river's floodway. A similar approach can be taken to create a safe area to protect critical farm equipment from flooding. The Thurston and Lewis County Conservation Districts are working with farmers to complete permitting and construction of critter pads in the Basin; at least four critter pads are planned in the upper watershed, Boistfort Valley, and Independence Valley. In addition, analysis is underway in the Grays Harbor area to determine the potential utility of critter pads in that area.
- ***Early Flood Warning Program.*** The Chehalis River Basin Early Flood Warning Program provides a publicly accessible, Internet-based flood data site (Contrail) which compiles and displays real-time data on rain, stream, reservoir, wind, temperature and other weather information. Users can access current conditions in the Basin along with the latest National Weather Service river forecasts, local road closures, and other flood preparedness information. The site also displays flood inundation maps to show where flooding is to be expected at each forecasted river stage.
- ***The DOT Mellen to Blakeslee Bridge Project***. The $155 million Washington Department of Transportation (WSDOT) Mellen to Blakeslee (MTB) junction project, which broke ground in late May, will provide access to medical and other critical community facilities in Centralia during flood events up to the 2007 flood level. The first stage of projects is expected to be completed in spring 2013; the second will begin in the summer of 2013 and finish late in 2014 or early in 2015. The project includes connecting Louisiana Avenue and Airport Road, constructing a "shared use" path for pedestrians and cyclists, and re-constructing the Mellen Street interchange. Another element of the project is the addition of collector-distributor (CD) lanes alongside of the freeway between Mellen Street and Blakeslee Junction. The CD lanes will allow drivers to pass from Centralia to Chehalis without using I-5.
- ***Forest Practices***. Approximately 84% of the land base in the Chehalis River Basin is forestland. Approximately 91% of the forestland is subject to the Washington Forest Practices Act and rules; the remaining forestland is federal or tribal land. Forest management activities such as timber harvest and forest road construction can increase the potential for flood damage unless the activities are controlled to minimize or mitigate adverse effects to these hydrologic cycle components. Washington State has a forest practices regulatory program which prescribes forest management practices to protect public resources such as water, fish and wildlife.

- *Action by individuals*. In addition to government actions to reduce flood damages, individuals throughout the Basin have taken action by flood proofing businesses, elevating homes, and creating evacuation routes and plans for farm equipment and livestock.

Additional Potential Flood Mitigation Projects

Flooding in the Chehalis Basin and potential flood hazard mitigation alternatives has been extensively studied. Beginning as early as the 1930s US Army Corps of Engineers (Corps) reports evaluated flooding in the Basin and potential flood mitigation. WSDOT compiled syntheses reports on Chehalis flooding information in 2008 and again in 2012, and summarized more than 50 major studies since 1948. Since the March 2012 synthesis report was finished four additional studies have become available, including the Anchor QEA Flood Storage Dam Fish Impact Study, the Washington Department of Natural Resources (DNR) draft Chehalis River Basin Forestland Section Report, the University of Washington Benefit-Cost Analysis Center Evaluation of Benefit-Cost Work Regarding Chehalis River Flood Control, and the WSE draft Chehalis Basin Hydraulic Modeling Report. In addition, the Lewis County Conservation District recently completed a Chehalis River Basin Studies Inventory and Evaluation.

"We know that when disaster strikes most of the country goes and sits in shelters and waits for the government to help. But not in Lewis County, because in Lewis County neighbors help neighbors…"

Rep. Richard DeBolt, R-Chehalis, United Way of Lewis County President

Over the years many different flood hazard mitigation approaches have been suggested and studied, and individuals in the Basin have developed perspectives about which projects might be the most effective, based both on studies and their personal experiences with flooding. The potential flood hazard mitigation projects summarized in this report were included based on the Legislative requirements and the current focus of interested parties in the Basin. They are predominately oriented around the Twin Cities area because of the extensive work there by the Corps and state and local governments over the past several decades. Other areas of the Basin have not been analyzed in detail with respect to flood relief, such as downstream of the Twin Cities and upstream on the mainstem, South Fork, Bucoda and Napavine.

Projects are grouped into two types: (1) capital and construction intensive projects that provide relatively large geographic effects, for example, a dam on the mainstem of the Chehalis; and (2) programmatic approaches that provide more individual or localized flood protection benefits, for example, elevating homes in the floodplain or creating farm livestock evacuation areas (so called "critter pads"). Of course, when applied broadly, even the smaller scale, more individual projects can have significant regional benefits and costs. Similarly within the capital and construction-intensive projects there is a wide range of costs. For example, improvements to the airport levee along are estimated at approximately $3.2 million, while construction of a dam upstream of Pe Ell is estimated at $245 million. There are many projects which do not have cost estimates. These include the floodwater bypasses, Skookumchuck levees, and the Bucoda levee. Projects that currently do not have cost estimates need more analysis of both project scope and impacts and costs. It will be possible to have additional cost information on some of the projects in the next few months.

Potential capital and construction-intensive projects include:

- Water retention project on the mainstem -- multi-purpose dam with 80,000 acre feet of dedicated flood control storage and 65,000 acre feet of flow augmentation/hydropower storage, located upstream of Pe Ell;
- Improvements to the levee around the Chehalis-Centralia Airport to raise the levee height to three feet above the 100-year flood level;
- Flood walls to protect Interstate 5 in the Chehalis / Centralia Area including earthen levees and structural walls, replacing bridges with bottomless arches at Dillenbaugh and Salzer Creek, and providing stormwater treatment systems;
- Raising/improving the US Army Corps of Engineers levee system around Centralia and Chehalis, the "Twin Cities Project" which would involve levee systems along the Chehalis River from Dillenbaugh to Salzer Creeks, levees on the lower Skookumchuck, raising some structures, and modification of the Skookumchuck dam;
- Dredging and sediment management to lower the channel bottom by as much as 15' from approximately Mellen Street in Centralia to Lincoln Creek;
- Alleviating constrictions from roads and bridges, including evaluation of SR-6, Mellen Street, Galvin Road, and Sickman-Ford Bridge;
- Floodwater bypass routes/structures near Mellen Street and near Scheuber Road in Centralia and Chehalis, which would provide high-flow routes for floodwater to move past existing development and constrictions; and
- More localized construction projects such as reconfiguration of the Skookumchuck levees to provide protection in the Edison District and other parts of Centralia, and the Bucoda levee.

Potential programmatic actions include:

- Additional land use and land management to control building and new fill in the floodplain;
- Additional flood proofing, home elevation, and buyout programs for structures already in the floodplain;
- Additional livestock and farm evacuation areas ("critter pads");
- Refinements to forest practices to increase water storage capacity provided by mature forests and improve water quality and habitat for fish;
- Improving riparian areas to reduce flood impacts and increase storage and improve habitat for fish;
- Additional bank erosion control to reduce loss of property; and,
- Flood projects in the Lower Chehalis Basin.

Information on the projects was compiled from a variety of available sources, including:

- Anchor QEA Chehalis River Flood Storage Dam Fish Population Impact Study;
- Chehalis River Basin Comprehensive Flood Hazard Management Plan;
- Chehalis River Basin Watershed Management Plan;
- Chehalis River Flood Water Retention Project Phase IIB Feasibility Study;
- Comprehensive Flood Hazard Management Plan for Confederated Tribes of the Chehalis Reservation;
- DNR Draft Chehalis River Basin Forestland Section;
- Flood Protection and Ecosystem Services in the Chehalis River Basin;
- Pacific International Engineering Chehalis River Basin Flood Reduction Report;
- US Army Corps of Engineers Centralia Flood Risk Management Project Draft Close-Out Report;

- Chehalis - Centralia Airport Levee Improvement Project - Preliminary Construction Estimates;
- Preliminary project details and cost estimates from the Washington State Conservation Commission on riparian improvement, bank erosion, and "critter pad" projects;
- Summary information from local jurisdictions in the Chehalis Basin on flood proofing, buyout, and elevation programs;
- Assessment interviews conducted by the Ruckelshaus Center with technical and policy experts throughout the Chehalis Basin;
- Meetings with stakeholders in the lower Chehalis Basin on potential flood mitigation projects in June 2012; and,
- Technical and policy workshops held in the Basin in May and June 2012.

Information on potential flood mitigation benefits was taken in large part from the WSE CHEHALIS HEC-RAS hydraulic model runs that evaluated the performance of each alternative against four individual flood scenarios: the 1996 flood, 2007 flood, 2009 flood, and a simulated 100-year flood.

Appendix A presents a description of each project and summarizes existing information on each project's potential benefits, adverse impacts (such as increased flooding or natural resource impacts), costs, and implementation issues. In addition, the four projects specifically listed in the Legislative charge for this Report are described below.

The Potential for Flood Mitigation through Upstream Water Retention Facilities

A number of potential locations were considered in the early analysis of potential water retention facilities, including locations on the Newaukum River, the Upper Chehalis and the South Fork Chehalis. Based on favorable topography and maximum drainage area, a single purpose flood storage dam and a multi-purpose dam that provides flood control, stream augmentation, and hydropower were further analyzed at a site upstream of Pe Ell on the Upper Chehalis River and a site on the South Fork of the Chehalis River. Although some residents, especially in the Boistfort valley, would still like to see a water retention on the South Fork, the flood retention project site still under consideration in the Basin is a multi-purpose dam upstream of Pe Ell, on the Upper Chehalis River. The structure would have 80,000 ac-ft of dedicated flood control storage, a structural height of 288 feet, and flow augmentation/ hydropower storage capacity of 65,000 ac-ft. In events such as the December 2007 flood, the dam currently under consideration is predicted to lower flood elevations in the upper watershed by 6-12 feet, by 3-4 feet in the Twin Cities, by 2-3 feet on the Chehalis Mainstem downstream of Twin Cities, and by almost 2 feet at Montesano.

According to the Anchor QEA Fish Impact Study, a dam could provide flow augmentation during summer months which may increase the number of spring Chinook salmon spawning in the upper mainstem of the river by22%-46%; however, there is not agreement among technical experts about the certainty or extent of these potential benefits. The Anchor QEA Fish Impact study predicts reductions in winter Steelhead populations to be 32%-81%, and reductions in Coho salmon populations are predicted to be 28%-67%, for those fish that spawn in the upper mainstem of the river. These reductions would be largely due to a decreased quantity of habitat and increased percentage of fine sediments downstream of the dam. People who support water retention recommend implementing fish restoration projects like side channel restoration and removal of passage barriers to mitigate these effects. There are significant opportunities to improve fish habitat identified in the

Anchor QEA Fish Enhancement Report and the Chehalis Basin Watershed Management Plan. It is not clear how the implementation of restoration projects would fully mitigate and enhance fisheries in the Basin with the impacts of the dam.

Even though the dam would reduce flood elevations, it would not fully protect Interstate 5 under all flood events considered. In events such as the December 2007 flood, the Interstate might still be impacted by minor flooding near the Salzer Creek and Dillenbaugh Creek crossings. Flooding at these locations could be several inches above the low point on the road surface. The on-ramp to Interstate 5 from State Route (SR) 6 would also be flooded to a depth of several feet deep. In an event like the January 2009 flood, which was more significant on the Newaukum/Dillenbaugh system and less so on the mainstem Chehalis River the freeway would still experience flooding at one location on the west side of I-5 north of the 13th Street interchange. In several other locations the floodwaters would be within several inches of the road surface. All of these results assume that in addition to the dam the airport levee is also raised to prevent flooding of the airport area, which would also prevent flooding of the low lying section of I-5 west of the airport. If the airport levee is not raised other measures would be required in this area to prevent flooding of I-5, even with the dam in place.

Based on the design work to date by EES Consulting, construction costs for the dam are estimated at $245 million; these costs could increase as design progresses. A benefit-cost analysis (BCA) developed by EES Consulting estimated the monetary benefits of the multi-purpose dam, over a 50-year period, to have a net-present value of $334 million; the estimated monetary costs, over a 50-year period, were predicted to have a net-present value of $296 million, for a Benefit-Cost Ratio of 1.13. A review of the EES's BCA by the University of Washington Benefit-Cost Analysis Center (BCAC) concluded that the analysis is well developed technically and the methodology would be useful as costs and benefits become more certain. The BCAC highlighted the need to assess whether the $80M in additional cost for the multi-purpose dam over the single purpose flood control dam would be the most effective expenditure of funds to achieve the non-flood reduction benefits, or whether spending those funds in other ways for fisheries, recreational and other purposes might gain more benefits.

In summary, based on the studies to date and a technical workshop held May 21 and 24, 2012, a dam on the mainstem would have the greatest reduction of flooding Basin-wide of any project and it also has the highest risk for damage to ecological functions. The monetary calculation of benefits and cost for a dam may change significantly as additional information is developed resulting in either an increase or decrease in the benefit-cost ratio.

The Current Alignment and Design of the Federal Flood Levees Proposed at Centralia and Chehalis

In the 1980s, the US Army Corps of Engineers began to evaluate a plan to build 11 miles of new levees in the Chehalis River floodplain through Chehalis and Centralia. The Corps presented a design to build miles of new levees to the Centralia City Council in 1980. This basic plan was authorized for further analysis by Congress as the Centralia Flood Damage Reduction Project ("Twin Cities project"), but not funded for construction. The project evaluated by the Corps included:

- Construction of a levee system designed to provide protection along the Chehalis River from approximately river mile (RM) 75 to RM 64 and along most of the lower 2 miles of both Dillenbaugh Creek and Salzer Creek.

- Construction of a levee along the lower approximately 2 miles of Skookumchuck River to the confluence with Coffee Creek that would provide 100-year level of protection.
- Raising the elevation of approximately eight structures that would incur induced damages from increased inundation as a result of the project, located near the Airport, Interstate-5, Skookumchuck River, and Salzer Creek.
- Modification of Skookumchuck Dam to provide for an additional 11,000 acre-feet of flood storage. The project would limit outflows from the dam and attempt to keep the flow in the Skookumchuck River Channel at the Pearl Street Bridge at or below 5,000 cfs.

In events such as the 100-year flood, the project was originally predicted to reduce flooding along the Skookumchuck River and drop flood peaks in the Twin Cities area, keeping most of Centralia dry in the Ford Prairie area, Zenkner Valley, and the Edison District. However, considering the updated hydrologic analysis that shows that the 100-year flood is now larger than previously thought, it is now known that the levees would not prevent widespread flooding in a 100-year event and would also not have prevented significant flooding in December 2007. While some locations in Centralia or Chehalis would show reduced flood levels, flood elevations are predicted to increase by up to 1.1 feet at the Newaukum confluence and up to 0.6 feet in other locations on the mainstem Chehalis downstream of the Twin Cities. The project would not protect Interstate 5 from flooding in events such as the 2007 flood or in the 100-year flood event. In addition direct impacts to approximately 35 acres of wetlands and indirect impacts to approximately 235 acres of wetland floodplain and 244 acres of undeveloped non-wetland floodplain were predicted.

The Chehalis Basin Flood Authority website lists a number of municipalities and organizations that passed Resolutions asking that the Twin Cities plan be shelved in favor of the study of upper Basin water retention; they are concerned that the Twin Cities project would not provide a truly Basin-wide solution to provide significant flood reduction for the families and communities in the upper Basin, and that water retention should be the preferred option. Work on the Twin Cities project was largely stopped by the Corps in 2011 after it determined that the proposed project would not have protected Interstate 5 during a 100 year flood event, would have increased flooding upstream and downstream of the Twin Cities and, at a cost of $205 million, would not pass the Corps cost-benefit test. However, there is still interest among parties in the Basin in reconfiguring and building some of the levees along the Skookumchuck in conjunction with other Basin flood reduction projects. The Corps has issued a draft close-out report for the project that has four options for how to proceed. The options include:

- Terminate the project; flood mitigation might be pursued under the Chehalis Basin General Investigation (which would require a local sponsor) or as smaller components under the Continuing Authorities Program (CAP) authority.
- Fully reformulate the project under a General Reevaluation Report.
- Conduct a limited Post Authorization Change Report and remove unjustified separable elements or modify separable elements to a level where they are justified.
- Move forward with a Post Authorization Change Report concurrently with a Basin wide flood risk management study under the Chehalis Basin General Investigation.

Decisions on how the State of Washington will respond to the Corps close out report will be made as part of the development of recommendations for priority flood hazard mitigation projects in the Basin.

Alternative Projects that could Protect the Interstate Highway and the Municipal Airport

Consistent with the Legislative requirements, WSDOT evaluated a number of projects to provide protection of Interstate 5 and the Centralia/Chehalis municipal airport. These included: raising I-5 using fill material, raising I-5 using a viaduct, relocating I-5 outside the flood area, and protecting I-5 with walls and levees. The fill, viaduct, and relocation projects had cost estimates ranging from $350 million - $2 billion. The I-5 protection option summarized below would use walls and levees to protect the Interstate. It would involve building earthen levees and structural walls, replacing bridges with bottomless arches at Dillenbaugh and Salzer Creek, and providing stormwater treatment systems and has a projected cost of $80-100 million. It would reduce flooding for some homes and businesses and increase it for others.

The airport levee part of the project would raise the existing 2.3 miles of earthen levee to an elevation three feet above the 100 year flood level as recently identified by FEMA. This is accomplished by widening the base of the levee and constructing it higher in a way that maintains existing side slopes. In addition to the improvements to the existing levee, the project would elevate Airport Road along the south side of the Airport and replace all utility infrastructure. The cost estimate for this project is approximately $3.2 million, with the roadway improvements responsible for the majority of the cost.

Protection of I-5 and the airport provides collateral flood hazard mitigation to homes and businesses in some parts of the Twin Cities and increases flood elevations in some other parts. Based on a preliminary analysis[3], in events such as the 2007 flood, it would completely protect (i.e., make dry) 470 residences and 150 commercial structures and lower flood elevations at 290 more residences and 130 more commercial structures. It would raise flood elevations by 0-1 feet at the Newaukum confluence, Dillenbaugh Creek, and Mellen Street and 1-2 feet along the Airport levee, which would raise flood levels at a total of 120 residences and 30 commercial structures. Flood elevations downstream of the Twin Cities are predicted to increase by up to 0.1 feet in a 2007 and 100-year flood event, and 0.1-0.2 feet in a 1996 event. Increases in flood elevation that would be caused by the I-5/airport project would need to be addressed through mitigation measures such as raising buildings, moving buildings, buyouts, and other measures. Impacts to fish and other natural resources have not been fully assessed and will need to be analyzed in more detail.

In addition, as described earlier in the section on work already underway, the Mellen to Blakeslee junction project will provide access to medical and other critical community facilities in Centralia during flood events up to the 2007 flood level. It includes connecting Louisiana Avenue and Airport Road, constructing a "shared use" path for pedestrians and cyclists, re-constructing the Mellen Street interchange, and adding collector-distributor (CD) lanes alongside the Interstate between Mellen Street and Blakeslee Junction. The CD lanes will allow drivers to pass from Centralia to Chehalis without using I-5.

Some policymakers and local officials in the Basin have expressed a strong concern over pursuing only I-5 and airport projects, because these projects do not, in their view, offer enough flood mitigation benefits to Basin communities. They are concerned that if Interstate 5 and the airport are protected the momentum for additional flood mitigation actions will dissipate, leaving the communities stranded. Some in the Basin are

[3] WSDOT was asked to provide an estimate of the number of residences and commercial structures that would be affected by different flood mitigation projects in the Twin Cities area. WSDOT is currently in the process of expanding this analysis upstream in the mainstem and may make revisions based on additional hydraulic model runs.

interested in approaches that acknowledge that, as part of living with flooding, I-5 will occasionally be overtopped; they suggest focusing on providing viable and reliable alternative routes for use during major flood events.

Other Alternatives that Could Provide Flood Relief and Protection in the Basin

In addition to water retention, the Corps levee project, and alternatives to protect Interstate 5 and the municipal airport, there are numerous other alternatives under discussion that could provide flood relief and protection in the Chehalis Basis. These include additional capital/construction projects, such as building floodwater bypasses at Mellen Street and near Scheuber Road, numerous programmatic alternatives such as land use regulation, home elevation, flood proofing and buyout programs, and projects to increase the "natural capital" of the area through improvements to riparian buffers and floodplain function and storage. These projects are listed at the beginning of this Section and are described in Appendix A, including, to the extent information is available, descriptions of their potential benefits, adverse impacts, costs and implementation issues.

Crafting a Basin-Wide Solution

In June 2012, local community leaders and representatives of the Confederated Tribes of the Chehalis Reservation and the Quinault Indian Nation met to discuss progress to date in flood mitigation and additional potential flood mitigation projects. One of the primary outcomes of this discussion was an overwhelming sense that policymakers and leaders are interested in a **Basin-wide solution** for the Chehalis. Individuals have different specific ideas about what a Basin-wide solution might look like, but a number of overall themes emerged:

- A Basin-wide solution needs to work for everyone in the Basin. It can't solve one area's problems by making another area's problems worse. Participants talked about every community "giving" something and every community "getting" something through a buffet of projects designed to optimize benefits and resources; and through approaches that maximize benefits and minimize negative impacts throughout the Basin.
- A Basin-wide solution will be a combination and sequence of projects in different places to address different aspects of the flooding. Participants discussed "a host of projects" up and downstream to provide benefits not just during major floods, but also during the many smaller flood events.
- A Basin-wide solution likely will involve continued progress on many of the programmatic actions, including land use management, flood proofing, home raising and buyouts, critter and farm pads, riparian buffers, bank erosion control, and small-scale storage projects.
- A Basin-wide solution is more than simply protecting Interstate 5; communities and people beyond the Interstate must be helped too.
- Historically, development has occurred in parts of the floodplain. Looking forward, solutions should optimize land use planning to prevent development that exacerbates the problem and to maintain, and where possible, improve floodplain function. But it is neither practical nor desirable to move whole cities and critical infrastructure; a Basin-wide solution needs to acknowledge and work with the development already in place.
- No alternatives will stop all flooding; a Basin-wide solution needs to understand that and work with nature.

Participants had different views about the extent to which any of the large construction projects should be part of the Basin-wide solution. Some participants strongly supported a dam on the upper Chehalis because of its ability to reduce flood levels throughout the Basin. These participants feel that the time to move forward with the dam is now, so that the benefits of water retention can be provided as soon as possible. Other participants expressed concern that a dam may not be feasible to permit and fund, and that even if it proved feasible, it might be better to spend the considerable investment in other ways. Some participants, while understanding and supportive of the need to find effective solutions to the damage flooding causes to human communities, were very skeptical of a dam and concerned about the potential for it to adversely affect fish and other natural resources.

"Lewis was Washington's first county in 1843 and its infrastructure has been developing ever since."

Ron Averill, Lewis County Commissioner

Some participants expressed concern about the potential timing of any of the larger, more construction-oriented projects, and the certainty around whether they could be built. Some participants favored approaches that would rely on smaller, more locally-tailored construction solutions, such as specific levee construction or improvement in specific locations, to protect certain neighborhoods and areas that are known to flood and particular bridge removals or improvements to address known constrictions. Participants discussed combining these smaller projects along with programmatic improvements that would continue to protect people and property already in the floodplain, such as land use planning, home elevations and buyouts, flood proofing, and critter pads.

Some participants emphasized the need to take a very long view and to be creative in thinking about what it would mean to successfully mitigate flood damages over the long-term. Some emphasized that flooding always has, and always will, be part of life in the Basin and work should focus on how to better live with the flooding by providing improved warning systems, fixing key health and safety concerns (such as through the current project to maintain access to the hospital in Centralia during floods), and increasing the "natural capital" of the Basin to better handle floodwaters through, for example, floodplain protection and restoration, riparian improvements, forest practice improvements, and small scale storage.

"One of the earliest floods was in November 1887. If there was an easy solution we would have solved it by now."

Edna Fund, Centralia City Council

Participants discussed the need to make sure that any floodwaters that moved out of the upper Basin more quickly were not simply moving adverse impacts downstream. Some participants described approaches that would start in the lower Basin to provide flood mitigation and then move upstream. Participants recognized the special challenges in the lower Basin where the potential combination of floodwaters, storm surges, and high tides could prove catastrophic.

"We were fortunate that the 2007 flood did not come at a time when we also had high tides, or the damage in our end of the Basin would have been much worse."

Vicki Raines, Mayor of Cosmopolis and Chair of Flood Authority]

Many participants favored the idea of combinations of construction, programmatic, and natural capital approaches as a Basin-wide solution to flooding.

Potential Capital and Construction Project Combinations

This Section focuses on potential combinations of some of the large-scale capital and construction projects that are a main focus of the Legislative charge for this report. As discussed above, as part of a Basin wide solution many leaders and policy makers favor approaches that combine large-scale capital and construction projects with programmatic approaches and approaches that improve the natural capacity of the Basin to handle floodwater through floodplain protection and restoration. Some favor programmatic and natural capital approaches instead of (rather than in combination with) large-scale capital and construction projects; an alternative that takes this approach is described later in the report.

Because of the complex hydrology and diverse geography and human communities in the Chehalis Basin, no single project can completely alleviate the adverse impacts of flooding. It is likely a combination of projects will be needed to maximize the benefits, address concerns, and resolve implementation issues; and even with combinations of projects, flooding will continue in the Basin and will continue to impact people and property in the Basin. Even the proposed dam on the upper mainstem of the Chehalis, while reducing flood scope (the "inundation area") and depth throughout the Basin, would not completely dry up the upper watershed, or reduce flooding enough to reliably prevent overtopping of Interstate 5.

This Section describes a number of potential project combinations. The purpose of these project combinations is to show how potential flood mitigation benefits would change if various projects were combined. They are not presented as preferred or recommended options, only as examples; many other possible combinations exist. For some of the projects included in the combinations, such as the I-5 protection alternatives and the Chehalis Mainstem dam, there is information on potential costs, benefits, and natural resource impacts. For other projects, such as the Skookumchuck levees and the floodwater bypasses, there is much less information, and further evaluation would be needed. Costs for these projects have not been estimated and would be significant.

COMBINATION 1 – LARGE CAPITAL FLOOD MITIGATION PROJECTS WITHOUT A DAM

Combination 1 is made up of the WSDOT floodwalls and berms to protect Interstate 5, the Airport levee improvements, and the Mellen Street and Scheuber Road floodwater bypasses. It also includes a modified concept for Skookumchuck Levees from the Corps' Twin Cities project, and modification of the Sickman-Ford and Wakefield Road (South Elma) bridges.

Protection of Interstate 5 and the municipal airport with floodwalls, berms and levees provides collateral flood mitigation for areas of the Twin Cities. It also raises flood elevations in some areas. Floodwater bypasses at Mellen Street and Scheuber Road increase flood mitigation benefits in the Twin Cities and reduce the areas where flood elevations are increased in the Twin Cities. Based on predicted water level reductions, which are shown in Figure 3, in events such as the 2007 flood it is estimated that Combination 1 would completely dry 680 residences and 230 commercial structures and reduce flood elevations at 240 additional residences and 70 commercial structures in the Twin Cities area. Flood levels would be increased at 60 residences and 20 commercial structures, and these impacts would require mitigation. The hydraulic model predicts downstream increases of up to 0.5 feet (near Porter Creek Road in the 100-year event) and a range of smaller increases depending on which event and location are looked at. It also predicts reductions of 1 foot or more at some locations (near the downstream bridge replacement projects).

Figure 3: Combination 1 - Flood Mitigation in Twin Cities Area by Combination 1

	2007			100 YEAR		
CHANGE IN WSEL (FT)	RESIDENCE	COMMERCIAL	TOTAL	RESIDENCE	COMMERCIAL	TOTAL
<-2	330	200	530	210	150	360
-2 to -1	330	50	380	170	70	240
-1 to 0	260	50	310	210	30	240
Sum Decreased Flooding	**920**	**300**	**1220**	**590**	**250**	**840**
0 to 1	50	20	70	30	20	50
1 to 2	10	0	10	0	0	0
>2	0	0	0	0	0	0
Sum Increased Flooding	**60**	**20**	**80**	**30**	**20**	**50**

WETTED VS. DRIED	RESIDENCE	COMMERCIAL	TOTAL	RESIDENCE	COMMERCIAL	TOTAL
Wetted	10	0	10	10	0	10
Dried (Total)	680	230	910	340	170	510
Dried (by Wall Protection)	80	30	110	60	20	80

Notes: 1) Structures with less than 0.1 ft change are not tabulated 2) Structures assumed to be located at centroid of parcel 3) Each structure counted once, regardless of size 4) A single parcel may have multiple structures 5) Wetted vs. Dried structures are not "in addition to" the structures in the Change in WSE tables.

Protection of Interstate 5 with floodwalls would impact some wetland and stream courses, requiring mitigation; in addition residents of the Twin Cities have expressed concerns about floodwalls, both from an aesthetic and from an access point of view. It has an estimated cost of $80-100 million. The Mellen Street and Scheuber Road floodwater bypasses have not been thoroughly evaluated, they may present issues for fish by acting as potential fish "sinks" and issues associated with existing development in the bypass areas. Their costs have not been estimated.

Modifications to the Sickman-Ford and Wakefield Road bridges would address the potential for these structures to constrain floodwaters and provide localized flood mitigation benefits. In past flood events, these bridges have been overtopped or access roads have been inundated. For purposes of this report the potential flood mitigation benefits of bridge modifications were modeled by simply removing the entire bridge and bridge approach fills. This provides an estimate of the maximum possible benefits of bridge work. Creation of new bridges and approach roads, which likely will be desired, are not addressed. Removal of the Sickman-Ford Bridge is estimated to reduce flood elevations in the area immediately upstream of the bridge to the Black River confluence and possibly further. Water surface elevations in the vicinity of the bridge could be reduced by up to 1.3 feet with a complete bridge removal. These would taper out to zero approximately 3 miles upstream. The Chehalis Tribe has evaluated options for changes to the Sickman-Ford Bridge and developed a scope for additional engineering design that is moving forward to provide further evaluation of this project. Removal of the Wakefield Road bridge (South Elma) is estimated to reduce flood elevations by up to a foot or more in the area immediately upstream of the road fill on the right (north) bank floodplain. The road currently acts as a dam impeding flow in the floodplain and causing high upstream water levels. Expanding the size of the overflow

bridge from 300 feet to 1,200 feet would offer localized benefits. The water surface reductions would be up to 0.6 feet at a distance of 4 miles upstream of the bridge in the 100-year event.

Improvements to the Skookumchuck River levees were originally evaluated as part of the Corps Twin Cities Project. A modified proposal might include only improvements to the levees along the lower 2 miles of the Skookumchuck River and the levee downstream of the Skookumchuck River confluence with the Chehalis. To be viable the alternative would need to ensure the levees were raised to a sufficient height to prevent overtopping in the 100-year and/or December 2007 flood events. This alternative project was evaluated using the hydraulic model and found to reduce flood elevations in the Ford Prairie area, Zenkner Valley, and the Edison District by several feet. In combination with the other project elements described above the Skookumchuck levee improvements could be a significant element in a Basin wide flood reduction alternative.

In summary, Combination 1 would reliably protect transportation infrastructure and provide some significant collateral flood mitigation benefits in the Twin Cities -- completely drying 910 residences and commercial structures. The addition of targeted bridge modifications and Skookumchuck levee work would provide additional localized flood mitigation benefits in those areas. Combination 1 does not provide flood mitigation in the upper watershed or in the Newaukum, or in the lower watershed or Grays Harbor. It also does not provide flood mitigation upstream in the Chehalis River tributaries such as Skookumchuck flooding in Bucoda. Flooding in those areas would need to be addressed through identification of local projects (such as the levee under discussion to protect the well field in Bucoda) and through programmatic approaches such as expanded flood proofing, home elevations and buyouts, livestock and farm pads, and riparian and other improvements that protect and restore natural floodplain function.

COMBINATION 2 – ADD A DAM ON THE CHEHALIS MAINSTEM AND REDUCE INTERSTATE 5 WALLS AND BERMS

Combination 2 includes a dam on the Chehalis Mainstem, the Airport levee improvements, and a small floodwall along I-5 near Dillenbaugh Creek (instead of the I-5 floodwalls and berms). Like Combination 1 it also includes improvements to the Skookumchuck Levees, and modification of the Sickman-Ford and Wakefield Road (South Elma) bridges.

Addition of the Chehalis Mainstem dam increases flood mitigation in the Twin Cities area and provides significant flood mitigation in both the upper and lower watershed. It is predicted to reduce flood elevations in the upper watershed by up to 10 feet or more on the mainstem and by up to 6 feet on the South Fork. The flood elevation at the Curtis Store would be decreased by 6.1 feet. Based on predicted water level reductions, which are shown in Figure 4, in events such as the 2007 flood the combination of a Chehalis Mainstem dam and Airport Levee is predicted to completely dry 700 residences and 210 commercial structures and reduce flood elevations at an additional 270 residences and 120 commercial structures in the Twin Cities area. In a flood such as the December 2007 event, it is predicted to reduce flood levels from 2.7 to 3.4 feet at the Skookumchuck Confluence and upstream of Galvin Road, and from .7 to 3.4 feet from Anderson Road to Wakefield Road.

Figure 4: Combination 2 – Flood Mitigation in Twin Cities Area by Combination 2

	2007			100 YEAR		
CHANGE IN WSEL (FT)	RESIDENCE	COMMERCIAL	TOTAL	RESIDENCE	COMMERCIAL	TOTAL
<-2	370	230	600	100	120	220
-2 to -1	400	60	460	330	110	440
-1 to 0	200	40	240	190	40	230
Sum Decreased Flooding	**970**	**330**	**1300**	**620**	**270**	**890**
0 to 1	0	0	0	0	0	0
1 to 2	0	0	0	0	0	0
>2	0	0	0	0	0	0
Sum Increased Flooding	**0**	**0**	**0**	**0**	**0**	**0**

WETTED VS. DRIED	RESIDENCE	COMMERCIAL	TOTAL	RESIDENCE	COMMERCIAL	TOTAL
Wetted	0	0	0	0	0	0
Dried (Total)	700	210	910	270	140	410

Notes: 1) Structures with less than 0.1 ft change are not tabulated 2) Structures assumed to be located at centroid of parcel 3) Each structure counted once, regardless of size 4) A single parcel may have multiple structures 5) Wetted vs. Dried structures are not "in addition to" the structures in the Change in WSE tables.

According to the Anchor QEA Fish Impact Study, a dam on the Chehalis Mainstem could provide flow augmentation during summer months which may increase spring Chinook salmon populations by22%-46%; however, there is not agreement about the certainty or extent of these potential benefits. The Anchor QEA Fish Impact Study predicts reductions in winter Steelhead populations to be 32%-81% and reductions in Coho salmon populations are predicted to be 28%-67%, due largely to a decreased quantity of habitat and increased percentage of fine sediments downstream of the dam. These impacts would need to be mitigated. EES Consulting estimates the cost of the dam at $245 million.

Combination 2 is predicted to protect Interstate 5; however, there is some uncertainty about the protection because water level predictions show water levels a few inches from the road surface in some areas. As in project Combination 1, targeted bridge modifications and Skookumchuck levee work would provide additional localized flood mitigation benefits in those areas.

In summary, because of the dam, Combination 2 would provide significant flood mitigation benefits in the South Fork Chehalis and throughout the mainstem Chehalis including in the Twin Cities where it is predicted to completely dry 910 residences and commercial structures. Like Combination 1 it does not provide flood mitigation in the Newaukum, or upstream in the Chehalis River tributaries such as flooding from the Skookumchuck River in Bucoda. Flooding in those areas would need to be addressed through identification of local projects (such as the levee under discussion to protect the well field in Bucoda) and through programmatic approaches such as expanded flood proofing, home elevations and buyouts, livestock and farm pads, and riparian and other improvements that protect and restore natural floodplain function. Combination 2 is predicted to protect I-5, but this protection is less certain that that provided by Combination 1 or Combination 3 because floodwaters in a 2007-like event would be within several inches of the road surface.

COMBINATION 3 – A DAM ON THE CHEHALIS MAINSTEM AND INCREASE INTERSTATE 5 PROTECTION WITH WALLS AND BERMS

Combination 3 is made up of a dam on the Chehalis Mainstem, the Airport levee improvements, and floodwalls and berms to provide additional certainty about protection of Interstate 5. As with the other two combinations, improvements to the Skookumchuck Levees, and modification of the Sickman-Ford and Wakefield Road (South Elma) bridges are also included. Combination 3 is essentially the same as Combination 1 except the dam on the Chehalis Mainstem is substituted for the Mellen Street and Scheuber Road floodwater bypasses.

As in Combination 2, addition of the Chehalis Mainstem dam instead of the Mellen and Scheuber floodwater bypasses increases flood mitigation in the Twin Cities area and provides significant flood mitigation in both the upper and lower watershed. Outside of the Twin Cities area Combinations 2 and 3 would have very similar benefits to each other, with substantial water surface elevation reductions in most locations. Within the Twin Cities there would be some differences as the I-5 flood walls and levees would cut off some flow paths leaving areas downstream of these protected and areas upstream with slightly higher water levels then if the flood walls were not present.

In Combination 3 additional protection of Interstate 5 would be provided through floodwalls and levees. This increases the certainty of protection for transportation infrastructure and likely would provide some additional flood mitigation benefits in the Twin Cities areas. These benefits have not yet been quantified. As in project combinations 1 and 2, targeted bridge modifications and Skookumchuck levee work would provide additional localized flood mitigation benefits in those areas.

Natural resource impacts from the dam and from impacts to wetland and stream courses from I-5 floodwalls and berms would require mitigation. In addition there may be community concerns from Twin Cities residents associated with floodwalls.

In summary, Combination 3 would provide the most robust flood mitigation of any of the project combinations – providing flood mitigation throughout the mainstem Chehalis including in the Twin Cities from the dam and protecting Interstate 5 with floodwalls and berms. This would be the most costly of the project combinations if the bypasses cost less than the $245M estimate for the dam.

Like Combination 1 and 2, Combination 3 does not provide flood mitigation in the Newaukum, or Bucoda. Flooding in those areas would need to be addressed through identification of local projects (such as the levee under discussion in Bucoda) and through programmatic approaches such as expanded flood proofing, home elevations and buyouts, livestock and farm pads, and riparian and other improvements that protect and restore natural floodplain function.

COMPARISON OF PROJECT COMBINATIONS

One of the purposes of the project combinations is to begin to illustrate where large construction projects have the potential to provide flood mitigation benefits and where they, as currently framed, so far do not, and to spark conversation and comparison about “tradeoffs” between potential projects and combinations.

A dam on the Chehalis Mainstem provides the most flood mitigation throughout the mainstem Chehalis; it also presents the most uncertainty and potential risk to natural resources particularly salmon and Steelhead and has the highest cost of those projects that have been estimated. Floodwater bypasses such as at Mellen Street and Scheuber Road also could provide flood mitigation in the Twin Cities; however they do not provide as much as a dam and they do not address flooding in other areas of the Chehalis mainstem.

Improvements to the Airport levee and at least some floodwalls will be needed to protect the airport and Interstate 5. This infrastructure is not completely protected by a dam on the Chehalis Mainstem in all storm events considered. Additional certainty for I-5 protection is provided by floodwalls and levees, however these structures raise aesthetic and natural resource concerns.

Figure 5: Flood Mitigation Project Combination Comparison Table

	COMBINATION 1	COMBINATION 2	COMBINATION 3
Upper Mainstem	No effect	Significant flood mitigation	Significant flood mitigation
Newaukum	No effect	No effect	No effect
Skookumchuck	Protected by levees	Protected by levees	Protected by levees
Twin Cities	Significant flood mitigation	Additional flood mitigation over Combination A	Additional flood mitigation over Combination A
Lower Mainstem	No effect	Significant flood mitigation	Significant flood mitigation
Grays Harbor	No effect	Some flood mitigation	Some flood mitigation
I-5 and airport protection	Protected by walls and levees	Generally protected	Protected by walls and levees

Local Projects & Programmatic Approaches: Another Way

None of the large construction alternatives currently under discussion address flooding on the Newaukum, or upstream in the Chehalis Tributaries such as flooding from the Skookumchuck River in Bucoda. Flooding in those areas would need to be addressed through identification of local projects (such as the levee under discussion in Bucoda) and through programmatic efforts such as additional home elevations or buyouts in the floodplain, flood proofing, livestock and farm pads, and land use management approaches and restoration

projects to protect and where possible improve floodplain function and storage. Local projects and programmatic approaches also might be used to amplify the protection provided by large construction projects in Twin Cities and, in the case of a dam, on the Chehalis Mainstem. Policymakers in the Basin favor continuation and expansion of programmatic approaches as part of a Basin-wide solution.

A very different approach than reliance on major construction projects such as in the three project combinations described above would be to leverage local projects to remove key obstructions in the floodplain and use programmatic changes to address the flood damage. Such an approach could include:

- Widening of culverts, bridges, and dikes and levees that cause localized flooding, such as the Adna Levee/Culver project, the Sickman-Ford Bridge project, and the Satsop River project.
- Programmatic options such as maintaining the early warning system, prohibiting any new development in the floodplain, raising or buying out structures already in the floodplain, improving other land use management practices, and improving forest practices to incentivize longer logging rotations.
- Completing smaller construction projects in localized areas such as the Bucoda levee, and the Centralia-Chehalis airport levee
- Protecting livestock and farm investment with farm/critter pads.
- Ensuring effective detour routes around Interstate 5 to accommodate periodic closures during flooding.

This kind of approach would be the least expensive to implement; however the risk of flood damage to existing development in the floodplain would remain high. The potential for this kind of approach to harm fish and wildlife is low, and it has some potential to, through restoration of floodplain function and riparian areas, improve the resilience and function of the ecosystem.

Benefit-Cost Analyses in the Chehalis Basin

One of the requirements of the Legislature is that this Report summarize the benefits and costs of recommended projects, using available information and accepted benefit/cost methods. To meet this requirement, the Benefit-Cost Analysis Center (BCAC) at the University of Washington (http://evans.washington.edu/research/centers/benefit-cost-analysis/) analyzed existing benefit-cost analyses (BCAs) related to various proposed alternatives for mitigating flood damage in the Chehalis River Basin. The main objective was to review the existing BCAs and available data in terms of strengths, barriers to decision-making, and comparability to different flood mitigation alternatives that have not had a formal BCA. A draft report of findings is provided in Appendix D.

The existing reports on the Chehalis Basin that were analyzed include:

- Anchor QEA - Chehalis River Flood Storage Dam Fish Population Impact Study
- EES Consulting - Chehalis River Flood Water Retention Project Phase IIB Feasibility Study
- Earth Economics - Flood Protection and Ecosystem Services in the Chehalis River Basin
- US Army Corps of Engineers - Centralia Flood Risk Management Project Draft Close-Out Report

The BCAC found that the existing BCAs for projects in the Chehalis Basin provide a solid framework for policymakers and other stakeholders to base decisions on the subjects of these BCAs and to conduct qualitative evaluations of benefits and costs for alternative projects in the Basin that have not had a formal BCA. This is because they provide clear causal linkages between costs and resultant project benefits, and use detailed flood damage assessment methodologies. For these reasons, flood model and damage estimates produced by EES can

be used as a basis for considering the flood prevention or mitigation value of other alternatives. Policymakers and stakeholders can use these estimated damages as a guide for thinking about what the returns to other projects might be as well. The report also found that the prior BCAs provide clarity in relation to assumptions and methods. This helps establish a framework for discussing points of disagreement in the various findings and allows stakeholders to explore the implications of differing assumptions in the models.

Specific to the water retention facility the BCAC confirmed that the methodology used in the EES BCA is appropriate and the assumptions are reasonable. They also pointed out there are a significant number of assumptions in the analysis that have a high level of uncertainty like the total cost of the project, impact on fisheries and mitigation costs. These uncertainties can affect the final conclusion of the benefit cost ratio and should be revisited as more information is available.

BCAC highlighted several other issues that must be taken into consideration when making inter-project comparisons. First, while BCA is an attempt to maximize social welfare and identify the most efficient projects, it does not take into account factors such as equity or security which may be important considerations for decision-makers. Second, while the existing BCAs provide useful baseline comparisons, they are for individual projects, and do not reflect future changes in the Basin that will happen regardless of if a particular project is implemented (for example, taking into account how continued home elevations, bank erosion control projects, or other smaller scale projects would affect the benefits or costs of large-scale projects like the WSDOT improvements to I-5 or water retention). Third, it is important to consider both net benefits and the benefit-cost ratio of projects. While a project may have a higher benefit-cost ratio than others, the net benefits it provides may be significantly less. Lastly, the report highlights the importance of properly reflecting uncertainty. Summarizing a project using a single point estimate, such as a benefit-cost ratio, is insufficient because it does not adequately reflect the full range of potential outcomes. Each of these findings is more fully explained in Appendix D.

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Section 4: Conclusions and Next Steps

As part of the effort to report on potential flood mitigation projects and alternatives in the Chehalis Basin, over 25 individual and project-combination alternatives were modeled against 4 potential storm events (storm types) generating over 120,000 points of information. Flood control and mitigation has been actively studied in the Basin since at least the 1930s. While there is a wealth of information, data and studies, critical information is still needed for some potential projects (such as the Skookumchuck levees) and programs to more precisely understand potential benefits and costs. Some projects have been studied intensively; others are just ideas. Flooding hazards in the Basin is like many systemic issues facing a community—there is no solution that solves the problem once and for all; and, of course flooding also is a natural occurrence one that has benefits for fish, wildlife and watershed function.

For now we have:

- Clear information about the major causes of the flooding and different types of storm events and floods. ,
- A more robust system for flood warning and flood response.
- A significant and ongoing effort by local governments in the Basin to limit increases in flood damage through land use management.
- Identification of the major construction projects of interest in the Basin that have the potential to further reduce flood damage to human communities; although more information is needed for all of them, the policy choices they present are clear. Decisions can be made on what to pursue based on their potential benefits, costs and risks.

There are different ideas about how best to achieve flood hazard mitigation. Some people are very interested in the large construction projects and their potential. Some people are more interested in approaches that emphasize smaller-scale more tailored solutions to local flooding problems combined with working with and improving the natural capacity of the Basin to handle floodwaters through protection and restoration of floodplain function. Some people are focused on using flood hazard mitigation investment as an opportunity to look comprehensively across the Basin for projects that achieve multiple benefits – reducing flood hazards and improving watershed health and resiliency. Many people seem open to parts of all of these points of view and are looking for combinations of projects that can most effectively and reliably provide protection to the most people in the Basin.

Residents, leaders and policymakers want to break the cycle of flood, study, fail to take action, flood, and study again that has been the history so far in the Basin. It is clear from the policy workshop in June 2012 that leaders want to work together to take action. The conversations that took place in June create a starting place for the types of conversations and mutual commitment that will be needed to take the next steps in successfully addressing flooding in the Basin.

The Ruckelshaus Center has been asked to continue working with leaders in the Basin to develop a recommended set of priority flood hazard mitigation projects for the Chehalis. In months to come the Ruckelshaus Center will facilitate leaders in the Basin as they attempt to craft a comprehensive set of recommendations for the Governor's consideration and inclusion in the 2013-2014 State biennium budget.

This report will be finalized in support of the ongoing projects to identify priority flood hazard mitigation projects for the Chehalis Basin. Comments on the draft report will be taken into account as the report is finalized and included in an appendix to the final report so they become part of the record of this process. The final report is intended to be available in late August/early September.

APPENDICES

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Appendix A: Flood Mitigation Alternatives – Project Descriptions

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Appendix A: Flood Mitigation Alternatives – Project Descriptions

This appendix provides details of the potential flood mitigation benefits, adverse impacts, and implementation considerations for each flood mitigation alternative under consideration; alternatives selected were based on the current focus of interested parties in the Basin. Projects are grouped into two types: (1) capital and construction intensive projects that provide relatively large geographic effects, for example, a dam on the mainstem of the Chehalis; and (2) programmatic approaches that provide more individual or localized flood protection benefits, for example, elevating homes in the flood plain or creating farm livestock evacuation areas (so called "critter pads"). Of course, when applied broadly, even the smaller scale, more individual projects can have significant regional benefits and costs. Similarly within the capital and construction-intensive projects there is a wide range of costs, for example, improvements to the airport levee along are estimated at approximately $3.2 million while construction of a dam upstream of Pe Ell is estimated at $245 million.

Potential large-scale, construction-intensive projects include:

- Water retention project on the mainstem (a dam upstream of Pe Ell);
- Localized I-5 protection and airport levee improvements;
- Flood walls and levees to protect Interstate 5;
- Raising/improving the US Army Corps of Engineers levee system around Centralia and Chehalis;
- Dredging and sediment management;
- Alleviating constrictions from roads and bridges; and,
- Flood water bypass routes/structures near Mellen Street and near Scheuber Road in Centralia and Chehalis.

Potential smaller-scale projects and programmatic actions include:

- Additional land use and land management to control building and new fill in the floodplain;
- Additional flood proofing, home elevation, and buyout programs for structures already in the floodplain;
- Additional livestock and farm evacuation areas ("critter pads");
- Refinements to forest practices to increase water storage capacity provided by mature forests and improve water quality and habitat for fish;
- Improving riparian areas to reduce flood impacts and increase storage and improve habitat for fish;
- Additional bank erosion control to reduce loss of property; and,
- Flood Projects in the Lower Chehalis Basin.

Information on the projects was compiled from a variety of available sources, including:

- Anchor QEA Chehalis River Flood Storage Dam Fish Population Impact Study;
- Chehalis River Basin Comprehensive Flood Hazard Management Plan;
- Chehalis River Basin Watershed Management Plan;
- Chehalis River Flood Water Retention Project Phase IIB Feasibility Study;
- Comprehensive Flood Hazard Management Plan for Confederated Tribes of the Chehalis Reservation;
- DNR Draft Chehalis River Basin Forestland Section;
- Flood Protection and Ecosystem Services in the Chehalis River Basin;
- Pacific International Engineering Chehalis River Basin Flood Reduction Report;
- US Army Corps of Engineers Centralia Flood Risk Management Project Draft Close-Out Report;
- Chehalis - Centralia Airport Levee Improvement Project - Preliminary Construction Estimates;
- Preliminary project details and cost estimates from the Washington State Conservation Commission on riparian improvement, bank erosion, and "critter pad" projects;
- Summary information from local jurisdictions in the Chehalis Basin on flood proofing, buyout, and elevation programs;
- Assessment interviews conducted by the Ruckelshaus Center with technical and policy experts throughout the Chehalis Basin;
- Meetings with stakeholders in the lower Chehalis Basin on potential flood mitigation projects in June 2012; and,
- Technical and policy workshops held in the Basin in May and June 2012.

Capital and Construction-Intensive Projects

The projects summarized here are relatively large-scale capital and construction intensive projects that provide relatively large geographic effects, for example, a dam on the mainstem of the Chehalis. Each project includes a brief description in terms of project details and background, as well as a separate discussion of potential benefits, concerns and implementation issues.

Information on potential flood mitigation benefits was taken in large part from WSE CHEHALIS HEC-RAS hydraulic model runs that evaluated the performance of each alternative against four individual flood scenarios: the 1996 flood, 2007 flood, 2009 flood, and a simulated 100-year flood.

WATER RETENTION PROJECT ON THE MAINSTEM CHEHALIS RIVER

Following the severe flood in 2007, the Chehalis Basin Flood Authority began to evaluate whether flood retention structures in the Chehalis River Basin might be part of a solution to basin-wide flooding. This built on early work by the US Army Corps of Engineers and the Lewis County Public Utilities District. After reviewing several sites, the flood retention project site under consideration is a multi-purpose dam located upstream of Pe Ell on the Upper Chehalis River. The structure would have 80,000 ac-ft of dedicated flood control storage, a structural height of 288', flow augmentation/hydropower storage capacity of 65,000 ac-ft, and an estimated construction cost of $245 million (EES Phase IIB). Based on recent model results from the CHEHALIS HEC-RAS model, the multi-purpose dam would need to be combined with improvements to the Airport Levee and a section of I-5 north of the 13th Street interchange to achieve the benefits estimated in the EES Phase IIB study. A single-purpose flood storage structure has also been examined, but does not have the added benefit to fish and wildlife of providing additional water flow and cooler instream temperatures from water pulled from deeper parts of the reservoir during the summer months, to mitigate environmental impacts.

What are the potential benefits of the water retention facility?

- The CHEHALIS HEC-RAS model predicts that in a simulated 100-year flood the project lowers flood elevations in the upper watershed 4-10 feet, 2-3 feet in Twin Cities, 1-2 feet at other locations on the mainstem downstream of the Twin Cities, and 0.8 feet at Montesano.
- The CHEHALIS HEC-RAS model predicts that in the 2007 flood the project lowers flood elevations in the upper watershed 6-12 feet, 3-4 feet in Twin Cities, 2-3 feet at other locations on the mainstem downstream of the Twin Cities, and 1.8 feet at Montesano.
- The Anchor QEA model predicts a 122%–146% increase in spring Chinook abundance, if the dam is operated to maximize fish habitat through water releases.
- The Anchor QEA model predicts flow augmentation in the summer months can enable higher concentrations of dissolved oxygen, leading to improved productivity of the Chehalis River system.
- The Anchor QEA model predicts the additional 65,000 acre-feet of storage can be used for controlled release in the summer, to improve water temperature.
- Some technical experts indicate that the water retention facility would address local concerns about higher and faster flood peaks in the upper watershed during the 2007 flood in particular.
- The project would provide capacity to manage for changing climate conditions by providing storage for both high and low flows.

- A benefit cost analysis by EES Consultants estimated a significant benefit to the upper watershed and Twin Cities area. The Chehalis HEC-RAS model predicts reductions in flood elevations downstream to Aberdeen. The benefit resulting from reductions in downstream flood elevations has not been calculated but would increase the benefit above what was calculated by EES in the IIB Study.

What are the potential concerns associated with the water retention facility?

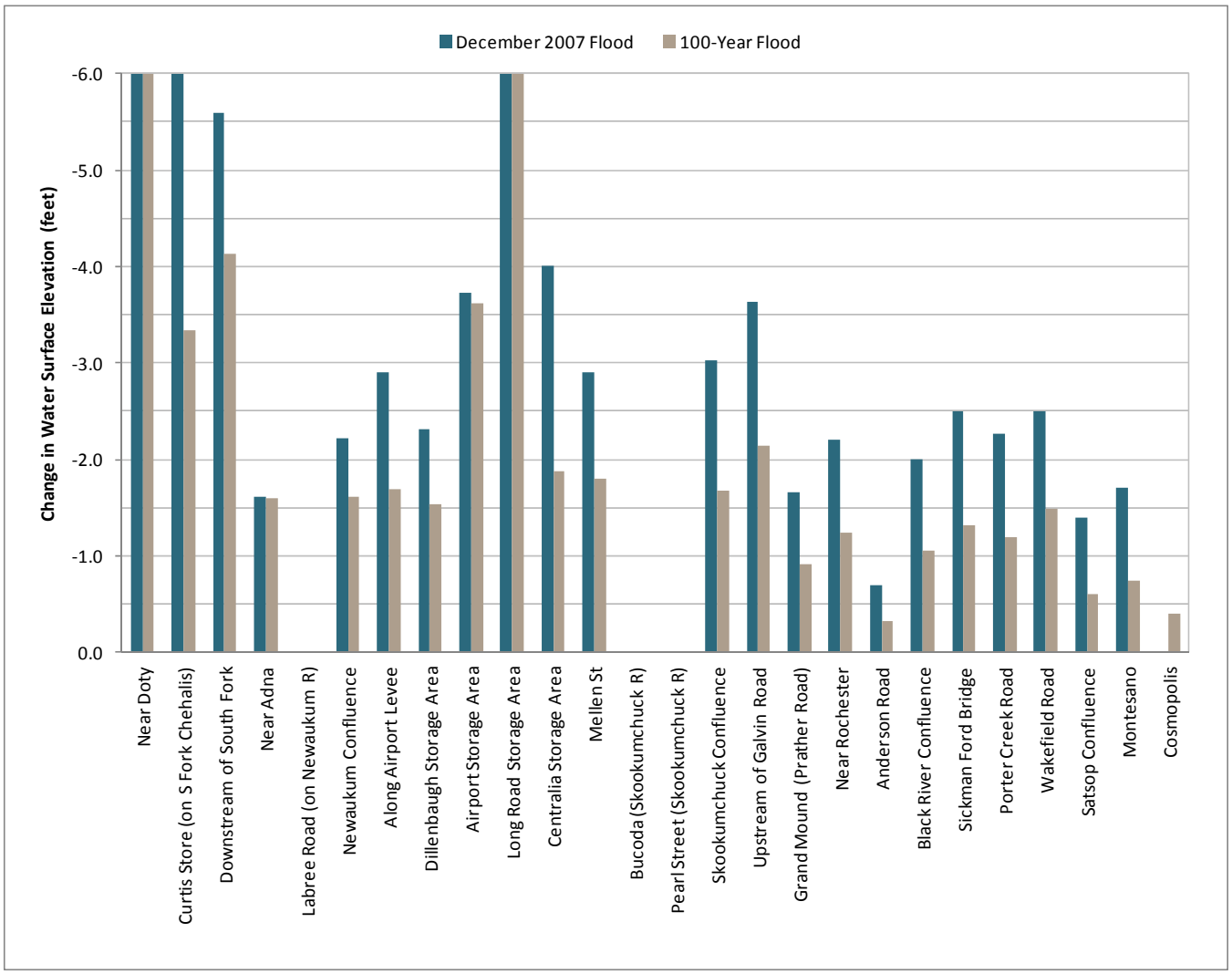
- The CHEHALIS HEC-RAS model predicts that in extreme storm events like 1996, 2007 or 2009, the proposed dam alone would not completely prevent flooding to I-5, particularly in areas near the Chehalis-Centralia airport and along Dillenbaugh Creek. In several areas flood waters in a 2007 event would be only a few inches from the roadway surface. Additional projects would have to be combined with the dam to completely prevent I-5 flooding.
- The Anchor QEA model predicts a 28%–81% reduction in winter steelhead and coho salmon populations.
- DFW staff have commented that the Anchor QEA model may not accurately reflect uncertainties about spring Chinook juvenile rearing behavior, adaptation timing, predator response, and the effect of optimized water releases downstream of the proposed site. They also commented that a dam could have negative effects on spring Chinook populations in the short and long terms.
- Mitigation of fisheries and other environmental impacts could significantly increase the cost of the dam.

What are the potential implementation issues for a water retention facility?

- There is limited federal funding for new large scale projects like water retention and the project would have to show a benefit/cost ratio of greater than one to be eligible for federal funding under the Water Resources Development Act, which the EES analysis estimates it would.
- Project design is still in early phase and cost estimates may change significantly.
- There is a need for significant additional technical and design work if the project moves forward, including for fish passage facilities.
- The process for approval and construction of a dam can take 8–15+ years, with many opportunities for challenge by opponents.

Table 1 describes the effect of the potential mainstem dam, in terms of changes in water surface elevation, at various USGS stream gages in the Chehalis Basin in a December 2007 and 100-year flood event.

Table 1: Effect of Potential Mainstem Dam Flood Relief Alternative



LOCALIZED I-5 PROTECTION AND AIRPORT LEVEE IMPROVEMENTS

Over the past few years the Chehalis-Centralia Airport has been working on a project to enhance the Airport Levee. The airport levee enhancement project is designed to provide protection for the Airport and, to a lesser degree, I-5.

The airport levee project would involve raising the existing 2.3 miles of earthen levee to an elevation three feet above the 100 year flood level as recently identified by FEMA. This is accomplished by widening the base of the levee and constructing it higher in a way that maintains existing side slopes. In addition to the improvements to the existing levee, the project would elevate Airport Road along the south side of the Airport and replace all utility infrastructure. The cost estimate for this project is ~$3.2 million, with the roadway improvements responsible for the majority of the cost. However, to achieve protection of the airport area in a 100-year event, some additional localized flood protection improvements would be needed along I-5 north of Salzer Creek and south by Dillenbaugh Creek.

What are the potential benefits of the Airport Levee Improvements?

- Improvements to the levee would protect the airport and business along I-5 from flooding during a 100-year flood event, if combined with other projects.

What are the potential concerns associated with the Airport Levee improvements?

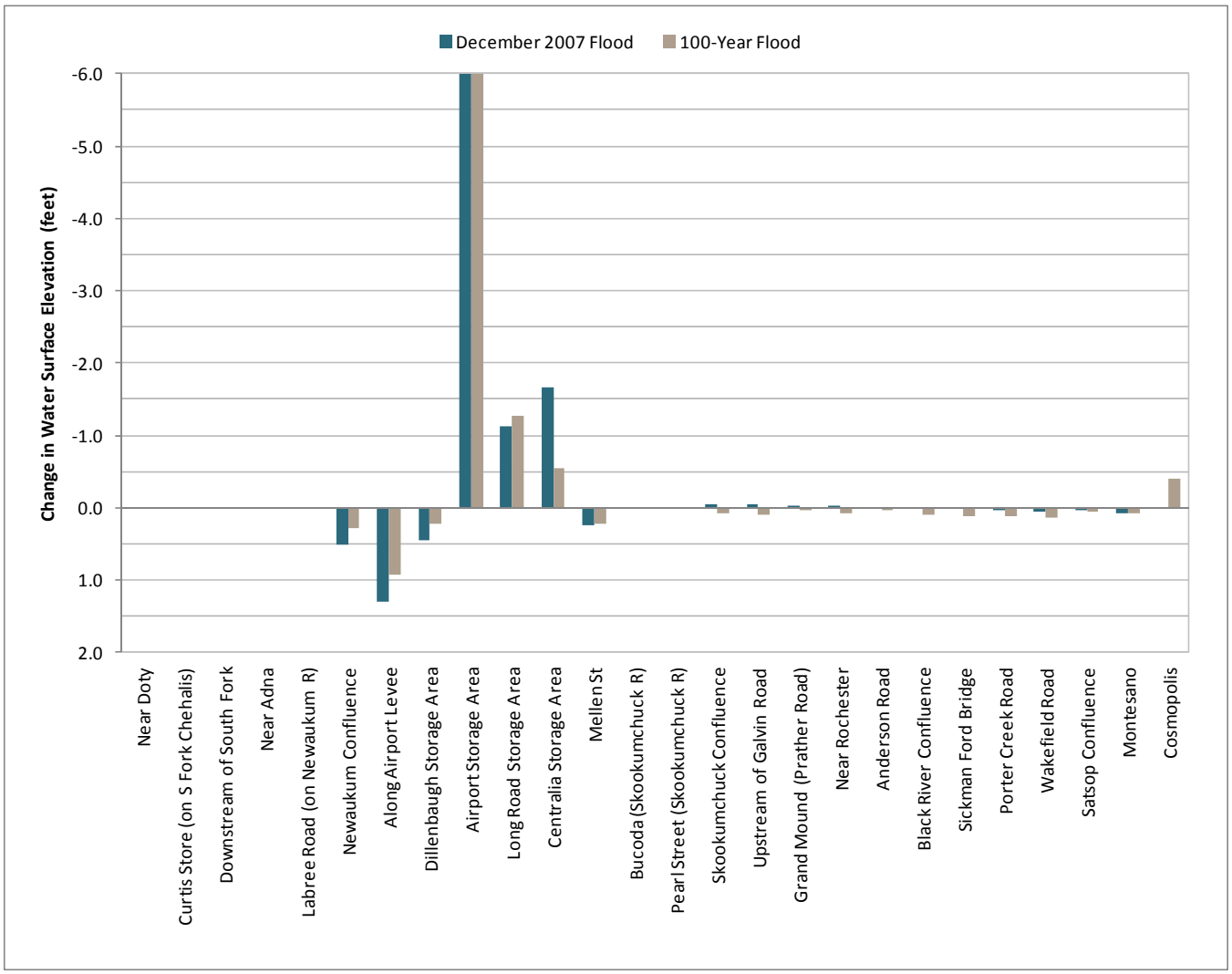
- The CHEHALIS HEC-RAS model predicts up to a 1.5 foot increase in flood elevations in 2007 and 100 year flood events in some locations if the Airport levee is improved.

What are the implementation issues associated with the Airport Levee improvements?

- The Airport levee by itself would increase flood elevations in some locations; these impacts would need to be minimized or mitigated in some manner.

Table 2 describes the effect of the potential airport levee improvements, in terms of changes in water surface elevation, at various USGS stream gages in the Chehalis Basin in a December 2007 and 100-year flood event.

Table 2: Effect of Potential Airport Levee Improvement Flood Relief Alternative



FLOOD WALLS AND LEVEES TO PROTECT INTERSTATE 5

Flooding in the Chehalis Basin has impacted access to I-5, closing it for four days in 1996, four days in 2007, and two days in 2009. The Washington State Department of Transportation (WSDOT) estimated the total loss in economic output to the state economy due to the closure of I-5 in 2007 at $47 million. The major costs from I-5 closure are freight delays, but closures also impact private operating companies from logistical and scheduling costs, and indirect market costs.

The Mellen Street to Blakeslee Junction (MTB) project now underway will provide access to the hospital in Centralia during flood events from downtown Centralia. In addition, the 2011 Washington State Legislature and the Washington State Office of Finance Management (OFM) directed WSDOT to evaluate alternative projects that could protect I-5 and the municipal airport at Centralia and Chehalis. OFM contracted with WSDOT to perform the work on I-5 alternatives. Project alternatives evaluated include raising I-5 using fill material, raising I-5 using a viaduct, relocating I-5 outside the flood area, and protecting I-5 with walls and levees. The fill, viaduct, and relocation projects had cost estimates ranging from $350 million–$2 billion.

The option summarized below is to protect I-5 with walls and levees, which has a projected cost of $80–$100 million. This project would involve building earthen levees and structural walls, replacing bridges with bottomless arches at Dillenbaugh and Salzer Creek, and providing stormwater treatment systems.

What are the potential benefits of the project?

- The CHEHALIS HEC-RAS model predicts that the I-5 levees and walls would protect the interstate from flooding under the 100 year flood, and 2007 and 2009 events. The walls and levees would provide 2 feet or more of freeboard above predicted flood elevations for an additional margin of safety and to address potential changes in climate and floods.
- The CHEHALIS HEC-RAS model predicts the project would lower the flood elevations in parts of the Twin Cities by as much as1 to 2 feet in an event like the 2007 flood.
- Based on a preliminary analysis by WSDOT[4], in events such as the 2007 flood, it would completely protect (i.e., make dry) 470 residences and 150 commercial structures and lower flood elevations at 290 more residences and 130 more commercial structures.

What are the potential concerns associated with the project?

- The cost of the I-5 levees and walls is significant and funding for major capital projects is difficult to secure in current economic times.
- The CHEHALIS HEC-RAS model predicts flood elevations downstream of the Twin Cities to increase by up to 0.1 feet in a 2007 and 100-year flood event, and 0.1-0.2 feet in a 1996 event.
- The Twin Cities may be affected by visual impacts of walls along the interstate.

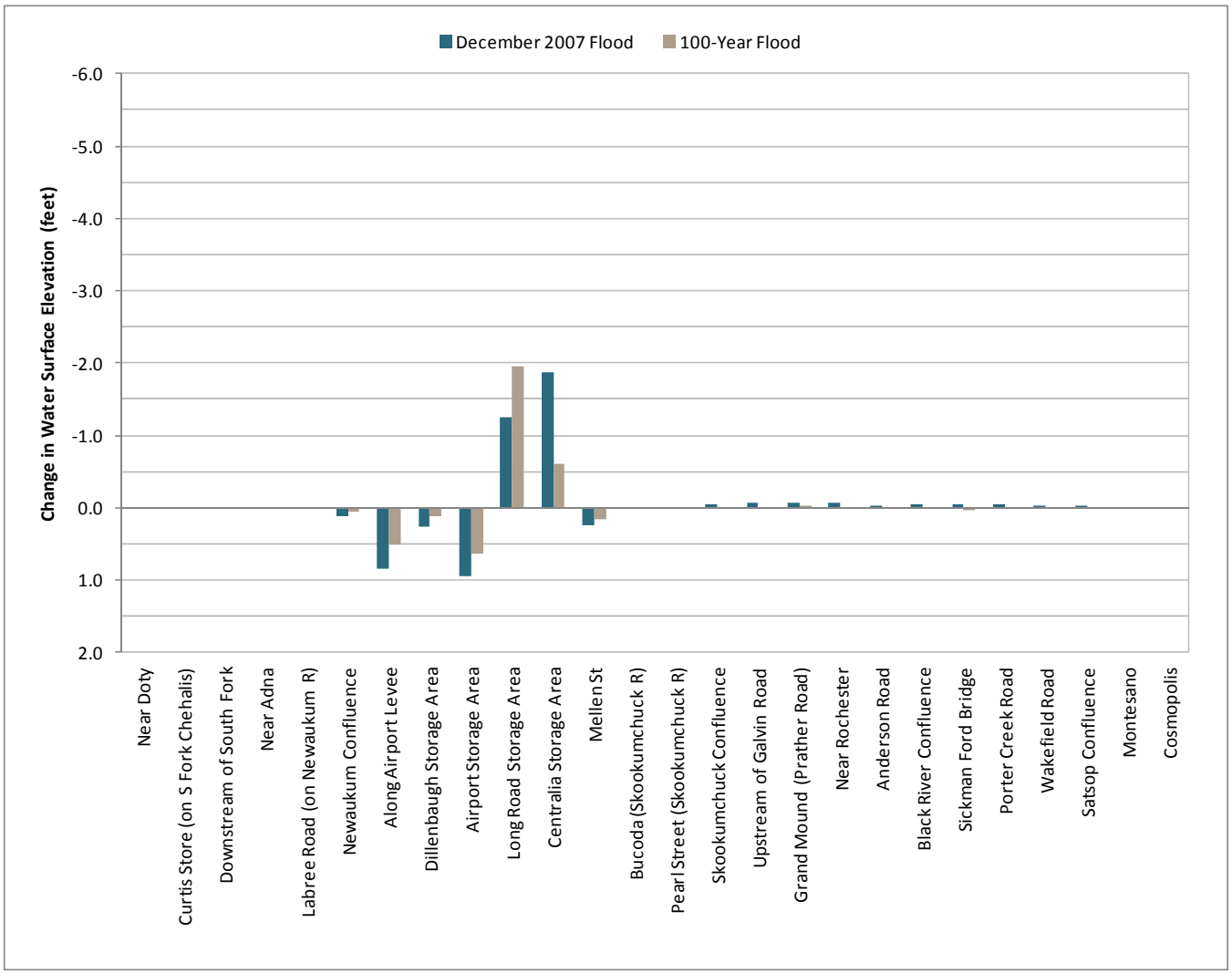
What are some of the major implementation issues?

- Some wetland and stream courses may be impacted, and mitigation will be required.
- The project would increase flood elevations in some locations; these impacts would need to be minimized or mitigated in some manner.

Table 3 describes the effect of the potential flood walls and levees to protect Interstate-5, in terms of changes in water surface elevation, at various USGS stream gages in the Chehalis Basin in a December 2007 and 100-year flood event.

[4] WSDOT was asked to provide an estimate of the number of residences and commercial structures that would be affected by different flood mitigation projects in the Twin Cities area. WSDOT is currently in the process of expanding this analysis upstream in the mainstem and may make revisions based on additional hydraulic model runs.

Table 3: Effect of Potential Flood Walls and Levees to Protect Interstate-5 Flood Relief Alternative



TWIN CITIES PROJECT - RAISING/IMPROVING THE US ARMY CORPS OF ENGINEERS LEVEE SYSTEM AROUND CENTRALIA AND CHEHALIS

Beginning in the 1980s the US Army Corps of Engineers began to evaluate a plan to build 11 miles of new levees in the Chehalis River floodway through Chehalis and Centralia. The Corps presented a design to build miles of new levees to the Centralia City Council in 1980. This basic plan was authorized for further analysis, but not funded for construction, by Congress as the Centralia Flood Damage Reduction Project ("Twin Cities project"). Work on the Twin City plan was largely stopped by the Corps in 2011 after the Corps determined that the proposed project would not have protected I-5 during the 2007 flood, would have increased flooding upstream and downstream and, at a cost of over $200 million, would not pass the Corps cost-benefit test.

The proposed project evaluated by the Corps included:

- Construction of a levee system designed to provide protection along the Chehalis River from approximately river mile (RM) 75 to RM 64 and along most of the lower 2 miles of both Dillenbaugh Creek and Salzer Creek.
- Construction of a levee along the lower approximately 2 miles of Skookumchuck River to the confluence with Coffee Creek that would provide 100-year level of protection.
- Raising the elevation of approximately eight structures that would incur induced damages from increased inundation as a result of the project, located near the Airport, Interstate-5, Skookumchuck River, and Salzer Creek.
- Modification of Skookumchuck Dam to provide for an additional 11,000 acre-feet of flood storage. The project would limit outflows from the dam and attempt to keep the flow in the Skookumchuck River Channel at the Pearl Street Bridge at or below 5,000 cfs.
- Total estimated cost of $205 million.

However, there is still interest among some parties in the Basin in reconfiguring and building some of the levees along the Skookumchuck. These levees would decrease flooding in Centralia from the Skookumchuck River that is not solved by other flood projects. The Corps has issued a draft close-out report for the project that has four options for how to proceed. The options include:

- Terminate the project; flood mitigation might be pursued under the Chehalis Basin General Investigation (which would require a local sponsor) or as smaller components under the Continuing Authorities Program (CAP) authority.
- Fully reformulate the project under a General Reevaluation Report.
- Conduct a limited Post Authorization Change Report and remove unjustified separable elements or modify separable elements to a level where they are justified.
- Move forward with a Post Authorization Change Report concurrently with a Basin wide flood risk management study under the Chehalis Basin General Investigation.

Decisions on how the State of Washington will respond to the Corps close out report will be made as part of the development of recommendations for priority flood hazard mitigation projects in the Basin.

What are the potential benefits of the Corps levees project?

- The HEC-RAS model predicts that in the 2007 and 100-year flood the project reduces flooding in the Skookumchuck River and drops flood peaks in the Twin Cities area, keeping most of Centralia dry in the Ford Prairie area, Zenkner Valley, and the Edison District. This assumes that the levees do not fail.
- The HEC-RAS model predicts that the project reduces the occurrence of flooding to I-5, but not in all storm events.

What are the potential concerns associated with the Corps levees project?

- The HEC-RAS model predict that in the 2007 event the project increases flood elevations up to 1 foot at the Newaukum confluence and up to 0.6 feet in other locations on the mainstem downstream of the Twin Cities.
- The current analyses show that in some cases, such as in December 2007 when flows in the Skookumchuck River were less than 5,000 cfs, the proposed operations at Skookumchuck dam could actually increase flows in the Skookumchuck River as opposed to reduce it.

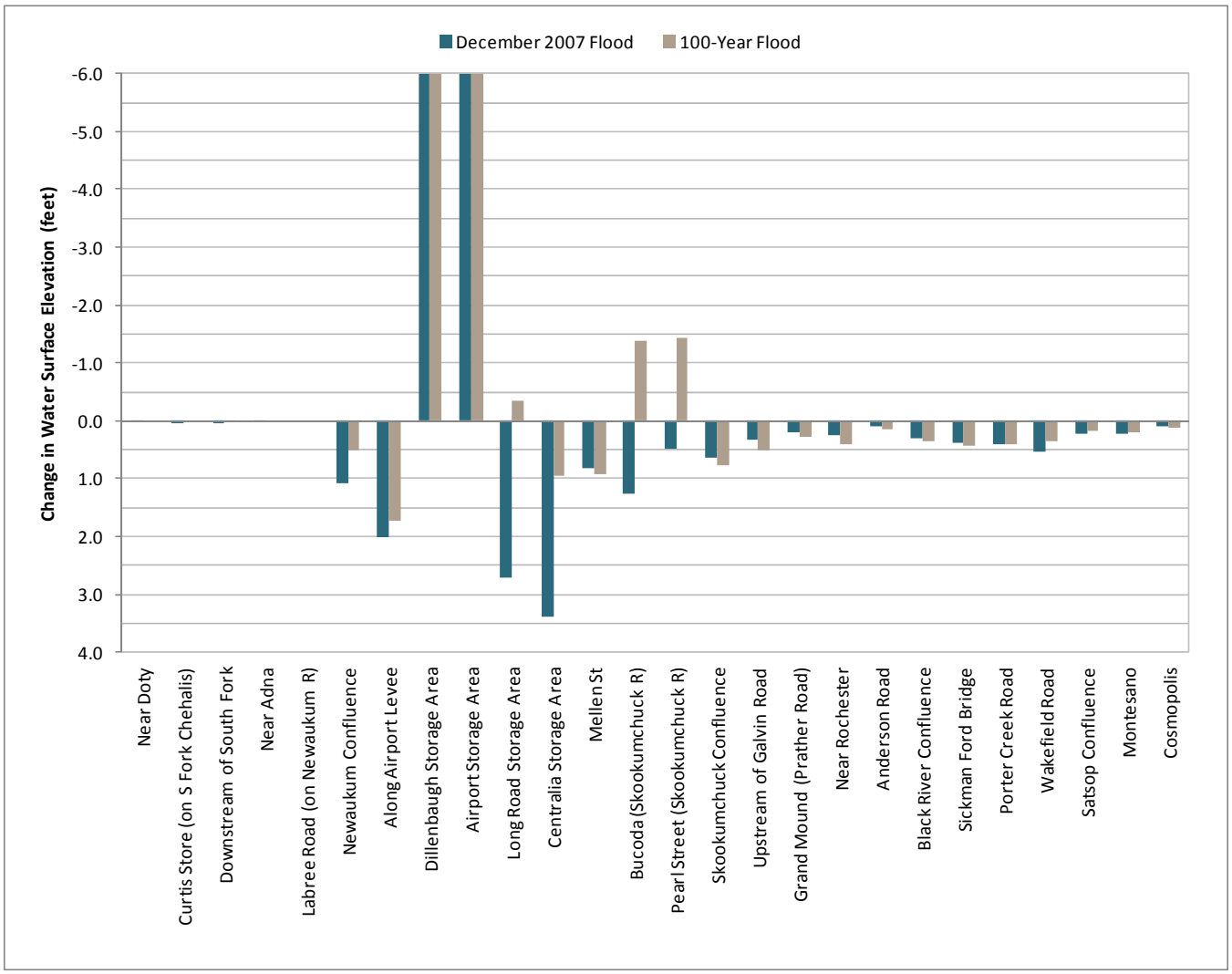
- The HEC-RAS model and Corps Closeout report predicts that the project does not protect I-5 from flooding in all storm events, including 2007, and therefore the avoided costs of raising I-5 cannot be included in the Corps' cost-benefit analysis.
- The Corps Closeout Report estimated direct impacts to approximately 35 acres of wetlands and indirect effects to approximately 235 acres of wetland floodplain and 244 acres of undeveloped non-wetland floodplain.

What are some of the major implementation issues of the Corps levees project?

- The Corps Closeout Report notes that if the project were approved, the design and construction after authorization would take multiple years to complete.
- A number of entities throughout the Chehalis River Basin have voiced their opposition to the project.
- Some technical experts have noted that changes to the spillway of Skookumchuck dam still need to be evaluated, and it is uncertain if owners of Skookumchuck dam would allow it to be used for flood control.

Table 4 describes the effect of the Corps Levees project, in terms of changes in water surface elevation, at various USGS stream gages in the Chehalis Basin in a December 2007 and 100-year flood event.

Table 4: Effect of Potential Flood Corps Levees Project Flood Relief Alternative



DREDGING/CHANNEL EXCAVATION

In the past, the Corps also evaluated a project to dredge or excavate the mainstem Chehalis River channel downstream of Mellen Street. WSE modeled a dredge/excavation project similar to the Corps investigated project, which would extend from just downstream of Mellen Street to just downstream of Lincoln Creek (RM 67.29 to RM 60.51). The excavation would have a 120 foot bottom width, trapezoidal channel, and would lower the channel bottom by as much as 15 feet in some locations (tapering into the existing channel at the upstream and downstream ends). According to PIE's Chehalis River Basin Flood Reduction Report (1998), there is a natural rise in the river bottom in this area; the substrate is most likely bedrock that would require blasting for removal. Part of the area under consideration for dredging is fairly high quality riparian zone dominated by black cottonwood, red alder, Douglas fir, Western red cedar, with an understory of salmonberry, snowberry, and other native shrubs and herbs. The portions of the area considered for dredging have good quality spawning habitat adjacent to it in the Chehalis River, and have a high quality riparian zone with seasonally connected side channels. Habitat diversity, species diversity, wetlands and refugia are good quality (Corps Closeout Report).

Dredging of the Chehalis River would also require some dredging in the lower reaches of the Skookumchuck River. Model cross sections between the mouth of the Skookumchuck River and RM 3.32 were cut to create a 20 foot wide trapezoidal channel in order to tie the Skookumchuck River channel into the lowered Chehalis River channel and provide model stability.

What are the potential benefits of dredging and channel excavation?

- The CHEHALIS HEC-RAS model predicts the project reduces flood elevations by up to 2 feet in Centralia and by about 1 foot along the airport levee.

What are the potential concerns of dredging and channel excavation?

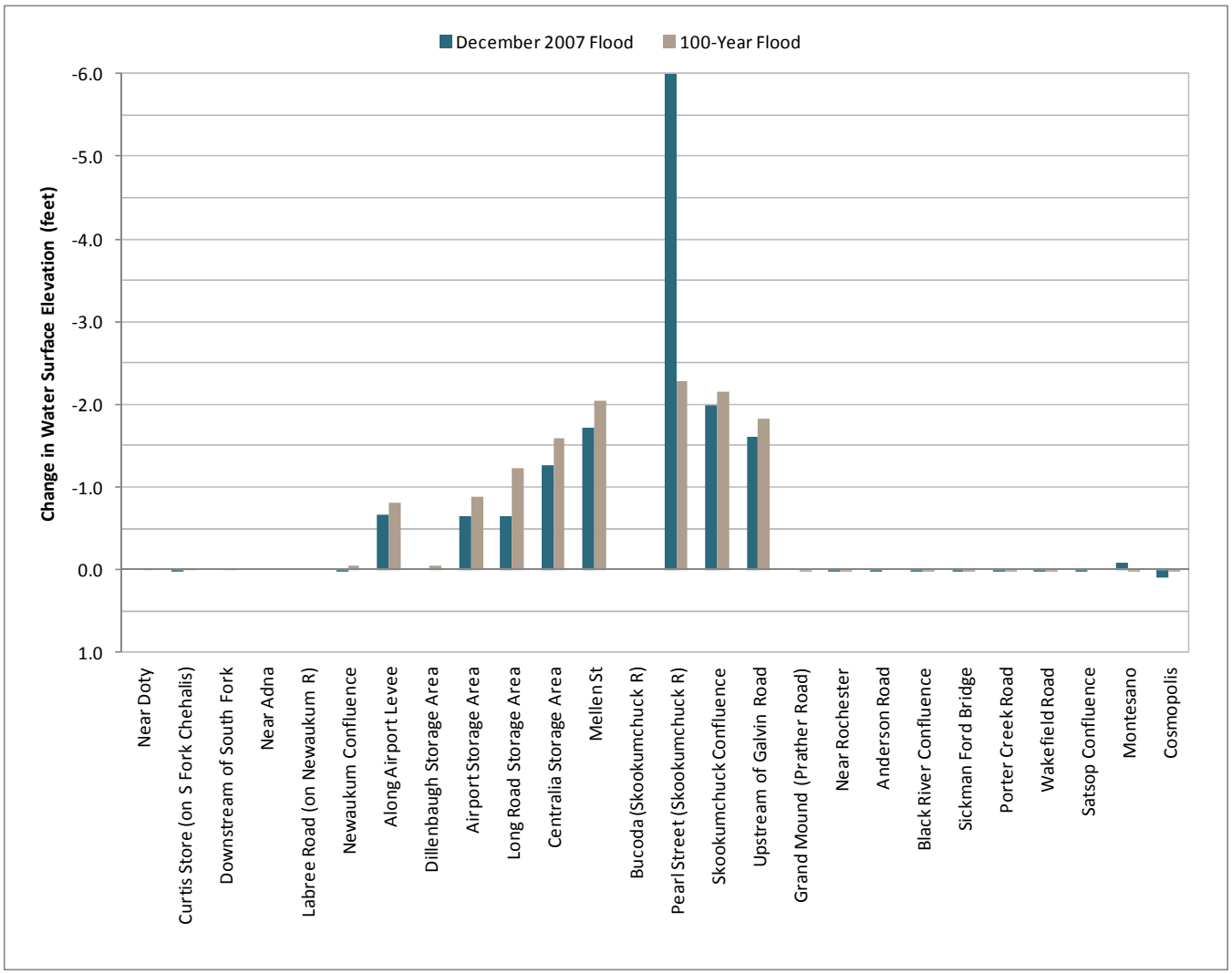
- The P.I.E. report states that channel dredging in this reach of the Chehalis River could result in potentially significant environmental impacts and would raise issues related to permitting feasibility.
- The CHEHALIS HEC-RAS model predicts that downstream flows and water levels would be increased (generally by less than 0.1 feet).
- Technical experts noted that the project would damage high quality habitat near the WDFW Pheasant Farm, with a potential to negatively impact Chinook, coho, and other species, that it is the only riparian forest in the area for miles, and also provides public access.
- The cost and/or feasibility of the dredging/sediment management project have not been evaluated.

What are some of the major implementation issues of dredging and channel excavation?

- The P.I.E. Report notes that long-term operation and maintenance would be required.
- The P.I.E. report states that water quality in the Chehalis River would likely be affected during construction as a result of sediment releases.
- Secondary impacts (groundwater, side channel disconnections) of the dredge/excavation project have not been evaluated.
- There could be significant permit issues with this project.

Table 5 describes the effect of the potential dredging and channel excavation project, in terms of changes in water surface elevation, at various USGS stream gages in the Chehalis Basin in a December 2007 and 100-year flood event.

Table 5: Effect of Potential Dredging and Channel Excavation Project Flood Relief Alternative



ALLEVIATING CONSTRICTIONS FROM ROADS AND BRIDGES

Road and bridge restrictions throughout the Chehalis Basin can constrain the flow of the Chehalis River and its tributaries during flood events. Major floods have resulted in bridges overtopping and the inundation of access roads; damage has occurred in areas such as upstream of SR-6, Mellen Street, Galvin Road, the Sickman-Ford Bridge, Porter Creek Road, and Wakefield Road. Modifications of the SR-6 Bridge and Mellen St. Bridge were proposed in the PIE Chehalis River Basin Flood Reduction Report (1998), and projects involving modifications to Sickman-Ford Bridge and Galvin Road were referenced in the Comprehensive Flood Hazard Management Plan for Confederated Tribes of the Chehalis Reservation. In fact, the Chehalis Tribe has evaluated options for changes to the Sickman-Ford Bridge and developed a scope for additional engineering design. Modifications to the Porter Creek Road and Wakefield Road (South Elma Bridge) were suggested as possible flood relief projects during lower basin stakeholder meetings in June 2012.

To better understand the potential for reduced flood impacts, various road and bridge removal projects were modeled using the Chehalis HEC-RAS model, including:

- Removing all bridges and approach fills in the entire model
- Removing the bridge and approach fill of SR-6
- Removing the bridge and approach fills of Mellen Street
- Removing the Bridge and approach fills of Galvin Road
- Removing the bridge and approach fills of Sickman-Ford Bridge
- Removing the bridge and approach fills of Porter Creek Road Bridge
- Removing the bridge and approach fills of Wakefield Road (South Elma) Bridge

Due to time and budget constraints bridge removals were modeled by simply removing the bridge structure, approach fills, and upstream and downstream ineffective flow areas from the model. That is, the entire bridge and approach was removed rather than modified. Obviously, this could create significant concerns for transportation and new bridges and approach roads would likely be necessary in some or all locations to replace the existing structures. The purpose of the current modeling effort was to identify the maximum possible benefit that could be derived from bridge removals so that future analysis efforts could be prioritized to structures that showed some possibility of reducing flooding rather than simply to bridges that have been previously identified as concerns.

What are the potential benefits of removing road/bridge constrictions?

- The CHEHALIS HEC-RAS model predicts removing all bridge/road restrictions results in a maximum 1.5 foot decrease in flood elevations in areas just upstream of some of the bridges, although in general decreases in flood elevations from the bridge removals are small to non-existent.
- The CHEHALIS HEC-RAS model predicts that complete removal of the Sickman-Ford Bridge and its associated approach fills would lower flood elevations just upstream of the bridge by 1.3 feet (the Chehalis Tribe is currently proposing an option that would drop flood elevation by 0.5 feet at a cost of $2 million.
- WDFW staff indicated that removal of bridges and constrictions could create some benefits for fish habitat and passage.

What are the potential concerns of removing road/bridge constrictions?

- River crossings are vital to transportation, commerce, and public safety and as such it would be necessary to replace some or all of the removed bridges with new roads and bridges. These new roads and bridges could have their own impacts on flooding.
- Benefits of bridge removal are typically only seen for a short reach upstream of the bridge. Removing constrictions and passing more floodwater downstream may exacerbate downstream flood problems. The model predicts increases of up to xx feet downstream of some bridge removals.

What are some of the major implementation issues of removing road/bridge constrictions?

- The cost and/or practicality of the individual bridge removals have not been evaluated, except for Sickman-Ford.

Table 6 describes the effect of the potential removal of all bridges and approach fills project, in terms of changes in water surface elevation, at various USGS stream gages in the Chehalis Basin in a December 2007 and 100-year flood event.

Table 7 describes the effect of the potential removal of Sickman-Ford Bridge project, in terms of changes in water surface elevation, at various USGS stream gages in the Chehalis Basin in a December 2007 and 100-year flood event.

Table 6: Effect of Potential Removal of all Bridges and Approach Fills Project Flood Relief Alternative

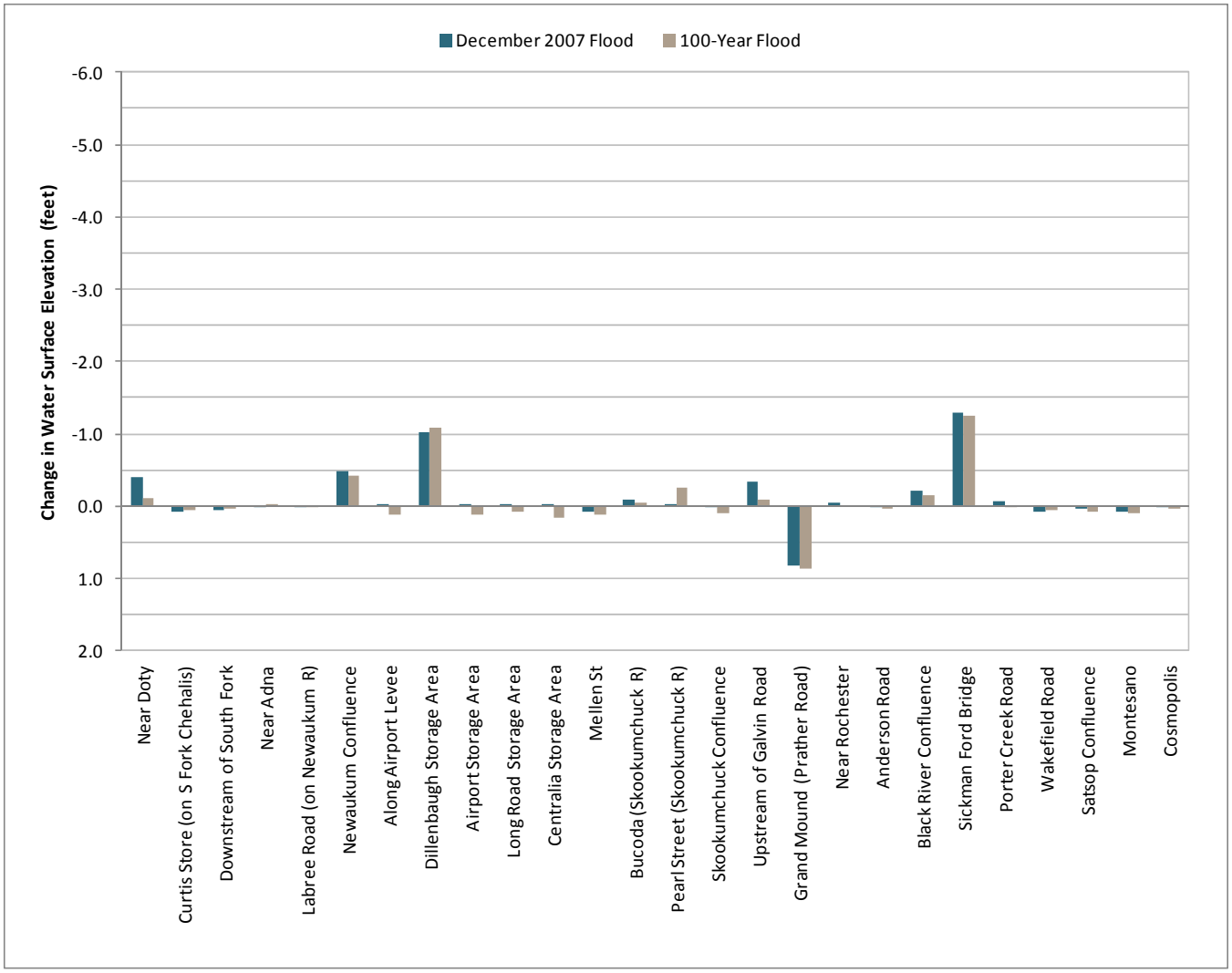
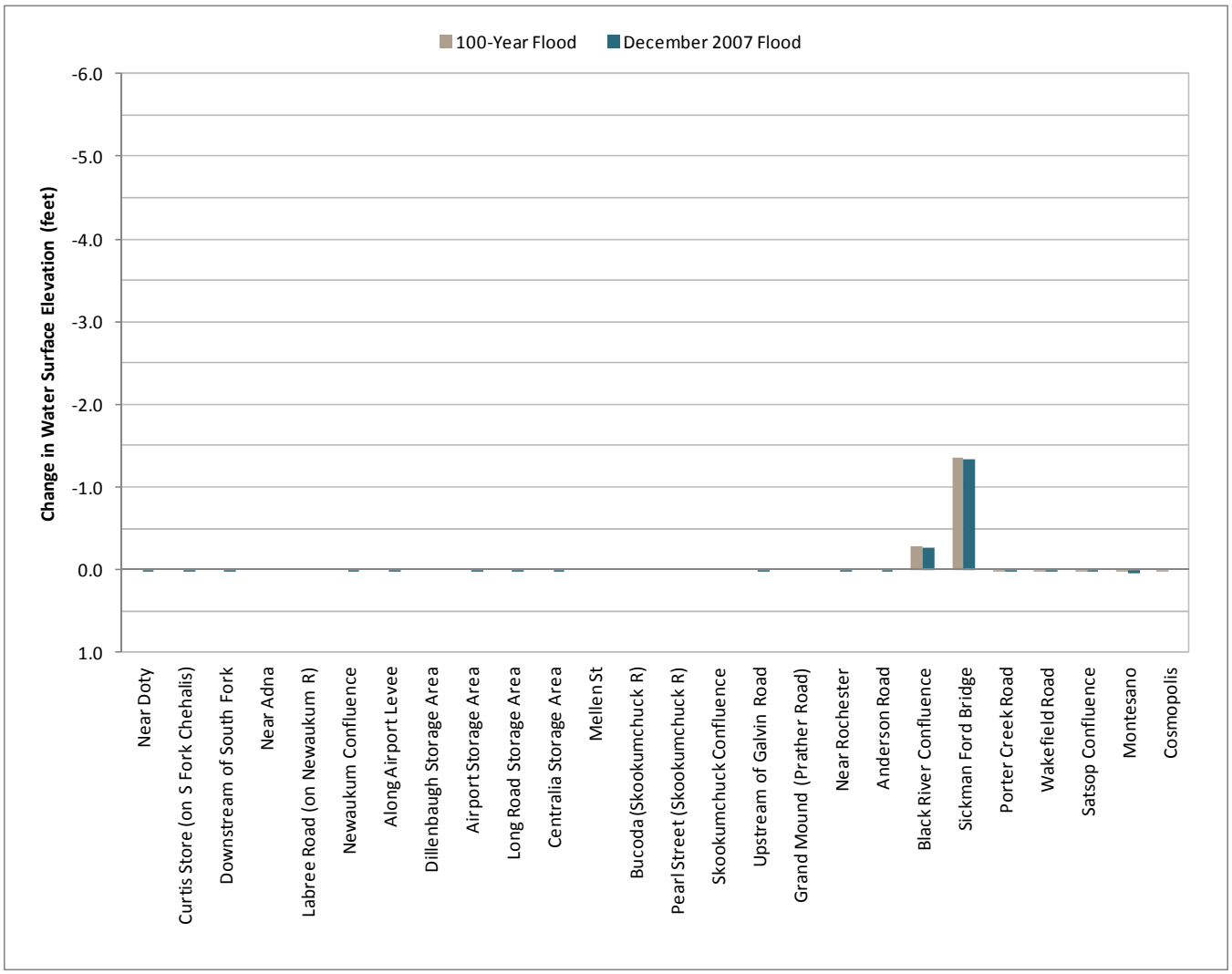


Table 7: Effect of Potential Removal of Sickman-Ford Bridge Project Flood Relief Alternative



FLOOD BYPASS ROUTES/STRUCTURES NEAR MELLEN STREET AND NEAR SCHEUBER ROAD IN CENTRALIA AND CHEHALIS

Historically, the bridge at Mellen Street has been suggested by some as a significant cause of flood impacts in the Twin Cities area. However, the Chehalis HEC-RAS model predicts that there would be little benefit from removing the bridge, in part because the natural topography, even without the bridge, acts as a constriction on flood waters. A different alternative would be to construct a high flow bypass from the left edge of the Chehalis River floodplain upstream of Mellen Street (RM 67.7) to downstream of the Skookumchuck River confluence (RM 66.16). The bypass channel would be approximately 700 feet wide and flow depths would be up to 10 feet deep in a flood such as December 2007.

The Chehalis River downstream of State Highway 603 flows parallel to Highway 6 for approximately 2.5 miles before turning north and flowing under the SR-6 highway bridge near the City of Chehalis. Water overtopping the highway upstream of the Newaukum River confluence enters the Scheuber Bypass reach that reconnects to the Chehalis River downstream of SR-6 near the Chehalis-Centralia Airport, effectively bypassing city of

Chehalis. The Scheuber Bypass Alternative would provide culvert or bridge connections under the highway to pass additional flow downstream and into the bypass, with the goal of reducing peak flood levels within the City of Chehalis. A modeled connection was made by placing a large opening within a portion of the lateral structure representing Highway 6 near River mile 77.3.

What are the potential benefits of the Mellen and Scheuber bypasses?

- The CHEHALIS HEC-RAS model predicts flood elevations reduced by up to 3 feet or more at the Mellen Street Bridge and by about 1.5 feet along the airport levee.
- The CHEHALIS HEC-RAS model predicts flood elevations in Centralia east of I-5 could be reduced by 2.5 feet.
- Some technical experts see the project as an opportunity for fish habitat restoration or ecological enhancement (e.g., off channel areas, wetlands, etc.).
- Local planners identified the opportunity for community open space and potential active recreation with certain design alternatives, but expressed concerns with permanent water features.

What are the potential concerns of creating the Mellen and Scheuber bypasses?

- The CHEHALIS HEC-RAS model predicts downstream flows and water levels could be increased by up to 0.25 feet.
- WDFW staff expressed concern about the potential for the project to become a "fish sink" where fish are moved into the area during flood events and then trapped.
- There may be historical and cultural artifacts in the area.

What are some of the major implementation issues of the Mellen and Scheuber bypasses?

- Additional issues, not anticipated based on the conceptual idea, might arise during the design phase.
- Existing development within the bypass area would have to be relocated and the feasibility of this has not been evaluated.
- The cost and/or feasibility of the bypass have not been evaluated.

Table 8 describes the effect of the potential Mellen Street Bypass project, in terms of changes in water surface elevation, at various USGS stream gages in the Chehalis Basin in a December 2007 and 100-year flood event.

Table 9 describes the effect of the potential removal of Scheuber Road Bypass project, in terms of changes in water surface elevation, at various USGS stream gages in the Chehalis Basin in a December 2007 and 100-year flood event.

Table 8: Effect of Potential Mellen Street Bypass Project Flood Relief Alternative

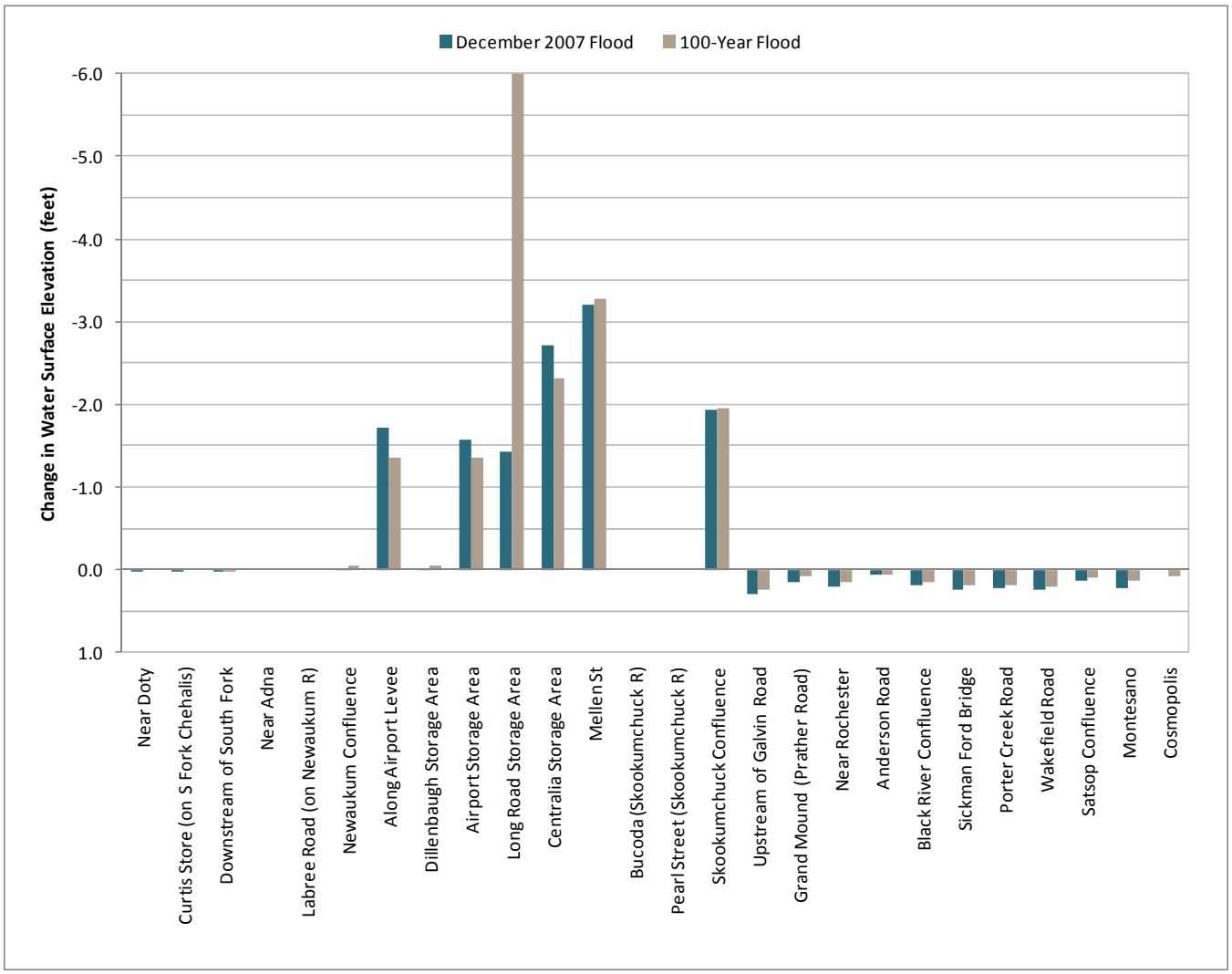
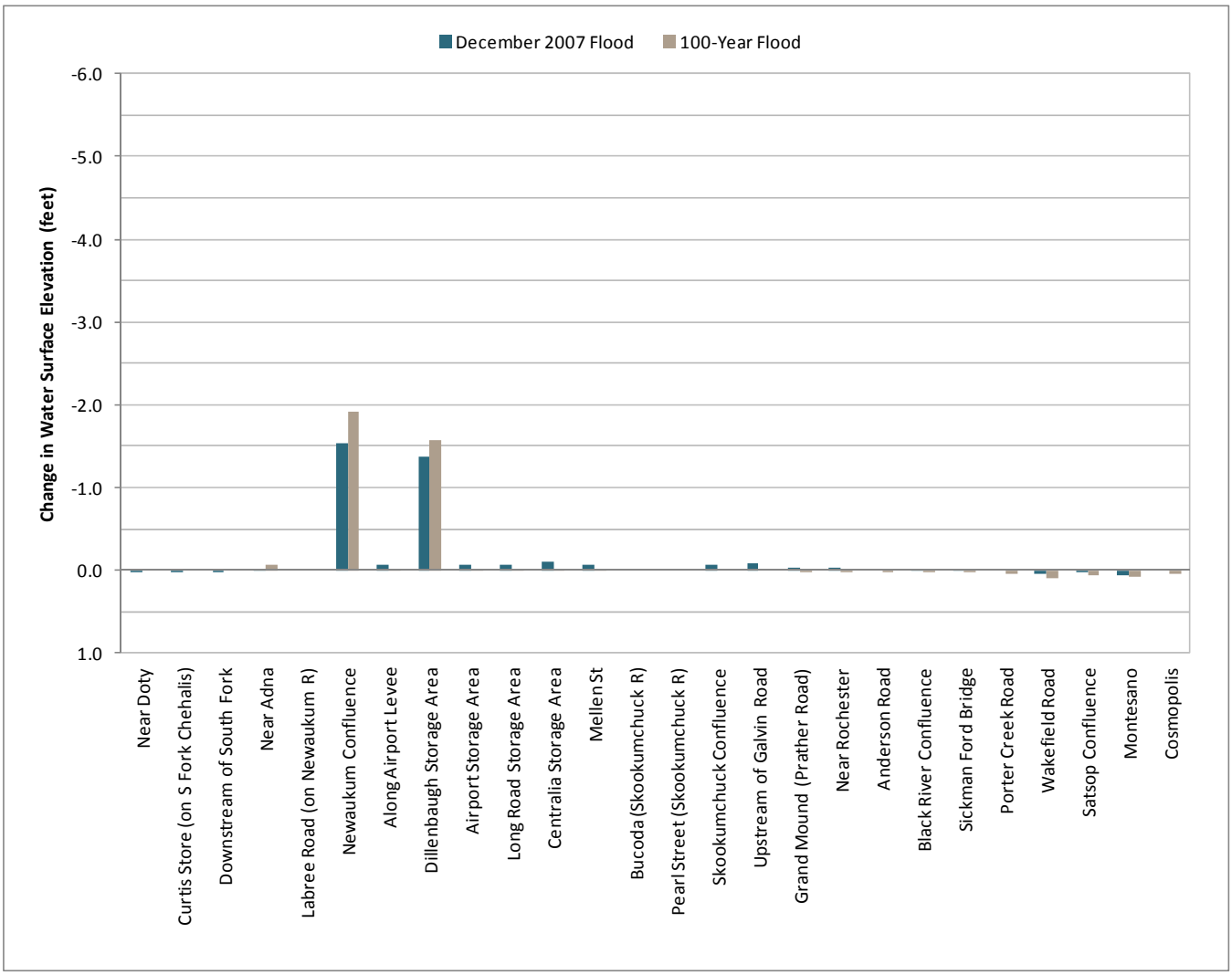


Table 9: Effect of Potential Scheuber Road Bypass Project Flood Relief Alternative



Programmatic Actions

The projects summarized here are non-structural or relatively smaller scale, less capital intensive projects and programmatic actions that provide more individual or localized flood protection benefits, for example, elevating homes in the flood plain or creating farm livestock evacuation areas (so called "critter pads"). Of course, when applied broadly even the smaller scale, more individual projects can have significant benefits and costs. They were selected based on the current focus of interested parties in the Basin.

For the most part, these projects would amplify or expand efforts already underway in the Basin to address flood impacts. Because they generally build on work already underway, they are presented slightly differently than the larger scale projects. Each project is described in terms of work underway, potential to expand this work, and potential costs. Information on potential benefits, concerns and implementation issues is integrated in the project descriptions.

ADDITIONAL LAND USE AND LAND MANAGEMENT TO CONTROL BUILDING AND NEW FILL IN THE FLOODPLAIN

City and county governments in the Chehalis basin have a number of ongoing land use management policies and actions to mitigate the impacts of flooding.

Most local governments meet or exceed the FEMA and state minimum requirements for restricting development and fill within the floodplain and for ensuring that development which does take place is appropriately flood proofed or elevated. In general, counties prohibit new lots that are wholly in the floodplain; cities allow some infill in the floodplain but require flood proofing and new homes to be elevated. The requirements for elevation vary from one foot above the base flood elevations (100 year) to several feet above the flood of record (2007).

Chehalis, Centralia, Lewis County and Thurston County participate in the FEMA Community Benefit Rating System and Grays Harbor County and Napavine are considering applying. This voluntary, incentive-based system gives jurisdictions recognition and encourages community floodplain management activities that exceed the minimum National Flood Insurance Program requirements. As a result, flood insurance premium rates are discounted to reflect the reduced flood risks.

Additional land use management actions might build on ongoing work and could be based on the recommendations of the Chehalis Basin Comprehensive Flood Hazard Management Plan. These include:

- Ensure any new residential structures in the floodplain area elevated at least 2 feet above the base flood elevation, and all new commercial or industrial structures at least 1 foot.
- Establish a lower threshold for when flood proofing and/or home elevation would be required as part of improvements/additions to structures in the floodplain
- Limit critical facilities in the floodplain
- Adopt subdivision and development regulations that avoid or minimize development in floodplains
- Adopt low density zoning in the floodplain
- Encourage all jurisdictions in the Basin to participate in the NFIP CRS program and achieve at least a class 5 rating, which would result in a 25% decrease in NFIP premiums in Special Flood Hazard Areas.

- Require compensatory storage for fill in the floodplain 1:1 or 1.5:1 requirement for storage
- Adopt a zero-rise policy in the floodplain

While some local jurisdictions have expressed support of additional land use management actions, they recognize that it is not a panacea. Each jurisdiction has unique land use regulations, CAOs, building codes, and flood mitigation objectives. Current land use requirements are summarized below in Figures 1 and 2.

Figure 1: Community Rating Service Scores for Chehalis Basin Communities

		LEWIS COUNTY		THURSTON COUNTY		CENTRALIA		CHEHALIS	
CRS CATEGORY	MAXIMUM POSSIBLE POINTS	POINTS EARNED	%	POINTS EARNED	%	POINTS EARNED	%	POINTS EARNED	%
310 (Elevation Certificates)	162	67	41%	147	91%	127	78%	122	75%
420 (Open Space Preservation)	900	328	36%	352	39%	160	18%	261	29%
430 (Higher Regulatory Standards)	2740	391	14%	856	31%	519	19%	402	15%
450 (Stormwater Management)	670	374	56%	531	79%	495	74%	495	74%
520 (Acquisition and Relocation)	3200	100	3%	100	3%	105	3%	264	8%
530 (Flood Protection)	2800	42	2%	84	3%	409	15%	44	2%

Figure 2: Land Use Regulations for Chehalis Basin Communities

		GRAYS HARBOR COUNTY	LEWIS COUNTY	THURSTON COUNTY	ABERDEEN	BUCODA	CENTRALIA	CHEHALIS	MONTESANO	CHEHALIS TRIBES	NAPAVINE
Code Citation		Grays Harbor County Code 18.06	Lewis County Code 15.35	Thurston County Code 14.38	Aberdeen Municipal Code 15.52	Bucoda Municipal Code 15.24	Centralia Municipal Code 16.12	Chehalis Municipal Code 17.21	Montesano Municipal Code 17.40 Article II	Flood Damage Prevention Ordinance, Comprehensive Plan and Zoning Code	Napavine Municipal Code 15.12
Is your community's **floodway boundary definition** more restrictive than FEMA's?		No.	No.	No.	No.	No.	No.	No.	No.	No.	No.
Do you use a more restrictive **floodway development** standard than FEMA's?		No. DRAFT CODE: Yes.	Yes.	Yes.	Yes.	Yes.	Yes.	Yes.	No.	No specification in code.	Yes.
Do you use a more restrictive elevation standard for **development within a floodplain** than the FEMA standard?	*Resi-dential*	No.	Yes.	Yes.	Yes.	Yes.	Yes.	Yes.	Yes. Shoreline Management Act.	Yes.	Yes.
	Non-resi-dential	No. DRAFT CODE: Yes.	Yes.	Yes.	Yes.	No.	Yes.	Yes.	No.	Yes.	Yes.
Do you require a **set-back** from the OHWM?		Yes. Setback is per CAO and SMP.	Yes. Setback is per CAO.	Yes. Setback is per CAO.	No specification in code.	No specification in code.	Yes. Setback is per CAO.	No specification in code.	Yes. Shoreline Management Act.	No specification in code.	No specificatio n in code.
Do you allow **critical facilities** within the 500-year floodplain?		No specification in code.	Yes.	Yes.	Yes.	Yes.	Yes	Yes.	No specification in code.	No specification in code.	Yes.
Do you require all new development in the floodplain to **determine the BFE** if one has not already been determined?		No specification in code.	Yes.	Yes.	No specification in code.	No specification in code.	Yes.	Yes.	Yes, Shoreline certificate required.	No specification in code.	No specificatio n in code.
Do you require new development to be elevated above the **flood of record?**		No.	Yes.	Yes.	No specification in code.	No specification in code.	No specification in code.	Yes. If higher than the BFE.	No specification in code.	No specification in code.	No specificatio n in code.
Do you require an **elevation certificate** for all new construction?		Yes.	Yes.	Yes.	Yes.	Yes.	Yes.	Yes.	Yes.	Yes.	Yes.

	GRAYS HARBOR COUNTY	LEWIS COUNTY	THURSTON COUNTY	ABERDEEN	BUCODA	CENTRALIA	CHEHALIS	MONTESANO	CHEHALIS TRIBES	NAPAVINE
Code Citation	**Grays Harbor County Code 18.06**	**Lewis County Code 15.35**	**Thurston County Code 14.38**	**Aberdeen Municipal Code 15.52**	**Bucoda Municipal Code 15.24**	**Centralia Municipal Code 16.12**	**Chehalis Municipal Code 17.21**	**Montesano Municipal Code 17.40 Article II**	**Flood Damage Prevention Ordinance, Comprehensive Plan and Zoning Code**	**Napavine Municipal Code 15.12**
Do you use a more restrictive standard for "**substantial damage**" than the 50% required by FEMA?	Yes.	No.	No.	No.	No.	No.	No.	No.	No.	No.
Are there provisions for **compensatory storage** beyond basic NFIP standards?	Yes.	Yes.	No.	No.	No.	Yes.	Yes.	No.	No.	Unsure.

ADDITIONAL FLOOD PROOFING, HOME ELEVATION, AND BUYOUT PROGRAMS FOR STRUCTURES ALREADY IN THE FLOODPLAIN

Many of the jurisdictions in the Basin already have programs that support flood proofing of businesses, home elevation, and buyouts of structures that are in the floodplain. Flood proofing involves changes to a structure or property using berms, flood walls, closures or sealants, which reduces or eliminates flood damage to buildings or property; it is used primarily for commercial structures and properties. Homes in the floodplain can be protected by home elevation, in which the structure is anchored against movement by floodwaters and the first floor of living space as well as all mechanical and services is at least one foot above the elevation of the 100-year flood.

The City of Centralia has raised 173 homes inside the city limits and has approximately 1100 additional homes inside the city limits or the Urban Growth Area that might be eligible for raising. Centralia has acquired two houses inside the floodplain. There are approximately 340 commercial buildings developed within the Centralia city limits and UGA of which some have already been flood proofed. Centralia has acquired three properties in the flood plain.

Thurston County has approximately 947 structures in the floodplain, 924 of which are residential. Thurston County has raised 19 homes in the Chehalis Basin; there are approximately three remaining homes that have suffered repetitive flood loses and county staff believes there may be up to twelve additional homeowners who would be interested in home elevation if it were available. In Lewis County, they have a waiting list for elevation and buyout projects, but no budget to move forward. In Grays Harbor County, most of their prime agricultural land is located in the floodplain, so their need for buyouts, elevating, and flood proofing is more limited.

The cost of home elevation is approximately $30,000 - $50,000 per home. The cost of flood proofing varies depending on the size of the structure and the original construction techniques. The cost of acquisition varies greatly based on the properties involved.

Additional work in these areas would expand and accelerate projects by providing more funding for land owner assistance and buyouts.

ADDITIONAL LIVESTOCK AND FARM EVACUATION AREAS (“CRITTER PADS”)

The State Conservation Commission (SCC) is currently working on a Basin wide project to determine where livestock and farm evacuation areas (critter pads) could help to mitigate potential farm losses during floods. Working with farmers, they have identified potential critter pad sites in the upper basin, and are now looking into the permitting process at seven sites where there has been livestock mortality in the past due to flooding. One site in the upper basin has already been permitted. Work is also underway to evaluate potential sites in the lower basin.

Preliminary studies show a cost of approximately $1 million for the seven potential critter pads currently identified (or an average of approximately $142,000 per pad). If approved, these projects would likely use onsite material that has already been stockpiled, so no new material would be used as fill. The current projects are only for commercial farms with livestock, but the SCC also is looking into other project options that can benefit smaller vegetable farmers. The SCC is continuing to hold landowner meetings with individuals in the

lower Chehalis Basin to document the potential need for critter pads in that reach of the Basin, and will have Basin wide details on potential critter/farm pad opportunities later in the summer.
Additional work in these areas would expand and accelerate permitting and construction for critter/farm pads by providing additional funding.

REFINEMENTS TO FOREST PRACTICES TO INCREASE WATER STORAGE CAPACITY PROVIDED BY MATURE FORESTS AND IMPROVE WATER QUALITY AND HABITAT FOR FISH

Forestland comprises approximately 84% of the land base in the Chehalis Basin. Of this land, approximately 91% is subject to the Washington Forest Practices Act (FPA); the remaining forestland is federal or tribal. Stakeholders in the basin have expressed concerns that timber practices may be causing more runoff and erosion and that harvest has removed the natural flood protection provided by mature forests. Certain forestlands in the Basin, like the area above Pe Ell, are in a rain on snow zone; in these zones, the greatest mitigating impact on storm events is provided when forests are over 10 to 15 years old.

Forest management has been criticized by some for encouraging short rotation of harvests, leading to an immature forest that contributes to flooding as well as harvest on steep slopes increasing the chance of landslides. There is little data on the status of forests in the upper watershed areas of the Basin and no definitive evidence that forest practices have contributed or not to flooding in the Basin.

The Washington State Department of Natural Resources (DNR) recently completed a draft report that proposed three projects that could provide tools and information to evaluate new forest practices protection options, and the effectiveness of existing protection in the Chehalis Basin. The full draft report and public comments are provided in Appendix D. The three priority projects, totaling $6.6 million, include:

- Geological mapping and updated LiDAR (Light Detection and Ranging) – estimated $4,274,600
- Evaluation of Hillslopes Regulated under Washington Forest Practices Rules – estimated $200,000
- Road prescription-scale effectiveness monitoring – estimated $2,200,000

LiDAR provides a base elevation model that is critical in developing better hydrogeologic models for flood evaluation; assists in location of wetlands and other critical habitat; and characterizes land cover. LiDAR data can be used to determine if potentially unstable landforms are correctly identified and evaluated for potential impact to public resources. This updated work would take some time to complete: LiDAR could be complete in one year; geologic mapping could take up to 5 years to complete and would need to be integrated into DNR's work plans; road prescription-scale effectiveness monitoring could take up to 10 years to complete.

IMPROVING RIPARIAN AREAS TO REDUCE FLOOD IMPACTS FROM DEBRIS AND INCREASE STORAGE AND IMPROVE HABITAT FOR FISH

The State Conservation Commission (SCC) is currently working on Basin wide project details for riparian improvements to reduce flood impacts from debris along stream banks, increase storage and improve habitat for fish. Riparian areas are land adjacent to streams where vegetation is influenced by the presence of water. Riparian vegetation can slow floodwaters, help maintain stable streambanks and protect downstream property, and improve habitat for fish. By slowing floodwaters and rainwater runoff, the riparian vegetation allows water

to soak into the ground and recharge groundwater. Slowing floodwaters allows the riparian zone to function as a site of sediment deposition, trapping sediments that would otherwise degrade the river to build stream banks.

The SCC has estimated that approximately 7,079 acres in the Lewis County portion of the Basin could benefit from riparian improvement work, at an estimated cost of $14 million ($2000 / acre). Costs include site preparation, purchase and planting of trees, and protection of existing trees. The SCC generally provides up to five years of maintenance after a riparian improvement project; maintenance varies in costs depending on the site and would be an additional expense.

It is important to note that the forthcoming SCC project details will provide a sense of magnitude, need, cost, and specific priority areas that would benefit from riparian projects. Future, additional work could build on the work ongoing by the SCC and on riparian restoration and improvement work identified in other documents such as watershed plans.

ADDITIONAL BANK EROSION CONTROL TO REDUCE LOSS OF PROPERTY AND ADDRESS OTHER IMPACTS

Erosion control refers to controlling unnatural rates of silt and sediment movement by reducing the force of flowing water or increasing the resistance of the bank to erosion. Approaches include planting stream-side vegetation, and use of woody debris or other materials on the bank.

The State Conservation Commission (SCC) reports that after the 2007 and 2009 floods, erosion sites have increased dramatically in the Basin. They have identified 119 sites upstream of the confluence of the South Fork of the Chehalis River alone. SCC staff report that they receive frequent calls from landowners concerned with bank erosion, mainly on the main stem and South Fork of the Chehalis, and the main stem and South Fork of the Newaukum River.

Cost estimates for bank erosion control projects are not available at this time; the SCC is continuing to work with landowners to develop a project inventory and cost estimates.

Counties throughout the Basin have noted an interest in various specific bank erosion control projects. Grays Harbor County has expressed interest in a project along the Satsop River, where soil erosion has gone beyond the river bank, resulting in significant amounts of sediment and rock build up. Lewis County has expressed the need for bank erosion projects where roads are threatened. In addition to bank erosion due to flooding, some counties also noted the need to address erosion from farmland throughout the Basin.
A comprehensive strategy for erosion control approved by the state regulatory agencies would expedite action by local landowners.

FLOOD PROJECTS IN THE LOWER CHEHALIS BASIN

The Chehalis Basin Flood Authority has created a Potential Projects Matrix that lists flood mitigation projects extracted from flood planning documents throughout the Chehalis River Basin. Within this matrix, potential projects have been identified in the lower Chehalis Basin/Aberdeen area, including: various floodplain projects involving filling, storm drain piping changes, and tide gates; reparation, maintenance, and potential new construction of levees and dikes in the Aberdeen area; and implementation of home elevation and buyout programs.

Additional meetings have been held recently throughout the lower Basin to discuss potential project needs and areas of concern. In Aberdeen, there is growing concern of the susceptibly to flooding if flows occur during high tides. In Montesano, the Mary River is anticipated to soon cut through an ox-bow and point towards Mary's River Lumber. Along the Satsop River, removing a portion of the levee could prevent the River from meandering into the historic channel migration zone, which is anticipated to reduce flooding and provide fish habitat. Others have highlighted the possibility of the Satsop River flooding areas upstream of Highway 12, but potential solutions have not been identified.

To better understand flow passage along South Elma Road, additional design and hydraulic modeling needs were identified. In the Cedarville/Sharon/Porter to Elma reach, some have identified the need for modeling of the Sickman-Ford Bridge/Harris Creek Culvert Replacement projects, to determine if additional work is needed to mitigate for potential downstream impacts. Finally, many in the lower Basin suggested the need for bank stabilization and sediment management to reduce the loss of land; this could be addressed through a coordinated effort of the Conservation Districts, landowners, and Department of Fish and Wildlife.

The projects documented are still preliminary and have not been prioritized. The projects are meant to serve as a potential baseline of projects to be considered for future funding, but additional details regarding project descriptions, flood benefits, and stages of readiness are still needed.

Appendix B: Individual Stories and Reflections on Flooding in the Chehalis Basin

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Appendix B: Individual Stories and Reflections on Flooding in the Chehalis Basin

This appendix is a compilation of individual stories and reflections on flooding and flood impacts shared by residents of the Chehalis Basin; we welcome additional stories and will include any that we receive in the final report.

Individuals were provided the questions below, though some individuals chose to simply reflect on their communities and experiences of flooding in the Basin.

1. What is special to you about the upper mainstem area (places, people and/or experiences)?
2. If you were to describe this area to out of town friend or visitor, what you would highlight?
3. What hopes do you have for the future of the area?
4. When you think of the major floods over the past two decades, what are the strongest memories?

The responses below are separated by the sub-areas described in the main body of the report:

- Upper Mainstem
- Newaukum
- Twin Cities
- Skookumchuck
- Lower Mainstem
- Grays Harbor Cities and Tributaries

Upper Mainstem

DAVE FENN, FARMER

Thanks, I think, for this "opportunity". I think you know how important this issue is to the area, so I feel pressure to make others recognize the effect 2007 and other floods has had on the area.

Q - What is special to you about the upper mainstem area (places, people and/or experiences)?

A - My experience is mainly in the Boistfort Valley, on the South Fork of the Chehalis. For me, the obvious is that I grew up here. My grandparents came here over 100 years ago, so the roots are pretty firm. In the south end of the valley where we live there was much turnover of settlers until after 1900. For whatever reason after that a group of families came here and most are still here.

Through the middle of the 1900s the valley, including the PeEll side on the mainstem, was an area of small farmers and loggers. In Boistfort my father was part of a group of people that started a volunteer fire department, a Lions club, a community water system and Little League. Weyerhaeuser was the main logging employer and was a wonderful partner in the community. I have come to realize that was a golden age in which to grow up. It was a good time for the whole of the United States and Boistfort was as good as anywhere. Life is never perfect, but our little school had some extraordinary teachers. Some were lifetime members of the community and did an extraordinary job. Another went on to become the dean of department of school administration for New York University on Long Island. Another ended his career as the superintendent of one of the Intermediate School Districts in the Seattle area.

My point is there was, and continues to this day, an extraordinary sense of community here. That was proven by the events following the flood and was true also in the PeEll, Doty area. By the way, "the flood " now means, 2007. There was a community plan in place to respond to an emergency and it worked. The mobilizing of people to help each other was amazing. And then the outside help that arrived kept the locals going through to the end. An example of spontaneous help involved my daughter's family. They live on Ceres Hill Rd. near the confluence of the two forks. I called at daylight to tell them it looked as though the River would be higher than it had ever been and they needed to take their cars and tractor to the hill. They only had time to get to the car, stop and get the 80 something neighbor lady and drive up the hill. A neighbor on the hill took them in for several days, until they were able to clean the house enough to move back in the upstairs.

Then the outside help started arriving. Through donations and locals that had not been flooded, the Grange fed helpers and affected people for months. The Mormon Church sent hundreds, if not thousands, to the area to do the initial cleanup. Then churches and other organizations came for months to assist. The Mennonites had members come from as far as Vanderhoff, B.C. and New York state There were donations from everywhere to help rebuild. As I told Jim, I had a church member from Tacoma tell of going to New Orleans to help rebuild and he was stunned by the difference between here and there. In New Orleans they were sitting and waiting for help. Here, everyone immediately had started helping each other begin the rebuilding process.

I have also told Jim of the aid from state and federal agencies to help landowners clean up and rebuild. Mark Clark, Valora Loveland and Doug Sutherland, working with the Legislature, the Governor and other agencies funded the Conservation District and DNR to allow aid to get the cleanup and repairs done. The FSA was also instrumental in that happening.

Even though there is a great sense of community and self reliance here and a heartwarming reaffirmation of the basic sense of human decency from the volunteer help., the flood has had serious consequences on the psyche and economics of the area. Several homes were removed, not to be rebuilt. Some good families moved away. There are potential serious restrictions on a number of homes and farms that may have long term effects on their use and value. Besides the money, people have spent untold hours dealing with cleanup and plans for the future. Flooding is a weight on the shoulders of the community.

I just reread question one and realized I had strayed from telling what is special to what the flood has done to us. Kind of proves that the flood has changed us.

Q -If you were to describe this area to out of town friend or visitor, what you would highlight?

A - The first two questions are really interrelated for me. First , our valley has a long history. The natives long used the area for hunting and gathering. The assumption is that the prairies here were the result of regular burning to keep open areas for hunting and gathering. Other than the Hudson's Bay Company, some of the first settlers north of the Columbia came to the valley. I am not a linguist, but my understanding is Boistfort is an Americanization of French words bois and faw (thus Baw Faw Grange and Peak) and means large or strong forest or a small park like valley surrounded by a large forest. The first settlers took out donation land claims, making for interesting property lines. Boistfort School District was the first in the territory and was No. 1 until consolidation of several districts made the current district. Somehow Steilacoom managed to take the No. 1 designation in that process. At one point the UW was proposed to be built here.

Weyerhaeuser and Long Bell were the main early logging companies in the area. Long Bell morphed to International Paper and that land has been sold several times. Weyerhaeuser had a logging camp and railroad that hauled logs to the water in Olympia to be towed to Everett. The current main fire station was built from salvaged lumber from the Weyerhaeuser logging camp. Weyerhaeuser is still a main player in the area.

In the early 1900's Herman Klaber developed what was reported to be the largest hop yard in the world. He went down on the Titanic on the return from Europe on a hop selling trip. The field north of the school is still known as the Hop Yard.

These bits of history show that the only constant in the world is change. The Valley today is a bit of a bedroom community with some commercial farms and a number of part time farms. These part time farms still produce a significant amount of revenue and maintain the valley floor as an ag area. One recent change is the development of specialty farms such as direct marketing and cheese producers.

Now I get back to the flood. The resiliency and determination of the community is there and important. Most folks love the beauty of the area and the people here and want to save it. A plan to reduce flooding is important to keep agriculture and forestry viable as well as protecting people's homes and land values.

Q - What hopes do you have for the future of the area?

A - I think I am a pragmatist and a borrower of good ideas, but I can also dream big. In my dream I see using PL 566 and its Watershed Protection and Flood Prevention program to revitalize the area. As I said Wednesday evening, the program goals fit perfectly with the needs of the Chehalis basin. I envision several water retention structures of two types: smaller ones that only held water for a short period of time to take the top off any flood;

larger structures that held water to the summer to also help fish, irrigation, recreation, small hydro production, cities and homes. Water for irrigation would make for a more certain crop production and enhance the prospect of people investing for the long term in ag production. The reduction in flood levels and danger would also make for a more certain economic future for the area.

I also see improvement of riparian habitat as part of the process, but not at the expense of severely restricting production agriculture or forestry. I see more committed and productive farms, large or small. I see more people taking pride in their community and home or farm. I see more people having appreciation for their streams and the wildlife that need them. In my big dream we find a way to extend the harvest interval on forest land. On steep slopes I feel that would have a significant conservation and water retention benefit. I know that is a very controversial issue, as certain regulations force timber owners to cut when they might not want to. They have also forced themselves into a corner economically by cutting to the point they must keep a short rotation just to have an income stream. I think the buffer issue needs to be modified in exchange for the issue of rotation length.

Our area suffers from a couple issues that plague many communities, especially rural ones. One is an aging population. Probably only time will take care of that. Any community needs young vibrant families to make it a thriving community; to get that you need good economic prospects. Our whole basin needs that without destroying our land base for farms and forestry that provides jobs and makes it a beautiful place to live. The growth management act and the counties have done a most uninspired job of that. In Lewis county we small parceled thousands of acres. We should have required clustering of home sites to save most of large parcels. Instead we have these 5 and 10 acre lots that are really blight on the land. This is really too long a discussion for here, but is a real issue.

The other rural problem is directly related to the flood for us. The flood lowered property values and drove some good people away. The result is cheaper homes and rentals, which may not bring your most sterling citizens to your area. Some people needing lower cost housing are great people getting started and working their way up. Others are people just trying to scrape by and are unwilling or unable to improve themselves. Many of them are not contributors, but takers. I am trying not to sound too negative, but there is a social cost to the nonproductive beyond just the public funds.

Maybe I could sum it up by saying I see a cleaner, more productive, more economically vibrant, more cohesive community for my family and neighbors. The history is here, the basis is here, we need a plan to carry us forward.

Q - When you think of the major floods over the past two decades, what are the strongest memories?

A - Should have quit after the last paragraph as I am not sure I can do better than that. I have covered a lot of this, but will see if I can list more. 2007 was by far the most significant for our area. One would be the effect on the outlook and response of people. It was varied. A very few cut and ran. Some people were almost frozen into inaction. Others took a deep breath and went to work. The extraordinary outpouring of money, time and support from total strangers still chokes me up. I think they and the community fed off each other. We kept working because they were helping and they kept coming because I think they knew they were making a real difference in helping people help themselves.

When government focuses on a problem with real determination to act, it really can work. Regulatory decisions were made quickly and in a relatively practical manner after the flood. After about a year things started to bog

down to the usual pace. The frustration with the politics and pace of the Flood Authority became indescribable. But the determination of the One Voice group and some others is significant and different than the history in the basin. I want to put Mark Clark and the Conservation Commission and myself and the Conservation District in the determined category. I have spent a lot of time and become far more involved in the District than I ever intended. Part of my determination is I have people tell me nothing can be done. We will see about that.

Newaukum

LIONEL PINN, COUNCILMEMBER, NAPAVINE

Q - What is special to you about the upper mainstem area (places, people and/or experiences)?

A - The historic value of the people and properties. Napavine is the third largest city in Lewis County, it can actually be impacted by both rivers (Newuakum and Chehalis). # 1 is the Newuakum River: three main stems on the 56 + mile long river runs strong during the flood season and has changed the lives of many as they rise through our community during past flood events. The Exit 72 region of I-5 is the most sensitive region and, without fail, is hit the hardest by flood events. This area is the key tax based for the city and livelihood for the businesses who have built there. # 2 is the Chehalis. When it reaches capacity it has to start pushing back on its creeks, stream and the mighty Newaukum. Eventually, in the right conditions, the water will start to run back up river, from north back to the south.

Q - If you were to describe this area to out of town friend or visitor, what you would highlight?

A - We are the third largest city in Lewis County but number one as it pertains to new home construction and fast growing economic structures. Love's Truck Stop and the Richie Brother Auction house are two examples. The main part of the city is well above the flood plain and it stays high and dry in all events, however the lower and northeast end of the city is well within the flood plain of the Newaukum River. People are good, the city is well run and it's a hometown kind of place that people love. Great school system, an in-town fire department, convenience store, barber, hair dresser, many upper end restaurants, gas stations, with a brand new hotel being built with a small conference room attached as well as additional retail space. You are never far away from a good conversation and good friends. Of special note is the one and only city owned outdoor amphitheater which has drawn many big name artist and shows.

Q - What hopes do you have for the future of the area?

A - More retail space at Exit 72 and on top of the hill in downtown Napavine; expansion of the UGA; more concerts and shows at the Amphitheater; also a possible location for a full on NASCAR racing facility.

Q - When you think of the major floods over the past two decades, what are the strongest memories?

A - Water covering the interchange at Exit 72; the closure of the entire I-5 freeway from Exit 71 to north of Centralia; the lifelong damage to homes, business and lives; the loss of livestock, damage to farmland and lack of preparation by the government.

Q - Feel free to tell us more if you like.

The other aspect of planning and concern is the Dike project in the Adna region. From what I have been told there we may be creating more of a problem with the diking than helping. Apparently the waters that would be roaring down the Chehalis River would eventually start backing into the Newaukum and thus back impact an already pressured river. I am in favor of building the Damn in Pe Ell. That is the best solution for a difficult challenge. Mitigating how that impacts others downstream is important too but the good of the all must outweigh the good of a few. I am also in favor of some, carefully conducted dredging, if done the correct way it would have little to no impact on the fish habitats. The fish are important; they will always be important to a variety of people and groups, and they must be a part of the conversation knowing that they are a resilient species and will survive no matter what we do with the river.

Twin Cities

EDNA FUND, COUNCILMEMBER, CENTRALIA

Q - What is special to you about the upper mainstem area (places, people and/or experiences)?

A - When I read "The [Chronicle's] Flood of 2007," on page 58, there is a picture of a woman wiping mud from a lady's face, who had several feet of water in her store. On page 22, is a picture of a volunteer rescuing a 4-year-old girl from the flood waters. Those pictures paint a picture of people helping people. Assistance provided without any remuneration. Our community pulls together in times like these.

Q - If you were to describe this area to out of town friend or visitor, what you would highlight?

A - Our area has high unemployment, has not solved the flood issue, yet the spirit of survival is here.

Q - What hopes do you have for the future of the area?

A - With flood mitigation, I am hopeful we can see the return of people and business to our area.

Q - When you think of the major floods over the past two decades, what are the strongest memories?

A - Some of my strongest memories are just arriving home in Centralia from my job in Olympia, before I-5 closed. I remember walking to Safeway and shelves being empty, since shipments could not arrive. I remember walking on the closed freeway, and it seemed almost like a ghost road.

I worked in The Chronicle Newsroom during the Flood of 2007, and it was a frenetic existence for many weeks. We then turned our work toward the book. Julie Zander and I co-authored the history chapter, and we found one of the earliest floods was in November 1887. If there was an easy solution, we would have solved it by now.

With our radio stations being off the air, I found most of my news on The Chronicle's blog. Folks were reporting all over Lewis County. The picture was changing hour by hour.

On page 108 of the [Chronicle] flood book is a picture of a farm which lost all of its livestock. On the front porch of the flooded home was a nativity scene, which normally was put up at Christmas. The family did not want to disappoint the community so they put it up. The picture brought tears to many people.

MERLIN MACREYNOLD, CITY MANAGER, CHEHALIS

Q - What is special to you about the upper mainstem area (places, people and/or experiences)?

- Recreational opportunities
- Rural lifestyle
- Pristine forestland, wildlife
- Timber harvest (employment) / sustainable forest opportunities
- Agricultural opportunities (farmland)

Q - If you were to describe this area to out of town friend or visitor, what you would highlight?

- Beauty of the area
- A community that gets things done (e.g., Chehalis Foundation projects, Library)
- Perfect location – within a couple hours drive to mountains, ocean, two major cities
- Great school district
- Friendly, close-knit community
- Responsive government
- Pride of our local history

Q - What hopes do you have for the future of the area?

- Family wage jobs
- Deal with flooding issues
- Growth, but still maintain small-town feel
- Geographical planning (unique opportunities and challenges)
- Economic development

Q - When you think of the major floods over the past two decades, what are the strongest memories?

- The devastation
- The shut down of I-5
- The quick and organized response of emergency management
- The can-do attitude of the people
- Neighbors helping neighbors
- The speed at which things get back to "normal" – people back in their homes, businesses reopening
- The increased awareness of the public of where (in a floodplain) they live
- Transportation challenges – 'can't get there from here'
- Lack of funding for localized flood damage reduction (home elevation / buyout programs)

RON AVERILL, LEWIS COUNTY COMMISSIONER

Q - What is special to you about the upper mainstem area (places, people and/or experiences)?

A - The Twin Cities is the center of population with about 1/3rd of the residents. It is also the seat of government and the most urban area of the county with two ports, an industrial park, hospital and commercial areas. The I-5 corridor and the BNRSF/UP rail lines run through this corridor offering opportunities for jobs, commerce and recreation. Lewis was Washington's first county in 1843 and its infrastructure has been developing ever since.

Q - If you were to describe this area to out of town friend or visitor, what you would highlight?

A - The Twin Cities is nestled in an agricultural valley surrounded by forested hills and mountains. It has the first Community College in the State of Washington, operating continuously since 1925. The seat of Government is in Chehalis and both Centralia and Chehalis have industrial ports. While the major industry used to be the natural resource industries, the communities have slowly been diversifying. This is an area where you have urban services in an area which is still predominantly rural.

Q - What hopes do you have for the future of the area?

A - Persistent flooding has always been a problem in the Twin Cities area prompting hundreds of studies – but all without success. When a major flood arrives all commerce comes to a stop, homes, businesses and commercial establishments are inundated and there are major threats to life and property. My real hope is to someday implement a solution that will end the cycle of damage and recovery. In my estimation, the best way to accomplish mitigation is water retention

Q - When you think of the major floods over the past two decades, what are the strongest memories?

A - Lots of water, interdicted roads and bridges and major property damage. Not only is the freeway closed, but routes into and out of communities are blocked as well, and not infrequently access to the major hospital is blocked for four to five days. During a flood an estimated 450,000 acre feet of water accumulates along the I-5 corridor. The only solution that can provide relief is water retention.

JULIE BALMELLI-POWE, TWIN CITIES RESIDENT

Q - What is special to you about the upper mainstem area (places, people and/or experiences)?

A - The culture, the history and generations of family ties

Q - If you were to describe this area to an out of town friend or visitor, what would you highlight?

A - Breathtaking natural beauty; a step back in time; low keyed and slower paced; where your neighbors are there when you need them and not when you don't; a stone's throw from just about any activity you desire

Q - What hopes do you have for the future of the area?

A - An end to severe flooding which in turn would set the stage for a thriving economy – hopefully without a huge influx of people to spoil the essence of the area {one can wish, can't they? ;o) }

Q - When you think of the major floods over the last two decades, what are the strongest memories?

A - (After the 2007 flood, it's hard to remember the others, except for the fact that they were major.)

The longest night of one's life – working in the dark and the rain to save our animals, equipment and supplies while yelling "Get back in the house!!" to our three small children who 'wanted to help', standing knee deep in

our carport, separated from us by 50 yds. of rapidly rising flood water; checking the water level every 20-30 minutes until it reached its peak around 3:00 a.m.

The pain and sorrow of friends and family – some who lost just a little, and some who lost almost everything, including the desire to go on

The disheartening sights and sounds – helicopters flying back and forth throughout the night rescuing those who were stranded on their rooftops; livestock and pets crying, frantically trying to escape the flood waters

The helplessness -- being cut off from everyone you care about – knowing that others are in need, but there is no way to reach them

The debris – everywhere – and I mean everywhere- dead things, yards and yards of plastic, jugs of oils and chemicals, fencing, haylage bales, commercial propane tanks, coolers, toys, wheels and tires, green house supplies, lumber, trees, piles of brush and dead grass, and lots and lots of garbage and mud -everywhere

The devastation – homes, farms, and businesses devastated; yards full of things that were once inside buildings – furniture, beds, fixtures, clothes, desks, papers, curtains, toys, carpet, sheetrock, livestock feed, all coated with 'flood mud'; flood mud, like pudding, was in and on everything – crawl spaces, mailboxes and inside homes and outbuildings – too soft to shovel, too thick to hose out

The horror stories – during the flood, one could only imagine the tragedies happening elsewhere, nothing you imagined was as bad as what really had – families, who the day before were secure in their homes, were now homeless with just the clothes on their backs; horses trying to swim to safety only to get caught in a fence under the water, unable to get free; having to listen to baby calves that were moved to a make-shift critter pad that never flooded before, crying in fear throughout the night, trying to escape the rising flood waters, but unable; the farmer who shot his whole bloodline of hand raised registered cattle, that after chasing them up on a hill, had followed him back to the barn where they had always felt safe - to him, shooting them was more merciful than watching them drown; sheep and cows stranded in barns, crawling on top of one another trying to stay above the water, some piles of dead animals reaching as high as the rafters, occasionally a bitter sweet ending with the animal on top surviving; and then there were the hundreds of cats, dogs, horses, sheep and cattle that were never found; the rescuers who dropped everything to help those in need, only to return to the fire station to find themselves victims of the flood as the cars were now submerged

The feeling of pride and thanksgiving – the resiliency of the communities, the generosity of friends, neighbors and total strangers willing to go miles and miles out of their way to bring food and supplies to those in need - everyone pitching in, helping out, rebuilding; FEMA employees thinking they were going to be swamped with people wanting their share of government handouts, surprised by how few showed up

The fear – the fear that comes back every time there is snow on Baw Faw; the fear that comes back every time the weather man mentions 'pineapple express'; the fear that comes back at the start of ***every*** flood season; the fear of not knowing if we will be as fortunate the next time it happens because it's not a matter of 'if', but 'when'; the fear that the next time it happens, people and businesses will just give up; the fear that the government will again build something in the floodway that gives them the 'biggest bang for the buck' to protect their infrastructure while again worsening the flooding for the people who live here; the fear that the Governor, like most politicians, will not keep her promise to protect the residents of the basin; and mostly the fear that a common sense solution like a dam, which our best science shows will protect I-5, reduce flooding for most with

no negative impacts to others, will improve water quality and quantity, and will improve the economy of depressed communities that in turn will benefit the state and feds, will be passed up due to the unsubstantiated fear that it 'might' not, or passed over for a cheaper solution that values commerce more that human life or the environment

Q - Feel free to tell us more if you like.

A- Homesteaders and early settlers of the basin moved into the valley knowing that it flooded. They adjusted their home sites and their livelihoods to live with flooding – even welcomed it as it renewed the nutrients in the fields and gave them an unexpected 'vacation' from their everyday chores.
Starting in the 1940's and continuing still today, government (because it knows what's best) began making improvements at the expense of those who were already living here. In an attempt to protect and improve public interest, the following projects were completed that have substantially contributed to increased flooding in the upper basin…

** Building of the airport levee during WWII to protect the airport for national security – this flood protected area is now home to K Mart, Walmart, Home Depot, Applebee's, Walgreens and strip malls

** Construction of I-5 and State Hwys. 6 and 12 to improve transportation up and down the western U.S. and to the ports on the coast

** Removal of overflow bridges on State Hwy.6 creating a levee

** Resurfacing of roads and highways without first grinding them down because it's cheaper that way, thus creating higher levees

Skookumchuck

There are currently no comments from residents in the Skookumchuck sub-area.

Lower Mainstem

KEN ESTES, MAYOR, MONTESANO

Q - What is special to you about the lower main stem area (places, people and/or experiences)?

A - Established businesses, farming and produce, light industry, it is a transportation hub, with fishing, recreation and scenic views.

Q - If you were to describe this area to out of town friend or visitor, what you would highlight?

A - Shopping, viewing, recreation, fishing, a place you can find nearly every service-from lumber companies, parts stores, vehicle sales, butchering, flying, the Rail Road station and freeways, and especially tourism (like the Veterans Museum).

Q - What hopes do you have for the future of the area?

A - That their flooding issues were solved without causing additional flooding here in the lower basin; that for the both of us, the economy would improve and we continue to work together to solve both problems.

Q - When you think of the major floods over the past two decades, what are the strongest memories?

A - Water over roads and the freeway, pretty much isolating us from supplies and needs; loss of livestock and their feed; flooded homes; flooding made worse by incoming tides and a west wind.

Q - Feel free to tell us more if you like.

A - Here in the lower valley we appreciate the surrounding hills down to the valley floor; which blends into the perfect setting for industry, logging, farming, residential, fishing, hunting, recreation and our beautiful small cities and resourceful people. And all this is away from the hustle-bustle of the big city. Truly, this is what makes America.

STEVE HALLSTROM, FARMER

Q - What is special to you about the lower mainstem area (places, people and/or experiences)?

A - Special for me is the natural environment, the forested hills, the wildlife all surrounding and comingling with a very fertile river valley. I have found the people mostly caring and friendly and have enjoyed being accepted as an oddity, an organic direct market farmer in a more traditional livestock based area.

Q - If you were to describe this area to out of town friend or visitor, what you would highlight?

A - The beauty of the natural setting, the abundance of wildlife, and the tranquil atmosphere as well as the closeness of the community.

Q - What hopes do you have for the future of the area?

A - That is remain natural, and not be over developed, that there be a return to profitable small farms, that local community groups become more active and involved in local service.

Q - When you think of the major floods over the past two decades, what are the strongest memories?

A - I've only been here one decade. On arriving it was interesting to see the COE tags on the Cedar tree in the yard designating the heights of the previous floods. Then the floods came. Being in the lower stem we get the high water a day or more later than upstream. Unusual though it may seem, it is often sunny when the waters rise, the storm having passed the previous day. So there is time to prepare, to get the equipment on high ground, to move animals etc. Probably the most vivid memory is working to move some hay stacked in an area that gets water in a flood. A nice sunny day, the neighbor came to help. At 3 pm she remarked that there was no hurry, the fields were not filling with water, the usual occurrence before a flood. At 5 pm we were isolated, the road to the farm inundated, and standing waves 2 feet high in the field next to the house. In both the high floods the water level was about the same as the 1996 flood marked on the cedar tree, even though the flow rates were much greater.

BILL GOERES, FARMER

Years blur together, but must have been fall of 2008. Dad had died 6 months previous and I had 24 hour care for Mom in her home. Rain cut loose, but it seems as if circumstances had me distracted and I was not paying attention to the Satsop River, which is incredibly fast in its rise. By the time I saw trouble, I had 30 minutes to get Mom, wheelchair, meds and helpers out. Luckily there was the disabled room available at the hotel. Then Satsop came up, Chehalis drowned us and I was stuck here with her care, which I am responsible for, going on 10 miles away. The next week was a blur, wet feed, dumped milk, wet barns, broken foot, workers ferried in and out. When it was done, I moved Mom to a nursing home, moved out Jenny's mother to a safer house. The flood zone is just too dangerous for them, and probably most senior citizens. Are the floods worse? I doubt it as the valley was not formed by gentle means. No place in the floodway is a safe place to live. Our grandfathers knew this, but the next generations slowly drifted into the floodway and now we cry because we have put ourselves in harm's way.

Hopes for the area: Ag has a bright future, especially here as water is plentiful, land inexpensive and markets close. Climate is great for cattle and many crops. This is probably as good as it gets for farm land.

We need to respect the flood zone. Over the years there have been many abuses to the zone that have led us partially to the place we are today. We have put farms, fill, houses, roads, stores, highways, gravel pits, construction overburden smack in the floodway and then we get the results that we do not like.

Look at the river. It wants to meander, fill a surge area. Fill to the extent of the need and not be stopped by dikes, freeways or fills.

We want 24 hour, 365 day north south traffic on I-5, but the pass has to close sometimes for avalanche, snow and water. Why not I-5?

Mitigation for fill put in the floodway does not work. It does not act the same. My opinion is that we have to start a removal process of obstructions starting west and working east. If my farm is named as a problem, so be it. We need a 100% stop to building in the flood way. No building permits issued for new, remodel or home raising. No new fills, no road lifts. No exceptions.

Surge zones need to be re-established. Maybe highway 12 needs to be lowered in places. Maybe I-5. Cross roads need to be lowered.

So....sorry, more than you asked for and down my old rabbit trail. It scares me more every year. Maybe it is time to get out.

Summary:

- A no BS study of real obstructions done yesterday
- Incentive for removal. Added incentive for voluntary removal
- Designated receiving area for removed material with expedited permitting
- Moratorium on any type of construction and fill Private, county , state, fed all included
- Authority for imminent domain to take, condemn, remove obstructions as needed

I understand that this looks crazy to you. Hey, it even looks crazy to me, but the insults to the flood zone are too many and have been in place too long for us to be gentle.

DAN THOMPSON, PUBLIC WORKS DIRECTOR, OAKVILLE

I live near Oakville now but have lived up and down the river over the past 38 years. In the upper area my thoughts and experiences are around the recreational aspects of the river. I raised three children in Chehalis and most of our summers were spent camping, swimming and fishing in the rivers and lakes surrounding the Chehalis River. The area is diverse economically and developmentally. Due to the interstate and central location of Centralia/Chehalis it is the retail hub of Lewis and Clark Counties. Manufacturing, natural resource harvesting and farming also play a huge role due to the forests and infrastructure available. Rail, trucking, airport's and state highways crossing the Cascade range to the eastern parts of the state make this area a great place to live. The people in the upper river basin are from all backgrounds and live different lifestyles from rural to urban or following college pursuits at the Centralia Community College.

If I was describing this area to a friend or acquaintance I would highlight the fact that you are 50 miles from the mountains. It's 60 miles to the Pacific Ocean and 85 miles in either direction to a huge metropolitan city. You can chose your lifestyle and be within an hour and a half to any one of them. My hopes for the future locally are to continue the emphasis on responsible land management and develop strategies to live with the river but remain driven to not make the mistakes of the past and mitigate flood caused suffering and economic loss with the best science available. My strongest memories are the floods of the 80's and 90's because my family lived thru the suffering and economic losses personally. As the Public Works superintendent for Oakville I have put the City back together after each flood and learned the mistakes of the past all too well. The present leaders of our state and local activists are on the right track with a basin wide solution led by local residents of the valley. I want to thank you for allowing me to express my own experiences of why I love this area so much.

JAY GORDON, FARMER, EXECUTIVE DIRECTOR WASHINGTON STATE DIARY FEDERATION

Q - What is special to you about the lower mainstem area (places, people and/or experiences)?

A - The lower Chehalis Valley is a place where most folks still know their neighbors; the valley floor is kept, tilled, tended and occupied by a small community of farmers, with a few fishermen, loggers and avid hunters. The area has had its share of economic struggles, but most farming and logging communities have, so our challenges are not all that different than other communities. The land has been in agriculture, relatively unchanged the past fifty or sixty years.

Q- If you were to describe this area to out of town friend or visitor, what you would highlight?

A - Our valley is a quiet place; trees growing on the hills and cows grazing in the valley, early on Sunday mornings make the loudest noises. It rains, a lot in the winter, much less in the summer. On summer Saturday nights you can hear, for miles, the sound of the cars racing at the fairground. It's an hour to the beaches, two to the Ski lift. If you want to meet most of the citizens of Elma and Montesano, you need only come to the High school football game between them in the fall. There are two stoplights in the lower 40 miles of the valley, if you don't count Aberdeen as lower valley (which it's not, really!)

Q - What hopes do you have for the future of the area?

A - A bit more prosperity, it's hard to sustain a community when our kids must leave to find work. Oh and a little lower flood levels.

Q - When you think of the major floods over the past two decades, what are the strongest memories?

A - They keep getting bigger, higher and more frequent, creating a question in the mind of how high will the next one be?

Grays Harbor Cities and Tributaries

VICKI RAINES, MAYOR, COSMOPOLIS

Q - What is special to you about the upper mainstem area (places, people and/or experiences)?

A - The upper main stem area of the Chehalis Basin is important to residents of the entire Chehalis Basin as land use, storm water runoff, and growth can affect everyone in lower reaches of the basin. This is an extremely important area to the economy of the State of Washington with I-5 being the main North South Corridor for our state; were you actually wanting our view regarding the lower basin?

Q - If you were to describe this area to out of town friend or visitor, what you would highlight?

A - The Grays Harbor Cities area is a nice place to live and is the most populated area in Grays Harbor County. We have a diversified economy of industrial, retail, tourism, transportation, and marine related jobs that support our economy. There are numerous recreational opportunities in our area with fishing, hunting, sports facilities, hiking, water sports etc. The City of Cosmopolis has two of the largest employers in Grays Harbor County in Weyerhaeuser and Cosmo Specialty Fibers. The Port of Grays Harbor is growing with new industries and shipping that are no longer timber dependant. The City of Hoquiam recently welcomed the re-opening of Hoquiam Plywood Company and are getting ready to reopen the Grays Harbor Paper Company. There are new housing developments in all three of the cities, and we have excellent school systems and available medical care.

Q - What hopes do you have for the future of the area?

A - We hope to see a continued diversification in our economy in the future with the development of the waterfront in Cosmopolis and Aberdeen. Numerous economic opportunities exist along the waterfront with the existing South Side Flood Control Dike in place that protects this area from flooding. In Cosmopolis we are working on gathering funding for the removal of the breached Mill Creek Dam so we can create a natural area for use in flood control and for educational programs. Another infrastructure item we have prioritized is a new Police Station, Court, Council Chambers, Admin Building that can replace facilities that are undersized and insufficient for our needs.

Q - When you think of the major floods over the past two decades, what are the strongest memories?

A - A couple of floods in the past two decades have had an economic impact on the City of Cosmopolis. In November 1990, the City of Cosmopolis received nearly six inches of rainfall in a 48 hour period combined with the flow in the Chehalis River from the upper reaches of the basin that cause US 101 to be under two feet of

water closing off the northern entrance to the city. This flood event closed off rail service and the trucking of materials for the Weyerhaeuser Company for a couple of days costing them thousands of dollars.

The second flood event that had and still does have an effect on Cosmopolis is the November 2008 flood that caused a breach in the Mill Creek Dam. Mill Creek is the main drainage for the entire City of Cosmopolis that flows into the Chehalis River. The breaching of this Dam cost an estimated $700,000 damage to the Dam and properties downstream. The City of Cosmopolis is still seeking funding to remove the Dam and restore the sight back to a natural area that could enhance flood control and be available for educational opportunities.

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Appendix C: Chehalis River Basin – Forest Practices

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Forestland Section

April 30, 2012
(Revised May 25, 2012)

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Washington State Department of Natural Resources
Forest Practices Program, Forest Practices Division

WASHINGTON STATE DEPARTMENT OF
Natural Resources
Peter Goldmark - Commissioner of Public Lands

Executive Summary

Forestland and the Chehalis Basin

Forestlands are an extensive and integral part of the Chehalis river basin, comprising approximately 84% of the land base. Approximately 91% of the forestland is subject to the Washington Forest Practices Act and rules, while the remaining forestland is federal or tribal land. The Earth Economics Study commissioned by the Chehalis River Basin Flood Authority (Batker et al. 2010), explains how natural systems, including forestlands, provide flood protection – protection that can be compromised when the natural systems are lost through such actions as conversion to industrial or home sites. Forestland offers protection from flooding through hydrologic processes. For example, trees intercept rainfall and subsequent evaporation from the foliage (forest evapotranspiration) returns some of the rainfall back to the atmosphere. Permeable soils found in forests and understory vegetation absorb water, decreasing the amount of surface water runoff. Forest management activities such as timber harvest or forest road construction have the potential to decrease the natural flood protection of the forests if executed in a way that does not minimize adverse effects to these hydrologic cycle components.

Washington State has a rigorous forest practices regulatory program which prescribes forest management practices in a way that protects public resources such as water, fish and wildlife. The forest practices regulatory program is flexible and responsive to new information, which provides the ability to make changes in protective measures as scientific knowledge evolves. Additionally, lands subject to the Forest Practices Act and rules are covered by the Forest Practices Habitat Conservation Plan, an unprecedented conservation plan, approved by the Federal government, which covers all of the state and private forestland in Washington. The current Forest Practices rules:

- Protect unstable slopes, riparian forests, and wetlands,
- Minimize the impact of even-aged harvest in rain-on-snow zones,
- Limit even-aged harvest size and timing,
- Minimize soil disturbance as a result of harvest methods,
- Ensure well designed, located, constructed, and maintained forest roads,
- Ensure fish passage to upstream habitat,
- Maintain an effective adaptive management program and compliance monitoring program.

Forest Practices Rules – Background and History

The Forest Practices Act which declared that “forest land resources are among the most valuable of all resources in the state” was passed by the legislature in 1974. This law and its corresponding rules regulate forestry activities on state and private lands and are designed to protect the environment and ensure that Washington continues to be a productive timber growing area. The Act also created the Forest Practices Board (the Board), a 13 member entity that is a separate agency from the Washington Department of Natural Resources (DNR). The Board, working with the public, stakeholder groups and DNR, adopts Forest Practices rules and approves guidelines (Forest Practices Board Manual) which help landowners implement the rules.

The 1974 Forest Practices Act was the first step toward protecting public resources on forestland. A flexible forest practices program was built as the infrastructure to implement the Forest Practices Act and has facilitated many changes since the original 1974 Act including:

- 1982 – rules addressing "excessively steep or slide prone slopes."
- 1987 and 1988 – new rules regarding protection of riparian areas, adaptive management and interdisciplinary teams.
- 1992 – new rules addressing cumulative effects in watersheds, retention of wildlife reserve trees; establishment of wetland management zones; limits on even-aged harvest size and timing; operations on unstable slopes; filling of wetlands; and a temperature prediction method to ensure retention of adequate riparian shade.
- 2001 – sweeping changes to the rules including: clarification and better tools for identifying unstable slopes; more rigorous protection of riparian areas and wetlands; more rigorous requirements for forest road construction and maintenance to reduce road impacts on public resources; and a requirement for road construction and maintenance planning and annual reporting. The 2001 changes also included a more robust adaptive management program and compliance monitoring program to help ensure the forest practices program continues to be responsive to new scientific knowledge and that forest practice activities are in compliance with the law.

The 2001 changes paved the way for the State of Washington to write a conservation agreement called a habitat conservation plan. The 2005 Forest Practices Habitat Conservation Plan (FPHCP) is a statewide, programmatic plan protecting over 9 million acres of state and private forest land and 60,000 miles of streams – a first of its kind in the nation due to its scope and collaborative process. The plan, approved by the federal fisheries agencies in 2006, was the result of a unified and coordinated conservation effort among state, federal, tribal and local governments, environmental interest, and small and large forest landowners.

The Board has continued to make changes to the Forest Practices rules and Board Manual since 2001. One of the most recent rule changes resulted from the December 3, 2007 storm and the profound impact it had in western Washington and Oregon and especially in the upper Chehalis River basin. Unusually heavy precipitation and high winds, along with rapid snow-melt caused severe damage to thousands of acres of forestland in the area. Significant water run-off from heavy rainfall, rapid snow melt and saturated soils resulted in extensive damage to some forest road systems due to significant water flow, numerous landslides, debris slides and slumps, and massive timber blow-down areas. The Board convened a group of experts to consider the effects of the 2007 storm in an effort to decide what, if anything needed to be done to minimize the effects of a similar storm in the future. The Board's review led to changes in the watershed analysis rules, particularly related to landslide-prone areas. The Board continues to address issues on an on-going basis as new scientific and natural systems information arises.

Peak Flows/ Unstable Slopes and the Forest Practices Rules

The scientific literature identifies peak flow and unstable slopes as key factors that could be impacted by forest management activities and that have a potential to effect downstream flooding. Peak flow impacts most likely occur during storm events. Peak flows can affect flooding, stream channel alteration, stream bank erosion, and redistribution of sediment and large organic debris. The two forest management activities that most likely affect peak flows are timber harvest and road building. The potential magnitude of the effect of these two activities may increase when either activity takes place in a rain-on-snow zone. The extent to which timber harvest alone has triggered substantially increased peak flows is likely rare (Storck et al. 1995). Indiscriminate road construction, however, can alter runoff by collecting subsurface and road-surface water that routes directly to stream channels (Chamberlin et al. 1991).

Whether or not a particular slope will fail at any given time is dependent on a variety of variables, including precipitation rate and quantity; soil moisture; hydrology; slope aspect, length, and curvature; the internal strength of the slope material (Coates and Higgins 1990; Dragovich et al. 1993a); and root strength of vegetation (Harp et al. 1997; Schmidt et al. 2001; Roering et al. 2003). Disturbances, including timber harvest and road building, that compact or weaken slope material, change the hydrology of the slope, or undercut marginally stable slopes can trigger landslide events (Rollerson et al. 1997; Swanson and Dyrness 1975; Amaranthus et al. 1985; Dragovich et al. 1993b; Gerstel 1996). Increased levels of planning and analysis can reduce the likelihood of landslides by identifying and avoiding potentially unstable landforms, as can minimizing disturbance from harvest activities in these areas (Gerstel 1994; Rashin et al. 1999; Dhakal and Sidle 2003).

Forest practices rules include specific rules that help to minimize any potential impact of forest management on peak flows and unstable slopes. The primary forest practices rule groups that minimize peak flows and provide protection to unstable slopes include:

- Roads rules which help prevent interception of surface and subsurface water by roads,
- Rain-on-snow and green-up rules which help regulate size and timing of even-aged harvesting to prevent excessive levels of immature forest cover in any given geographic area,
- Unstable slopes rules which help minimize disturbance of unstable slopes.

The Forest Practices rules related to roads serve to maintain surface and groundwater hydrologic regimes by disconnecting road drainage from the stream network, thereby preventing increases in peak flows. This is accomplished, in part, through the proper location, design, construction, maintenance and abandonment of forest roads. Additionally, forest landowners are required to have a road maintenance and abandonment plan and provide annual status reports on the plan implementation.

The potential effects of forest management on peak flows is higher in the rain-on-snow zones through the influence of increased snow accumulation in canopy openings and melt during rain-on-snow precipitation events. Forest Practices rules address rain-on-snow effects in two ways, first through the hydrology module in watershed analysis and second through the rain-on-snow rule which gives DNR authority to set conditions for forest practice activities that propose even-aged harvesting in the significant rain-on-snow zone. DNR may limit even-aged harvest size when it determines that peak flows have caused material damage to public resources. The “green-up rule” also addresses limitations on even-aged harvesting. Under the green-up rule, the size and timing of even-aged harvesting is regulated to prevent excessive levels of immature forest cover in any given geographic area.

The Forest Practices rules are designed to reduce the frequency and magnitude of debris flows and debris avalanches from slope failures. If a field review confirms the presence of unstable slopes and timber harvest and/or road construction is proposed in those areas, the forest practice is classified as Class IV-Special and becomes subject to review under the State Environmental Policy Act. Conditions can be placed on the application and when applicable, mitigation measures for unstable slopes range from avoiding unstable slopes to altering the methods or techniques used in timber harvest and/or road construction operations.

The forest practices program also has a robust Adaptive Management program (AMP) and an on-going compliance monitoring program and enforcement authority. The AMP provides science-based recommendations and technical information to assist the Board in determining if and when it is necessary or advisable to adjust rules and guidance in order to achieve established goals and objectives. The compliance monitoring program and enforcement authority help to ensure that on-going forest practice activities are in compliance with the law.

Recent and Ongoing Research through the Cooperative Monitoring, Evaluation, and Research Committee

DNR, and its statewide partners, support and participate in monitoring, evaluation, and research projects through the Adaptive Management Program. The Forest Practices Adaptive Management Program is a multi-caucus program that includes representatives from state departments (including Fish and Wildlife, Ecology, and Natural Resources), federal agencies (particularly National Marine Fisheries Service, U.S. Fish and Wildlife Service, and Environmental Protection Agency), forest landowners, county governments, the environmental community, and tribal governments. Representatives of these caucuses participate on two key Adaptive Management Program committees established by the Forest Practices Board: the Forests and Fish Policy Committee (Policy) and the Cooperative Monitoring, Evaluation, and Research (CMER) Committee.

The CMER Committee oversees and conducts research and monitoring related, in part, to assessing the effectiveness of the Forest Practices rules. Its purpose is to advance the science needed to support adaptive management. The CMER Work Plan includes projects related to unstable slopes and forest roads that are particularly relevant to the forested landscape found in the Upper and Lower Chehalis basins. Unstable slope related projects will look at landslides that occur as part of natural hydrologic processes and as well as landslides within harvested areas to help understand the potential impact of harvest on the rate of landslides. Other studies will review the rule-identified landforms in the Forest Practices rules to determine the effectiveness of buffering these landforms in preventing or avoiding an increase in landslides beyond natural background levels. Forest road related projects will continue to monitor the rate of sediment delivery from surface erosion and determine if the road characteristics that affect runoff and sediment delivery to streams are improving through time as forest roads are improved through Road Maintenance and Abandonment Planning (RMAP) implementation.

Recommended Projects for Future Funding

DNR is recommending three projects, in priority order, for funding consideration. All three projects will provide tools and information to help provide flood relief and protection in the Chehalis basin.

Project #1: Geological mapping and updated LiDAR (Light Detection and Ranging)

LiDAR and photography will supply data on floodplain elevations that are needed to understand flooding patterns, geomorphology, floodplain management, and development. In the upper Chehalis basin, LiDAR will provide data on slopes and where landslides have occurred. This will be used to test

the predictive models. Because parts of the Chehalis basin have been flown for LiDAR, a comparison of the two LiDAR data sets can be made. Geologic mapping will identify the location and physical characteristics of geologic materials, surface and subsurface constrictions, what controls groundwater divides, what controls channel migration, landforms, what is controlling the rates of erosion and landsliding, depth to bedrock, as well as the fractures and faults within the geologic materials. This information provides critical stratigraphy and geohydrologic information for informed decisions.
Estimated Cost: $4,274,600

Project #2 - Unstable Slope Criteria Project: An Evaluation of Hillslopes Regulated under Washington Forest Practices Rules.
This project will evaluate the degree to which the landforms described in the Forest Practices rules identify potentially unstable areas with a high probability of impacting public resources, as well as identify and characterize additional potentially unstable landforms. The results of the project would help inform decisions regarding forest management activities.
Estimated Cost: $200,000

Project #3 – Road Prescription Scale Effectiveness Monitoring Project
The primary purpose of this project is to evaluate the effectiveness of road maintenance categories in meeting road performance targets and to identify sensitive situations where prescriptions are not effective.
Estimated Cost: $2,200,000

Introduction

In 2011, Engrossed Substitute House Bill 2020 directed the Office of Financial Management, in collaboration with other state and federal agencies, tribes and local governments to provide a report to the governor and legislature that identifies and prioritizes flood hazard mitigation projects for the Chehalis river basin. The purpose of this chapter of the report is to provide pertinent forest practices information for the community, decision makers and other interested stakeholders to use to make decisions relating to flood relief and protection in the basin.

Forestlands are an extensive and integral part of the Chehalis river basin, comprising approximately 84% of the land base. Approximately 91% of the forestland is subject to the Washington Forest Practices Act and rules, while the remaining forestland is federal or tribal land. The Earth Economics Study commissioned by the Chehalis River Basin Flood Authority (Batker et al. 2010), explains how natural systems, including forestlands, provide flood protection – protection that can be compromised when the natural systems are lost through such actions as conversion to industrial or home sites. Forestland offers protection from flooding through hydrologic processes. For example, trees intercept rainfall and subsequent evaporation from the foliage (forest evapotranspiration) returns some of the rainfall back to the atmosphere. Permeable soils found in forests and understory vegetation absorb water, decreasing the amount of surface water runoff. Forest management activities such as timber harvest or forest road construction have the potential to decrease the natural flood protection of the forests if executed in a way that does not minimize adverse effects to these hydrologic cycle components.

Washington State has a rigorous forest practices regulatory program which prescribes forest management practices in a way that protects public resources such as water, fish and wildlife. The forest practices regulatory program is flexible and responsive to new information, which provides the ability to make changes in protective measures as scientific knowledge evolves. Additionally, lands subject to the

Forest Practices Act and rules are covered by the Forest Practices Habitat Conservation Plan, an unprecedented conservation plan, approved by the Federal government, which covers all of the state and private forestland in Washington.

Much of the material in this report is taken (in some cases quoted directly) from three primary documents: the Forest Practices Habitat Conservation Plan (FPHCP) (DNR 2005); The Forest Practices Habitat Conservation Plan Environmental Impact Statement (FPHCP EIS) (U.S. Department of Commerce, NMFS and U.S. Department of Interior, USFWS, 2006); and the National Oceanic and Atmospheric Administration (NOAA) Biological Opinion on the Washington State Forest Practices Habitat Conservation Plan (U.S. Dept. of Commerce, NMFS, 2006). (Original research and analysis for this report was not feasible given the limited time available). The three documents offered existing literature and statewide forestland characteristic summarization that helped inform this report. Most of the data characteristics such as forest land ownership, stream length and traits (fish-bearing or non-fish bearing) and all of the maps were obtained from the DNR's Geographic Information System database.

The forestland report:

- explains the evolution of Washington's public resource protection on forestland and its responsiveness to new information;
- summarizes scientific conclusions found in the literature regarding potential impacts of forest management during flooding events;
- clarifies how those impacts are mitigated through Washington State's forest practices program and rules; and
- summarizes on-going research from the forest practices Adaptive Management Program that is relevant to the Chehalis basin, and
- describes and prioritizes projects that, if funded, would provide tools and information to understand flooding patterns, geomorphology, floodplain management, and development; and reduce the risk of forest practices activities (primarily timber harvest and forest road construction) contributing during flooding events in the Chehalis river basin.

Evolution of Responsive Public Resource Protection

The citizens of Washington State value its forestland for many reasons, including public resources found on forestland such as fish, wildlife and water. Developing ways of protecting public resources on forestland during forest practices management operations is important to the citizens of the State. This section describes the evolution of the system that was developed in Washington to protect public resources on forestland. The system is flexible and responsive to new information, which provides the ability to make changes as scientific knowledge evolves.

The value of Washington's forestlands and the need to protect them has become increasingly recognized since the nineteenth century. Initially, in the 1800's, Washington's forests were viewed as a limitless resource, providing a seemingly cheap and inexhaustible supply of lumber for houses, buildings, railroads, ships and bridges—the raw materials for a nation of immigrants expanding westward (McCune and Schroedel 1998). Through the end of the nineteenth century and much of the first half of the twentieth century, forest practices in Washington were unregulated. Early in the 1900s, after Washington State experienced devastating forest fires, the legislature appointed the first State Fire Warden and Forester to oversee fire laws and to focus on suppressing forest fires (Rodgers 1995; DNR 1975). In 1945 the first legislation, commonly referred to as the "reforestation law" was enacted to regulate forest practices activities. The new law required forest landowners to reforest following

logging. This was the first of many laws and Forest Practices rules to come, that would focus on protecting Washington's forests, forest industry, and public resources.

As time passed, knowledge and understanding of society's impact on the natural environment increased as concerns about its protection heightened. Two such concerns were diminished air quality and polluted rivers and streams. These concerns spurred a national environmental movement in the 1970s and passage of the Federal Water Pollution Control Act of 1972, commonly known as the Clean Water Act (CWA) (EPA 2003).

Washington State chose to address the new federal environmental laws by passing the Forest Practices Act in 1974 which declared that "forest land resources are among the most valuable of all resources in the state; that a viable forest products industry is of prime importance to the state's economy; that it is in the public interest for public and private commercial forestland to be managed consistent with sound policies of natural resource protection; that coincident with maintenance of a viable forest products industry, it is important to afford protection to forest soils, fisheries, wildlife, water quantity and quality, air quality, recreation, and scenic beauty" (RCW 76.09.010). The Act was the state's first comprehensive law addressing the impact of forest practices activities on the environment. This law and its corresponding rules regulate forestry activities on state and private lands and are designed to protect the environment and ensure that Washington continues to be a productive timber growing area. The Act also created the Forest Practices Board (the Board), a 13 member entity that is a separate agency from the Washington Department of Natural Resources (DNR). The Board, working with the public, stakeholder groups and DNR, adopts Forest Practices rules and approves guidelines (Forest Practices Board Manual) which help landowners implement the rules.

The Board adopted the first set of Forest Practices rules in 1976. Since its inception, the Board has responded repeatedly to improved understanding and knowledge to ensure continual protection of public resources. The current Forest Practices rules and guidance are, in part, the result of scientific efforts over the years to learn more about the complex ecological relationships that shape forests. And through federally approved habitat conservation plan (Forest Practices Habitat Conservation Plan) and subsequent Incidental Take Permits (described later in this section), the State of Washington provides long-term conservation of federally listed (and unlisted) aquatic species and riparian habitat on over 9 million acres of state and private forestland. The current Forest Practices rules present a robust set of protection measures to:

- Protect unstable slopes, riparian forests, and wetlands,
- Minimize the impact of even-aged harvest in rain-on-snow zones,
- Limit even-aged harvest size and timing,
- Minimize soil disturbance as a result of harvest methods,
- Ensure well designed, located, constructed, and maintained forest roads,
- Ensure fish passage to upstream habitat,
- Maintain an effective adaptive management program and compliance monitoring program.

The first modification to the Forest Practices Act came in 1975 when the Act was changed to establish a system of four classes of forest practices based on their potential to adversely impact public resources. Forest practices are classed as Class I, Class II, Class III or Class IV, with Class I having no direct potential of damaging public resources and Class IV having the greatest potential. Class IV forest practices are subject to review by means of additional State Environmental Policy Act (SEPA)

procedures. The State Environmental Policy Act provides a way to identify possible environmental impacts that may result from governmental decisions and may require preparation of an Environmental Impact Statement (EIS).

In the early 1980's research began showing the importance of riparian forests and led the Board to focus on addressing riparian management zones (FPB 1985). Subsequent studies increasingly highlighted the role of large woody debris (LWD) in streams. Also, scientists were gaining a better understanding of the effects of increased in-stream sediment levels resulting from harvesting and road construction on unstable slopes. In total, new research indicated the original 1976 Forest Practices rules were likely inadequate to meet the resource protection goals of the Act. The environmental community and tribal representatives expressed concern about not only the effects of individual forest practices activities on aquatic habitat, but also the combined and synergistic effects of multiple forest practices within a watershed, known as "cumulative effects." In response, the Board commissioned a study on cumulative effects in 1983. The report, *Cumulative Effects of Forest Practices on the Environment*, was completed in 1984 (Geppert et al. 1984). The study provided a first approximation of the nature, source and extent of cumulative effects as related to forest practices activities.

In response, the Board began to consider changes to the Forest Practices rules to improve protection for riparian areas, fish and wildlife habitat, and to address cumulative effects. In a historic effort to resolve increasingly contentious natural resource protection issues without lengthy and costly lawsuits, representatives from state natural resource agencies, industrial and small forest landowners, tribes and environmental groups came together. The group developed a new, collaborative way of working on resource protection challenges through a consensus process. Their work became known as the Timber/Fish/Wildlife (TFW) Agreement, and was finalized in 1987. The agreement, in part, established ground rules for developing rule proposals, which would be forwarded to the Board for consideration (FPB 1987). The TFW Agreement also included an approach to address cumulative effects associated with forest practices, and recommended implementing an adaptive management program and the use of risk assessment techniques to identify potential problems. The TFW Agreement recommendations, together with the 1984 cumulative effects study, were used to guide the development of the watershed analysis rules adopted by the Board in 1992.

The TFW Agreement also led to significant forest practices rule revisions in 1987 and 1988, with protection of riparian areas as a primary focus (FPB 1988). These rules added width to riparian management zones and defined the number, size and species of trees required to be left standing to protect wildlife habitat and provide shade and large woody debris for fish habitat (FPB 1988 WAC 222-30-020). Two other important components of these rules were the introduction of an adaptive management program and the use of interdisciplinary (ID) teams (FPB 1988). Adaptive management uses a science based research and monitoring approach to make recommendations to the Board for modifications to the rules or guidance as needed to protect public resources. ID teams are made up of technical experts—fisheries biologists, hydrologists and geomorphologists, among others—and individuals from various stakeholder groups. The team evaluates the environmental impact of proposed forest practices and recommends potential protective measures.

The 1992 watershed analysis rules recognized the importance of using a science-based approach for assessing watershed problems and sensitivities of an entire basin, rather than reviewing forest practices activities on a site-by-site basis. Although the rules provided protection on a site-by-site basis, there were concerns that the cumulative effects of all the forest practices activities in a watershed basin may impact the watershed as a whole. The watershed analysis process resulted in identification of specific

management prescriptions, which when implemented within a watershed, would reduce negative cumulative effects.

In addition to establishing the watershed analysis program to specifically address concerns about cumulative effects, the 1992 rule changes also included retention of wildlife reserve trees; establishment of wetland management zones; limits on even-aged harvest size and timing (the size and timing of even-aged harvesting is regulated to prevent excessive levels of immature forest cover in any given geographic area); more stringent environmental review of the application of chemicals; operations on unstable slopes; archaeological, historical and cultural sites; and filling of wetlands. The rules also imposed restrictions on the use of pesticides, fertilizers and other forest chemicals, and added a temperature prediction method to ensure retention of adequate riparian shade (FPB and Ecology 1992).

New watershed analyses rules facilitated the completion of approximately 60 watersheds between 1991 and 1996. Although watershed analysis was a useful tool for determining cumulative effects to watersheds, it was found to be very time-consuming and expensive to conduct, prohibiting some landowners from participating. However, the information gathered over the years and the prescriptions crafted from the completed watershed analyses across the state was very informative and established a basis for recommended rule changes in the Forests and Fish Report (FFR) described below (DNR 1999). One of the results from watershed analyses indicated that forest roads were an ongoing contributor of sediment to water bodies, in many areas, adversely impacting water quality.

In the mid-1990s, three issues emerged that led to TFW negotiations, and ultimately, revised Forest Practices rules:

- A growing number of streams were not meeting water quality standards as defined in the Federal Clean Water Act.
- The accuracy of water type base maps used to establish fish presence—and absence—for purposes of implementing appropriate forest practices protection measures were less than desirable.
- The Board needed to respond to the federal government's pending listing in 1998 of several species of salmonids in Washington as threatened or endangered under the Endangered Species Act (ESA).

These issues combined with the results from the watershed analysis process suggested that riparian buffer widths and leave-tree requirements might be inadequate to ensure healthy, functioning riparian systems. The TFW collaborative negotiation process was a preliminary step which eventually led to the production of a science-based plan—the Forests and Fish Report —for protecting water quality and aquatic and riparian-dependent species on state and private forestland in Washington State. Author groups of the Forest and Fish Report included representatives from Federal agencies (National Oceanic and Atmospheric Administration (NOAA) Fisheries, United States Fish and Wildlife Service (USFWS), Environmental Protection Agency (EPA) and the United States Department of Agriculture Forest Service (USFS) and state natural resource agencies (DNR, Ecology, Washington Department of Fish and Wildlife), the office of the governor, tribes, county representatives, large industrial forest landowners and small forest landowners.

Specific key highlights of the FFR recommendations included adoption of rules to:

- establish mature, conifer-dominated riparian forests to provide function;
- disconnect roads (particularly road runoff) from the stream network;

- protect streambank stability;
- ensure fish passage to upstream habitat;
- prevent or avoid an increase or acceleration of the naturally occurring rate of landslides due to forest practices;
- require landowners to prepare and implement Road Maintenance and Abandonment Plans (RMAPs) designed to address road-related impacts by 2016;
- establish a productive adaptive management program.

The Washington legislature passed the 1999 Salmon Recovery Act, (also known as the "Forests and Fish Law"), which directed the Board to adopt Forest Practices rules consistent with the recommendations in the Forests and Fish Report (DNR 1999). The Board adopted permanent Forest Practices rules in May 2001. These permanent Forest Practices rules which are designed to protect water quality and aquatic and riparian-dependent species and reduce cumulative effects across the landscape (FPB 2001) also help reduce the effects of forest practices activities on forest hydrology, unstable slopes and public safety. This set the stage for the State to obtain federal assurances regarding federally listed species by developing a conservation plan and obtaining Incidental Take Permits with the federal government.

The State of Washington produced a conservation plan, *2005 Forest Practices Habitat Conservation Plan* (FPHCP), which was accepted by the USFWS and NMFS. Acceptance of the FPHCP led both agencies to issue an incidental take permit to the State of Washington for federally listed aquatic species. The permits allow forest practices activities in the State to proceed without threat of lawsuit because the habitat conservation measures in the plan are sufficient to protect aquatic habitat and therefore minimize harm to federally listed aquatic species. The FPHCP is a statewide, programmatic plan protecting over 9 million acres of state and private forest land and 60,000 miles of streams – a first of its kind in the nation due to its scope and collaborative process. It includes a robust Adaptive Management Program that uses science-based information to assist the Forest Practices Board in making changes to the forest practices rules when necessary to ensure the protection of fish habitat and water quality. It also includes an ongoing Compliance Monitoring Program to determine if forest practice activities are being conducted in compliance with the Forest Practices rules.

The Board has continued to make changes to the Forest Practices rules and Board Manual since the sweeping 2001 rules changes. One of the most recent rule changes resulted from the December 3, 2007 storm and the profound impact it had in western Washington and Oregon and especially in the upper Chehalis River basin. Unusually heavy precipitation and high winds, along with rapid snow-melt caused severe damage to thousands of acres of forestland in the area. Significant water run-off from heavy rainfall, rapid snow melt and saturated soils resulted in extensive damage to some forest road systems due to significant water flow, numerous landslides, debris slides and slumps, and massive timber blow-down areas.

After the storm, the Washington Departments of Agriculture, Natural Resources, and Fish and Wildlife took immediate steps to help landowners who incurred severe damage from the storm. These agencies facilitated approval of forest practices applications to repair storm damage, assessed the impact of the storm, analyzed current processes in place to deal with a similar storm event and determined what, if anything could be done in the future to minimize the effects of a similar storm. The Forest Practices Board considered the effects of the storm and the sufficiency of the Forest Practices rules to protect against forest damage during future storms. They convened a group of experts to focus on the mass wasting prescriptions developed under watershed analysis (chapter 222-22 WAC).

The Forest Practices Board review led to these actions to help ensure public safety and public resource protection:

1. The Forest Practices rules related to watershed analysis and potentially unstable slopes and landforms were analyzed and amended in May 2011,
2. The Forest Practices Board Manual Section 11, *Standard Methodology for Conducting Watershed Analysis* was clarified and changes approved in May 2011,
3. All watershed analyses were reviewed to see if a reanalysis of the watershed for mass wasting prescriptions was needed,
4. Forest landowners were notified to assess if they wanted to sponsor or co-sponsor reanalysis of mass wasting prescriptions in watersheds where reanalysis was needed. Landowners also had a choice to rescind the mass wasting prescriptions and agree to apply Forest Practices standard rules instead of performing a watershed reanalysis for the mass wasting module.

The May 2011 rule language changes were a product of the Adaptive Management Program. Most of the effects of the rulemaking were contained in the amendments to WAC 222-22-090, *Use and review of a watershed analysis* and WAC 222-16-050, *Classes of forest practices*. The salient points of the language changes included:

- Reinforcing that watershed analyses must be kept up to date,
- Requiring that landowners interested in maintaining prescriptions (that DNR has identified for reanalysis) are responsible for committing sufficient resources to complete the reanalysis,
- Specifying that DNR will review approved prescriptions to determine the needs for reanalysis every five years, or sooner when certain conditions apply,
- Confirming that DNR can rescind prescriptions if no affected landowners wish to participate and commit resources,
- Classifying a forest practices application as Class IV-special if a watershed analysis is not current or is not being conducted in accordance with conditions required by DNR during reanalysis, and
- Giving DNR the authority to rescind prescriptions if the established timeline is not met for completing a reanalysis.

Additionally, the Forest Practices Board approved a study called the Mass Wasting Effectiveness Monitoring Project (also known as the Post-Mortem Study). This project is designed to statistically compare landslide rates among five harvest treatments and five road treatments. The treatments are sets of prescriptions associated with forest practices activities within the period in which different Forest Practices rules were in effect. It is estimated that the Post-Mortem study will be completed in the summer of 2012. More information on this study can be found in *Recent and On-Going Research Relevant to the Chehalis Basin* later in this report. Completion of this study is the first step in a series of studies. Follow-up studies will look at landslides that occur as part of natural hydrologic processes and as well as landslides within harvested areas to help understand the potential impact of harvest on the rate of landslides. Other studies will review the rule-identified landforms in the Forest Practices rules to determine the effectiveness of buffering these landforms in preventing or avoiding an increase in landslides beyond natural background levels.

The process of rescinding mass wasting watershed analysis prescriptions in watersheds where landowners did not choose to do a reanalysis of the watershed, is on-going. Currently, it appears that three watershed analyses will perform mass wasting prescription re-analyses. Thirty-six watersheds will have their mass wasting prescriptions rescinded. Only one watershed in the Chehalis basin, the Upper

Skookumchuck, will have a reanalysis performed and when complete, landowners in that watershed will be able to continue to follow the mass wasting prescriptions in the watershed analysis.

Characterization of the Upper and Lower Chehalis WRIAs

This section provides a summary of the underlying characteristics of the forestland in the Upper and Lower Chehalis Water Resource Inventory Areas (WRIA) that includes a description of the climate, geology, topography, hydrology, land cover and use, and ownership patterns within the basin.

The upper and lower Chehalis WRIAs fall under a coastal hydrologic regime where rain and rain-on-snow are dominant (see Figure 1: Chehalis Basin "Rain-On-Snow" Zones). The maritime climate is characterized by mild, wet winters and warm dry summers. Average annual precipitation ranges from 40 inches in the Puget Lowland to nearly 100 inches in the adjoining Willapa Hills. Nearly all of the precipitation falls as rain, with snow occurring infrequently. The area receives more than 75% of its annual precipitation from October through March.

The Chehalis River drains much of the area and flows into Grays Harbor at the town of Aberdeen. The Chehalis basin is the second largest basin in Washington State, second only to the Columbia River basin. Some of the major stream systems include the Wynoochee, Hoquiam, Satsop, and Chehalis river basins, as well as other smaller tributaries. The Chehalis valley is wide, draining portions of the Olympic Mountains, Cascade foothills, Black Hills and the Willapa Hills. Portions of Grays Harbor, Thurston, Pacific, Lewis, Mason, Jefferson, and Cowlitz Counties are contained within the WRIAs. Elevations range from sea level to a little over 3,000 feet. The primary surface features of the basin are the 'coastal hills' and the Chehalis valley. The coastal hills are currently one of the key timber producing areas of the State.

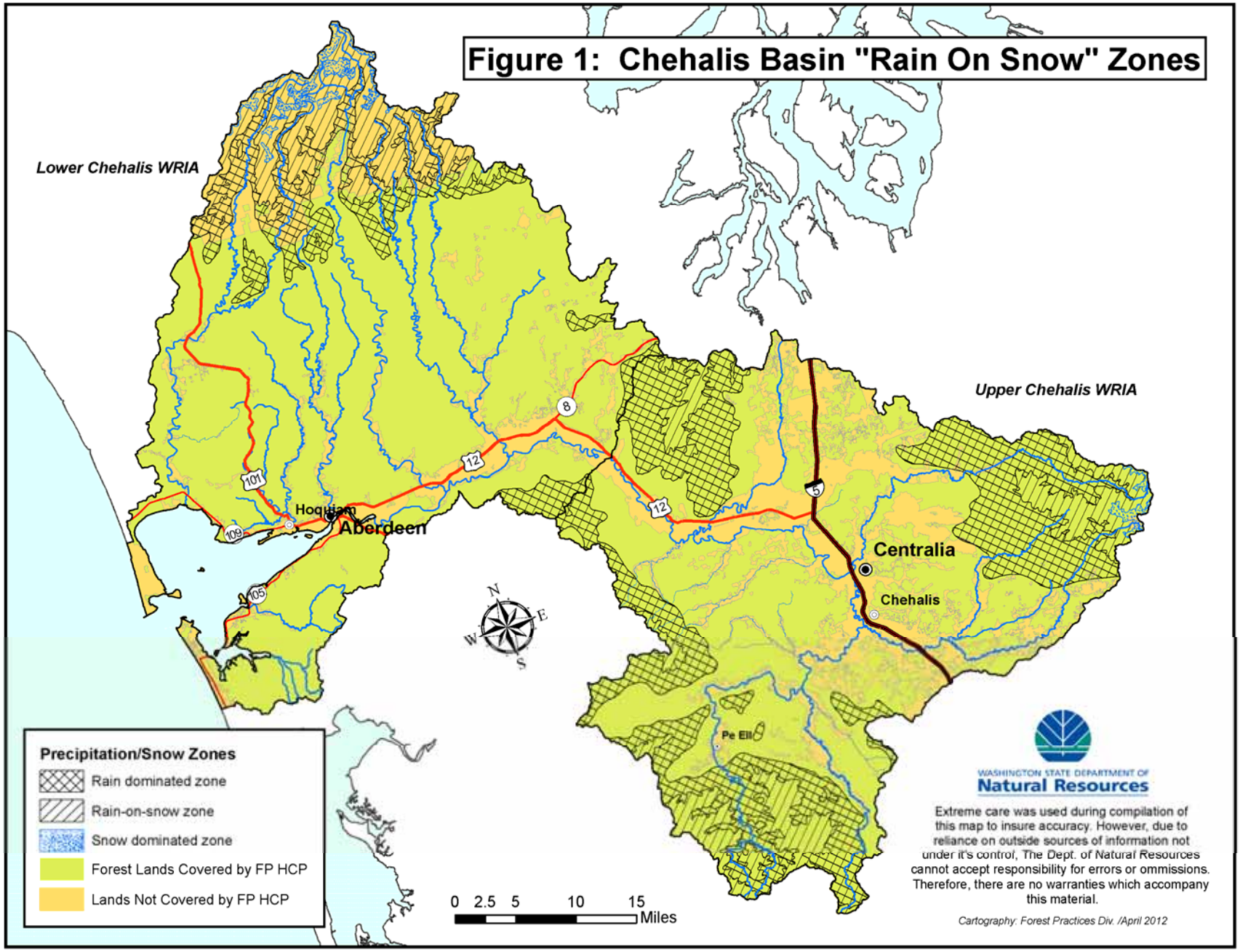
Figure 1: Chehalis Basin "Rain On Snow" Zones
Lower Chehalis WRIA
Upper Chehalis WRIA
Hoquiam
Aberdeen
Centralia
Chehalis
Pe Ell
101
109
105
12
8
5
N
E
S
W
Precipitation/Snow Zones
Rain dominated zone
Rain-on-snow zone
Snow dominated zone
Forest Lands Covered by FP HCP
Lands Not Covered by FP HCP
0 2.5 5 10 15
Miles
WASHINGTON STATE DEPARTMENT OF
Natural Resources
Extreme care was used during compilation of this map to insure accuracy. However, due to reliance on outside sources of information not under it's control, The Dept. of Natural Resources cannot accept responsibility for errors or ommissions. Therefore, there are no warranties which accompany this material.
Cartography: Forest Practices Div. /April 2012

Forestland makes up approximately 84% of the WRIAs within the Chehalis basin. Agricultural lands comprise 6% to 13% of the area with the largest percentage of agricultural lands in the river valleys of the Upper Chehalis WRIA. The hydrologic maturity of the forests in the WRIAs is primarily early to mid seral stage with a smaller percent in the late seral stage. Additional information on seral stage/sizes of timber can be found in research by Lunetta et al. (1977) which provides information on riparian areas and Batker et al. (2010) which provides information on all forests in the Chehalis river basin.

Approximately 9% of all forestland in these WRIAs are in Federal ownership. Tribal lands represent less than 0.5% of the WRIAs. State lands represent approximately 13% of all lands in the region, other government lands are approximately 2.5%, and private lands represent approximately 75% of all lands. Private lands dominate the WRIAs, except for the northern portion of the Lower Chehalis WRIA (see Figure 2: Chehalis Basin Forest Land by Major Ownership or HCP).

Overall, lands covered by the Forest Practices rules represent approximately 91% of the forestland in these WRIAs. Although the Forest Practices Habitat Conservation Plan covers all state and private forest land, there are other habitat conservation plans covering approximately 25% of the WRIAs, including the Department of Natural Resources State Lands habitat conservation plan and other private industry habitat conservation plans.

There are 16,326 miles of mapped streams in the Chehalis basin and 13,920 stream miles on forestland subject to Forest Practices rules in these WRIAs. This represents about 84% of all streams in the WRIAs. Approximately 3,957 stream miles or 28% of the 13,920 stream miles on lands subject to Forest Practices rules are determined to be fish-bearing (Collins 2012).

Geologically, this region has been formed by a gradual uplifting of land, with the oldest rocks approximately 57 million years old. The coastal hills are some of the most landslide-sensitive areas of the State because of the highly weathered marine sedimentary and volcanic bedrock. The degree of sensitivity depends on the underlying bedrock formation and the elevation of the hills. However, most of the underlying bedrock decays directly to sand, silt and/or clay, providing weak hillslope support, and providing little or no large substrate to armor the stream channels. Erosion in this area is dominated by mass wasting events. Mass wasting in the form of debris avalanches, debris flows, and debris torrents are by far the most common processes. In the Chehalis Headwaters Watershed Analysis Unit (WAU), 93% of inventoried landslides were classified as either debris avalanches or debris flows. Surface erosion from hillslopes is uncommon and typically does not contribute significant amounts of sediment to streams.

Heavy precipitation in the area has been conducive to erosion and landslides. The geological features resulting from highly weathered marine sedimentary and volcanic bedrock and heavy precipitation are relatively short steep slopes and low gradient stream channels. Most of the watershed analyses conducted within the Chehalis watershed resulted in the inventory of hundreds of landslides. Forest roads, and to a lesser extent, even-aged harvesting on steep slopes, contributed to many of these landslides. Deep-seated landslides and slumps occur in certain geological formations, and are scattered throughout the coastal foothills (DNR 1994a; 1994b; 1994c; 1997).

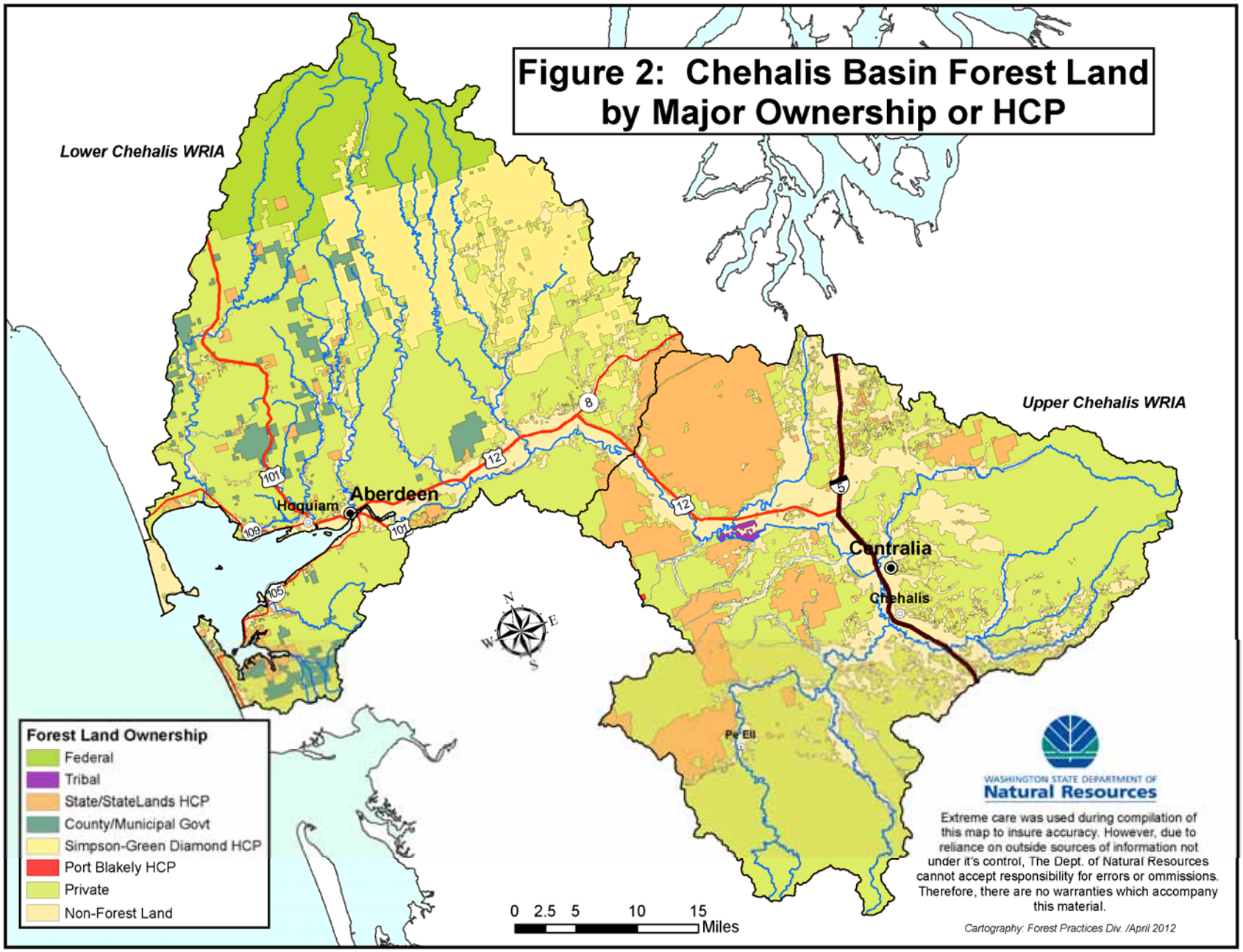
Figure 2: Chehalis Basin Forest Land by Major Ownership or HCP
Lower Chehalis WRIA
Upper Chehalis WRIA
Aberdeen
Hoquiam
Centralia
Chehalis
Pe Ell
101
109
105
102
12
8
5
Forest Land Ownership
Federal
Tribal
State/StateLands HCP
County/Municipal Govt
Simpson-Green Diamond HCP
Port Blakely HCP
Private
Non-Forest Land
0 2.5 5 10 15
Miles
WASHINGTON STATE DEPARTMENT OF
Natural Resources
Extreme care was used during compilation of this map to insure accuracy. However, due to reliance on outside sources of information not under it's control, The Dept. of Natural Resources cannot accept responsibility for errors or ommissions. Therefore, there are no warranties which accompany this material.
Cartography: Forest Practices Div. /April 2012

Landslides are not a factor in the lowlands of the Chehalis basin; however, streambank erosion is a problem in some areas and a significant source of fine sediment. Loss of riparian forests to agricultural land and conversion to urban land uses is a primary cause of stream bank erosion. Increased peak flows from loss of soil permeability (due to urban development) may also be a factor (WSCC 2001). The underlying geology and heavy rainfall in the coastal foothills contribute to road surface erosion. In addition, unpaved forest and rural residential roads require significant maintenance to minimize sediment delivery to channels. Forest roads require well-built drainage structures where necessary to divert road run-off on to the forest floor. In some areas, hard rock for quality road surfacing is difficult to find (DNR 1994a; 1994b; 1994c; 1997), and the next best available material must be used for road surfaces. Lower gradients in the Chehalis Valley help minimize surface erosion from unpaved roads; however, there may be pockets of locally significant road surface erosion.

Past old-growth timber harvest processes included the removal of trees within the riparian forests. In the Chehalis basin WRIAs, this harvest practice started in the early 1860s and was substantially completed by the 1960s. Subsequent conversion of forest lands to agricultural and urban lands has permanently altered riparian vegetation in the river valleys, leaving either no trees or a thin band of trees. The riparian areas along many agricultural lands provide substantially reduced large woody debris recruitment and are now dominated by alder, invasive canary grass and blackberry. It is difficult or impossible for native conifer species to re-establish within riparian areas with these vegetative characteristics. The limiting factors reports (WSCC 2001) made frequent note of the deficiencies in riparian areas adjacent to agricultural and urban lands. A photometric study by Lunetta et al. (1997) suggests that functional riparian buffers in agricultural and urban areas are substantially lacking.

The Chehalis basin floodplain has seen extensive conversion to agricultural land use. Streambank damage and erosion by livestock are scattered throughout the region (WSCC 2001). Agricultural activity has also occurred in the floodplains of smaller coastal rivers, including the Humptulips, Wynoochee, Satsop and Willapa basins. The Chehalis basin has also experienced industrial and urban development near the river mouth (Cosmopolis) and in the upper basin (Chehalis and Centralia). Rural residential development has occurred on the flatter and more accessible land throughout this region. The widespread agricultural and urban conversion in the lower reaches of the Chehalis basin has reduced the percolation of precipitation into the soil, and has likely contributed to scour and stream bank erosion.

Loss of forest canopies may increase peak flow during rain-on-snow events, which occur when heavy warm rain falls on a snow pack and the resulting run-off is the combined water content of the rain event and the water contained in the melting snow pack (see *Rain-on-Snow and Peak Flows* on page 12). However, this region generally lacks extensive areas above 1,000 feet, the average elevation above which heavy snow packs can accumulate within the Chehalis basin. There are three relatively small areas (including some area in Stillman Creek drainage and south Olympic foothills) in the WRIAs high enough in elevation to trigger this concern (See figure 1 above).

Research on the Impacts of Forest Management

Forestland is the primary land use in the Upper and Lower Chehalis basins. This section summarizes what the scientific literature says about potential impacts of forest management during flooding events. The section is focused on forest hydrology and unstable slopes – two primary aspects with the potential for impact.

Forest Hydrology and Unstable Slopes

Hydrology is the study of the distribution and circulation of water on and below the earth's surface. Surface water quantity in a forested environment is affected by climate, vegetation, and transport pathways. Climate determines the rate of precipitation amount and form (snow or rain) delivered to a watershed. Vegetation influences the delivery of water to the forest floor via interception, evaporation, condensation, evapotranspiration (water absorbed through tree roots, passed through the tree and transpired from the foliage into the air), and the canopy snowmelt processes. Transport pathways, both surface and subsurface, determine the transportation of water through the forested land. The hydrologic functions of a watershed are dependent upon these processes. When these processes are individually or cumulatively altered by forest road construction, harvesting, or other forest practices, the hydrologic continuity of the watershed is altered (Montgomery1994; Rashin et al. 1999).

In a working forest, the hydrologic processes recover from timber management activities over time as vegetation grows back. Its rate and trajectory depend upon the rate of regrowth and the suite of species occupying the site (Moore and Wondzell 2005).

Three primary water quantity metrics are generally discussed regarding forestland and potential impacts of forest harvest and road building: annual water yield, low flows, and peak flows. Water yield is the amount of water that is transported from a watershed over the course of the year. Low flows are the flows provided by groundwater to the streams during the lowest precipitation months of the year. While forest practices can impact both annual water yield and low flows, the effects are not generally associated with potential flood issues. Peak flow is the maximum instantaneous discharge measured in stream channels during high flow periods, which makes it the primary water quantity metric of interest with regards to flooding.

Urbanization, agriculture, grazing and forest management may all impact peak flow. Forest management activities may affect peak flows based upon their site specific effect, elevation within a watershed, and proportion of forest basin that has been altered by timber-related activities (Bauer and Mastin 1997).

Peak flow impacts would be most likely to occur during storm events. The direct effects of peak flows can affect flooding, stream channel alteration, bank erosion, and redistribution of sediment and large organic debris. Timber harvest and forest road construction/maintenance are the two most likely forest management activities to affect peak flows. The potential magnitude of the effect of either of these activities could increase when the activity takes place in a rain-on-snow zone. Rain-on-snow events can occur on mountain slopes in the transient snow zone, which extends from elevations of approximately 1,000 feet to 3,000 feet above sea level (Harr 1986), but can shift upward or downward during any given storm due to varying meteorological conditions.

Timber Harvest and Peak Flows

Timber harvesting alone may have an effect on flows but is likely minor. Studies that have shown peak flow increases in rain dominated watersheds (Harr et al. 1975; Harr 1986) have correlated the increases with soil compaction, rather than timber harvest. Yet other studies indicate no change in peak flow after harvest (Benda et al. 1998). If a peak flow following harvest occurs, small basins seem to be more likely to experience effects than large basins. Soil compaction caused by heavy equipment and yarding can decrease infiltration capabilities, increasing surface runoff. Forest management activities that substantially disturb the soil, such as yarding, burning, or road and skid trail construction, can alter both surface and subsurface pathways that transport water to streams (Thomas et al. 1993; Murphy 1995). Logging can also alter the internal soil structure. As tree roots die, soil "macropores" collapse or are filled in with sediment. These subsurface pathways are important for water transmission. When

subsurface flow pathways are destroyed over a sizable area of steep slope, the flow can be routed to the surface and increase gully erosion and sediment delivery (Keppeler and Brown 1998). Removing trees can also result in less delivery of water to streams. In one study, researchers found that about half the yearly water inputs to a higher elevation conifer forest came from fog-drip, i.e., cloud water that condenses on tree limbs (Lovett et al. 1982). Cutting trees in a coastal and mountainous fog-drip zone could remove a large fraction of annual water inputs. The extent to which timber harvest alone has triggered substantially increased peak flows is likely rare (Storck et al. 1995).

Road Construction and Peak Flows

While timber harvest alone most likely has little effect on peak flows, indiscriminate road construction can alter runoff by collecting subsurface and road-surface water that routes directly to stream channels (Chamberlin et al. 1991). These potential effects are based upon the road management and drainage criteria, and potential for decrease (e.g., abandonment) in roads. The design, construction, and maintenance of roads interact with watershed characteristics of soil, topography, and geology and natural disturbances (such as large storms) to determine the effects of roads on the hydrology of a particular watershed. The interception of surface runoff during storms and interception of shallow groundwater flow by a road prism can affect the routing of surface water, extend the channel network (Wemple et al. 1996), increase the potential for higher peak flows, and increase the potential for mass-wasting (Montgomery 1994). In a general sense, roads can act as extensions of the drainage network if the roads drain to streams. Road-influenced peak flows have been demonstrated in small watersheds (Ziemer and Lisle 1998); however, the effects of roads on a river basin scale are less understood (Jones and Grant 1996; Beschta and Boyle et al. 1995).

Rain-On-Snow and Peak Flows

The significance of rain-on-snow events in harvested areas is the increase in water delivered to the stream system during these events compared to rainfall alone. Snow retention is modified by the nature of the forest canopy. Removal of the forest's canopy increases snow accumulation. The canopy also has a major influence on the rate of snow melt which is strongly controlled by energy movement into the snowpack. When the forest is immature or recently harvested, wind and rain can more rapidly move energy into the snowpack, substantially accelerating the rate of melt (DNR, 1991). When warm air and rain occur on areas with a snowpack, rapid melting of the snow can occur, resulting in a pulse of water into the drainage network. Peak flow events associated with rain-on-snow might be of greater magnitude than rain-only events because the rainfall is augmented by snowmelt. However, research in the Pacific Northwest has not consistently demonstrated this effect. While Cheng (1989) found as much as a 35% increase in peak flows within 30% of the even-aged harvest in British Columbia, Fowler et al. (1987) found no effect in small watersheds in Oregon. The two most important watershed variables that affect rain-on-snow events seem to be elevation and extent of timber harvest on forestland.

Riparian and Wetland Areas

Two forested areas are particularly important to the hydrologic regimes of forestland; riparian areas and wetlands. Riparian habitat is the area adjacent to streams, rivers, lakes, and wetlands and includes floodplains and stream-associated seeps and springs. Wetlands are formally defined as those areas that are inundated or saturated with surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances, do support a prevalence of vegetation typically adapted for life in saturated soil conditions (WAC 222-16-010). This definition includes forested swamps, marshes, bogs, and other similar areas.

A wide variety of hydrologic, geomorphic, and biotic processes determine the character of riparian areas. The most important recognized functions of stream riparian areas with regards to hydrology include: streambank stability, groundwater recharge, stream energy dissipation, the routing and trapping of sediment, and large woody debris recruitment. Disturbance processes unique to stream systems (e.g., bank erosion, peak flows, and floods) all affect riparian areas (Benda et al. 1998; Montgomery and Wohl 2004; Spence et al. 1996; Reeves et al. 1995).

Riparian vegetation is important for maintaining streambank and floodplain integrity. Vegetation slows water velocity on the floodplain, and plant roots inhibit erosion along streambanks, reducing sediment deposition in streams. Riparian vegetation also helps to provide large woody debris, which is an important component of instream structure. Streamside buffers can substantially reduce fine sediment that is transported overland (Rashin et al. 1999). Riparian areas are an important source of large woody debris that enters the stream channel. Large woody debris creates storage sites for sediment in all sizes of streams and important stream structure.

Both timber harvest and stream-adjacent roads can cause the loss of some or all riparian functions within riparian lands depending on the level of harvest, level of disturbance to riparian vegetation and soil, and location of road construction. The roots of riparian vegetation help bind soil together, making soils more resistant to erosion and slope failure (Wu and Sidle 1995). In most cases, vegetation immediately adjacent to a stream channel is most important in maintaining stream bank integrity (FEMAT 1993). There can be loss of large woody debris potential when roads are built in the riparian area or timber harvest takes place.

Wetland ecosystems provide a variety of physical and biological functions. Additionally, they provide many values to society including flood attenuation, recreation, and water quality enhancement. The National Wetland Policy Forum (Conservation Foundation 1988) identified eight natural functions that wetlands may perform at a landscape level. Three of these functions are related to hydrology: 1) shoreline and bank stabilization, 2) flood flow alteration (attenuation), and 3) groundwater recharge. Headwater riverine and depressional wetlands can delay discharge of peak run-off into streams and impede passage of overbank flow downstream during storm events, thus reducing the potential for downstream flooding (Winter 1988; Roth et al. 1993).

Road construction and maintenance may have the greatest direct impact on wetland sites by permanently removing portions of the affected wetland from the landscape. Further, roads that cross wetlands without adequate provision for cross drainage can lead to hydrologic changes (Stoeckeler 1967; Boelter and Close 1974). Additionally, sedimentation from road construction and use has been found to indirectly impact wetland ecosystems (Stoeckeler 1967; Boelter and Close 1974). Timber harvest may alter wetland hydrology and cause a rise in the water table elevation (Verry 1997). Additionally, the altered water table and associated streamflow relationship could increase localized runoff and flooding (Grigal and Brooks 1997). Soil rutting and compaction from timber harvest activities can reduce infiltration, redirect flow, and alter pathways by which water moves through and from wetlands. Harvest and associated activities can deliver sediment to wetlands, diminish water quality, and lead to the filling of wetland sites.

Unstable Slopes and Landforms

Erosion is the detachment and movement of soil particles either individually, in small aggregates, or in large masses (Brooks et al. 1991). The two dominant processes of erosion on forestland are surface erosion and mass wasting. Surface erosion is the detachment and subsequent removal of soil particles

and small aggregates from land surfaces by wind or water. Mass wasting includes erosion in which cohesive masses of soil are displaced. (U.S. Department of Commerce, National Marine Fisheries Service 2006).

Under natural conditions, mass wasting is the more common form of erosion on forestland in the Pacific Northwest, particularly in steep terrain (Sidle et al. 1985). Forest management activities contribute to mass wasting in the form of shallow landslides, the most common type of landslide. They occur within the rooting depth of trees. Types of shallow landslides include relatively minor rock falls, ravels, and small slumps to more serious debris avalanches, debris flows, and hyper-concentrated floods.

Debris avalanches and debris flows, the usual types of shallow landslides in steep forestland, are typically initiated by high magnitude rain or rain-on-snow events during the fall and winter months (Swanson et al. 1987). Debris avalanches and debris flows can turn into debris torrents. Debris torrents usually transport more material than the initiating event, due to scouring action on the slope or in the stream channel. Debris torrents stop moving when the channel gradient decreases substantially or when the torrent encounters a sharp bend in the channel. Debris torrents contain substantial amounts of wood and can travel varying distances, which can result in variable degrees of impact depending upon stream channel gradient, confinement, layout of the channel network, and other characteristics (Fannin and Rollerson 1993).

Debris torrents can have long-lasting effects on stream channels. The channel location and cross-section can be radically altered in such a way that normal flows and normal peak flows cannot reconfigure the channel easily (Lamberti et al. 1991). This is important because even though mass wasting for example may affect only 1% of a watershed, debris torrents can affect up to 10% of the stream system because of their mobility (Swanson et al. 1987). These channel alterations from debris torrents, however, are not always negative. For example, Benda et al. (2003) found that channel morphology and fish habitat complexity (e.g., pool density, substrate texture, and channel widths) increased in proximity to low order tributary confluences prone to debris flows. In addition to having impacts on the stream channel, debris torrents can also affect riparian buffer functions and streamside forests when bank scour is so great that streamside vegetation is removed.

Whether or not a particular slope will fail at any given time is dependent on a variety of variables, including precipitation rate and quantity; soil moisture; hydrology; slope aspect, length, and curvature; the internal strength of the slope material (Coates and Higgins 1990; Dragovich et al. 1993a); and root strength of vegetation (Harp et al. 1997; Schmidt et al. 2001; Roering et al. 2003). Disturbances, including timber harvest and road building, that compact or weaken slope material, change the hydrology of the slope, or undercut marginally stable slopes can trigger mass wasting events (Rollerson et al. 1997; Swanson and Dyrness 1975; Amaranthus et al. 1985; Dragovich et al. 1993b; Gerstel 1996). Increased levels of planning and analysis can reduce the likelihood of landslides by identifying and avoiding potentially unstable landforms, as can minimizing disturbance from harvest activities in these areas (Gerstel 1994; Rashin et al. 1999; Dhakal and Sidle 2003).

Forest practices such as timber harvesting and road construction have the potential to accelerate the rate of erosion by disturbing soils, reducing infiltration and increasing surface runoff (Swanson et al. 1987). Sidle et al. (1985) summarized several studies (Swanston 1970, 1974; O'Loughlin 1974; Ziemer and Swanston 1977; Burroughs and Thomas 1977; Gray and Megahan 1981; Ziemer 1981) indicating that slope stability depends partly on reinforcement from tree roots, especially when soils are partly or completely saturated. Even-aged timber harvesting on unstable slopes or landforms decreases rooting

strength, increasing the potential frequency and magnitude of debris avalanches and debris flows (Ziemer and Swanston 1977; Wu and McKinnell III 1978). In addition to the loss of root strength, timber harvest can result in slow infiltration rates, loss of canopy interception, and loss of evapotranspiration.

In the past three decades, a greater level of understanding of risks to public resources, greater restrictions on harvest, and more requirements for mitigation related to harvest and road construction on potentially unstable areas has substantially decreased landslide frequency from historical levels (DNR 2005). The Forest Practices rules are designed to reduce the frequency and magnitude of debris flows and debris avalanches. For more detailed information, see Unstable Slope and Landforms in the next section for an extensive description of the Forest Practices rules and processes that protect unstable slopes.

Mitigation Measures for Potential Impact of Forest Management on Forestland

While research shows forest management activities have the potential to impact peak flows and unstable slopes, steps can be taken to minimize/eliminate that potential impact. This section describes the many protective measures provided by Washington's forest practices program and how the measures help to minimize impacts to forest hydrologic processes and unstable slopes.

The Forest Practices rules and regulations provide protections that help reduce possible risks from timber management practices on forest hydrologic processes and unstable slopes. The 2001 changes to the Forest Practices rules (see above "Evolution of…") increased protection significantly with regards to riparian areas, wetlands, sensitive sites, road construction/maintenance, and unstable slopes. These changes led the National Marine Fisheries Service to make the following conclusions in their biological opinion regarding statewide hydrologic impacts of forest practices. "Under the Forest Practices Habitat Conservation Plan and Incidental Take Permit, the influence of timber harvest and road management on hydrologic processes will gradually lessen as riparian buffers mature and 'road maintenance and abandonment plans' are implemented. In the long-term, effects of timber harvesting and road management on hydrologic processes will be negligible" (U.S. Department of Commerce, NMFS, 2006).

The primary types of Forest Practices rules that can help avoid impacts to hydrologic processes and unstable slopes are those that help to protect against:

- soil compaction or soil disturbance,
- impacts to riparian and wetland areas,
- interception of surface and subsurface water by roads,
- open canopy in rain-on-snow zones,
- size and timing of even-aged harvest, and
- disturbance of unstable slopes.

Forest Practices rules address each of the above potential results to minimize or avoid impact to the resource. The following Forest Practices rule groups contain protection measures that specifically help minimize negative effects on forest hydrology and unstable slopes; logging practices, riparian, wetland, and sensitive site areas, forest road construction/maintenance, rain-on-snow zones, green-up, and unstable slopes.

Logging Practices
Forest Practices rules include rules that regulate the methods of harvest. These protection measures include limits on the felling and bucking (i.e. limbing and cutting to length) of timber, the use of ground-based equipment and cable yarding (i.e. transporting logs to the landing site). Many of these measures are designed specifically to minimize soil disturbance and reduce the potential for erosion and sedimentation.

Felling and Bucking: Protection measures are designed to minimize soil disturbance, damage to residual trees and delivery of slash to typed waters (WAC 222-30-050).

Ground Based Equipment: Ground-based equipment is commonly used to fall and yard timber and to construct, maintain and abandon roads and skid trails. Ground-based equipment use is regulated to limit direct physical impacts to waters and wetlands and to minimize indirect impacts such as soil disturbance and associated erosion and sedimentation (WAC 222-30-070). Protection measures address typed waters, wetlands, riparian management zones, wetland management zones, soil moisture, residual trees, skid trails and slope restrictions. Protection measures also include a 30 foot equipment limitation zone adjacent to non-fish bearing waters (WAC 222-16-010 and WAC 222-30-021(2)).

Cable Yarding: Limitations on cable yarding in and across typed waters and wetlands are intended to minimize soil disturbance and impacts to their beds and banks (WAC 222-30-060).

Riparian Protection
Early riparian rules only considered changes in stream temperature and bank stability for the aquatic ecosystem. All riparian trees could be cut, sparing only the understory on certain temperature-sensitive streams. Over time, the Forest Practices rules have undergone numerous revisions. Currently, the conservation objective of the riparian strategy is to restore riparian function to high levels on lands covered by the Forest Practices Habitat Conservation Plan and to maintain those levels once they are attained (WAC 222-30-010(2)). Protection measures for different type waters in western Washington include protecting channel migration zones, establishing riparian management zones along fish bearing waters and perennial non-fish bearing waters; retaining no-harvest buffers adjacent to non-fish bearing perennial water sensitive sites; and establishing zones where equipment is limited along non-fish perennial and seasonal waters (WAC 222-30-021). Other riparian protection measures that apply to typed waters include restrictions on the salvage of down woody debris and the disturbance of stream banks.

Fish Bearing Waters: In fish-bearing water riparian management zones there is a core, inner and outer zone with differing prescriptions delineated in rule. No timber harvest or road construction is allowed in the 50 foot core zone (zone closest to the water) except for the construction and maintenance of road crossings and the creation and use of yarding corridors. The inner zone (middle zone) ranges from 90 feet to 200 feet depending on several factors. Timber harvest of “surplus” wood in the inner zone is only allowed if pre-determined stand requirements are met which are intended to result in a mature riparian forest stand at 140 years of age. Timber harvest is allowed in the outer zone (zone farthest from the water); however, 20 riparian leave trees per acre must be retained following harvest (WAC 222-30-021(1) (c).

Non-fish Bearing Waters: Protection measures for non-fish bearing waters in western Washington include the establishment of equipment limitation zones and riparian management zones adjacent to the

waters and associated sensitive sites (WAC 222-30-021(2). An equipment limitation zone is a 30 foot wide area where equipment use is limited in order to minimize ground and soil disturbance and thus protect stream bank integrity and prevent sediment delivery to non-fish-bearing waters WAC 222-30-021(2)(a). Riparian management zones are required on at least 50% of non-fish bearing waters that run perennially throughout the year (WAC 222-30-021(2) (b).

Streambank Integrity: Timber harvesting can reduce stream bank rooting strength and log yarding can disturb stream bank structure. Both impacts can lead to accelerated erosion and sedimentation (Rashin et al. 1999). Forest practices activities in the riparian management zone core zone for fish bearing streams and in riparian management zones for non-fish bearing perennial waters must be conducted in a manner that maintains stream bank integrity (WAC 222-30-030).

Salvage logging: Down woody debris in streams and rivers stores sediment, dissipates stream energy, and provides many other functions. In riparian areas, down wood reduces the erosive power of overbank flows and creates microsites for seedling and other vegetation start-up and growth. Forest Practices rules protect these ecological functions by restricting salvage of down wood in all typed waters, channel migration zones and riparian management zones (WAC 222-30-045).

Wetland protection measures

The forest practices program includes measures to prevent, minimize and mitigate forest practices-related impacts to wetland habitats. Measures are intended to protect important ecological functions such as maintenance of surface and shallow subsurface hydrology, large woody debris recruitment, sediment filtration and others. Protection measures include providing wetland management zones adjacent to wetlands and the use of low-impact harvest systems in forested wetlands and no net loss of wetland function from road building.

Roads, Rain-on-Snow, and Unstable Slopes

The goal of the roads, rain-on-snow and unstable slopes rules is to prevent, avoid, minimize, or mitigate forest practices-related changes in erosion and hydrologic processes and the associated effects on public resources. Specific objectives include preventing forest practices-related landslides, avoiding capture and redirection of surface or groundwater, limiting sediment delivery to all typed waters, surface water and other hydrologic management, woody debris passage, protecting stream bank stability, minimizing the construction of new roads, and ensuring that there is no net loss of wetland function. The goal is to maintain surface and groundwater hydrologic regimes (magnitude, frequency, timing and routing of streamflows) by disconnecting road drainage from the stream network, preventing increases in peak flows causing scour and maintaining the hydrologic continuity of wetlands.

Roads

As mentioned earlier, roads may adversely affect riparian and aquatic habitats by altering hydrologic flowpaths, accelerating erosional processes and increasing sediment delivery to surface waters and wetlands. Forest Practices rules are designed to minimize negative road impacts through the proper location, design, construction, maintenance and abandonment of forest roads. The Forest Practices rules require that road drainage be disconnected from the stream network. Stream crossings are required to be minimized, and except for crossings, roads are to be kept out of natural channels, Channel Migration Zones, Riparian Management Zones, Equipment Limitation Zones, and sensitive sites.

Location of Roads: Forest Practices rules require that roads be fit to the topography to minimize alteration of natural features. This includes avoiding at-risk areas such as surface waters, wetlands,

channel migration zones, riparian management zones, sensitive sites (including headwall seeps, side-slope seeps, alluvial fans, headwater springs), and equipment limitation zones. Forest Practices rules also require the use of existing roads in areas where new construction would lead to duplicative or unnecessary roads (WAC 222-24-020).

Road Design: Forest Practices rules include road design standards (WAC 222-24-020) which are mainly related to construction techniques and water management:

- Forest Practices rules encourage road designs that utilize balanced construction to avoid placement of excess loose dirt from excavation beside the road. In steep terrain (> 60% slopes), rules require the road to be fully cut into the slope so no fill material is used to construct the road prism and waste material is taken to stable locations.
- Water management requirements focus on maintaining hydrologic flowpaths and minimizing sediment delivery by limiting road-induced rerouting of water. Forest Practices rules include design standards for culvert sizing and drainage structure spacing. Rules also require that roads be designed so that ditch water is relieved onto the forest floor to facilitate infiltration and minimize sediment delivery.

Road Construction: Road construction requirements focus on maintaining stable road prisms and water crossing structures, and on minimizing sediment delivery to surface waters and wetlands. Maintaining stable, intact road prisms and water crossing structures is important in controlling erosion and sediment delivery, particularly in steep terrain where mass wasting is common. Forest Practices rules recognize the importance of road prism and crossing stability, and include construction measures to minimize the risk of road failure. Measures that focus on maintaining the stability of water crossing structures require the installation of structures that pass the 100-year flow, the construction of fills and embankments to withstand the 100-year flow, and the construction of headwalls and catch basins to accommodate the 100-year flow. Other construction-related Forest Practices rules are contained in WAC 222-24-030, 222-24-035, and 222-24-040.

Road Maintenance and Abandonment Plans: In an effort to reduce road-related sediment in streams, to identify roads with evidence of existing or potential instability that could adversely affect public resources, and to identify road-related blockages to upstream habitat for fish, the 2001 Forest Practices rules resulting from the Forests and Fish Report require forest landowners to develop Road Maintenance and Abandonment Plans (RMAPs) for roads within their ownership (WAC 222-24-051).

The RMAPs for large forest landowners includes an inventory of forest roads within a particular ownership, an assessment of the current road conditions, the identification of and a timetable for necessary repairs, ongoing maintenance and/or abandonment. In areas where watershed analysis has been conducted and approved, large forest landowners may elect to follow the watershed administrative unit-road maintenance plan rather than developing an RMAP under WAC 222-24-051.

Planning requirements differ for small and large forest landowners. Small forest landowners may follow the road maintenance and abandonment process for large landowners described above, or they may submit a “checklist” road maintenance and abandonment plan with each forest practices application or notification (WAC 222-24-0511).

Forest Practices rules require large forest landowners to prioritize road maintenance and abandonment planning based on a “worst first” principle. Road systems or watersheds where maintenance and

abandonment work would produce the greatest benefit for public resources receive highest priority. The road maintenance and abandonment plans must prioritize work according to the following:

1. removing fish blockages,
2. preventing or limiting sediment delivery,
3. disconnecting the road and stream networks,
4. repairing or maintaining stream-adjacent parallel roads,
5. restoring hydrologic flowpaths, and
6. capitalizing on operational efficiencies.

On the anniversary date of an RMAP submittal, large forest landowners must report work accomplished during the previous year to DNR. A detailed description of work planned for the upcoming year must also be submitted for approval including any modifications to the existing work schedule. DNR's review and approval is conducted in consultation with Ecology, WDFW, affected tribes and interested parties (WAC 222-24-051).

The RMAP process is intended to bring all roads owned by large forest landowners into compliance with forest practices standards by 2016, however, landowners can request an extension to 2021. The forest roads standards require landowners to:

- Keep drainage structures functional,
- Divert captured groundwater from ditchlines onto stable portions of the forest floor,
- Maintain road surfaces to minimize erosion and delivery of water and sediment to typed waters,
- Slope or waterbar road surfaces to prevent water accumulation.

Rain-on-snow and Green-up

The potential for effects of forest management on peak flows is higher in the rain-on-snow zones through the influence of increased snow accumulation in canopy openings and melt during rain-on-snow precipitation events. Forest Practices rules address rain-on-snow effects in two ways. First, watershed analysis includes an assessment of timber harvest-induced changes in rain-on-snow generated peak flows and potential impacts to public resources. Three watershed analyses – Upper Skookumchuck, Stillman Creek and the Chehalis Headwaters have been completed in the upper and lower Chehalis WRIAs. As a result of 2011 changes to the watershed analysis Forest Practices rules, two of the watershed analysis units – Stillman Creek and Chehalis Headwaters – will have all unstable slopes prescriptions of the watershed analysis rescinded and revert to standard rules because the landowners have chosen not to perform the 5-year review. All of the prescriptions for the Upper Skookumchuck will remain viable.

The watershed analysis assessment, known as the "hydrologic change" module, is conducted for each watershed administrative unit (WAU) where watershed analysis is performed. The assessment relies on the use of a quantitative model to estimate changes in snow accumulation and melt under different harvest scenarios, and the resulting effects on peak flow magnitudes. Specific management prescriptions are developed to address rain-on snow effects in parts of the WAU where significant hydrologic change is likely to occur and resources are sensitive to those changes. Prescriptions typically involve limits on even-aged harvesting to maintain a minimum level of hydrologically mature forest cover in the watershed or sub-watershed. Once approved by DNR, the management prescriptions become the Forest Practices rules for the WAU. In the Upper Skookumchuck watershed analysis, the hydrologic module resulted in a prescription to maintain a 10% or less increase in peak flows by using the Timber, Fish, and Wildlife model for predicting peak flows to evaluate harvests in listed sub-basins (DNR 1997). The

hydrology module in the Stillman creek watershed rated the potential effects of peak flow due to harvest on flooding as low risk. However, the analysis recommended the "maintenance of 40% or more mature cover in the rain-on-snow zone as added insurance against any peak flow changes" (DNR 1994b). Prescriptions in the Chehalis headwaters watershed suggest that there should be "not less than 40% hydrologically mature cover and should not exceed 40% hydrologically immature cover" in rain-on-snow zones (DNR 1994a).

Secondly, Forest Practices rules address rain-on-snow effects in areas where watershed analysis has not been performed. A forest practices rule commonly known as the "rain-on- snow rule" gives DNR authority to set conditions on permits for forest practices applications and notifications that propose even-aged harvesting in the significant rain-on-snow zone (WAC 222-22-100(2)). Under the rain-on-snow rule, DNR may limit even-aged harvest size when it determines that peak flows have caused material damage to public resources including water, fish, wildlife and public capital improvements (WAC 222-22-100(2)). Guidelines direct applicants and DNR to consider alternatives to even-aged harvests in high-risk areas.

In addition to the rain-on-snow rule, a set of forest practices standards collectively known as the "green-up rules" (WAC 222-30-025) also mitigate hydrologic changes associated with timber harvest. Under the green-up rule, the size and timing of even-aged harvesting is regulated to prevent excessive levels of immature forest cover in any given geographic area. Harvest proposals that result in more than 120 acres of contiguous, even-aged harvest within a single ownership require review by an interdisciplinary team. Harvest proposals that result in more than 240 acres of contiguous even-aged harvest within a single ownership are prohibited (WAC 222-30-025).

Unstable Slopes and Landforms

The Forest Practices rules – and program as a whole– address, in part, the potential for forest management-related landslides that could deliver sediment or debris to public resources or threaten public safety. While most protection measures are prescriptive in nature, those related to unstable slopes and landforms are not. Instead, protection is provided through an outcome-based, decision-making process that is conducted in accordance with the Forest Practices rules and the State Environmental Policy Act (SEPA) (chapter 43.21C RCW; and chapter 197-11 WAC (SEPA Rules). The only exception to this outcome-based, decision-making process occurs in areas where watershed analysis has been conducted and approved, management prescriptions are in place to address unstable slopes and the prescriptions are specific to the site or situation and do not call for additional analysis (WAC 222-16-050(1)(d)(iii)). In these cases, proposed timber harvest and construction activities on unstable slopes must adhere to the approved management prescriptions stated in the watershed analysis. The only watershed analysis unstable slope module prescriptions that will remain valid in the Upper and Lower Chehalis basin WRIAs are those in the Upper Skookumchuck watershed.

The first step in the outcome based decision making process is a review of forest practices applications. All forest practices applications are reviewed to determine the class of the application as well as for other administrative reasons. Forest practices are classed based on the potential for the proposed operation(s) to adversely affect public resources – from Class I forest practices that have no direct potential for damaging a public resource to Class IV – Special forest practices having the greatest potential for impact. During review, the applications are screened for unstable slopes using data provided by Geographic Information Systems. Foresters conduct a field review to assess if unstable slopes are indicated. If the field review confirms the presence of unstable slope and timber harvest

and/or road construction is proposed in those areas, the forest practices application is classified as Class IV-Special and becomes subject to review under the State Environmental Policy Act.

Class IV-Special forest practices related to unstable slopes include – as described in WAC 222-16-050 (1)(d) – timber harvest, or construction of roads, landings, gravel pits, rock quarries, or spoil disposal areas, on potentially unstable slopes or landforms (see WAC 222-16-050 (1)(d)(i) below) that has the potential to deliver sediment or debris to a public resource or that has the potential to threaten public safety, and which has been field verified by the department.

Unstable slopes are often classified according to dominant landslide type. WAC 222-16-050 (1)(d)(i) recognize four classes of unstable slopes:

- Landforms typically associated with debris avalanches, debris flows and debris torrents. This class includes inner gorges, bedrock hollows and convergent headwalls with slopes greater 70%.
- Landforms susceptible to debris avalanches. This class includes toes of deep-seated landslides with slopes greater than 65% and the outer edges of meander bends along valley walls or high terraces of unconfined meandering channels.
- Groundwater recharge areas of deep-seated landslides in glacial sediments. This is an area up-gradient that can contribute water to a deep-seated landslide in glacial sediments. A change in the hydrologic regime of these landslides has the potential to accelerate a wide range of mass-wasting processes commonly associated with deep-seated landslides.
- Areas with indicators of potential slope instability that cumulatively indicate the presence of unstable slopes. These can include hummocky or benched surfaces; fresh deposits of rock, soil, or other debris at the base of a slope; ponding of water in irregular depressions; cracks in roads across or along slopes; seepage lines or springs; or missing stumps on steep convergent slopes.

Forest practices applications classed as Class IV - Special require compliance with both the Forest Practices Act and the State Environmental Policy Act because they have the potential for a substantial impact on the environment. The State Environmental Policy Act provides a way to identify possible environmental impacts that may result from governmental decisions. Through this process, DNR evaluates proposed timber harvest and construction activities on unstable slopes to determine if the activities will have a “probable significant adverse impact.” The determination is based on the agency’s evaluation of the proposal – conducted in consultation with other affected agencies and tribes – as well as comments received from interested parties through the SEPA review process.

The State Environmental Policy Act rules require applicants to complete an environmental checklist for Class IV-Special forest practices applications. The checklist is a detailed listing of potential environmental impacts associated with the proposed activity. The Board has established additional SEPA policies that are specific to forest practices (WAC 222-10-030). These policies require, in part, specific mitigation measures or conditions designed to avoid accelerating rates and magnitudes of mass wasting that could deliver sediment or debris to a public resource. The policies also require applicants to conduct and submit a geotechnical assessment of proposed forest practice(s). A qualified expert must prepare the assessment. A qualified expert is a highly qualified individual who is licensed with the state’s Geologist Licensing Board (WAC 308-15) with an engineering geologist’s license and at least three years of experience in evaluating forestland.

In addition to reviewing information submitted by the applicant, DNR staff conducts their own evaluation of proposals involving unstable slopes, including the applicant’s geotechnical assessment. The evaluation often includes review by a DNR geologist and/or interdisciplinary team. DNR geologists

meet the forest practices definition of a "qualified expert" and are licensed under the state's Geologist Licensing Law. Interdisciplinary team members typically represent other agencies and affected tribes and often have unstable slopes expertise.

After reviewing the proposal, consulting with other affected agencies and tribes, and considering comments received from other interested parties through the SEPA review process, DNR issues a decision under the SEPA commonly known as a "threshold determination." In making a decision, Forest Practices rules require DNR to consider:

1. if the proposal is likely to increase the probability of mass movement on or near the site,
2. whether sediment or debris would be delivered to a public resource or be delivered in a manner that would threaten public safety, and
3. whether such movement and delivery are likely to cause significant adverse impacts (WAC 222-10-030(2)).

If DNR determines the proposed activities are likely to have a probable significant adverse impact, a "determination of significance" is issued and the applicant must prepare an Environmental Impact Statement (EIS) in accordance with SEPA requirements. If DNR determines the adverse impacts identified in the EIS are significant and reasonable measures are insufficient to mitigate the impacts, the forest practices application is denied. If DNR determines the proposed activities are not likely to have a probable significant adverse impact, a "determination of non-significance" is issued and the forest practices application is approved. In many cases, DNR's approval of a forest practices application contains "conditions" or additional requirements with which the applicant must comply. The conditions usually include protection measures that must be implemented to mitigate impacts associated with the proposal.

Mitigation measures range from avoiding unstable slopes to altering the methods or techniques used in timber harvest and/or construction operations. Unstable slopes avoidance is the most commonly used mitigation measure and results in the lowest hazard and risk. Where timber harvest and/or construction activities occur on unstable slopes, a variety of mitigation measures are employed to reduce the likelihood of mass wasting. Harvest-related mitigation measures typically include minimum stand density requirements to maintain rooting strength and slope hydrology, and full suspension log yarding to reduce soil disturbance and damage to residual vegetation. Construction related mitigation measures often relate to the design and/or location of roads and landings. Full-bench end-haul (i.e., no fill or sidecast material) construction techniques are routinely required on unstable slopes. Where fill material is necessary, the use of quarried rock rather than "native" soil or fill is often required to increase the structural strength of road prisms and stream crossings. These are just a few examples of the many mitigation measures used to address unstable slopes issues. The measures used in a given situation are dependent upon the nature of the impact being mitigated.

In addition to the Forest Practices rules, and the State Environmental Policy Act and process, DNR also provides unstable slopes training for DNR staff, forest landowners, and staff from cooperating agencies and organizations. The training includes topics such as landslide processes, factors affecting slope stability, indicators of slope instability and identification of unstable slopes and landforms.

Compliance and Enforcement

DNR region forest practices staff, forest landowners, timber owners and operators are responsible for ensuring that ongoing forest practices are in compliance with the Forest Practices rules. Field staff visit on-going timber operations to ensure compliance and prioritize compliance visits based largely on the

potential risk to public resources posed by the operation. For example, forest practices that propose substantial road construction in steep terrain are more likely to receive regular compliance visits than those with limited road construction on gentle slopes.

In addition to the ongoing region forest practices staff compliance visits, WAC 222-08-160(4) describes a continual review of the Forest Practices rules through a compliance monitoring program. This program-wide, state-wide effort helps to determine whether forest practices are being conducted in compliance with the Forest Practices rules. The Forest Practices Board receives regular compliance monitoring reports. The results of the reports help inform the Board regarding improvements that may be needed – including rule modification, rule language clarification, or training and education needs.

Field staff have several tools available to them for compliance and enforcement purposes. The Forest Practices Act (76.09 RCW) and the Forest Practices Board, by policy, encourage informal, practical, result-oriented resolution of violations and action needed to prevent damage to public resources. It is also Board policy to use a progressive approach to enforcement that begins with consultation and voluntary efforts to achieve compliance while reserving civil penalties (i.e. monetary fines) to more serious infractions. Compliance and enforcement tools available to field staff include; supplemental directives, informal conferences, notices to comply, stop work orders, technical assistance compliance notices, notices of correction, corrective actions, civil penalties, disapprovals, financial assurances and criminal penalties (WAC 222-46).

It's important to note that DNR has the authority to issue a stop work order if there is any violation of the Forest Practices Act or rules, there is a deviation from an approved application or immediate action is necessary to prevent continuation of or to avoid material damage to a public resource. This is an official, formal notice served to an operator to temporarily or permanently shut down all or part of an operation in progress. This action may be taken to prevent material damage to public resources when no violation, unauthorized deviation or negligence has occurred (WAC 222-46-040)**.**

Reforestation

In Washington, reforestation is required following harvest unless the forest practices application indicated that the land would be converted to another use, or DNR has determined that the remaining trees are considered an established stand. Generally, the harvested area is considered reforested when, within three years of harvest, there are an average of 150 (eastern Washington) or 190 (western Washington) or more vigorous, undamaged commercial species seedlings per acre that have survived on the site for at least one growing season (WAC 222-34**)**.

Recent and On-Going Research Relevant to the Chehalis Basin

Scientific research regarding forest management and its impact on hydrology and unstable slopes was summarized above (see "Research on the Impacts of Forest Management"). However, scientific study is ongoing. This section summarizes the most recent and on-going research from Washington State's Forest Practices Adaptive Management Program that relates to forestland and water quantity issues and is relevant to the Chehalis basin.

DNR, and its statewide partners, support and participate in monitoring, evaluation, and research projects through the Adaptive Management Program. The Board adopted a more formalized Adaptive Management Program (WAC 222-12-045) in concurrence with the 1999 Salmon Recovery Act (see section above "Evolution of…protection). The intent of the Adaptive Management Program is to produce technical information and science-based recommendations to assist the Forest Practices Board

in determining if and when it is necessary or advisable to adjust Forest Practices rules and guidance in order to achieve resource goals and objectives.

The Forest Practices Adaptive Management Program is a multi-caucus program that includes representatives from state departments (including Fish and Wildlife, Ecology, and Natural Resources), federal agencies (particularly National Marine Fisheries Service, U.S. Fish and Wildlife Service, and Environmental Protection Agency), forest landowners, county governments, the environmental community, and tribal governments. Representatives of these caucuses participate on two key Adaptive Management Program committees established by the Forest Practices Board: the Forests and Fish Policy Committee (Policy) and the Cooperative Monitoring, Evaluation, and Research (CMER) Committee.

Policy, in part, makes recommendations to the Forest Practices Board regarding CMER Committee priorities and projects, final project reports and forest practices rule and/or guidance amendments. The CMER Committee oversees and conducts research and monitoring related, in part, to assessing the effectiveness of the Forest Practices rules. Its purpose is to advance the science needed to support adaptive management. CMER's work is independently peer-reviewed to determine if it's scientifically sound and technically reliable.

Based on recommendations from Policy and CMER, CMER annually develops a work plan and associated budget for approval by the Forest Practices Board. The CMER Work Plan presents an integrated strategy for conducting research and monitoring to provide scientific information to support the Forest Practices Adaptive Management Program. The primary purpose of the work plan is to inform CMER participants, Policy constituents, the Board and interested members of the public about CMER's research and monitoring activities. Continued annual revisions are anticipated in response to research findings of CMER and the broader scientific community, as well as changes in policy priorities and funding.

A complete list and current status of CMER projects, along with the current CMER workplan, can be found on the CMER website – http://www.dnr.wa.gov/AboutDNR/BoardsCouncils/CMER/Pages/Home.aspx. The CMER projects cover a range of topics related to the Forest Practices rules and are at various stages of development or completion. Projects originated as priority research topics in Schedule L-1 of the 1999 Forests and Fish Report (DNR 1999), which was later revised and adopted by the Forest Practices Board in 2001 and incorporated into the Forest Practices Habitat Conservation Plan.

The CMER Work Plan is organized in a hierarchical format consisting of rule groups, programs, and projects. Two rule groups in particular, the Unstable Slopes Rule Group and the Roads Rule Group, describe selected projects (in response to critical questions below – *A, B, C* (Unstable Slopes Rule Group), *D* and *E* (Roads Rule Group) that are particularly relevant to the forested landscape found in the Upper and Lower Chehalis basins.

Unstable Slopes Rule Group

A. What screening tools can be developed to assist in the identification of potentially unstable landforms that minimize the omission of potentially unstable landforms? (Unstable Landform Identification Program)

The purpose of the Unstable Landform Identification Program is to provide a set of screening tools to identify forested areas containing potentially unstable slopes and to focus field verification activities on potential problem areas, thereby improving the ability to avoid them.

The Unstable Landform Identification Program consists of five projects that provide statewide information on the distribution of unstable landforms:

1. Shallow Rapid Landslide Screen for GIS Project
2. Technical Guidelines for Geotechnical Reports Project
3. Regional Unstable Landforms Identification Project (RLIP)
4. Landform Hazard Classification System and Mapping Protocols Project
5. Landslide Hazard Zonation Project

1. Shallow Rapid Landslide Screen for GIS Project

Description: This project has three phases. The first phase of this project compared different slope stability models. Based on the results of that study, Policy directed DNR to develop a GIS-based screen of modeled slope stability based on digital elevation model (DEM) topography for the westside. This first phase was completed in 2001 and was released as TFW Report 118 titled, "Comparison of GIS-Based Models of Shallow Landsliding for Application to Watershed Management." The second phase produced a modeled slope stability screen, which is available on the DNR forest practices website. A third phase has been proposed to identify topographic model(s) appropriate for similar mapping on the eastside and is on hold.
Status: Phase 1 and 2 — Complete; Phase 3 — On hold.

The Shallow Rapid Landslide Screen is used by all DNR regions in screening FPAs for classification. Geologists and forest engineers use this screen as a first cut to determine if further investigation is needed.

2. Technical Guidelines for Geotechnical Reports Project

Description: This project develops technical guidelines for geotechnical reports used in the SEPA review process. The guidelines include identification of appropriate analytical tools and techniques appropriate for different projects and at different scales.
Status: Complete.

The Technical Guidelines for Geotechnical Reports are being used in all submitted Class IV special reports. Having a standard for reports is vital to the consistency of the review process.

3. Regional Unstable Landforms Identification Project (RLIP)

Description: This completed project provided a coordinator to work with Timber, Fish and Wildlife (TFW) cooperators within each DNR region in order to identify unstable landforms that do not meet the statewide landform descriptions. Its results also serve as an interim screen for deep-seated landslides by identifying lithologies that promote deep-seated landslides; however, the project did not actually map individual deep-seated landslides but rather the areas where they occur in abundance. In 2005, data from this project were placed into the hazard zones spatial database, which is used by DNR for classifying applications and by the Landslide Hazard Zonation team as preexisting work that they incorporate into their studies.
Status: Complete.

The results of the Regional Unstable Landforms Identification Project have been rolled into the Landslide Hazard Zonation (LHZ) hazard areas. Copies of reports on all identified regional landforms are used in each DNR region.

4. ***Landform Hazard Classification System and Mapping Protocols Project***
   Description: This project developed a detailed protocol to be used to map landslides and potentially unstable landforms in a consistent manner, leading to the assignment of hazard to unstable slopes in the forested environment. This project was completed in 2004; the protocol has subsequently been used for the implementation of the LHZ Project (described below) and by state lands geologists for large blocks of land under state ownership.
   Status: This project was completed in 2004 and has been utilized in the LHZ Project.

   The Landform Hazard Classification System and Mapping Protocols Project is the written and accepted protocol for the Landslide Hazard Zonation (LHZ) Project. These LHZ protocols are designed to ensure that all the final documents are consistent and comparable.

5. ***Landslide Hazard Zonation (LHZ) Project***
   *Descriptio*n: This is a multiphase project. During Phase 1, all mass wasting modules from completed watershed analyses and other information on unstable landforms, landslides, and unstable slopes were collected and compiled in a GIS database. This database has been made available for free download to the public and is utilized as a screening tool in the forest practices application review process.

   During Phase 2, mass wasting modules from 22 incomplete watershed analyses were either finished, reviewed, and added to the database or were rejected. Eleven of these were never completed.

   During Phase 3, the protocol was being implemented at the watershed scale following a list of priority watersheds based on presence of steep slopes and FPHCP lands.

   The LHZ protocol was used to complete 59 WAUs. Due to a suspension of legislative funding in July 2009, completion of the LHZ project has been postponed. If and when funding is available, priorities will be reassessed, as 34 of the original 56 priority WAUs for watershed analyses have not been completed.
   Status: Phases 1 and 2 – Complete; Phase 3 – On hold waiting for additional funding.

B. *Are the forest practices unstable slopes rules reducing the rate of management-induced landsliding at the landscape level? Are the mass wasting prescriptions and mitigation measures effective at preventing landslides from roads and harvest units?* (Mass Wasting Effectiveness Monitoring Program)

The purpose of the Mass Wasting Effectiveness Monitoring Program is to assess the degree to which implementation of the Forest Practices rules is preventing or avoiding an increase in landsliding beyond natural background levels.

1. ***Mass Wasting Effectiveness Monitoring Project (aka Post-Mortem)***
   Description: This project is designed to statistically compare landslide densities among five harvest treatments and five road treatments. The treatments are sets of prescriptions associated

with the period in which different Forest Practices rules were in effect. Given a storm event that produces a significant population of landslides, landslide data will be collected within 4-square-mile blocks, and all area encompassed by the block will be classified into one of the five harvest and five road treatments. Harvest and road landslides will be analyzed separately, and all analyses will be made relative to the block response. Tests will be conducted to determine whether there are differences in the density or sediment delivery volume of landslides associated with each of the harvest and road strata.

Independent Scientific Peer Review (ISPR) of the study design was completed over the summer of 2007. The study design was being revised when the landslide-producing December 2–3, 2007 storm occurred. Final approval of the study design was given by CMER in January 2008. Policy and the Forest Practices Board approved moving forward with implementation in February 2008. The project was implemented in the spring of 2008. Additional data were incorporated into the study in the fall of 2009.

Status: The study report has undergone ISPR review and is expected to be finalized in 2012.

C. Are unstable landforms being correctly and uniformly identified and evaluated for potential hazard? (Mass Wasting Effectiveness Monitoring Program)

2. ***Unstable Slope Criteria Project: An Evaluation of Hillslopes Regulated under Washington Forest Practices Rules***
   Description: This project will evaluate the degree to which the landforms described in the unstable slopes rules identify potentially unstable areas with a high probability of impacting public resources. The project will be designed to evaluate the original Forests & Fish Report Schedule L-1 research topic: "*Test the accuracy and lack of bias of the criteria for identifying unstable landforms in predicting areas with a high risk of instability"* (DNR 1999). Policy's direction to CMER is to evaluate the landslide susceptibility of different slopes/landforms in the interest of evaluating current rule-identified landforms and identifying/characterizing additional potentially unstable landforms.

   Status: The project is currently being scoped (and is included in the "Recommended Projects" section at the end of this report).

The Roads Rule Group

The intent of the Forest Practices rules for roads is to protect water quality and riparian/aquatic habitat by minimizing sediment delivery to fish and non-fish bearing waters from road erosion and mass wasting, as well as minimizing changes in hillslope and stream hydrology due to roads. The road rules protect water quality and riparian/aquatic habitats through prescriptions and road best management practices.

Implementation of these prescriptions through road maintenance and abandonment plans (RMAPs) is intended to minimize road surface sediment production and the hydrologic connection between the road system and the stream network, and the risk of road-related landslides caused by inadequately built and maintained roads.

D. Are field or analytical methods needed to support the monitoring program? (Road Sub-Basin- Scale Effectiveness Monitoring Program)

The purpose of the Road Sub-Basin-Scale Effectiveness Monitoring Program is to determine the degree to which the road rule package is effective at meeting performance targets for surface erosion sediment and water established at the sub-basin scale as a whole across the state.

1. ***Road Surface Erosion Model Update Project***
   Description: The road surface erosion model within the Surface Erosion Module of the Washington Forest Practices Board Manual on Standard Methodology for Conducting Watershed Analysis (version 4.0, November 1997) is an empirically derived model for estimating surface erosion and sediment delivery to streams from forest roads. The primary purpose of this project is to refine and adapt the model for use in forest road monitoring and as an assessment method. Revisions include standardizing input variables and developing repeatable application protocols. This project also includes development, testing, and refinement of standardized protocols for field application of the revised road surface erosion model for use at the site and road-segment scale.

   Status: This project was completed in 2003 and produced the Washington State Road Surface Erosion Model (WARSEM).

E. Are road prescriptions effective at meeting sub-basin-scale performance targets for sediment and water? (*Road Sub-Basin- Scale Effectiveness Monitoring Program)*

1. ***Road Sub-Basin-Scale Effectiveness Monitoring Project***
   Description: The main purpose of this project is to provide data that can be used to assess the degree to which sub-basin-scale performance targets, and therefore resource objectives, are being met throughout the state. This project also characterizes the extent of road conditions that reduce surface erosion (e.g., improved surfacing, reduced runoff to streams). Data collected at the sub-basin scale will determine the status and assess trends of key indicators of road connectivity using WARSEM-modeled sediment delivery through time. Forest road systems in randomly selected sample areas that are proportionately distributed statewide in areas under Forest Practices rules, independent of ownership, are being monitored. Small forest landowner properties are included in the study whenever they fall within the sampling blocks. Data are collected to determine the degree to which roads meet established performance targets and the strength of the relationship between those reported measures and the percentage of sample area under implemented RMAPs.

   Status: There are three phases of this research.

   Phase 1 sampled of 60 four-square-mile blocks randomly selected across Washington State. It is intended that sampling occur once or twice (Phase 2 and 3) more during the years of RMAP implementation to understand the long-term trend of road erosion and to determine if the performance targets are achieved at the end of RMAP implementation.

   Results from Phase 1 show road managers reported that over half of the sample units had at least 85% of road length meeting post-RMAP standards. Across all samples, an average of 11% of the road length was hydrologically connected to streams or wetlands, though much variability exists between regions and blocks. Sixty-two percent of the road samples met the regional performance

target for hydrologic connectivity, and 88% of the samples met the sediment target. These are all favorable results, given that they were observed less than halfway through the RMAP implementation period. Sediment delivery performance by sample block was statistically correlated with progress toward RMAP standards. However, hydrologic connectivity was not statistically related to progress toward rule standards, reflecting that connectivity targets are difficult to achieve for roads located in areas of high stream density. The results of future monitoring events (planned interval of five years) will identify what changes in road performance result from additional road improvements.

Results from Phase 1 underwent Independent Scientific Peer Review and were approved by CMER in early 2010. Sampling during Phases 2 and 3 are scheduled to occur, respectively, later within the RMAP implementation period and following completion currently scheduled for 2016. Phase 2 and 3 will determine if road characteristics that affect runoff and sediment delivery to streams are improving through time.

Advisory language was placed in the Board Manual Section 3 – Guidelines for Forest Roads – recommending that landowners identify those road segments which they believe are in good repair, but which the study indicates remain highly connected to the channel network.

Recommended Projects

The literature indicates that forest management on forestland has the potential to have an effect on peak flows and unstable slopes (see "Research on the Impacts of Forest Management" section). The forest practices Adaptive Management Program is currently involved in on-going projects to produce technical information and science-based recommendations to assist the Board in determining if and when it is necessary or advisable to adjust Forest Practices rules and guidance in order to achieve resource goals and objectives. However, there are additional projects that if funded, could provide valuable knowledge or tools, which when used, have the potential to measurably improve public resource protection. DNR is recommending three projects, in priority order, for funding consideration that have a direct link to the Chehalis Basin and flooding impacts.

Project #1: Geological mapping and updated LiDAR (Light Detection and Ranging)

The 2007 storm was the third time in 20 years that flooding has closed I-5. The following project (in two parts) offers needed tools to assist in solving some of the problems in the Chehalis basin.

LiDAR will supply data on floodplain elevations that are needed to understand flooding patterns, geomorphology, floodplain management, and development. In the upper Chehalis basin, LiDAR will provide data on slopes and where landslides have occurred. This will be used to test the predictive models. Because parts of the Chehalis basin have been flown for LiDAR a comparison of the two LiDAR data sets can be made.

Part 1(a) – Surface and subsurface geological mapping

Year 1 - Accomplish surface and subsurface geological mapping of the Centralia and east half of the Adna 7.5 minute quadrangle. Geological mapping will be useful in solving many of the problems associated with flooding and floodplain development and for evaluating levees, dredging, and dam proposals.

Geologic mapping will identify the location and physical characteristics of geologic materials, surface and subsurface constrictions, what controls groundwater divides, what controls channel migration,

landforms, what is controlling the rates of erosion and landsliding, depth to bedrock, as well as the fractures and faults within the geologic materials. This information provides critical stratigraphy and geohydrologic information for informed decisions. For example, it will provide a picture of the subsurface geology and shape of the basin, which is necessary to determine hydrologic characteristics. These could be mapped starting summer 2012. Initial mapping can begin without new LiDAR. Subsequently, more detailed mapping may be needed to resolve site specific issues. LiDAR will dramatically enhance the quality of the geologic mapping in Lewis County.

Estimated Cost for mapping the first one and ½ quadrangles: $261,000

Years 2 through 5 - Accomplish geological mapping of the middle and upper Chehalis basin. Geologic mapping will identify the location of existing landslide deposits and failure prone geologic materials. This information is necessary for geomorphologic and slope stability analyses, both of which can model the areas susceptible to future landslide activity as well as provide estimates of the amount of sediment that will be delivered to the streams in the Chehalis basin. This information is critical to determining hydrologic capacities within the basin and thereby determining what the effectiveness of a flood control plan will be. For example, the mapping will help define aquifers and aquacludes within the basin. The Chehalis basin is a very large basin and DNR recommends that at least the area upstream of Capital Forest be geologically mapped. There are 13 7.5 minute quadrangles that should be mapped in Lewis and Thurston counties.

Estimated Mapping Cost for 13 quadrangles: $2,260,000

Part 1(b) – Updated LIDAR for high resolution elevation model
In the *Chehalis Basin Ecosystem Restoration General Investigation Study Baseline Hydrology and Hydraulics Modeling, Draft Hydrologic Analysis Report* (USAE 2011), the scope of work for the update phase recommends adding previously unmodeled parts of the Chehalis to the previous models. DNR suggests that it is time to do a comprehensive model using 3-D methods and current conditions of topography. That would require acquiring post-2007 topography by LIDAR with a common specification, preferably acquired as a new contiguous block.

The Upper Chehalis WRIA is 830,805 acres and the Lower Chehalis WRIA is 939,467 acres. The cost to fly LiDAR is currently $.78/ac for large blocks such as these. An additional 27% is included for indirect costs, for a total estimated cost of $1,753,600.

Estimated Total Cost for LiDAR: $1,753,600

Total Estimated cost for Project #1 **$4,274,600**

Project #2 - Unstable Slope Criteria Project: An Evaluation of Hillslopes Regulated under Washington Forest Practices Rules.
The project will address the following question:
Are unstable landforms being correctly and uniformly identified and evaluated for potential hazard?
This project is part of the 2013 CMER Work Plan and is estimated to begin in July, 2013. It will evaluate the degree to which the landforms described in the Forest Practices rules identify potentially unstable areas with a high probability of impacting public resources, as well as identify and characterize additional potentially unstable landforms.

Estimated Cost: **$200,000**

Project #3 – Road Prescription-Scale Effectiveness Monitoring
The project will address the following question:
Are road prescriptions effective at meeting site-scale performance targets for sediment and water?
The primary purpose of this project is to evaluate the effectiveness of road maintenance categories in meeting road performance targets and to identify sensitive situations where prescriptions are not effective.
This 10-year project includes development, field implementation, data assimilation, and report writing stages.

Estimated Cost: **$2,200,000**

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Comments on DNR Chehalis River Basin Forestland Report

SUBMITTED VIA EMAIL BY PAUL PICKETT, WASHINGTON DEPARTMENT OF ECOLOGY - JUNE 8, 2012

Subject: RE: Chehalis Flooding Technical Workshop

My focus for comments is on:

- What points does there seem to be agreement on?
- What points is there disagreement on?
- What are the information gaps?

1. The report asserts that the forest practices rules will help protect and restore hydrologic processes. There are beneficial effects on hydrology from the rules, such as those for rain-on-snow, maximum cut size, green-up, and stream buffers. There is uncertainty about the effectiveness of implementation, i.e. are landowners doing the practices as intended. And there is uncertainty about the effectiveness of existing rules to protect and restore hydrologic processes.
2. Page 1, Executive Summary 1st paragraph, "Forest management activities such as timber harvest or forest road construction have the potential to decrease the natural flood protection of the forests if executed in a way that does not minimize adverse effects to these hydrologic cycle components.": This statement is confusing and somewhat disingenuous, since it suggests that impacts can be avoided entirely. If they make this claim, they should support it with scientific literature, but it appears unlikely that literature exists to support that claim. A better statement would be "Forest management activities such as timber harvest or forest road construction have the potential to decrease the natural flood protection of the forests, and the impacts of activities can be minimized by the use of appropriate Best Management Practices."
3. Page 1, Executive Summary 2nd paragraph: This paragraph is worded in a way to suggest that the forest practices regulations effectively "protect public resources" in a way that is "flexible and responsive". The rules are <u>intended</u> to protect resources, but recognize that effectiveness is uncertain and that additional studies are needed to determine the extent of effectiveness. Blanket assertions of this sort are less helpful than understanding where the effectiveness and responsiveness of the program has been documented and where additional study or improvements are needed.
4. Page 2-3, "Peak Flows/Unstable Slopes and the Forest Practices Rules":
    a) The response to forest harvest is strongly seasonal. In conifer-dominated forest basins, streamflow may increase by several hundred percent during the late summer and early fall period in the first five years after harvest. (also page 18, last paragraph)
        i. Jones, J. A., and Post, D. A., 2004, Seasonal and successional streamflow response to forest cutting and regrowth in the northwest and eastern United States: Water Resources Research, v. 40, no. 5.
    b) Other citations are available to show that forest harvest can increase the volume of water for rain-on-snow events.
        i. Coffin, B. A., and Harr, R. D., 1992, Effects of forest cover on volume of water delivery to soil during rain-on-snow: Timber Fish & Wildlife, Washington Department of Natural Resources.
        ii. Marks, D., Kimball, J., Tingey, D., and Link, T., 1998, The sensitivity of snowmelt processes to climate conditions and forest cover during rain-on-snow: a case study of the 1996 Pacific Northwest flood: Hydrological Processes, v. 12, no. 10-11, p. 1569-1587.
    c) "The extent to which timber harvest alone has triggered substantially increased peak flows is likely rare" (also p.19, end of 1st paragraph): Not an accurate statement. This is an area of active research with new studies showing potential impacts.

i. Moore, R. D., and Wondzell, S. M., 2005, Physical hydrology and the effects of forest harvesting in the Pacific Northwest: a review: Journal of the American Water Resources Association, v. 41, no. 4, p. 763-784.
ii. Alila, Y., Kura, K., P., Schnorbus, M., and Hudson, R., 2009, Forests and floods: A new paradigm sheds light on age-old controversies: Water Resour. Res., v. 45, no. 8, p. W08416.

d) Other citations are available that show the impact of road runoff.
i. Tague, C., and Band, L., 2001, Simulating the impact of road construction and forest harvesting on hydrologic response: Earth Surface Processes and Landforms, v. 26, no. 2, p. 135-151.
ii. Wemple, B. C., and Jones, J. A., 2003, Runoff production on forest roads in a steep, mountain catchment: Water Resources Research, v. 39, no. 8, p. [np].

5. Page 3, 4th paragraph: How are road maintenance and abandonment plans reported? Are they being fully implemented, and are they effective?
6. Page 3, last paragraph, "Forest Practices rules address rain-on-snow effects in two ways, first through the hydrology module in watershed analysis…": Currently watershed analyses are rarely conducted, and the hydrology module may be outdated.
7. Page 3, last paragraph, "DNR may limit even-aged harvest size when it determines that peak flows have caused material damage to public resources": How often has this analysis been done in the Chehalis basin? Could it be done more often in the future as a flood mitigation measure?
8. Page 19, "Timber Harvest and Peak Flows",
   a) "Timber harvesting alone may have an effect on flows but is likely minor.": This assertion is not well-supported by studies. For example, one study states: "Peak flow frequency increases after harvesting increase with return period, with the largest events (100 year) becoming 5–6.7 times more frequent, and medium-sized events (10 year) becoming 1.7–2 times more frequent." (Kuras´, P. K., Y. Alila, and M. Weiler (2012), Forest harvesting effects on the magnitude and frequency of peak flows can increase with return period, Water Resour. Res., 48, W01544, doi:10.1029/2011WR010705.)
   b) "If a peak flow following harvest occurs, small basins seem to be more likely to experience effects than large basins." No explanation or citation is provided to support this statement. You would expect it would be easier to detect peak flow changes in small watersheds where a higher proportion of the basin will have undergone harvest, but there would still be an effect in a large basin.
9. Page 19, "Road Construction and Peak Flows", "While timber harvest alone most likely has little effect on peak flows,…": Disagree with wording. Better would be: "While there is uncertainty around the effect of timber harvest on peak flows,…"
10. Pages 20-21, "Riparian and Wetland Areas": The hydrologic functions of riparian and wetland areas are described, but the impact on their disturbance on peak flows is not addressed. In the context of the Chehalis Basin, the cumulative effect of forest management on riparian and wetland areas and hydrology is unknown. This is an area of further research.
11. Page 31, "Compliance and Enforcement": The report should note that unstable slopes are not evaluated for compliance or included in DNR's compliance monitoring summary report.
12. Page 38 and onward, "Recommended Projects": In general the price-tag on the projects should be examined closely before a decision is made to support them.
    a) Project #1(a): Geological mapping provides valuable information. The cost and timing should be weighed against other funding priorities. This is likely a long term project, but the quads should all be prioritized and a program defined for completing this work over the next 5 to 10 years.
    b) Project #1(b): This would be a very useful project and could provide the basis for better GIS mapping and a predictive hydrologic model of the basin.
    c) Project #2: The value of this project for flood mitigation is unclear.
    d) Project #3: The value of this project for flood mitigation is unclear.
    e) Project #4: It's not clear if this project will focus on the Chehalis basin. The estimated cost should be reviewed

13. The cumulative effects of timber practices and the potential for watershed restoration to mitigate flooding would be better understood if a hydrologic model of the basin were available. Some thought should be given to the input needs of such a model and the data gaps identified. Then research could be targeted to fill those gaps. Questions for the upland forested areas could include:
    a) What are the stand ages and current vegetation cover for forest lands?
    b) What are the heights and density of vegetation in riparian buffer areas?
    c) Where are the current, historical, and potential wetland and pond areas?
    d) How do stand age and forest practices affect infiltration and what infiltration rates apply to different forest areas?
    e) Where are the current and historical forest roads, and what condition are they in with respect to channeling runoff and connection to streams?
    f) What are the channel slope, width, and substrate composition of upland tributaries in forest areas?

Seattle Times article on the ongoing scientific debate about the contribution (if any) of forest practices to flooding

LANDSLIDE STUDY BOGGED DOWN BY SCIENTIFIC DISPUTE

Originally published Sunday, June 24, 2012 at 8:12 PM
Corrected version
By Hal Bernton, Seattle Times staff reporter

A $1.5 million study by the state Department of Natural Resource to see whether current logging restrictions were reducing landslides is more than two years behind schedule as scientists argue over the report's conclusions.

Four years ago, the Washington Department of Natural Resources launched a $1.5 million study to find out if state logging restrictions on unstable slopes were helping reduce the frequency and size of landslides.

Field crews tramped through the steep backcountry of Western Washington to catalog 1,147 landslides triggered during powerful storms of December 2007.

But the study is some two years overdue. It's now bogged down by a bitter dispute among scientists over what knowledge can be gleaned from the formidable accumulation of data, preventing it from being finalized.

The study is intended to help guide state rule-makers in the high-stakes effort to determine which trees should be left behind on slide-prone timberlands to help protect streams and other public resources.

The draft conclusion appears relatively tame, noting that the findings support "the hypothesis that avoidance of clear cut harvests on unstable terrain reduces the size and frequency of landslides," according to a draft copy obtained by The Seattle Times.

Critics say the study has numerous problems and doesn't offer evidence to back up the key conclusion that buffers reduce landslides.

"Correct the misinterpretations, and make it clear that the unstable slope buffer effectiveness could not be determined," wrote A.J. Kroll, a scientist for Weyerhaeuser, which owns Southwest Washington timberlands that were hit by many of the slides.

The study "simply does not address the rules. ... In fact, the effectiveness of the rules may be much better or much worse than indicated in this study," wrote Leslie Lingley, a geologist with the state Division of Forestry that regulates the timber industry.

The five scientists who authored the study include two who work as private consultants, two who at the time of the study were employed by tribal organizations, and a timber-industry geologist with Rayonier.

They note the study already has gone through peer review and say much of the criticism was raised "well after the appropriate stage."

"The authors are not convinced that further dialogue is likely to be productive," they wrote in response to their critics. "We do not see a path forward with respect to issues raised."

The study focused on 55,000 acres of timberlands in the Willapa Hills, the epicenter of 2007 storms, and some 550 miles of logging roads.

The slides dumped mud and debris into swollen rivers, helping fuel the floods that slammed houses, barns and farm fields downstream

The scientific clash over the study unfolds amid continuing controversy over logging on slide-prone landscapes.

Current rules typically require buffers of uncut trees to remain on unstable slopes where landslides might send mud and debris into waterways or other public resources. Unstable slopes are defined under rules put into place in 2001 as steep inner gorges, bedrock hollows and other terrain prone to slide.

The study found that the current rules often did not appear to be followed, identifying some 47 slides that occurred on slopes that had been clear-cut since 2001, even though the land met the state definition for unstable terrain.

The study also found that more than 40 percent of the landslides occurred on slopes that did not meet the state definition.

Environmentalists who have reviewed the study believe it offers ammunition for tougher enforcement of current rules and for expansion of the definitions of unstable slopes to cover more land.

"This study is evidence that steep and unstable slope rules and regulations are inadequate and enforcement is appalling," said Peter Goldman, of the Washington Forest Law Center.

Kevin Godbout, a Weyerhaeuser official, says that his company already has taken a number of steps since the 2007 slides to improve identification of unstable terrain that could be buffered with uncut trees.

"We have beefed up our staff of geologists, and reviewed the whole process of how we screen for unstable slopes," Godbout said.

The future of the study remains unclear.

It emerged from a scientific research committee established by the state to develop studies that can guide review and potential change to state forestry rules.

Chris Mendoza, a co-chair of that committee, says that many of the objections to the study were raised after a vote was taken to end the formal review process, and that it should now become final.

Others disagree. To resolve the dispute, a state policy group, at a meeting earlier this month, recently discussed whether the state should eventually hire a mediator.

Bridget Moran, a Department of Natural Resources deputy supervisor, is confident that common ground eventually will be found.

"We're trying to resolve whatever issues are out there, so we can proceed ahead and finalize the report," Moran said. "This is a big important study, and we want to get it right."

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Information in this article, originally published June 24, 2012, was corrected on June 25, 2012. A previous version of this story incorrectly summarized one of the findings. The study found that more than 40 percent of the landslides occurred in areas that did not meet the state definition of unstable slopes.[5]

[5] http://o.seattletimes.nwsource.com/html/localnews/2018521201_landslidestudy25m.html

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Appendix D: Evaluation of Benefit-Cost Work Regarding Chehalis River Flood Control

A Conceptual Evaluation of Benefit-Cost Work Conducted Regarding Chehalis River Flood Control

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July 12, 2012

Executive Summary

The Benefit-Cost Analysis Center at the University of Washington has been asked by the William D. Ruckelshaus Center to analyze the benefit-cost analyses produced concerning various proposed alternatives for mitigating severe flooding in the Chehalis River basin. This is in keeping with Engrossed House Substitute Bill 2020,[6] which requires that the state Office of Financial Management prepare a report on flood hazard mitigation in the Chehalis basin that summarizes "the benefits and costs of recommended projects, using available information and accepted benefit/cost methods" (Section 1033, 2:e). We find that the existing analyses, namely EES Consulting's flood retention project analysis[7] and the Army Corps of Engineer's levee system analysis[8] provide a sound basis for assessing the social benefits and costs not just of the structural projects they directly consider but also for the portfolio of alternatives, including numerous programmatic or non-structural actions, under consideration by the Chehalis Basin Flood Authority. Given the inherent uncertainty of any complex modeling exercise and the necessity of analyst discretion in any benefit-cost analysis (BCA) application, we do not focus on specific model parameter estimates or valuations. Instead, we focus on conceptual strengths and weakness, particularly as related to the ability to make inter-project comparisons. We highly encourage clear presentation and transparency, since the goal for BCA is not to foster full consensus but to provide a framework for a coherent discussion of values and preferences.

We find that one of the primary strengths of the current portfolio of analyses is that it provides a conceptual basis for qualitatively evaluating the benefits of projects that have not been formally analyzed. The HAZUS flood model damages estimated by EES in their evaluation of the flood retention alternatives provide an anchor for considering the flood prevention or mitigation value of other alternatives. Even in the absence of further HAZUS model runs that examine the potential effects of other policies, policy makers can use these estimated damages as a guide for thinking about what the returns to other projects might be as well. Thus, the current data means that policy makers should not require BCAs of comparable scope (and expense) for all other projects. For instance, the 2003 "Multi-Purpose Water Storage Assessment" prepared for the Chehalis Basin Partnership estimates costs for several programmatic projects: Block agricultural drainages ($207,000); low-impact development ($120,000); beaver reintroduction ($170,000); and forest conservation/restoration ($300,000). With the benefit of existing data, these types of projects can be analyzed without using a full, separate BCA. Given the massive flood damage figures provided in EES's analysis (hundreds of millions of dollars in flood damages from severe events such as the 2007 flood), such measures would appear to be sound investments given their comparatively miniscule costs and relatively low uncertainty (i.e., project costs would not likely balloon and flood mitigation effects will likely be realized).

Lastly, we identify several issues that are not sufficiently addressed by existing analyses that policy makers should be mindful of as they make inter-project comparisons, including:

(1) A clear focus on flood prevention/mitigation policy as a public investment: It is not enough to simply determine whether estimated project benefits exceed estimated project costs. Instead, net project benefits should be evaluated against the potential returns from an alternative project or an alternative use of public funds.

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[6] ESHB 2010, Chapter 49
[7] Chehalis River Flood Water Retention Project Phase IIB Feasibility Study, finalized April 14, 2011.
[8] Centralia Flood Risk Management Project, Chehalis River: Draft Close-out Report, as of January 2012

(2) The inadequacy of simple benefit and cost estimates for reflecting uncertainty: In evaluating project alternatives, a single benefit and cost cannot demonstrate how much confidence policy makers should place in an estimate. Such "points estimates:" are an insufficient basis for project selection because they do not speak to project "upside" and "downside". In other words, it is critically important to consider potential outcomes should assumptions and estimates prove incorrect (e.g., if an estimated cost proves far to low, or an environmental impact prove far greater than anticipated).

(3) The time frame on which benefits and costs are modeled to occur: Due to the opportunity cost of funds, the financial viability of a project is greatly determined by interest rate, or time value, assigned to project costs and benefits. This means that *when* benefits and costs are modeled to occur greatly affects the outcome?

(4) An appropriate basis for comparison: A BCA should estimate the difference in outcomes between what is likely to occur if a project is funded and if it is not. In other words, project benefits and costs should not include changes or expenditures that are likely to happen even if a project is not implemented. This is particularly important when considering the selection of multiple projects, since numerous small programmatic or non-structural projects might obviate the benefits of a large structural project.

In what follows, we discuss each of these points in greater detail.

▪ ▪ ▪

I. Introduction

The Benefit-Cost Analysis Center at the University of Washington has been asked by the William D. Ruckelshaus Center to analyze the benefit-cost analyses produced concerning various proposed alternatives for mitigating severe flooding in the Chehalis River basin. As a rubric for this task, the investigators have drawn on the current theoretical understanding and best practices found in the benefit cost literature. Particularly, the investigators have used the recent MacArthur Foundation report, produced by the Center: Principles and Standards for Benefit-Cost Analysis (Zerbe et al. 2010).[9]

The BCAs conducted regarding the various policy alternatives (including EES Consulting's analysis of flood-retention facilities and the US Army Corps of Engineer's analysis of new levees on the Chehalis River), involve different data, models, and analysts; thus, in each section we emphasize the ability to make meaningful comparisons across policy alternatives. We envision this review as a conceptual analysis of methodology and key issues. Given the inherent uncertainty of complex social-ecological systems (Folke et al. 2005; Gunderson and Holling 2002) and the reality that no counting exercise is wholly value-neutral (Stone 2012), it is important to consider that no BCA can expect to be fully accurate or address all policy considerations. However, what is most important is that BCA facilitates a better, more-informed policy decision, not that a BCA be completely accurate. A simple, "back of the envelope" analysis can still help policy makers select the most efficient policy alternative. This reality is of particular importance in this case, since only a few alternatives under consideration have been formally analyzed. Moreover, even if stakeholders disagree about a particular model assumption (for instance, salmon survival rate passing through the water retention facility), BCA provides a means by which to explore the potential ramifications of such disagreement.

We employ this philosophy in our review, emphasizing the role of BCA in facilitating a robust discussion of the assumptions, methods, and concerns for policy decision-making raised by BCA about the various policy alternatives. In other words, we emphasize the decision-making usefulness (and barriers to usefulness) found in the existing portfolio of project analyses. Clarity and transparency is most important in this regard. For instance, stakeholders might disagree on the value estimated for a model parameter (e.g., how many users will visit the recreation site), but so long as this estimate is clearly shown in the analysis, each stakeholder can evaluate model results in light their preferred number. Thus, the ultimate goal of a benefit-cost analysis should not be to foster complete consensus, but rather to constructively guide debate about policy alternatives and ground this debate in a scientific evaluation of economic effects.

In our review of the benefit-cost work presented to us, we find that the authors of the various reports have provided a strong knowledge base regarding the economic impacts of various flood protection alternatives. In the next section, we describe how the existing works provide a basis for decision making going forward. We then describe how the projects considered in detail in these analyses can be reasonably compared to projects that have not been studied at the same level of detail. In conclusion, we also provide several recommendations as to how these analyses can be made even more useful for policy makers. These "points for consideration" are all oriented towards the goal of facilitating comparison across projects and developing a common basis for discussion about policy alternatives and impacts. We identify and discuss five important issues that merit consideration in this regard: (1) Policy goals and objectives; (2) Risk and uncertainty; (3) The yearly distribution of benefits and costs over the project time horizon; and (4) An appropriate baseline for comparison.

[9] Other recent texts that reflect the state-of-the-art include Adler and Posner 2001, Boardman et al. 2011, Brent 2008, de Rus 2012, and Zerbe and Bellas 2006.

II. Moving Forward With Existing Analyses and Data

Benefit-cost analysis, carefully done, is an exceedingly difficult exercise and the works we have reviewed demonstrate meticulous research, careful consideration, and artful problem solving. In what follows, we describe several important takeaways from the existing body of analyses that provide as basis for decision making as policy makers move forward.

1. Clear causal linkages

Causality, a question as to whether an expenditure directly results in a change in net benefits, is central to BCA (Drake et al. 2009). As a general principle, the further removed causal drivers are from estimated effects, the less confidence decision makers should place in estimated values. For most alternatives considered in this case, the causal link between costs and benefits is largely straightforward. For instance, whether policy makers choose to improve the levee system or implement a suite of non-structural policies, there is no doubt that such measures would reduce or prevent flooding should such an event occur. This holds true for livestock pads, , flood retention facilities, , temporary water storage on farmland, and other alternatives as well, since there is a concrete physical link between such measures and flood mitigation. While the magnitude and geographic nature of a flood event will always be uncertain, policy makers can be confident, for instance, that walls along I-5 will prevent I-5 from closing under designated conditions.

One caveat we would add in this regard, however, is that as more and more assumptions are required in order to predict a causal effect, policy makers should be more and more wary of the validity of our estimate. For instance, an estimate of benefits associated with changes in land use management by local governments requires assumptions about future growth patterns, the cumulative impact of a diverse spate of management actions, and the degree to which such measures are implemented (and enforced) successfully going forward. Thus, the overall cost and benefit estimates for this alternative are dependent on an assumed link from zoning and land-use regulations to actual land use behavior to resultant flood prevention/mitigation; if regulations are insufficiently enforced, for example, then the estimated level of flood reduction benefits will not be achieved.

As another example, consider the predicted effect of the multi-purpose dam on the spring-run Chinook salmon stock: Anchor QEA's model predicts that the stock will increase by 140% under optimal stream flow management and target survival passage rates at the dam. Regardless of one's view on the validity of this prediction, we must bear in mind that it hinges upon the accuracy of multiple assumptions, including: (1) those related to the impact of the dam on stream flow and water temperature; (2) those related to how the dam will be managed; (3) those related to fish passage survival rates (4) the behavior of juvenile and adult Chinook in response to a major change in their environment where there is little currently known about the behavior of juvenile fish in the river. However, there is absolute certainty that the dam eliminates some salmon-spawning habitat.

Conversely, if policy makers were to choose to put walls along I-5 and re-vegetate upstream land, this re-vegetation would also be predicted to increase the salmon stock by creating improving water and habitat quality. However, if this did not prove the case, re-vegetation would most certainly at least not *reduce* the salmon stock. In other words, avoiding significant harm to the Chehalis River spring-run Chinook stock under the multi-purpose dam scenario depends on policy makers being *right* about numerous predictions; on the other hand, avoiding harm to salmon under several other scenarios can be achieved even if policy makers are *wrong* about many of the predicted effects.

Thus, in assessing the various policy alternatives, policy makers must remain mindful of the robustness of benefit and cost estimates. Figure 1 provides an example from Anchor QEA's salmon impact study that demonstrates such an approach. Figure 1 demonstrates the potential range of impacts on Winter Steelhead spawners in the Chehalis River, providing not only the most likely estimate but upper and lower boundaries reflecting the overall distribution of potential outcomes:

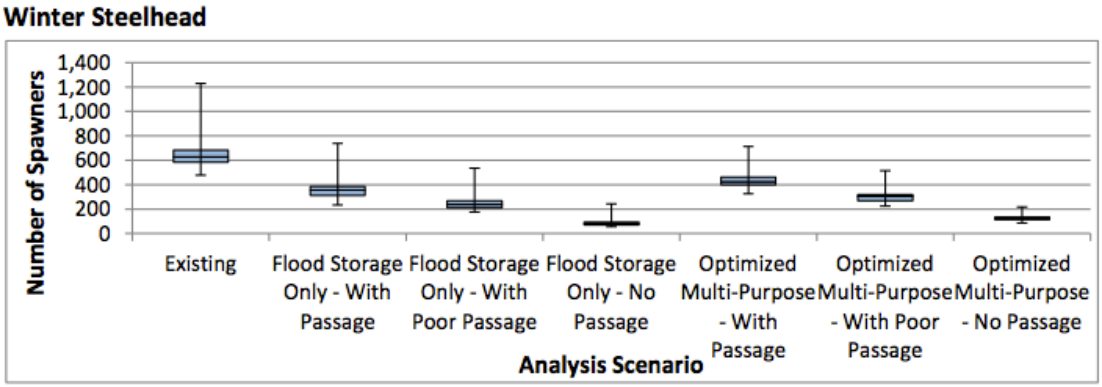

Figure 1: Example of estimate range from Anchor QEA study, figure 6-2, page 75.

In other words, it is important to consider how likely it is that the hypothesized chain of events actually occurs, and how different the policy outcome might be if these assumptions are not borne out. While we pointed out an example regarding salmon impacts above that might give cause for concern, in the aggregate we find this to be a cause for confidence in the existing analyses. With the exception of environmental impacts such as to salmon stocks, the causal link between project costs and benefits appears robust, well established, and straightforward.

2. Tractable estimation of benefits

The estimation of flood reduction benefits, such as avoided structural damages and transportation closures, has been carefully conducted and excellently detailed. The HAZUS model used to project flood events is widely accepted in the published literature (for recent examples, see Dierauer et al. 2012 and Whitehead et al. 2009). Often the estimation of non-monetary benefits and costs injects a great deal of uncertainty into BCA. This is especially the case when state-preference methodologies are used (e.g., the Earth Economics report on ecosystem services benefits).[10] However, the projects under consideration, both structural (e.g., levies or dam facility) and non-structural (e.g., riparian restoration or land-use protocols) achieve benefits associated with preventing damages to structures, livestock, crops, and other built capital that have market prices. In other words, many of these items are bought and sold in markets, and thus their market prices can be used to estimate damages. Likewise, the revealed preference methodology[11] used to assess the cost of interstate and railway

[10] In stated-preference valuation, benefits and costs are estimated using answers provided in hypothetical choice scenarios (see Champ et al. 2003). For instance, an analyst might choose to use contingent valuation to model the value of a salmon stock, asking people how much they would be willing to pay to prevent the stock from decreasing or how much they would except in exchange for the stock decreasing by a specified amount.

[11] Revealed preference methods use actual market behavior to estimate the values of nonmarket goods associated with the observable transaction (Boardman et al. 2010). For instance, there is no actual price associated with a one-day closure of Interstate 5, but by estimating the cost of additional time, added transportation costs, and lost commerce fostered by a closure, analysts can develop an estimate as to how much a one-day closure decreases net

closures utilizes market behavior as well. While the uncertain nature of flood events means prior estimation of damages is a somewhat impossible exercise, decision makers should be confident that these estimates provide a suitable basis for inter-project comparison that is well founded in actual market outcomes.

III. Inter-project Comparisons (including projects without formal BCAs)

We find that one of the primary strengths of the current portfolio of analyses is that it provides a conceptual basis for qualitatively evaluating the benefits of projects that have not been formally analyzed. The HAZUS flood model damages estimated by EES in their evaluation of the flood retention alternatives provide an anchor for considering the flood prevention or mitigation value of other alternatives. Even in the absence of further HAZUS model runs that examine the potential effects of other policies, policy makers can use these estimated damages as a guide for thinking about what the returns to other projects might be as well. Thus, the current data means that policy makers should not require BCAs of comparable scope (and expense) for all other projects.

For instance, the 2003 "Multi-Purpose Water Storage Assessment" prepared for the Chehalis Basin Partnership estimates costs for several programmatic projects: Block agricultural drainages ($207,000); low-impact development ($120,000); beaver reintroduction ($170,000); and forest conservation/restoration ($300,000). With the benefit of existing data, these types of projects can be analyzed without using a full, separate BCA. Given the massive flood damage figures provided in EES's analysis (hundreds of millions of dollars in flood damages from severe events such as the 2007 flood), such measures would appear to be sound investments given their comparatively miniscule costs and relatively low uncertainty (i.e., project costs would not likely balloon and flood mitigation effects will likely be realized).

Similarly, if a portfolio of projects, such as additional/increased levees, livestock pads, and walls along I-5, provides a similar flood protection footprint as the flood retention facility project, then decision makers can be confident that the flood reduction benefits will be similar and can tractably compare these alternatives on the basis of their cost and associated risks.

Section D below provides five key points that are not only intended to improve the use of existing analyses, but to aid in comparison between fully quantified projects and those with cost estimates and qualitatively described benefits.

IV. Important Issues For Consideration In Comparing Projects

1. Policy Goals and Objectives

Benefit-cost analysis (BCA), and cost-benefit-analysis (CBA),[12] which are generally regarded as equivalent terms, are accounting frameworks used to evaluate the economic consequences of decisions (Boardman et al. 2010; Zerbe and Dively 1994). One might think of BCA as being the public-sector equivalent of a typical investment

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social welfare.

[12] Zerbe (2007) has attempted to treat BCA as "better-defined subcategory of CBA", whose legal foundations tend to ameliorate or eliminate the criticisms of CBA.

analysis as conducted by a firm. However, whereas in a typical financial analysis the objective is simply to maximize the difference between revenues and the total cost market-priced inputs, in an economic BCA the objective is to maximize social welfare benefits (de Rus 2012; Zerbe and Bellas 2006). This vastly increases the complexity of the exercise, as the exact definition of social welfare is of course a vexing political question. However, given the caveat that social welfare is a fluid term, what is wholly unambiguous about BCA then is that takes efficiency to be the justification for policy decision-making. While in reality, policies are justified on grounds of equity, security, and liberty (Stone 2012) as well, it is important to bear in mind that the BCA framework does not allow us to measure how policy alternatives fare in these other three regards. Whether or not a policy is justified on these alternative grounds must be considered outside the framework of the benefit-cost model itself.

The empirical implication of this is that BCAs must view public projects as investments in social welfare. Of course, other policy goals besides efficiency must be considered in this decision making process; indeed, the desire to provide security and safety for citizens of the region is a primary motivation for flood prevention and mitigation. However, BCA only considers project efficiency, and thus must be evaluated using an investment-oriented approach. An investment-oriented approach evaluates a project in terms a comparison between the social value achieved from project outputs and the value of goods sacrificed elsewhere for the sake of the project (de Rus 2012). In other words, a project should be evaluated not in terms of whether its benefits are greater than its costs, but instead in terms of whether the net benefits gained by the expenditure of project costs exceeds the opportunity cost of those funds. As an analogy, a private individual would presumably weigh any investment or purchasing decision against the return gained from leaving funds in an interest-accruing savings account, not against the return from leaving money buried in his backyard. Public investment decisions (made on the justification of efficiency) should be subject to this same principle of opportunity cost.

Thus, in evaluating these project alternatives it is important to look beyond benefit-cost ratios. A benefit-cost ratio, simply the ratio of project benefits over project costs, only reveals whether project benefits exceed project costs (i.e., a B/C ratio greater than one). This is the policy equivalent of burying money in the backyard, as it effectively equates to there being no opportunity cost. For instance, consider a project that costs $100 million but receives $150 million in benefits. This project would have a benefit-cost ratio of 1.5. An alternative project, costing $50 million and receiving $90 million in benefits, would have what would appear to be a more favorable benefit-cost ratio of 1.8. However, the first project actually produces $50 million in net benefits, while the second produces $40 million. Because benefit-cost ratios are insensitive to magnitude, project selection according to this metric would potentially forgo an additional $10 million in social welfare.

For this reason, having a benefit-cost ratio greater than one is an important, but not sufficient, condition for project selection on the basis of efficiency. When considering project efficiency, a project should be prioritized if it creates greater net benefit than other policy alternatives.Net social benefits are the fundamental basis on which efficiency should be determined (Zerbe et al. 2010). This is represented as net present value (NPV), which is calculated as the present value of all project benefits minus the present value of all project costs. This metric allows for the ordering of projects in terms of their net change in social welfare. Note that efficiency is only one of several public policy goals. Projects having a benefit-cost ratio that is less than one (and a negative NPV) might be selected, but on the basis of other social goals and political criteria. In such cases, a benefit cost ratio greater than one is neither necessary nor sufficient.

A second important reason for considering projects on the basis of NPV is that this statistic is insensitive to the choice of which side of the benefit-cost ledger values are counted on (Boardman et al. 2010). For example, the cost savings associated with not having to raise I-5 given the flood prevention offered by the flood retention

project could logically be counted as either benefits or negative costs. This choice would not affect the flood retention project's NPV whatsoever, but could dramatically affect the benefit-cost ratio. Consider a project with $2 million in benefits and $1 million in costs. If an additional cost savings of $500,000 is counted as a benefit, the benefit-cost ratio becomes 2.5. Those same cost savings, if counted as a negative cost, produce a benefit-cost ratio of 4. Empirically, the outcome in terms of net benefits would be exactly the same; there is no difference between the two projects. However, the benefit-cost ratio metric would lead one to believe that the second project is far superior to the first. Given that a benefit to one party can represent a cost to another, the concept of benefit and cost categories is not necessarily useful (Boardman et al. 2010). Due to these concerns, we recommend that the presentation of analyses move away from a focus on benefit-cost ratios and instead clearly present the NPV associated with various policy alternatives. For instance, EES's report presents project benefits and costs, but uses several tables of benefit-cost ratios as a summary metric (see pages 5 and 6). It would be more helpful to present net benefits such that projects can be better compared.

As an additional concern in this regard, we advocate that an investment-oriented approach be used when considering ancillary project costs and benefits as well. Projects with multiple components should be considered both in total and in terms of how different project components perform. Thus, analyses should clearly present not only overall benefits and costs, but the isolated benefits and costs associated with the different optional components of an omnibus project.

For instance, one policy alternative, the multi-purpose dam, has benefits and costs associated not only with flood prevention but also with recreation, ecosystem services, energy production, and renewable energy credits. The benefit and cost differences between the flood-control only and multi-purpose facilities have nothing to do with flood control, and so it is inaccurate to simply model the additional benefits of the multi-purpose dam as simply getting "more bang for the buck" from a flood prevention project. These additional benefits come at a real cost. Since the same level of flood protection is achieved whether the dam is built as a flood-control only or multi-purpose facility, the question that must be asked then is whether the additional cost of the multi-purpose dam represents an efficient investment in recreation, ecosystem services, and energy production? In other words, is there a different project or suite of recreational, environmental, and energy production projects that might provide a better return on the approximately $90 million in additional funds required to build the multi-purpose facility?

As an example, Anchor QEA's Chehalis Fish Study finds that the multi-purpose facility could be managed to significantly *improve* the stock of spring-run Chinook salmon in the Chehalis River by improving stream conditions in warm, low-flow periods. This benefit comes at a cost, however, and thus it is important for policy makers to consider whether a similar outcome could be more efficiently achieved via other means (e.g., upstream habitat restoration). This same principle applies to the benefits of hydropower production and recreation.

2. Uncertainty

The Army Corps' Draft Close-out analysis on levees gives only a single benefit and cost estimate (page 16). Such use of "point estimates" in benefit-cost analysis conveys a degree of understanding and certainty that is not in keeping with the true nature of our predictive abilities. There is a vast body of literature demonstrating that complex socio-ecological systems, such as the Chehalis basin, are characterized by inherent, irreducible uncertainty (see Folke et al. 2005; Gunderson and Holling 2002; Holling 1973).[13] In other words, even with perfect, complete data, system outcomes cannot always be accurately or precisely predicted. Moreover, analysts of course do not have the benefit of perfect information, and instead must estimate numerous benefits and costs within the model. This reality should not in any way discredit BCA modeling, since as previously discussed a model need not be correct to be useful. The lack of a fully comprehensive, let alone perfect, analysis should not prevent completion of a useful analysis (Farrow and Viscusi 2011).

Nonetheless, the use of point estimates (e.g. presenting a benefit figure and a cost figure) for summarizing a benefit-cost analysis does not paint an adequate picture of uncertainty with which to make policy decisions. The way in which uncertainty is treated (or perhaps more accurately, not treated) in the analyses we have examined is especially troubling given the high variability associated with flood events. Not only is the year-to-year occurrence of flood events highly variable (as evidenced by the rash of severe floods in recent decades) but the nature of flood events themselves varies greatly as well. For instance, flood damages are dependent not just on the amount of precipitation, but also on the location of the precipitation and preceding conditions (e.g., already high water levels).

The analyses we have examined use an expected-value framework for valuing uncertain outcomes. This method is widely used, since it offers a tractable means by which to develop a single monetary estimate of the value of an uncertain payout. The expected value framework simply multiplies the value of an event by its probability of occurrence. For instance, the prevention or mitigation of a 500-year level flood event, which is hypothesized to occur once every 500 years, is given a yearly value of 1/500th of the cost associated with the estimated damages from such an event.

The issue with the expected valuation method is that the one outcome we know with absolute certainty will not occur is that the benefits of flood prevention and mitigation will not simply accrue as an even, yearly benefit flow. Instead, there will be zero monetary benefits from flood protection in most years, and significant monetary benefits from flood protection in those (likely few) years that floods do occur. Moreover, the expected value framework assumes dependence between years within a project's lifespan by modeling outcomes such that a 10-year level flood, for instance, can possibly occur only five times in the life of a 50 year project. In reality, an event of this magnitude could occur any number of times or even not at all within a 50-year period. Though unlikely, a 10-year event might occur three years in a row, and then not again for 30 years. Fixing the number and distribution of flood events projects a degree of certainty into project evaluation that does not adequately inform decision makers about the likely economic outcome of flood mitigation or prevention policies.

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[13] Note that risk and uncertainty are traditionally defined as distinct, with risk referring to a source of imprecision for which the probability of different outcomes can be assigned, and uncertainty denoting an unknown or stochastic process for which precise quantitative description is unfeasible or unavailable. However, Farrow and Viscusi (2011) point out that in the context of policy-making, probabilities associated with different outcomes are largely treated in the same fashion whether precisely quantified or poorly understood; this renders the distinction largely meaningless empirically.

One method to better address uncertainty, used in several of the analyses, is to conduct sensitivity analysis. A sensitivity analysis simply varies a given parameter or estimate within the BCA model and evaluates how the overall benefit-cost estimate changes as a function of that value (see Karoly 2010). This is easily accomplished and yet adds a great deal of information value to the analysis. For instance, EES's evaluation of flood retention facilities models presents not only expected construction costs but low and high estimates as well, (see Figure 2); the report does not, however, take the simple next step of conducting a sensitivity analysis regarding project costs. Using the low, base, and high cost estimates, it is relatively straightforward to generate three net benefits estimates using this range of cost estimates. This would demonstrate how "sensitive" project efficiency is to the project cost estimate. Sensitivity analyses should be more fully incorporated into the analysis so that policy makers can better see the effect of specific model assumptions.

Table 3
Project Cost Estimates[26]
2010 Dollars

	Base	Low	High
Flood Reduction			
Upper Chehalis	$165,230,000	$129,258,200	$235,079,000
South Fork	$93,060,000	$72,800,100	$141,258,000
Both Projects	$258,290,000	$202,058,300	$376,337,000
Multi-Purpose			
Upper Chehalis	$245,060,000	$191,708,200	$338,858,000
South Fork	$148,540,000	$116,202,600	$213,382,000
Both Projects	$393,600,000	$307,910,800	$552,240,000

Figure 2: Example of sensitivity analysis from EES Phase IIb report, page 27.

More importantly however, the most informative way of presenting a benefit-cost model is to use a probabilistic analysis method (often referred to as Monte Carlo simulation).[14] Monte Carlo simulations should be the standard means by which to assess net policy benefits (Vining and Wiemer 2020). A Monte Carlo simulation entails specifying probability distributions for the various model parameters and then running the model a large number of times (typically 10,000). Each model "run" selects from the distribution of each parameter to get a specific value for use in that particular iteration of the model. The resultant distribution of model results can provide valuable information about overall model variability and sensitivity to changes in parameter values. Given that all values included in the benefit-cost analysis are of course estimates, this can demonstrate the degree to which the predicted outcome is dependent on the specific values of these estimates. Another way of conceptualizing this is to think of this simulation as representing a simultaneous sensitivity analysis on multiple parameters within the model. The resultant output, for instance, could describe how the estimated net benefits of a water retention facility vary as the discount rate changes or as the frequency or severity of flooding varies.

The value of a Monte Carlo simulation, as opposed to a sensitivity analysis, is that provides significantly more information to policy makers. Should a project actually be implemented, the accuracy of prior estimates are likely to prove highly varied. Some assumptions will prove correct and some will prove incorrect, and some

[14] See Caulkins (2002, 489-490) for an excellent (and succinct) discussion of concerning the use of Monte Carlo simulation for policy decision-making.

estimates will prove too high and some will prove too low. A Monte Carlo simulation treats each of these assumption and estimate as uncertain, and thus over the course of thousands of model iterations the simulation can develop a picture of policy outcomes as a function of this representative assortment of estimates. This facilitates three key informational benefits:

a. Relative importance of different sources of uncertainty

Just as in a sensitivity analysis, one can view the overall trend in net social benefits as the function of a particular parameter or other model input. This allows policy makers to determine how much importance should be placed on a particular aspect of the model. For instance, if the multi-purpose flood retention facility shows a similar likelihood of producing positive net benefits whether renewable energy credits are valued highly, at close to the predicted point estimate, or near zero, then policy makers can be less concerned about factoring in uncertainty over the continuation of this program, since the project would appear to be a "winner" in any case.

b. Variability in project outcomes

One can observe not only mean estimates of net benefits, but outcome variability as well. For example, one can observe whether net benefits are clustered closely to the mean value across all simulations (i.e., low variability), or whether there a widely divergent pattern of modeled outcomes. This is useful not only for looking at overall variability, but particularly for analyzing the risk-reward tradeoffs associated with the project. Outcome variance is not necessarily normally distributed. For instance, imagine a scenario in only 51% of simulated projects produced positive net benefits, but among the "losing" projects the mean net benefit estimate was -$100 million, while among the "winning" projects the mean net benefit estimate was $10 million. Presumably, policy makers would consider such a scenario differently than if faced with a policy showing the same percentage of winning projects but with winning projects now having a mean net benefit of $100 million and losing projects having a mean net benefit of -$10 million.

c. Treatment of high-consequence, low-probability events

Perhaps most importantly in the case of projects related to low-probability, high-consequence events such as severe flooding, a Monte Carlo simulation can be used to paint a more useful picture of potential outcomes given different states of the world. A Monte Carlo simulation allows us to move away from the expected value framework and develop an overall picture of how policy outcomes might vary given different temporal and severity patterns of flood events. For instance, simulation results can demonstrate how relatively dependent the net benefits of different projects are on the occurrence of high-magnitude events as opposed to smaller flood events.[15] Examining project outcomes under different potential world states (e.g., with or without a severe 500-year flood) provides a more comprehensive assessment of the policy decision. Modeling the protection benefits associated with flood events in this fashion can give policy makers a more realistic picture of potential project outcomes, and should be included in these analyses.

[15] A simple means of modeling in this fashion is to simulate a real number from a uniform distribution of 0 to 1 for each project year and each flood level included in the model (e.g, 10-year, 50-year, 100-year, and 500-year floods). As an example, a ten-year flood is hypothesized to have a 10% chance of occurring each year. If the number generated in associated with a given year and the ten-year flood level was greater than .90, a flood (and thus flood prevention benefits) could be modeled to occur for that year.

3. Intertemporal Valuation

A significant challenge in benefit-cost analysis is addressing the intertemporal distribution of project costs and benefits. Benefits and costs occurring in the future are discounted to present day value to reflect the opportunity cost of funds. While the practice of discounting is generally accepted (Boardman et al. 2010), a significant issue for modern BCA is that there is considerable theoretical disagreement in the published literature as to what the most appropriate rate of interest is (see Moore et al. 2004; Weitzman 2001) and great inconsistency in the application of discounting empirically (Hahn et al. 2000; Morrison 1998; Zerbe and Dively 1994).

The use of a discount rate in BCA is hugely important, because the choice of a particular rate can determine whether a project is estimated to have positive net benefits. Consider the temporal characteristics of any of the large infrastructure projects evaluated for flood mitigation in the Chehalis basin: The costs associated with building a flood retention facility, walling-off I-5, and raising levees are all borne up front, while flood protection benefits are evenly distributed throughout the life of the project. A higher discount rate, i.e. one that reflects a higher opportunity cost, will make these types of projects seem less efficient than will a lower rate, since the discounting effect on future benefit flows will be felt more severely than on near-term cost expenditures.

In evaluating the economic merits of various project alternatives, it is important to be very clear about what the discount rate represents, and what it does not. For instance, the Earth Economics ecosystem services valuation report defines the discount rate as reflecting the importance of future events and the likelihood of capital depreciation. In other words, the report states that if we place a greater value on long-term flood protection, than a lower discount rate is called for in the analysis. We find this to be inaccurate. For government projects the present value of future cash flows is not determined by the relative importance placed on near or long term effects, but rather the opportunity cost of funds. In other words, if a government project were to produce $1 million of benefits in ten years time at an up front cost of $500,000, then the project's selection would only be justified (on the ground of efficiency) if the government did not have an alternative investment that could engender a greater return over that same time period. This has nothing to do with the degree to which people value long-term flood protection relative to short-term flood protection.

It must be stated that there is nothing that precludes policy makers from favoring a long-term project with lower yearly benefits over a short-term project with higher yearly benefits. Economic efficiency is only one of many goals held for public policy, and numerous values can –and should- enter into the project decision-making process. However, in assessing the temporal distribution of monetary benefits and costs to determine the economic efficiency of a project, there is no justifiable discount rate other than one that reflects the sponsoring party's opportunity cost of funds. With regard to selecting an appropriate discount rate, we again emphasize that public projects should be viewed as an investment in social welfare. Thus as a basic rule of thumb, every project selected on the basis of efficiency should at the very least engender a return on investment greater than could be achieved simply by investing in treasury bonds or a comparable asset (Burgess and Zerbe 2011).[16] Burgess and Zerbe (2011) find this rate of return to be between 6% and 8%.

Our primary recommendation, however, is that regardless of rate, the important aspect with regards to discounting in BCA is to be very explicit about the rate employed in an analysis and to discuss the rationale behind the selection of that rate. We find that this is not treated adequately in the BCAs reviewed. Moreover, BCAs should employ a sensitivity analysis of the discount rate, evaluating project outcomes using a low, median,

[16] It is important to stress that the criteria of efficiency is only one heuristic by which to make policy decisions, and so it would be incorrect to hold that all policies must adhere to such a rule. However, any decision-making process that intends to be based on a examination of benefits and costs (i.e., efficiency), as is the case for Chehalis flooding mitigation, should appropriately consider the social opportunity cost of funds.

and high interest rate. If the ranking of project alternatives remains stable across these rates, then the choice of a discount rate likely does not need to be a key point of consideration in the decision-making process. However, if choice of a discount rate does greatly affect the rank ordering of alternatives, this indicates that the various alternatives have very different temporal characteristics. In such cases, the choice of a discount rate matters greatly, and should be carefully vetted and justified within the analysis.

4. Developing an appropriate basis for comparison

A significant challenge in benefit-cost analysis is that benefits and costs must be defined relative to an appropriate null alternative. In other words, benefits and costs should be calculated in terms of the difference between what is likely to happen in the absence of a given policy and what is likely to happen should the policy be implemented (Zerbe et al. 2010). This issue would appear to be highly significant in the analysis of the various flood protection/mitigation projects, since the implementation of one project might eliminate the need for another. While we find no methodological issues with the way in which analysts have developed their basis for comparison, we find that a more detailed discussion about how this it is defined and analyzed within the BCA is greatly warranted. This is yet another issue in BCA where clarity and transparency are of utmost importance, since a clear discussion of the comparison being employed serves to evaluate the degree to which a BCA accurately reflects the nature of the policy decision (Karoly 2010).

Of specific concern in this regard is the treatment of project alternatives within analyses. For instance, the analysis of flood-retention facilities credits cost savings from no longer raising Interstate 5 as a benefit to the project. We support the technical approach EES Consulting has used to model this. However, it is not clear to us what the most appropriate basis for comparison is in this case, given that recent data indicates the dam would not be sufficient to prevent I-5 from flooding in an event comparable to the 2007 flooding (personal communication with WDOT).

Note that this would seem to be an area ofclarity is need, as EES's report states that WDOT has said that further I-5 flood protection would not be initiated so long as the flood retention facility prevented I-5 from flooding in a 100-year level event. Communication with WDOT indicates that a levee or roadbed raising project considered if I-5 will still flood during an event comparable to the flooding in 2007 (a 500-year event in some parts of the Chehalis Basin). Until such ambiguity can be resolved, models should present outcomes under each of these scenarios. As an example, we envision three scenarios for the flood retention facility: (1) Scenario 1, in which the flood retention facility is credited with I-5 flood prevention benefits in years 1-10 of the project and then credited with the cost savings of not raising I-5 in year 11 *and debited the flood prevention benefits forgone by the fact that the dam alone does not eliminate the risk of flooding in years 11-50*; (2) Scenario 2, in which the flood retention facility is simply credited with flood prevention benefits for all 50 years of the project; and (3) Scenario 3, in which both the flood retention facility and levees around I-5 are built, and the flood retention facility is credited with any cost savings associated with reducing the size/scope of the I-5 wall/levee system built.

V. Conclusion

In this document, we analyze the existing BCAs prepared concerning flood prevention or mitigation projects in the Chehalis Basin. We find that the existing analyses provide a sound basis for assessing the social benefits and costs associate with the suite of programmatic, structural, and non-structural policy measures currently being

weighed by the Chehalis River Basin Flood Authority. As described, one of the primary strengths of the current portfolio of analyses is that it provides a conceptual basis for qualitatively evaluating the benefits of projects that have not been formally advertised. Even in the absence of further HAZUS model runs that examine the potential effects of other policy measures, policy makers can use the damages estimated in association with the flood retention facility and levee alternatives as a guide for thinking about what the returns to other projects might be as well.

We find that several issues insufficiently addressed by existing analyses, including the use of net benefits instead of benefit-cost ratios for the consideration of projects, the need for estimate ranges, sensitivity analyses, and probabilistic simulations for modeling the effects in such complex scenarios, clear discussion of project benefit and cost time frames, and the comparative basis on which benefits and costs are estimated. All of these concerns can be readily addressed with minimal effort and without additional analysis. For more guidance on these and other benefit-cost techniques, please refer the UW BCA Center's recent Benefit-Cost Analysis Principles and Standards Report (Zerbe et al. 2010); this report provides a definitive discussion of state-of-the-art BCA.

In conclusion, we would advocate that the Flood Authority use the existing body of benefit-cost data to inform the decision process, but not as a decision making device. BCA is most useful for crafting equitable, efficient policy when decision makers weigh BCA data alongside numerous other bodies of knowledge and policy concerns. Moreover, it is critical that policy makers pay careful attention not only to what is in a BCA, but also to what is not included in the analysis and what outcomes might result if the analysis does not prove wholly accurate. Lastly, it is crucial that policy makers consider that BCA does not need to be completely accurate or fully comprehensive in order to improve policy decision making. Thus, informational concerns should not prevent the Flood Authority from moving forward in addressing the pressing policy problem of flooding in the Chehalis Basin.

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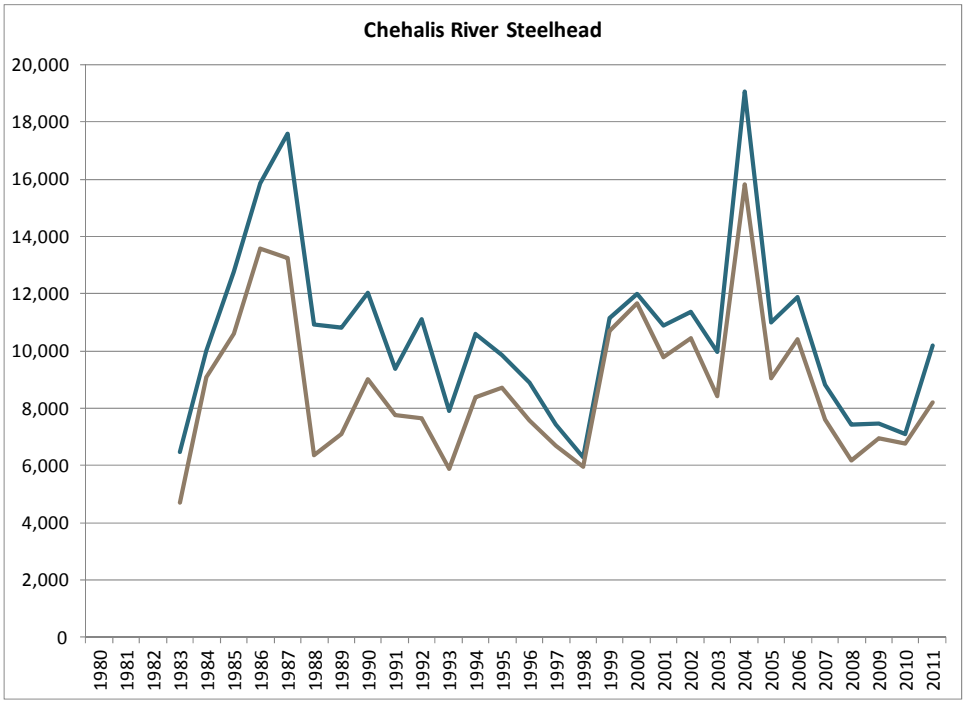
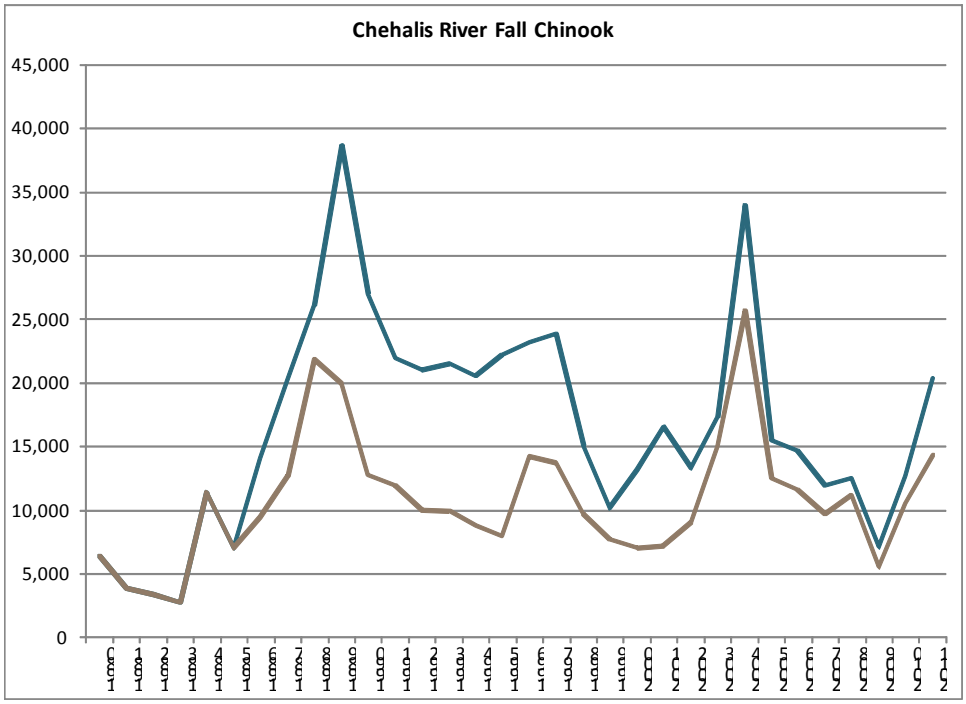
Appendix E: Chehalis River - Salmon Runsizes and Escapements

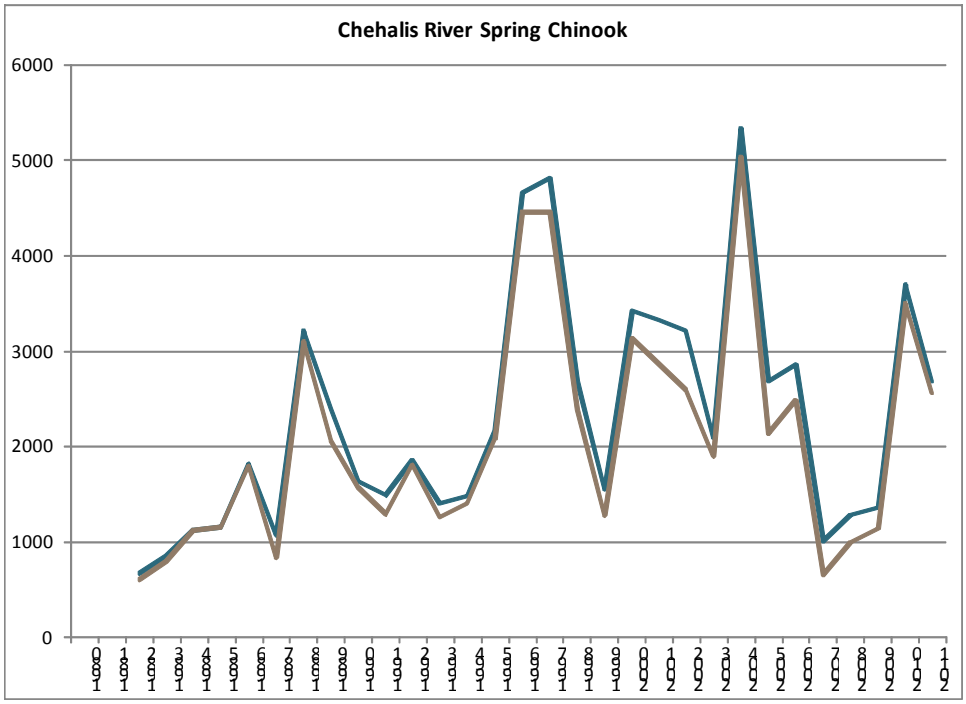
Appendix E: Chehalis River Salmon Runsizes and Escapements

This appendix from the Washington Department of Fish and Wildlife (WDFW) provides annual runsizes and spawning escapement numbers for Chehalis River Steelhead, fall Chinook, spring Chinook, Chum, and Coho salmon for the years 1980 - 2011.

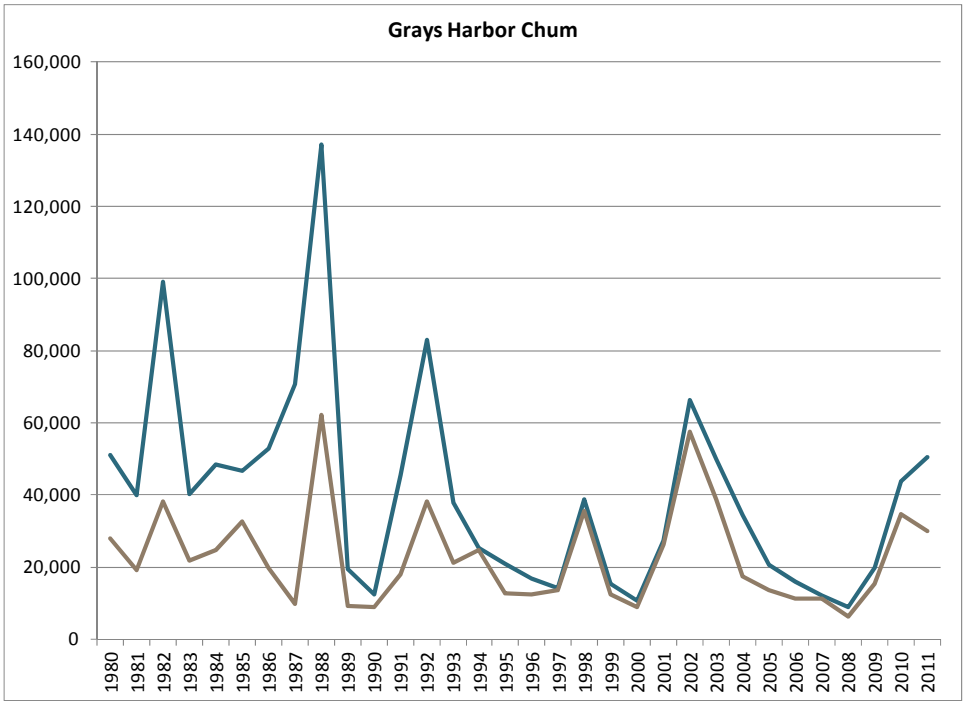


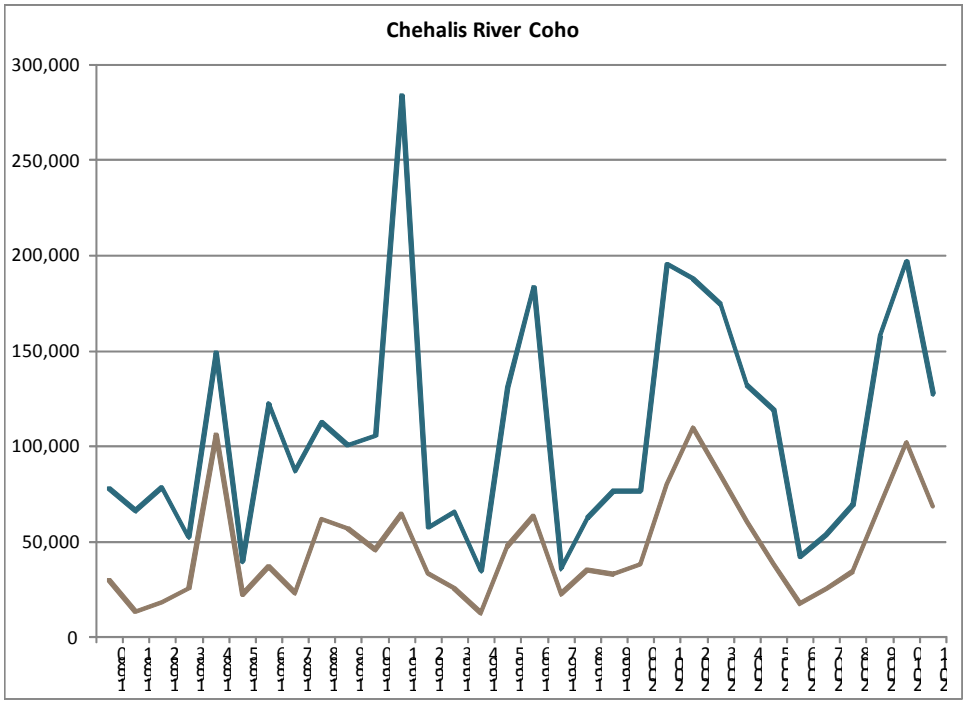
Runsize Escapement





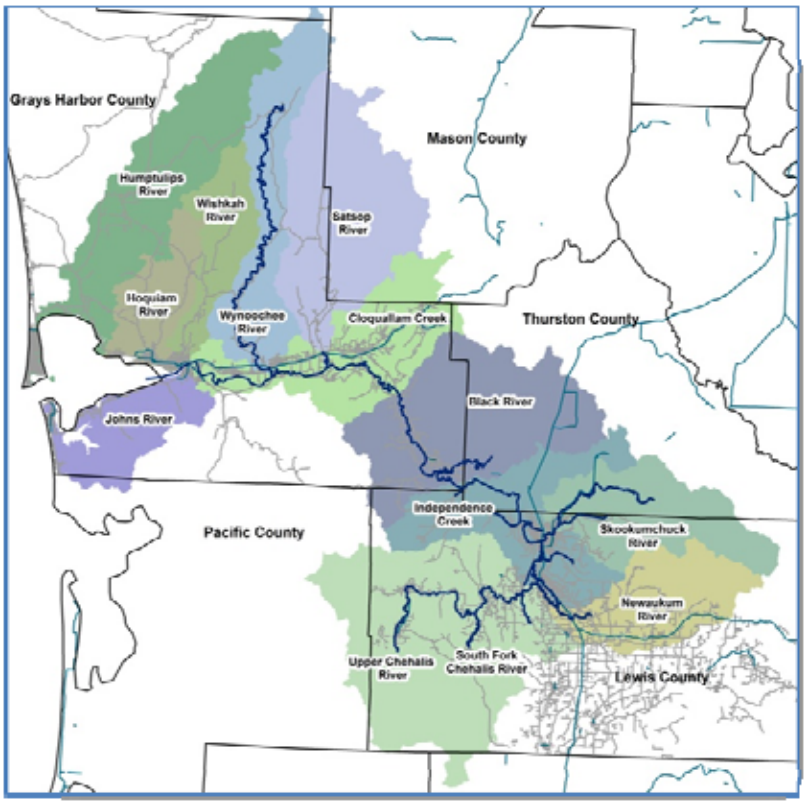
Runsize Escapement





Appendix F: Chehalis River Hydraulic Model Development

Draft Report - Chehalis River Hydraulic Model Development Project



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Executive Summary

Numerous studies have been undertaken to evaluate flood damage reduction in the Chehalis River basin. These include work for the Federal Emergency Management Agency (FEMA), the US Army Corps of Engineers (Corps), Lewis County, and the Lewis County Public Utility District (PUD). Much of the effort has focused on the development of a hydraulic model for the mainstem of the Chehalis River and application of that model to simulate the "100-year flood". The studies have provided insight into floodplain management issues; however, work to date has focused primarily on the Chehalis River upstream of Grand Mound. The Chehalis River Basin Flood Authority (Flood Authority) recognized a need to extend the work downstream from Grand Mound to the mouth of the Chehalis River at Grays Harbor.

The Washington State Legislature concurred with the Flood Authority regarding the need to study the lower portions of the river. Through a budget proviso in Engrossed Substitute House Bill (ESHB) 2020 the Legislature provided funding to "complete the hydraulic model for the Chehalis River to calculate flood levels, flood damages, and benefits of proposed flood mitigation projects for the lower portions of the river."

The Flood Authority retained WATERSHED Science & Engineering (WSE) and subconsultants WEST Consultants, Pacific Geomatic Services and Minister & Glaeser Surveying to develop a hydraulic model and evaluate flood relief alternatives for the Chehalis River basin. While the primary objective of the Flood Authority project are to develop the hydraulic model, additional tasks identified over the course of the project have been completed to the extent possible considering funding and schedule constraints. These include collection of field survey data, workshops and education regarding basin flood issues, and evaluation and reporting on a wide range of flood relief alternatives.

The hydraulic model developed for this study extends from the mouth of the Chehalis River to upstream of Pe Ell, a distance of more than 108 miles. The model also includes significant portions of key tributaries including the following: Wynoochee River (54 miles), Satsop River (2 miles), Black River (10 miles), Lincoln Creek (4 miles), Skookumchuck River (21 miles), Hanford Creek (6 miles), Salzer Creek (5 miles), Newaukum River (10 miles), Dillenbaugh Creek (3.5 miles), and South Fork Chehalis (5.8 miles). While the model was developed primarily to evaluate the effects on the main stem Chehalis River of large-scale flood relief projects it can also serve as a tool for the evaluation of hydraulic conditions and flooding on these tributaries. In fact, the model has already been used by WSE to evaluate the effects of potential modifications to the railroad bridge downstream of Bucoda on the Skookumchuck River.

The hydraulic model developed for this study was used to evaluate 15 individual flood relief projects, and the results of those evaluations were reported to the Flood Authority and stakeholders at meetings in April and May 2012. Based on feedback from the Flood Authority the projects were grouped into combinations and additional modeling was conducted. The additional modeling was presented to a broader group of basin stakeholders at meetings in Lacey in May 2012 and in Grand Mound in June 2012. After receiving feedback at those meetings three additional combinations were formulated and evaluated. In total more than 25 potential flood relief projects or combinations of projects were evaluated with the results reported herein. The results have also been provided to the State Office of Financial Management and the Flood Authority for use in defining an appropriate path forward for basin wide flood relief.

The baseline hydraulic model developed for this project represents the best available information on hydraulic conditions in the modeled reaches. However, it must be recognized that the model includes both newly modeled reaches (e.g. Chehalis River between Porter and Aberdeen) and reaches based on older models. Some of the older model reaches were updated with newly collected cross section surveys, while others use cross sections collected as long ago as 2001. Similarly, in some portions of the model floodplain topographic data were updated to reflect new LiDAR data while in other reaches the topographic data dates back to 2002. While it would have been preferable to update the entire model with new field surveyed cross sections and up to date topographic data the model is still a significant improvement over any tool that has been previously available and it should benefit flood relief investigations throughout the basin. As time and resources allow it is recommended that the model be updated to use new topographic and survey data, that the updated model be refined to address any new infrastructure that has been built since the original model development, and that the updated model be calibrated to available flood information.

Chehalis Basin Hydraulic Model Report

Background

Over the past 15 years numerous studies have been undertaken to evaluate flood damage reduction in the Chehalis River basin. These projects include work for the Federal Emergency Management Agency (FEMA), the US Army Corps of Engineers (Corps), Lewis County, the Lewis County Prosecuting Attorney's Office, and the Lewis County Public Utility District (PUD). Much of this recent work has focused on the development of a hydraulic model for the mainstem of the Chehalis River between Doty and Grand Mound and application of that model to simulate the "100-year flood". Work for Lewis County and the PUD focused on application of the FEMA model to evaluate the potential benefits or impacts of various proposed flood damage reduction projects including upstream water storage. Work by the Corps has focused on evaluation of new and heightened levees along the Chehalis River near the cities of Chehalis and Centralia and flood storage at Skookumchuck dam.

The previous studies have provided insight into issues related to floodplain management in the upper basin; however, work to date has focused primarily on the Chehalis River upstream of Grand Mound. The Chehalis River Basin Flood Authority (Flood Authority) recognized the need to extend the hydrologic and hydraulic modeling downstream from Grand Mound to the mouth of the Chehalis River at Grays Harbor and to use the extended model to evaluate the potential impact of upstream flood damage reduction projects on downstream flooding.

The Washington State Legislature concurred with the Flood Authority regarding the need to study the lower portions of the river. Through a budget proviso in Engrossed Substitute House Bill (ESHB) 2020 the Legislature provided funding to "complete the hydraulic model for the Chehalis River to calculate flood levels, flood damages, and benefits of proposed flood mitigation projects for the lower portions of the river." The Office of Financial Management also showed support for this study in an agreement signed with the Flood Authority in early August 2011.

Concurrent with the efforts of the Flood Authority, the U.S. Army Corps of Engineers (Corps) identified a need for additional hydraulic modeling to support "ecosystem restoration" planning in this same area, and procured funding to support this through the Corps' Basinwide General Investigation process. Considering the need for hydraulic modeling to support both ecosystem restoration and flood risk reduction, and a desire to make the best use of available resources, the Flood Authority retained WATERSHED Science & Engineering (WSE) to work with the Corps, WSDOT, and other basin stakeholders to develop a basinwide hydraulic model and conduct analyses of potential flood damage reduction projects. This report documents model development and application efforts by the WSE team.

Engrossed Substitute House Bill 2020

As noted above, the current study effort is funded through a budget proviso in ESHB 2020. The specific sections of the bill that are relevant to the work of the Flood Authority are found in Section 1033 starting on Page 19 and read as follows:

Catastrophic Flood Relief (20084850)

(1) The appropriations in this section are subject to the following conditions and limitations:

(a) $1,320,000 of the appropriations are provided solely for the Chehalis basin flood control authority or other local flood districts

(i) to study, develop, construct, maintain, operate, and fund flood control measures throughout the basin,

(ii) to complete by December25 2011 the ongoing study of the effect of possible retention structures on fish in the basin, and

(iii) to complete the hydraulic model for the Chehalis river to calculate flood levels, flood damages, and benefits of proposed flood mitigation projects for the lower portions of the river; and

(b) $1,200,000 of the appropriations are provided solely for nonfederal matching funds and state agency costs associated with the United States army corps of engineers flood hazard mitigation projects for the Chehalis river basin. p. 19 ESHB 2020.SL

(2) By July 2012, the office of financial management, in collaboration with the department of transportation and the department of ecology, and affected and interested federal agencies, tribal governments and local governments, must provide a report to the governor and legislature that identifies recommended priority flood hazard mitigation projects in the Chehalis river basin for continued feasibility and design work. The report must:

(a) Address the potential for flood mitigation through upstream water retention facilities, including benefits and impacts to fish and potential mitigation of impacts;

(b) Describe the current alignment and design of the federal flood levees proposed at Centralia and Chehalis, including extent of protection provided to these communities, and any upstream or downstream effects of the levees;

(c) Evaluate alternative projects that could protect the interstate highway and the municipal airport at Centralia and Chehalis, and ensure access to medical and other critical community facilities during flood events;

(d) Discuss other alternatives that could provide flood relief and protection in the basin, such as replacement of highway bridges that constrain flood waters, flood easements on agricultural lands, livestock evacuation facilities and routes, small-scale water diversion and retention, use of riparian habitat and environmental restoration projects to mitigate damages from flood waters, and other projects or programs;

(e) Summarize the benefits and costs of recommended projects, using available information and accepted benefit/cost methods; and

(f) Identify the responsible parties and procedures for making final decisions on funding, construction and governance of recommended flood projects, any related and necessary government agreements, and a schedule for these decisions.

(3) It is the intent of the legislature to fulfill the commitment of section 101, chapter 179, Laws of 2008 and chapter 180, Laws of 2008, by appropriating funds when the federal match requirement is needed.

Flood Authority Contracting

Given the need to develop hydrologic and hydraulic modeling to evaluate ecosystem restoration and flood risk reduction projects the Flood Authority issued a request for qualifications on July 25, 2011. Four responses were received by the August 8, 2011 deadline. Flood Authority staff then worked with technical staff from state, federal, and local agencies to develop screening criteria and review and score the responses. After consultation with the technical team, the Flood Authority's Executive Committee selected three firms to interview and ultimately asked two firms (WATERSHED Science & Engineering and WEST Consultants) to collaborate to complete this project. WSE and WEST revised their proposals into a joint effort with WSE as the prime and overall technical lead and WEST as their key subconsultant. This collaboration provided the Flood Authority with the technical and management expertise they wanted and addressed the Flood Authority's desire to leverage available resources, as WEST was already under contract to the Corps of Engineers to develop modeling for portions of the basin as part of the General Investigation.

The Executive Committee approved the WSE contract and recommended to the Lewis County Board of County Commissioners (BOCC) (as the lead agency for the Flood Authority) that this contract be adopted. On September 6th the BOCC entered into a contract with WATERSHED Science & Engineering (WSE) and subconsultants WEST Consultants (WEST), Pacific Geomatic Services (PGS) and Minister Glaeser Surveying (MGS) to develop a hydraulic model and evaluate flood relief alternatives for the Chehalis River basin. While the primary objective of the Flood Authority's project was to develop a hydraulic model, other, secondary objectives identified over the course of the project have been addressed to the extent possible considering funding and schedule constraints.

Scope of Work

The Scope of Work for the hydraulic model development project was finalized in October 2011. The scope was prepared by WSE in coordination with the Flood Authority to define the tasks necessary to address the ESHB 2020. The scope was amended in January 2012 to include hydraulic modeling and analysis of key tributaries. Key tasks in the final scope are summarized below:

Task 1 - Overall Project Management, Stakeholder Involvement, Regular Communication with Flood Authority
WSE is responsible to the Flood Authority for the overall management of the model development project including administering the contract and providing monthly invoicing and progress reports. This task also includes presentations at key milestones and as necessary to keep the Flood Authority fully informed about the status of the work.

Task 2 - Initial Basin Reconnaissance
The project team conducted targeted field reconnaissance of the basin, contacted key stakeholder groups, coordinated with the State technical team, and gathered information (including topographic and survey data).

Task 3 - Conduct Adequacy Review of Existing Floodplain Topographic and LiDAR Data
This task was deferred. No work was conducted under this task.

Task 4 - Detailed Work Plan Development

A detailed Work Plan was developed to guide the Chehalis River hydraulic model development project. The Work Plan included schedule milestones, scope information and estimated costs for each task. The draft Work Plan was distributed by the Flood Authority to interested agencies and Tribes for review and comment.

Task 5 - Refine Hydraulic Model to reflect Flood Authority Interest

WEST Consultants is currently under contract to the Corps to develop a hydraulic model of the Chehalis River (Pe Ell to Montesano with the exception of Grand Mound to Porter) under the Basin-wide General Investigation (GI). The Corps project includes collection of bathymetric survey data for model cross sections in several reaches and the development of hydrologic data for the basin. Based on stakeholder input, the Flood Authority tasked the WSE project team with modifying, enhancing, or refining the Corps hydrologic and hydraulic modeling. The following sub-tasks were completed:

Task 5a - Obtain new channel survey data for the Chehalis River between Grand Mound (RM 60.6) and Porter (RM 33) - The Twin Cities hydraulic model includes cross sections in this reach but the exact location of those cross sections was not known. A portion of the reach, from RM 41 to Grand Mound, was surveyed by Minister Glaeser in 2001 for the Corps but that survey data is now more than 10 years old and not likely to be representative of current channel conditions. Given these considerations and knowing that a reliable model of this reach is critical for meeting ESHB 2020 requirements, additional survey data collection to support model development for this reach (Task 5b) was needed.

Task 5b - Refine model of Chehalis River between Lewis/Thurston County line and Porter - This reach was included in the earlier Twin Cities hydraulic model. The Corps GI study contract did not call for additional model refinement, however, considering the date of the cross section and topographic information in the model the accuracy and reliability of the simulations in this reach is a concern. This task included developing a new hydraulic model using the new cross section data described in Task 5a and the 2002 PSLC LiDAR data and then validating the model against available observations.

Task 5c - Extend Corps Hydraulic Model downstream from Montesano to Aberdeen - the GI Study contract included development of a hydraulic model for the Chehalis River upstream of the confluence with the Wynoochee River at Montesano. The Chehalis River reach downstream of the Wynoochee River is significantly tidally influenced and more hydraulically complex due to significant side channels and backwater channels in the floodplain. Under this task the HEC-RAS model was extended to Aberdeen including collecting additional channel and overbank survey data. Model development for this reach also required additional hydrologic analysis to provide data for hydraulic model calibration and validation.

Task 5d - Refine hydraulic model of main stem Chehalis River - as noted previously WEST is concurrently working with the Corps to develop a hydraulic model of the mainstem Chehalis River from Montesano to Pe Ell. However, that model was not sufficiently detailed in some locations to meet the needs of the Flood Authority and stakeholders. The Corps model (including the Twin Cities portion of the model) was updated under this task to facilitate Flood Authority investigations.

Task 6 - Extend Hydraulic Modeling (Including Survey, Hydrology and Hydraulics)

The work currently being done by the Corps has been leveraged extensively to meet the Flood Authority's needs for hydraulic modeling in the lower Chehalis River. However, the following sub-tasks were included in the detailed work plan to address specific considerations in the model development:

Task 6a - Expand or refine Corps hydrology analysis – The Corps hydrologic data for the basin were refined and additional hydrologic data were developed as needed to address the needs of the Flood Authority and stakeholders.

Task 6b - Refine/revise/extend hydraulic modeling of tributaries - as noted previously the Twin Cities hydraulic model included several tributaries, but these were not always sufficiently modeled to meet the needs of the Flood Authority. Additional modeling efforts were undertaken on the Satsop River, Black River, Skookumchuck River, and Newaukum River.

Task 6c - Review and refine Twin Cities model – Cross sections orientations in the Twin Cities portion of the Chehalis River model were reviewed and modified where appropriate. Storage area connections and other model assumptions were also evaluated and modified as necessary to improve model calibration.

Task 6d - Re-cut cross sections using "best available" LiDAR – After modifying the orientation of some cross sections in the Twin Cities model the cross sections were re-cut using the best available LiDAR data described above.

Task 7 - QA/QC Technical Review of WEST Consultants Hydrologic and Hydraulic Modeling

WEST Consultants developed hydrologic and hydraulic data for the Chehalis River basin under contract with the Corps. These baseline analyses were subject to independent technical review by WSE to ensure they adequately meet the needs and objectives of the Flood Authority as defined in the work plan.

Task 8 - Technical Evaluation, Reporting of Flood Relief Alternatives to Flood Authority

A range of possible flood damage reduction projects are under consideration in the basin. These include (1) upstream storage projects on the Upper Chehalis, South Fork Chehalis and Skookumchuck Dams, (2) USACE proposed levee modifications and (3) combinations of storage and levee projects. The following tasks were completed:

Task 8a - Under this sub-task, the proposed upstream retention facility on the main stem Chehalis River above Pe Ell was modeled and evaluated.

Task 8b - Under this sub-task, dozens of other flood relief alternatives in the watershed were modeled and evaluated.

Task 9 - Provide QA/QC Technical Review of WSE Flood Relief Alternatives Analysis

The flood relief alternatives analyses described in Task 8 were subject to independent technical review to ensure the needs and objectives of the Flood Authority were met.

Task 10 - Milestone Meetings / Conference Calls with Flood Authority

The project team coordinated presentations, communications, and information transfer to the Flood Authority at key milestones in the project to ensure that Flood Authority members were kept fully informed.

Task 11 - Comprehensive Project Report

This report has been prepared to document the findings of the hydraulic model investigations.

Other Hydraulic Modeling and Analysis Efforts

Federal, State, and local efforts are currently underway in the Chehalis River Basin to reduce flood damages and restore the ecosystem. The Federal Emergency Management Agency (FEMA) recently prepared a revised Flood Insurance Study (FIS) for Lewis County including the Chehalis River, Hanaford Creek, Lincoln Creek, Salzer Creek, Skookumchuck River, South Fork Chehalis River, and Stearns Creek (FEMA, 2011). The FIS hydraulic model was based on a previously developed UNET model of the Chehalis River and tributaries, which was converted to a HEC-RAS model. The final FIS HEC-RAS model consisted of approximately 150 river miles and 700 river cross-sections. While the model extended downstream to the town of Porter in Grays Harbor County, the portion of the model that was geo-referenced and calibrated ended at Grand Mound.

The Corps is currently conducting a Basinwide General Investigation (GI) including the development of hydrologic and hydraulic modeling for portions of the basin (USACE, 2012). The GI models will be used to establish baseline conditions to evaluate potential aquatic ecosystem restoration measures. Concurrent with the GI effort the Corps and its local partner, Washington State, are reevaluating the authorized Twin Cities flood damage reduction project, which proposed the construction of levees to protect parts of Centralia, Chehalis, and I-5, as well as modifications to Skookumchuck Dam (USACE, 2012). In addition to that effort, WSDOT is evaluating a range of options for protecting I-5 from flooding (WSDOT, 2012).

Relationship of current project to concurrent efforts by USACE and WSDOT

WEST is working under contract to the Corps to develop the baseline hydrologic and hydraulic modeling for the Chehalis River basin (GI Study). That work includes hydraulic modeling for the Chehalis River between Montesano and Porter and between Doty and Pe Ell as well as the lower 51 miles of the Wynoochee River. The Corps project to model the lower Chehalis River between Montesano and Porter is of particular relevance to the Flood Authority. When combined with the FEMA Twin Cities hydraulic model (Porter to Doty) and the Flood Authority model being developed by WSE (Montesano to Aberdeen) the result is a comprehensive hydraulic model extending from Aberdeen upstream as far as the proposed retention facility site on the main stem Chehalis River near Pe Ell, a distance of 108 river miles (plus tributaries).

Basin Characteristics and Flood Issues

Basin Characteristics

The Chehalis River basin is located in southwest Washington, encompassing a drainage area of approximately 2,100 square miles (See Figure 1). The river rises in the Willapa Hills and runs generally east, then north, and then west to its mouth at Grays Harbor. Elevations range from over 3,000 feet in the headwaters to 150 - 200 feet in the Twin Cities area to sea level at the mouth. Major tributaries to the Chehalis River include the South Fork Chehalis, Newaukum, Skookumchuck, Black, Satsop, and Wynoochee Rivers. Communities along the Chehalis River include Doty, Pe Ell, Chehalis, Centralia, Oakville, Montesano, and Aberdeen. Mean annual precipitation in the upper watershed ranges from 45 near Chehalis to more than 120 inches per year in the Willapa Hills upstream of Pe Ell.

Figure 2 and Figure 3 show the schematic of the stream network in the Upper and Lower Chehalis River basins, respectively. The upper portions of tributaries such as the South Fork Chehalis River, the Newaukum River, the

Skookumchuck River, the Satsop River and the Wynoochee River are located in steep, mountainous terrain, with steep channel slopes and very narrow floodplains. The lower portions of these tributaries, as well as most of the smaller tributaries that join the Chehalis River lower in the basin are characterized by lower gradient, meandering channels with broad floodplains. These lower reaches offer significant temporary flood storage.

Flood Characteristics

Floods in the Chehalis River Basin typically occur in the November to February time frame. They are driven for the most part by atmospheric river (aka "Pineapple Express") weather systems, which tap moisture from the tropics and funnel it to locations in western Washington, resulting in heavy precipitation. Significant flood events have occurred frequently in the Chehalis River basin. The annual peak flow record at the Chehalis River gage near Doty indicates that, in the last forty years alone, significant floods (greater than 20,000 cfs) occurred in January 1972, January 1990, November 1990, February 1996, December 2007, and January 2009. The gage on the Chehalis River near Grand Mound shows that the five largest peak flows in the past 85 years, all of which exceeded 50,000 cfs, have occurred since 1986 (December 2007, February 1996, January 1990, November 1986, January 2009). Significant widespread flooding and damage was associated with each of these events.

For the purposes of the current project only extreme, basin wide, floods were evaluated. These are large throughout the basin, have high flows on the mainstem Chehalis River (as measured at Grand Mound), and have a range in contributions from the major tributaries. The basin wide floods evaluated for this study were not selected to capture individual tributary design flood events, extreme high tide events, or anomalous conditions (e.g. dam break flood, etc). The modeled floods include the historical events of February 1996, December 2007, and January 2009, as well as a hypothetical basin wide flood event, developed by WEST for the Corps GI study. The characteristics of each of these events are described below:

February 1996 Event – This was a large frontal storm with very broad rainfall distribution throughout the Chehalis River basin and beyond (from north of Seattle to southern Oregon). The 24-hour rainfall totals throughout the basin generally ranged from 10+ year to 100+ year recurrence. It was extremely cold in the month prior to the storm and there may have been some snow accumulations in mid elevations. The resulting flood was the second largest in the historic record at many basin streamflow gages including Grand Mound (82 year record), Porter (63 year record), and Doty (71 year record) and the 4th largest in the historic record on the South Fork Chehalis (71 years aggregate record). It is still the largest flood in the observed record on the Skookumchuck River (71 years aggregate record) and Newaukum River (71 year record).

December 2007 Event – This event was a classic atmospheric river (pineapple express) type event with a fairly narrow path of extreme rainfall. The highest rainfall center was concentrated in the Willapa Hills in the Upper Chehalis River Basin (main stem and South Fork). Unlike 1996, the December 2007 storm was focused in the Chehalis Basin and parts of the Olympic mountain range, and was much smaller south of the Chehalis Basin. Additionally, there was not much low level snow immediately prior to the event. The 2007 storm set records for 24-hour precipitation in the upper basin, although the heaviest precipitation was actually limited to about 12 hours or less at many locations. The resulting flood was the largest in the historic record at Grand Mound (82 years), Porter (63 years), Doty (71 years), and the South Fork Chehalis (71 years aggregate record). It was the third largest storm in the 71 year record on the Newaukum River. On the Skookumchuck, however, it was only the 55th largest storm in the 71 years aggregate record due in part to less rainfall seen in that portion of the basin and in part due to incidental storage at Skookumchuck Dam. The peak discharge on the Chehalis River at

Doty (USGS estimate 63,100 cfs) was more than double the next highest flood in the 72 year record (28,900 cfs in 1996) and was approximately 67% greater than the current estimate of the 100-year flood. In contrast, at Grand Mound the USGS estimated flow was only about 6% higher than the next highest event (1996).

January 2009 Event – This event was focused primarily in the eastern and northern portions of the Chehalis River Basin although significant rain still fell in the upper watershed. Flooding, or near flooding, of Interstate 5 was caused by high flows on the Newaukum system which peaked well in advance (12 hours or more) of the arrival of the peak Chehalis River flow from the upper basin. The January 2009 event also caused very high flows in many lower basin tributaries (Satsop, Black…etc.). The resulting flood was the 5th largest in the 82 year historic record at Grand Mound and the 7th largest in 71 years at Doty. The January 2009 event was the second largest observed flood on the South Fork Chehalis (after 2007) and Newaukum Rivers (after 1996) and the third largest on the Skookumchuck (after 1996 and 1953). At Porter on the Chehalis River, the 2009 flood was the 3rd largest in the 63 year record reflecting large contributions from lower basin tributaries. The January 2009 event was the third largest event in the historic record on the Wynoochee (in 39 years since the construction of the dam) and the 5th largest event on the Satsop (in 82 years). Considering the flow at Porter and on the lower basin tributaries the January 2009 event is estimated to be the second largest event in the historic record downstream of Montesano.

100-year Design Event – The 100-year design event developed by WEST is described fully in the Corps GI Report (USACE, 2012). On the recent floods in the basin, the design event is most similar to February 1996 with broadly distributed extreme precipitation. The analysis targeted matching the 100-year discharge at Grand Mound and then distributed tributary inflows based on statistical analyses of observed flows on the tributaries versus mainstem flows (with regard to both magnitude and timing of flows). The design event sought to match both instantaneous peaks and longer durations (from 1 to 15 days).

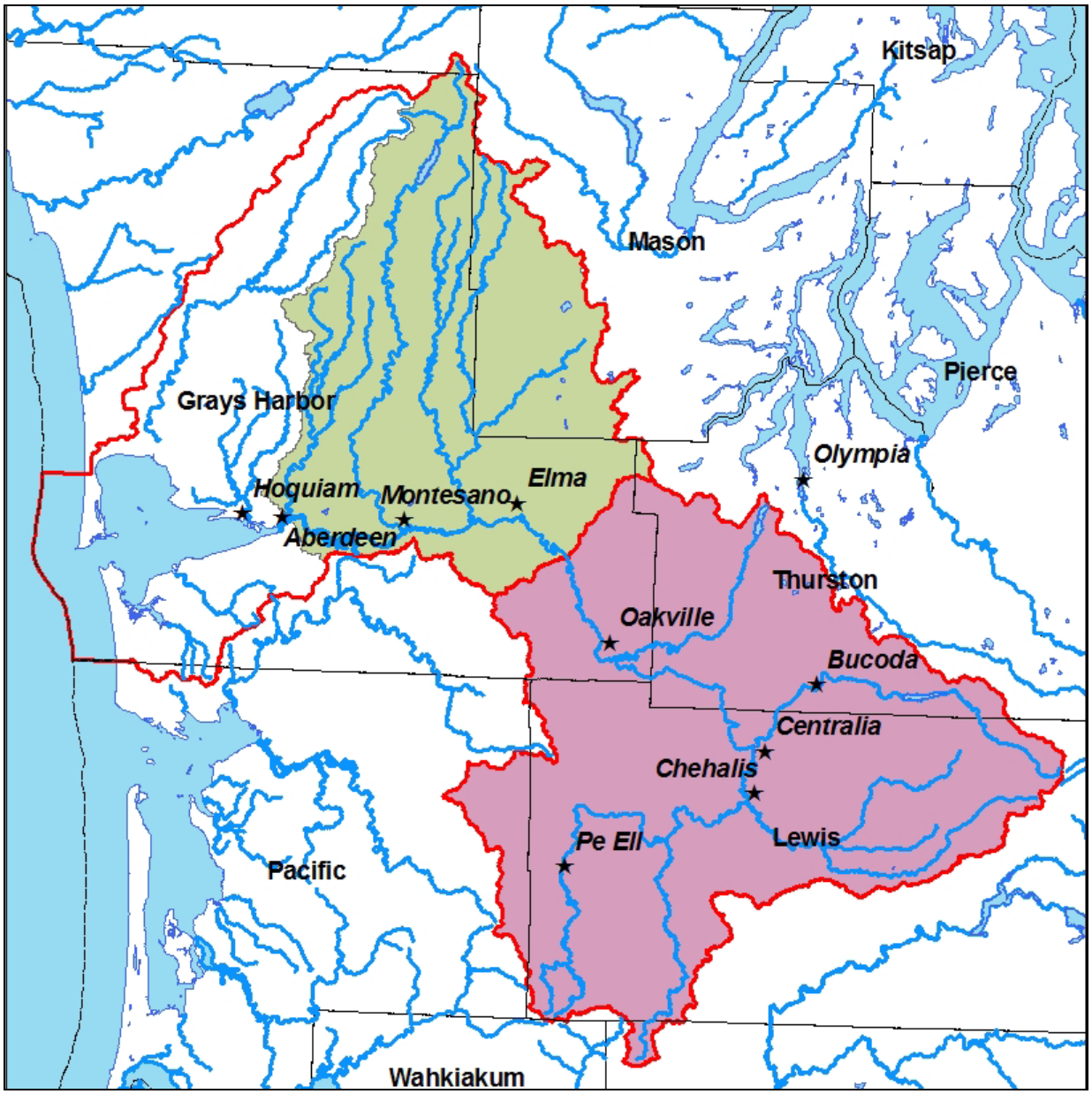


Figure 1. Study Area within the Watershed Boundaries of WRIAs 22 and 23

Figure 2. Upper Chehalis River Basin (WRIA 23)

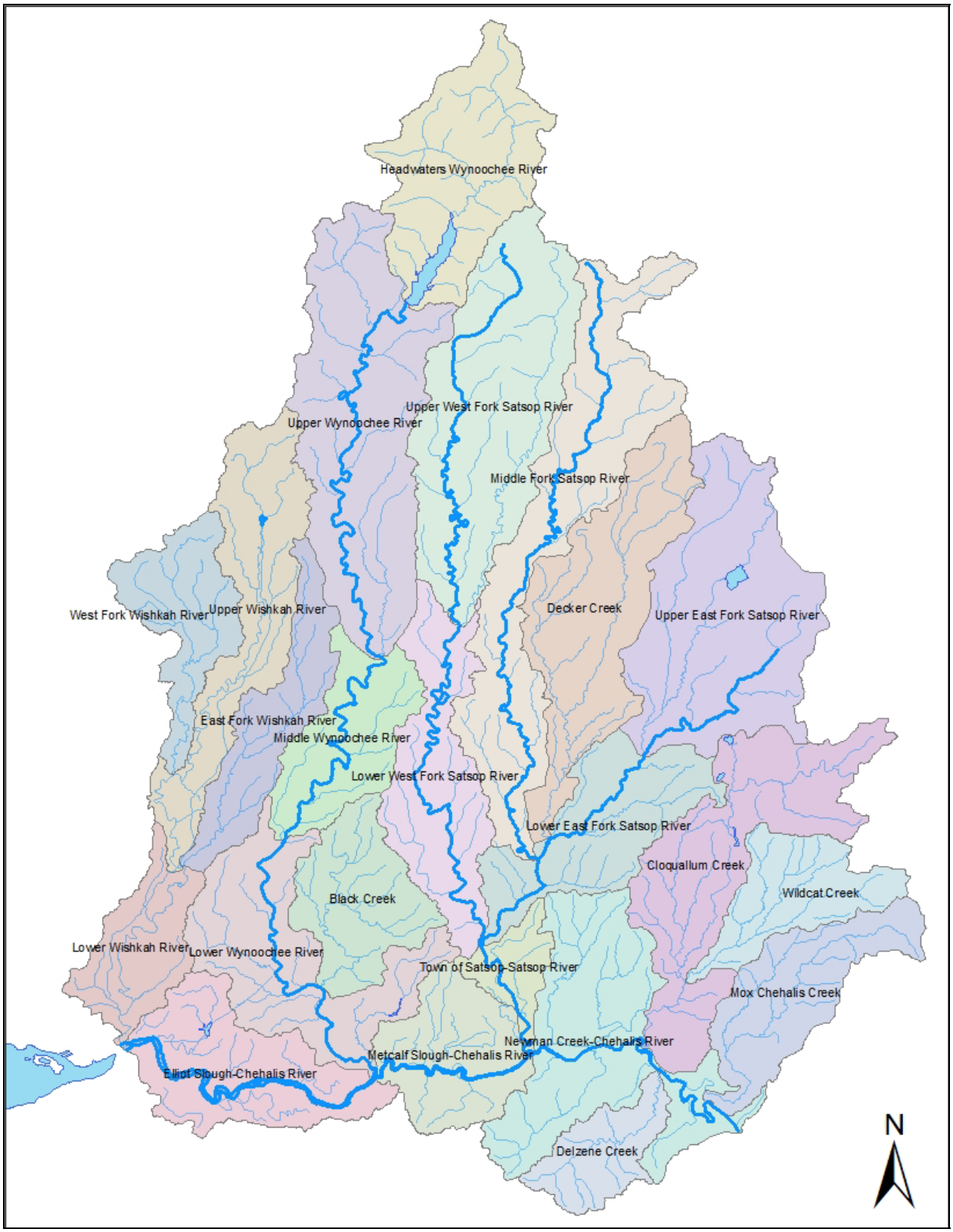


Figure 3. Lower Chehalis River Basin (WRIA 22)

Model Development

Basic Data and Information

Existing Hydraulic Models

As described previously, numerous hydraulic studies have been completed in the Chehalis River basin. Many of these have developed and applied hydraulic models to analyze rivers and streams within the basin. These models, and data used in their development, have been incorporated into the current modeling effort wherever feasible.

The original Chehalis River Basin Flood Insurance Study (FIS) completed for FEMA (c. 1982) included steady state hydraulic modeling (HEC-2) of portions of the Chehalis River, Black River, Newaukum River, Hanaford Creek, and South Fork Chehalis River. That effort was superseded by a study conducted by Pacific International Engineering (PIE) for the Corps in 2001. The PIE work included development of a UNET unsteady state hydraulic model including the main stem Chehalis River between Porter and Doty plus portions of significant tributaries including the Black River, Lincoln Creek, Skookumchuck River, Hanaford Creek, Salzer Creek, Newaukum River, Dillenbaugh Creek, Stearns Creek, and the South Fork Chehalis River. That model was used in the Corps 2003 General Reevaluation Report (GRR) study of the Chehalis River basin.

FEMA recently completed a revised Flood Insurance Study for Lewis County including the Chehalis River, Hanaford Creek, Lincoln Creek, Salzer Creek, Skookumchuck River, South Fork Chehalis River, and Sterns Creek (FEMA, 2011). For the hydraulic modeling, the previously developed UNET model of the Chehalis River and tributaries used in the USACE 2003 GRR study was converted to a model using the USACE Hydrologic Engineering Center (HEC)'s River Analysis System (HEC-RAS) software (HEC, 2010). The complete HEC-RAS model used in the study consists of approximately 150 river miles and 700 river cross-sections, and extends to Porter in Grays Harbor County.

The current modeling effort for the Flood Authority began with the existing FEMA Twin Cities Model as its basis. The model was extended both upstream and downstream and up some of the tributaries as described below. New cross sections were surveyed for portions of the model and topographic data were replaced with more recent data wherever possible. Model branches for the Satsop and Wynoochee Rivers were also added as follows:

The Corps previously developed a HEC-RAS model of the lower Satsop River, from its mouth to Highway 12 (approximately 2 miles) in 2004 as part of a gravel pit restoration project (WEST, 2004). Cross section data used in that model were based upon 2002 channel survey and 2002 LiDAR. That Satsop River model was incorporated into the Flood Authority Model as a branch, although it is recognized that the channel cross sections in that model have changed considerably since 2002.

WEST, under contract to the Corps of Engineers, recently completed a hydraulic model of the Wynoochee River (USACE, 2012). That model extends 51 miles upstream from the confluence with the Chehalis River near Montesano, to the Wynoochee Dam based on 2009 survey and LiDAR. The Wynoochee River model was incorporated into the Flood Authority model as a branch.

Topographic Data

Topographic data from various sources were used in the development of the Chehalis River hydraulic model. Digital elevation models (DEMs) were used to provide information on the overbank geometry, to evaluate

hydraulic connections in the model, and to analyze the areas and depths of inundation under the different flood scenarios. The topographic data sets are primarily based on LiDAR flown within the last 10 years, with the exception of USACE contours, which come from aerial photogrammetric survey completed in 1999. Because the topographic data were collected at different times, and for different purposes, there are many areas where two or more DEMs overlap. In such cases, the most recent DEM was used for the hydraulic modeling and analysis. The following list details topographic datasets used in this study (See Figure 4):

South West Washington 2009 – A one meter resolution LiDAR grid flown for FEMA and the Oregon LiDAR Consortium in 2009, which covers the Wynoochee River Basin and the lower 13 miles of the Chehalis River Floodplain. Data was accessed through the Puget Sound LiDAR Consortium website.

Centralia 2006 – LiDAR coverage of City of Centralia flown in 2006 including the lower portions of Hanaford, Salzer and Lincoln Creek, and the Skookumchuck River. Additionally covers the Chehalis River from River mile 67.86 to 61.05 and the Skookumchuck Overflow Reach.

Lewis County 2005-2006 – LiDAR coverage from 2005 and 2006 including the upper portions of the Newaukum, South Fork Chehalis, and Chehalis River, as well as the upper portions of Lincoln, Salzer, Newaukum, Dillenbaugh, and Sterns Creek. Data provided by Lewis County.

PSLC 2002 – LiDAR coverage for the Puget Sound Lowlands from 2002, accessed from Puget Sound LiDAR Consortium website, covers a large portion of south west Thurston County including the upper 15 miles of the Skookumchuck River, and extends down the Lower Chehalis River from mile 61 to its mouth.

USACE 1999 – Topographic survey collected by the USACE in 1999 covers portions of the Chehalis and Newaukum River, and Dillenbaugh Creek near Centralia and Chehalis, and the upper Chehalis River between river mile 95 and 104.

NOAA Bathymetric data is available for Grays Harbor and portions of the Lower Chehalis River, although the date these were collected and the accuracy specification of the data are unknown. These data were used for in-channel portions of the three most downstream cross sections of the Lower Chehalis River, which extend into Grays Harbor.

Several new LiDAR data sets are currently in development. LiDAR for the main Chehalis river valley upstream of Montesano to Grand Mound and in various parts of Lewis County are being developed through a joint effort between FEMA and Lewis County. The LiDAR flights were completed in January and February 2012 but data are not available for use in the Flood Authority project. It is anticipated that these data will become available in summer 2012. New LIDAR for Thurston County was also collected in June and July 2011 but the post processed, quality controlled data did not become available until June 2012. These new LiDAR data sets are expected to provide much better resolution in areas of the basin, especially in regions that are currently only covered by the 1999 Corps photogrammetry or the PSLC 2002 LiDAR data. The new data will reflect channel and floodplain changes that have occurred since the previous data collection efforts and provide a good representation of current topographic conditions. This is particularly important for the Satsop River channel, which is very dynamic, and for potions of the Chehalis River between Grand Mound and Montesano.

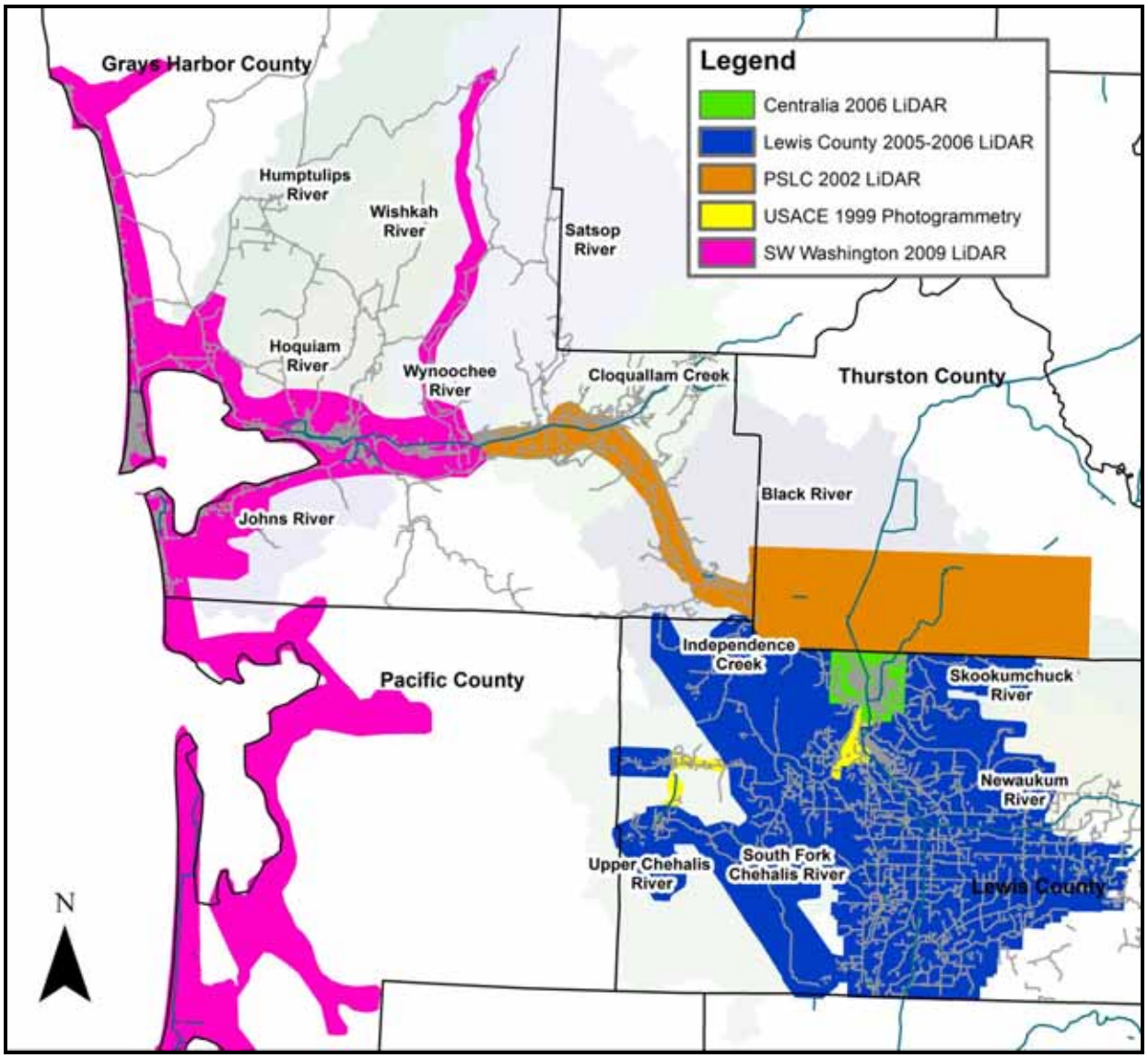


Figure 4. Chehalis Topographic Coverage Boundaries over WRIA 22 and 23

New Cross Section Surveys

New cross section surveys were collected to support the upstream and downstream extensions of the model and to provide current bathymetric data in areas that were previously modeled. Pacific Geomatic Services (PGS) collected forty five (45) cross sections within the Chehalis River channel between the mouth of the river and river mile 12, plus a depth profile along Preacher's slough, a main overflow path in the lower Chehalis floodplain. PGS also collected twenty-one (21) cross sections within the Skookumchuck River channel between river mile 9.8 and 12 and twenty (20) cross sections within the Satsop River between Highway 12 and the Chehalis River. These data were collected in November and December 2011

Minister Glaeser surveyed 70 sections within the Chehalis River between Pe Ell and Doty, 84 sections between Grand Mound and Porter, and 60 sections between Porter and Montesano.

WSDOT Additional Survey of I-5 and Airport Levee

In April 2012 WSDOT completed topographic survey to detail portions of I-5, the Chehalis-Centralia Airport levees, and the Highway 6 / I-5 overpass near the city of Chehalis, WA. These data were used to refine connections in the model including airport levee overtopping, I-5 overflows, Market Street overtopping, and Dillenbaugh creek breakout flow at I-5.

Hydrology (from USACE study)

Hydrologic data for the current modeling effort is being obtained from the concurrent Corps GI study (USACE, 2012). For that study WEST was tasked with developing basin wide flood flow hydrographs at return periods ranging from 1.5 to 500-years and seasonal low flow data. In addition, hydraulic model inputs were developed for three calibration events; February 1996, December 2007, and January 2009. The data developed for the Corps study are being used without modification for the current study, providing consistency between the two modeling efforts.

In addition to the Corps hydrologic data a downstream boundary condition at Aberdeen was required. Observed data is not currently collected at Aberdeen; therefore, a correction factor was applied to NOAA tide predictions at Aberdeen based on a comparison of observed and predicted tides at Westport. Applied corrections could be either positive or negative and ranged as high as 3 feet or more. Transposition of the differences between Westport and Aberdeen included a half hour offset to account for the difference in peak tide timing between the predicted tides at the two stations.

Model Configuration

As documented above, the final Chehalis River Basin baseline hydraulic model developed for the Flood Authority leveraged concurrent modeling efforts being conducted for the Corps, and utilized new survey to further refine and extend the earlier FEMA Twin Cities model. Table 1 lists the agency that funded development of each segment of the model, the surveyor and date for new cross section surveys, and the firm responsible for the development of the hydraulic model. Additional details for the model development are provided below.

Table 1. Chehalis River Model Reach Summary

	Reach	Client	Cross Section Survey	Model Development
Chehalis River	Pe Ell to Doty	USACE	MGS, 2011	WEST
	Doty to Grand Mound	FEMA	USACE, 2000	NHC, WEST, WSE[1]
	Grand Mound to Porter	FA	MGS, 2011	PIE, WEST
	Porter to Montesano	USACE	MGS, 2011	WEST/WSE
	Montesano to Mouth	FA	PGS, 2011	WSE
Tributaries	Satsop	USACE	USACE 2001, PGS, 2012[2]	WEST/WSE
	Wynoochee	USACE	USACE, 2009	WEST
	Skookumchuck	FA	PGS, 2012	WEST/WSE[3]
	Newaukum	FA	USACE, 2001	WSE
	Black	FA	MGS, 2011	WEST/WSE

[1]The original HEC-RAS model was developed by NHC for FEMA based on an earlier PIE UNET model. WEST georeferenced and re-cut cross sections in the model under the Flood Authority contract. WSE made final refinements and revisions to the model to improve the calibration and better reflect physical features in the Twin Cities area.

[2]New surveyed geometry was used for a comparison of channel changes but was not incorporated into the final model.

[3]WEST georeferenced the Skookumchuck model. WSE incorporated new survey and added a bypass reach in Bucoda (RM 9.8)

Upstream Extension (Pe Ell to Doty - WEST for USACE)

WEST extended the Chehalis River model upstream of Doty to Pe Ell as part of the Corps GI study. Channel geometry data in the model were based on new MGS field surveys. Overbank topography was based on 1999 USACE contours and 2005-2006 Lewis County LiDAR where available.

Twin Cities (Doty to Grand Mound)

The model between Doty and Grand Mound is based on the FEMA Twin Cities model. Although reach refinement was not originally scoped for this portion of the model, the Twin Cities model reach was ultimately refined considerably by WSE and WEST to resolve legacy issues such as overlapping cross sections and inaccurate reach lengths at tributary junctions that were discovered during model integration. The model was also revised by WSE to better reflect physical features in the Twin Cities area (railroads, road grades, Interstate 5, culverts, etc.) and to better calibrate to observed high water marks from February 1996 and December 2007.

Grand Mound to Porter (WEST for USACE and Flood Authority)

Although the Chehalis between Grand Mound and Porter was included in the earlier Twin Cities modeling, previous efforts by the Corps and/or FEMA did not include georeferencing or otherwise refining the model in the reach downstream of Grand Mound. Under the Corps GI Study effort WEST reconfigured this reach using new channel survey data collected by MGS under Task 5b of the Flood Authority Contract. The new model development used topographic data from the 2002 PSLC LiDAR data set.

Porter to Montesano (WEST for USACE and WSE for Flood Authority)

Extension of the model downstream of Porter to Montesano was completed by WEST as part of the USACE GI study. New MGS survey collected under contract to the Corps was used in channel, with 2002 PSLC LiDAR for overbank areas. This reach of the model was subsequently refined by WSE to better match observed water marks near the South Elma and Porter Creek roads provided by lower basin landowners in June 2012.

Montesano to Aberdeen (WSE for Flood Authority)

No previous hydraulic modeling was found for the lower 12 miles of the Chehalis River between Montesano and Grays Harbor. WSE developed the model geometry for this reach based on new PGS channel survey and 2009 LiDAR data. Unsteady capabilities within HEC-RAS allowed the incorporation of a time varying tidal boundary condition at the downstream end of the model. The model was calibrated to data for the USGS stage gage at Montesano.

Tributaries

Modeling of four tributaries to the Chehalis River: the Skookumchuck, Black, Newaukum and Satsop Rivers, was expanded or refined under Task 6. In addition, a branch representing the Wynoochee River was incorporated into the basin wide model. The intent of work on the tributaries was to evaluate existing models and refine/replace/extend them as necessary to meet the needs of the Flood Authority and basin stakeholders.

Satsop (WSE for Flood Authority)

Grays Harbor County indicated that a hydraulic model of the Satsop/Chehalis River confluence area would be very useful in light of upcoming project proposals on the Satsop River. Using a model developed by WEST as part of a Corps of Engineers floodplain restoration project in 2004 the lower Satsop River, from SR 12 to its mouth, was included as a branch in the Chehalis River hydraulic model. The 2004 model was based on cross sections that were field surveyed in 2002 and overbank data from the PSLC 2002 LiDAR data set. Unfortunately, there has been significant lateral movement of the Satsop River channel since the previous surveys were obtained and therefore the model is somewhat outdated. However, until new LiDAR data are available for the overbank floodplain it is not possible to refine the lower Satsop River branch.

In lieu of an updated model, WSE assessed how changes to the Satsop River channel since the earlier Corps project affect the accuracy of the existing model. Twenty (20) cross sections were surveyed along the Satsop River and the new cross section surveys were graphically compared to the earlier survey data using Excel. Comparisons of the channel location (as estimated from the LiDAR data at the time of the earlier survey and a recent aerial photograph) were also made. The results of these comparisons determined that the Satsop channel has shifted considerably, although it is not possible to conclude based on the survey data alone whether the Satsop channel has gained or lost conveyance capacity since 2001. The evaluations are summarized in an earlier WSE memorandum; “Satsop River Channel and Cross Section Comparisons” (WSE, 2012a).

Skookumchuck (WSE for Flood Authority)

The Twin Cities Skookumchuck model reach (from RM 6.42 to 21.77) was georeferenced by WEST, including an update of channel overbank elevations based on 2002 PSLC LiDAR. WSE then refined the model in the vicinity of Bucoda (RM 9.8 - 12) using channel survey collected by PGS, and calibrated the model using high water elevations from the January 2009 flood event. Refinement of the Skookumchuck River model reach included the

addition of a "Bucoda Bypass" reach, which allows a much more accurate representation of the split-flow flooding that occurs through the town of Bucoda.

The refined Skookumchuck model was then utilized to determine the impact of bridge constrictions on flood levels within the town of Bucoda. This analysis is documented in an earlier WSE memo - "Skookumchuck River Model Update and Bucoda Flood Reduction Alternative Investigation" (WSE, 2012b).

Newaukum (WSE for Flood Authority)

The Twin Cities model included portions of the Newaukum River from its mouth upstream to approximately River Mile 4.1 at Labree Road, as well as the lower 3.45 miles of Dillenbaugh Creek, which receives overflows from the Newaukum River both upstream and downstream of Labree Road. Modeling conducted for the Corps of Engineers in the 1990s by PIE using UNET, and more recently in 2001 by Northwest Hydraulic Consultants (NHC) using HEC-RAS, covered the entire main stem of the Newaukum River including upstream of Labree Road to RM 10.63 (just below the North Fork confluence). NHC's modeling used data from various sources but primarily the UNET model developed by PIE. Neither the PIE nor the NHC model was geo-referenced (e.g. tied to a fixed horizontal coordinate system); however, AutoCAD files from PIE are available to show the location and alignment of the model cross-sections.

WSE geo-referenced, refined, and extended the existing model of the Newaukum River, upstream of Labree Road from RM 4.11 to RM 10.63, and incorporated this extension into the Flood Authority model. The floodplain portions of all cross-sections were re-cut using 2002 LiDAR data obtained from the Puget Sound LiDAR Consortium (PSLC) and merged with channel cross section data from the NHC model. Cross-sections in the NHC model that were not shown on the PIE AutoCAD drawings were located along the channel based on their reach lengths, then extended appropriately across the floodplain and cut from the LiDAR data.

The work performed by WSE is fully documented in "Newaukum River Model Extension and Refinement" (WSE, 2011c).

Black (WEST for Flood Authority)

Georeferencing of the Black River model was updated by WEST using 2001 cross section surveys obtained from W. & H. Pacific. Storage area locations, volumes, and connections were updated using the 2002 LiDAR data. The revised/refined model was calibrated to high water mark information for the confluence area obtained from Glen Connelly of the Chehalis Tribe.

Model Review

The HEC-RAS Hydraulic Model developed by the WSE/WEST Project team was subject to detailed review by the State Technical Team (comprised of staff from WSDOT, WADOE, and WDFW), by the Corps, and by WSDOT. The goal of these independent reviews was to ensure that the model was technically well developed and to facilitate acceptance by other stakeholders working in the basin. In particular, having the model reviewed and accepted by WSDOT and the Corps was instrumental in those agencies acceptance of the model for future hydraulic investigations. The fact that WSDOT, the Corps, and the Flood Authority are all working from the same baseline hydraulic model should make future discussions of flood relief alternatives more productive.

State Technical Team

WSE and WEST presented a preliminary version of the Chehalis River hydraulic model to a group of State technical staff at a coordination meeting at WEST's offices on February 23, 2012. Following that meeting the model and available documentation were provided to the State team for review and comment. Three State reviewers provided detailed written comments on the model: Paul Pickett (DOE), Casey Kramer (WSDOT), and Guy Hoyle-Dodson (DOE). These comments were well formed and generally helpful in identifying areas in the hydraulic model that required additional consideration and/or refinement. The comments were reviewed and discussed by the WSE-WEST team and a number of modifications were made to the model to address concerns. In some cases, no changes to the model were necessary, either because the model was already configured appropriately or because the comments raised questions beyond the scope of the current study. General responses to the reviewer's comments were provided in a memorandum entitled "Response to State team comments on Chehalis River Hydraulic Model" (WSE, 2012d). These responses were discussed further with the individual reviewers to ensure that the model could be refined appropriately. Brief summaries of the comments and responses are provided below:

RE: Paul Pickett comment letter of 3/30/2012:

Mr. Pickett's comments focused primarily on the hydrologic data proposed for use in the evaluation of flood relief alternatives. He noted that flood events in a basin as large and complex as the Chehalis Basin can come in many different forms and that a comprehensive analysis of flood relief alternatives would require a range of design events to be simulated. In our response we provided data showing that the largest flood events observed in the Chehalis basin have similar enough characteristics to make the proposed design event modeling approach reasonable for the current effort. We also noted that the hydrology for this project was done as part of the concurrent Corps project and using the same hydrology maintains consistency between the modeling efforts.

To evaluate basin hydrology data from the top 10 annual peaks at the Grand Mound gage were compared to the corresponding peaks at major upstream gages. The key findings of this analysis are as follows:

1) A large flow (herein defined as among the top 10 highest peaks recorded) on the Chehalis at Grand Mound has never happened without a correspondingly large flow on the Chehalis River at Doty.
2) A large flow at Doty is a reliable (although not perfect) indicator of a large flow at Grand Mound.
3) A large flow on the Chehalis at Grand Mound can happen with or without a significant flow contribution from the Skookumchuck River.
4) A large flow on the Skookumchuck is not a very good indicator of large flows at Grand Mound.
5) Peak flows on the Newaukum and South Fork are similarly correlated to the flows at Grand Mound, less so than the Doty flows but more so than the Skookumchuck flows.

The hydrologic analyses indicated that the Corps approach provides a reasonable representation of large flood events in the Chehalis River basin. However, as we agreed with Mr. Pickett that there is significant variability in storm timing and magnitude in the Chehalis River basin, the work plan for the project was modified to include analysis of three historical floods (1996, 2007, and 2009) in addition to the 100-year design event modeling.

RE: Guy Hoyle-Dodson comment letter of 4/1/2012:

Mr. Hoyle Dodson's comments on the HEC-RAS model were particularly comprehensive including comments on general modeling approaches as well as a number of specific areas of concern or question. While many of these

related to the new model reaches being developed for this study, a large number were specifically related to the "Twin Cities" portion of the model previously developed by others. That said, and in an effort to make the model as robust and useful as possible, we reviewed all of the comments and attempted to address all of them in refining the model. We also provide responses to Mr. Hoyle- Dodson's comments in our detailed response letter (WSE 2012d).

RE: Casey Kramer comment letter of 4/2/2012:

Mr. Kramer's comments were discussed between Mr. Kramer, WSE, WEST, and NHC staff in a meeting at WSE's office on March 27, 2012. A plan of action was agreed upon for updating the model to address the comments. It should be noted that Mr. Kramer's model comments focused on the Twin Cities portion of the model constructed by others and not actually part of the current model development effort. However, to ensure that future analyses conducted with the model are as useful as possible modifications were made to the model to better simulate the area upstream of Mellen Street and along the lower reaches of Dillenbaugh Creek where it passes under I-5. These are detailed in WSE's April 2012 comment response letter and discussed further below.

USACE

As noted previously, the Corps has a concurrent project to develop a hydraulic model of the Chehalis River for use in ecosystem investigations (USACE 2012a). The work being conducted by the WSE/WEST team under contract with the Flood Authority is highly integrated with WEST's work for the Corps. Specific deliverables developed by WEST, including the hydrology and hydraulic modeling, have been submitted and subject to the Corps rigorous ITR process. The comprehensive model generated by the WSE project team has also been provided to the Corps for review and comment. It is our understanding that the Corps review is currently on hold pending allocation of funding. Any comments provided by the Corps will be responded to and reflected in future refinements to the model as appropriate.

WSDOT

In addition to the comment letter from Casey Kramer described above, WSDOT and its consultant Northwest Hydraulic Consultants (NHC) provided additional review of the Chehalis River hydraulic model after initial refinements were made. This work included direct coordination between NHC and WSE to refine portions of the model in the Twin Cities area, a re-release of the existing conditions geometry on May 2, 2012, and a technical team meeting at WSDOT headquarters on May 9, 2012. WSDOT is currently applying the model to evaluate a range of possible alternatives for protecting the Interstate 5 from flooding. As such, they have great interest in ensuring that the model is well formulated and appropriate for modeling, particularly in this area. Model issues raised by NHC and WSDOT were addressed in revisions to the existing conditions model that was subsequently distributed to WSDOT and the other members of the State tech team. That revised existing conditions model forms the basis for the alternatives analyses described below.

Final Model Refinements

As described above, the Chehalis River HEC-RAS model was developed through an open and participatory process involving the Flood Authority, the Corps, WSDOT, and other members of the State tech team. The model was widely distributed facilitating review by basin stakeholders and key agencies. The intent of this process was that the model would provide a broadly accepted and shared tool for making future decisions

regarding flood relief in the basin. A number of general and specific refinements were made to the model in response to the detailed reviews. Several of these warrant additional detailed descriptions as provided below:

WSDOT 2012 Survey (WSE and WEST)

Considering their desire to have as accurate a calibration as possible in the Twin Cities area, to facilitate detailed planning and design of I-5 flood protection projects, WSDOT collected additional field topographic survey in April 2012 for Interstate 5 and the Chehalis-Centralia Airport levee for use in updating the model. The original data for these features were derived from the remote sensed topographic data sets (LiDAR and/or photogrammetric mapping). As such, the accuracy of the data was generally limited to plus or minus 1 foot (although the data are often more accurate for "hard" surfaces in open terrain (roads, railroads, etc)). The new survey data were used to update the model, thus improving its ability to accurately simulate existing conditions flooding.

Dillenbaugh Creek Area (WSE)

To better approximate December 2007 flood conditions near the Dillenbaugh Creek/Chehalis Junction, two lateral weirs (0.120 and 0.092) were added along Dillenbaugh to model flow entering the north- and southbound lanes of I-5 and flowing under the Highway 6 overpass. Weir elevations were based on the April 2012 survey completed by WSDOT. Additionally, the weir coefficient (C_d) for Main Street was reduced from 2.0 to 1.5 to approximate losses as water exiting Dillenbaugh flows through vegetation and around buildings on its path to Storage Area #303.

A section of the I-5 weir (LS 74.41) was then lowered (as discussed during the March 27th meeting with WSDOT and NHC) to simulate the portion of I-5 that does not have a jersey barrier along its east side, and the failure of the centerline jersey barrier that occurred during the Dec 2007 flood event. With these changes the maximum simulated depth of flow over I-5 in between SR-6 and NW West Street was about 2.0 ft, which may be somewhat high based on photographs from the 2007 flood. Additional model refinement might reduce the peak stages over the freeway in this area but it is not clear that there is enough information to definitively state how high the flow may have gotten and/or the direction and magnitude of breakout flows from Dillenbaugh Creek during the event. As such, no additional model refinement was completed.

Bridges and Revised Calibration (WSE)

Following the incorporation of the revised I-5 and airport levee survey data and the refinements to the modeling of Dillenbaugh Creek the model calibration in the Twin Cities area was reviewed. This review showed that model calibration at several locations, particularly just upstream of Mellen Street and in the reach between the airport levee and the Newaukum River confluence, could be improved. The model configuration was refined by adjusting ineffective flow limits and modifying "n" values to improve calibration. While the model changes were generally minor, improvements in calibration by up to 0.5 feet were attained at some locations. The revised calibration focused on the December 2007 flood event due to the fact that this event was significantly larger in the Twin Cities area and there were more observed high water marks distributed throughout the Twin Cities than for any other event. However, the other calibration events, February 1996 and January 2009 were also simulated to verify that the revisions also improved model calibration for those events.

MTB Project (NHC for WSDOT)

WSDOT has received permit approvals and obtained funding to construct a series of improvements collectively known as the Mellen to Blakeslee Bridge (MTB) Junction Project. The $155 million project, which broke ground in late May, will provide access to medical and other critical community facilities in Centralia during flood events up to the 2007 flood level. The first stage of the projects is expected to be completed in spring 2013; the second will begin in the summer of 2013 and finish late in 2014 or early 2015. The project includes connecting Louisiana Avenue and Airport Road, constructing a "shared use" path for pedestrians and cyclists, and re-constructing the Mellen Street interchange. Another element of the project is the addition of collector-distributor (CD) lanes alongside of the freeway between Mellen Street and Blakeslee Junction. The CD lanes will allow drivers to pass from Centralia to Chehalis without using I-5.

Because the MTB project is being actively implemented at present, it was decided that the Chehalis River existing conditions hydraulic model should be updated to include this project. NHC used the existing conditions geometry distributed by WSE on May 2, 2012 and updated it to reflect the planned MTB project. The modified geometry produced by NHC forms the "Baseline" geometry being used by all parties for purposes of evaluation of impacts and benefits of flood relief alternatives.

Lower Basin Model Refinements (WSE)

In coordination with the Flood Authority, the Ruckelshaus Center, and the Washington Dairy Federation, a series of meetings and workshops were held in Porter and Montesano in June 2012 to discuss specific flooding problems in the lower Chehalis River basin. During those workshops additional calibration information was obtained including high water marks for the December 2007 flood and anecdotal information about flooding during the January 2009 and February 1996 events. Using these new data the lower Chehalis River model calibration was refined, specifically with respect to the modeling of the Porter Creek Road and Wakefield Road (South Elma) bridges and approach fills. Ineffective flow limits and Manning's roughness values in the model were adjusted to reflect observations and to allow a better match to the high water mark data. The model was also modified in a manner that facilitates evaluation of several lower basin flood relief alternatives that were discussed at the workshops, specifically modifications to the overflow bridges on Porter Creek Road and/or Wakefield Road. The model refinements were incorporated into all earlier versions of the model and all previously modeled alternatives were re-simulated.

Final Model Calibration Summary

The Flood Authority Chehalis River HEC-RAS model was calibrated to the February 1996 and January 2009 storm events, with the storm event of December 2007 used for model validation. The calibration and validation data used were the observed stage and discharge hydrographs and rating curves at Doty on the Chehalis River, RM 101.549, Grand Mound on the Chehalis River, RM 59.909, Porter on the Chehalis River, RM 33.22, the Newaukum River near Chehalis, RM 4.11, the Skookumchuck River below Bloody Run, RM 20.7, the Skookumchuck River near Bucoda, RM 6.4, and the Skookumchuck River at Centralia, RM 2.41.

Model calibration was achieved by adjusting channel and overbank values of the Manning's n bottom roughness coefficient, flow roughness factors, and the placement of ineffective flow areas, until good agreement was found between the computed and observed stage and flow hydrographs and computed and observed rating curves at the gages listed above.

Results

The following discussion provides an overview / summary of calibration results for each of the calibration events (February 1996, and January 2009) and the validation event (December 2007) – a more comprehensive discussion of model calibration can be found in the GI Study report (USACE 2012a).

February 1996 Calibration

Table 2 shows the comparison between modeled and observed peak flows at various locations on the Chehalis, Newaukum, and Skookumchuck Rivers for the February 1996 event. For illustration, plots of simulated and observed stage and flow hydrographs at Grand Mound are included in Figures 5 and 6.

Table 2. Summary of model calibration for flow for February 1996 event

Location	Computed Peak Flow (cfs)	Observed Peak Flow (cfs)	Difference in Peak Flow Magnitude (%)	Difference in Event Volume (%)	Peak Time Difference (hours)*
Chehalis River at Doty	28,055	28,900	-2.9	-0.3	0
Chehalis River at Grand Mound	74,485	74,800	-1	15.3	5
Chehalis River at Porter	82,420	80,700	2.1	39.3	10
Newaukum River near Chehalis	11,960	13,300	-10.1	-0.3	2.5
Skookumchuck River below Bloody Run	9,053	N/A	N/A	N/A	N/A
Skookumchuck River near Bucoda	11,635	11,300	3	-5.7	-2

*A negative time difference denotes the simulated peak occurring before the observed peak

Though the estimated inflows produce hydrograph volumes that are high compared to the observed data, the flow magnitudes are within 10 percent and the timing of the peak flows are within a few hours of observed data - with the exception of the simulated peak at Porter, which is 10 hours early. Further investigation suggests that this is likely an anomaly within the gaged data at Porter (USACE 2012a).

In general, the flow hydrograph calibrations look reasonable. At gages where the majority of the upstream contributing flow is gaged (Chehalis at Doty, Newaukum near Chehalis, Skookumchuck below Bloody Run and near Bucoda), the calibration of the flow hydrographs appear relatively tight. At the gages where the majority of the contributing flow is ungaged (Chehalis River at Grand Mound and Porter), the simulated flows tend to be

high compared to the observed. This in turn yields stage hydrograph calibrations that look reasonable for the Chehalis River at Doty and the Skookumchuck gages. The stage hydrographs for the Chehalis River at Grand Mound and Porter are slightly high, which is to be expected due to the high simulated flow peaks.

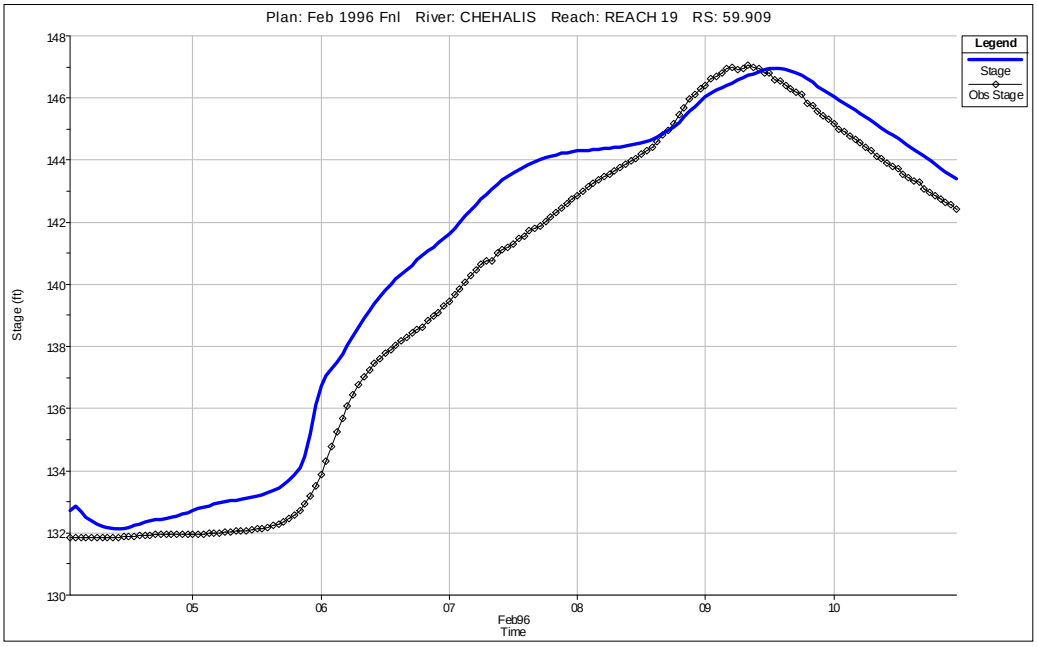


Figure 5. Stage hydrographs for Chehalis River at Grand Mound– February 1996

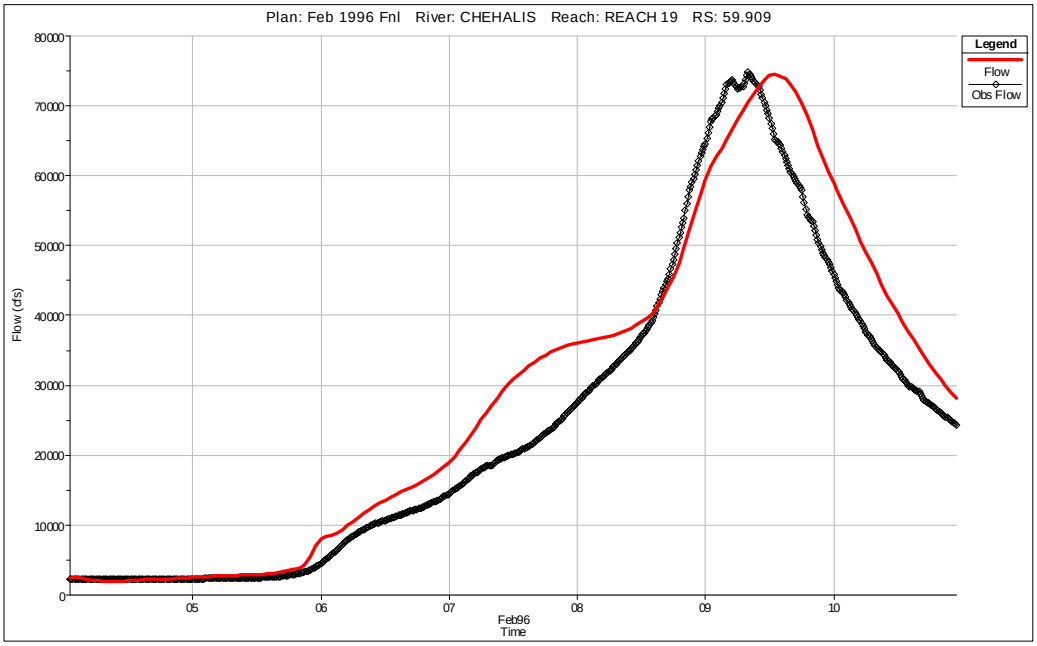


Figure 6. Flow hydrographs for Chehalis River at Grand Mound– February 1996

In addition to the stream gage data that were available for calibration, high water mark data are also available in specific locations throughout the basin. A comparison of simulated water surface elevations to recorded high water marks for the February 1996 event is shown in Table 3.

Table 3. Summary of high water mark data – February 1996

River	HEC-RAS River Station (RM)	Simulated Water Surface Elevation (feet NAVD88)	Observed High Water Mark (feet NAVD88)	Difference (feet NAVD88)
Black River	9.09	112.56	113	-0.44
Black River	4.62	101.04	100.95	0.09
Black River	3.44	97.43	97.48	-0.05
Black River	2.5	95.1	96.12	-1.02
Chehalis River	81.03	199.93	199.37	0.56
Chehalis River	76.1	186.01	185.93	0.08
Chehalis River	75.09	184.77	185.75	-0.98
Chehalis River	74.82	183.66	184.9	-1.24
Chehalis River	74.02	182.3	183.4	-1.1
Chehalis River	72.8	181.57	181.9	-0.33
Chehalis River	67.86	178.8	179.61	-0.81
Chehalis River	67.43	177.26	177.7	-0.44
Chehalis River	66.88	175.59	176.54	-0.95
Chehalis River	66.73	175.2	175.61	-0.41
Chehalis River	66.36	172.71	173.12	-0.41
Chehalis River	64.2	162.69	164.53	-1.84
Chehalis River	63.2	158.19	158.9	-0.71
Chehalis River	61.96	155.27	156.73	-1.46
Chehalis River	59.909	146.95	147	-0.05
Chehalis River	54.476	123.75	124.43	-0.68
Chehalis River	54.045	120.08	120.11	-0.03
Chehalis River	51.158	104.04	106.36	-2.32
Chehalis River	50.022	100.89	99.72	1.17
Chehalis River	45.217	88.17	87.21	0.96
Chehalis River	42.283	77.79	71.2	6.59
Dillenbaugh Creek	1.25	185.95	187.1	-1.15
Dillenbaugh Creek	0.09	183.79	185.41	-1.62
Newaukum River	4.11	204.59	206.69	-2.1
Newaukum River	1.66	186.84	187.9	-1.06
Salzer Creek	1.56	180.32	180.4	-0.08
Salzer Creek	1.28	180.32	180.4	-0.08
Salzer Creek	0.36	179.92	180.12	-0.2
Skookumchuck River	20.7	334.58	333.98	0.6
Skookumchuck River	6.4	216.29	216.2	0.09
Skookumchuck River	3.84	201.42	201.66	-0.24
Skookumchuck River	2.42	191.47	190.69	0.78
Skookumchuck River	2.21	189.33	188.4	0.93

River	HEC-RAS River Station (RM)	Simulated Water Surface Elevation (feet NAVD88)	Observed High Water Mark (feet NAVD88)	Difference (feet NAVD88)
Skookumchuck River	2	187.99	187.7	0.29

January 2009 Event

Table 4 shows the comparison between modeled and observed peak flows at various locations on the Chehalis, Newaukum, and Skookumchuck Rivers for the January 2009 event. For illustration, a plot of simulated and observed stage and flow hydrographs at Grand Mound are included in Figures 7 and 8.

Table 4. Summary of model calibration for flow for January 2009 event

Location	Computed Peak Flow (cfs)	Observed Peak Flow (cfs)	Difference in Peak Flow (%)	Difference in Event Volume (%)	Peak Time Difference (hours)*
Chehalis River at Doty	19,602	20,100	-2.5	-0.2	0.0
Chehalis River at Grand Mound	57,928	50,700	14.3	17.3	0.5
Chehalis River at Porter	66,992	68,100	-1.6	6.9	-0.5
Newaukum River near Chehalis	12,629	13,000	-1.7	6.5	1.0
Skookumchuck River below Bloody Run	7,018	6,900	1.7	3.5	-0.75
Skookumchuck River near Bucoda	9,962	10,500	-5.1	-4.2	1.0

*A negative time difference denotes the simulated peak occurring before the observed peak

Flow volumes in the Chehalis River tend to be slightly higher than observed data, especially in the lower Chehalis River. The majority of the contributing area between the gage at Doty and the gage at Grand Mound is ungaged; therefore, the majority of the contributing flow between Doty and Grand Mound is estimated using procedures discussed the GI Report (USACE 2012a). These results suggest that the inflow estimates between Doty and Grand Mound are high. Although the estimated inflows produce hydrograph volumes that are high compared to the observed data, the flow magnitudes are generally within 10 percent.

At the Newaukum River and Skookumchuck River gages, both the simulated flow volumes and peak flow magnitudes are within 10 percent of the observed volumes and magnitudes for the 2009 event. Simulated and observed peak times also agree well; all differences are within one hour.

In general, the flow hydrograph calibrations look reasonable. For observed flow hydrographs where the majority of the upstream contributing flow is gaged (Chehalis at Doty, Newaukum near Chehalis, Skookumchuck below Bloody Run and near Bucoda), the calibration of the flow hydrographs appear relatively tight. At the gages where the majority of the contributing flow is ungaged (Chehalis River at Grand Mound and Porter), the simulated flows tend to be high compared to the observed, as noted previously. This in turn yields stage hydrograph calibrations that look reasonable for the Chehalis River at Doty and the Skookumchuck gages. The stage hydrographs for the Chehalis River at Grand Mound and Porter are slightly high which is to be expected due to the high simulated flow peaks.

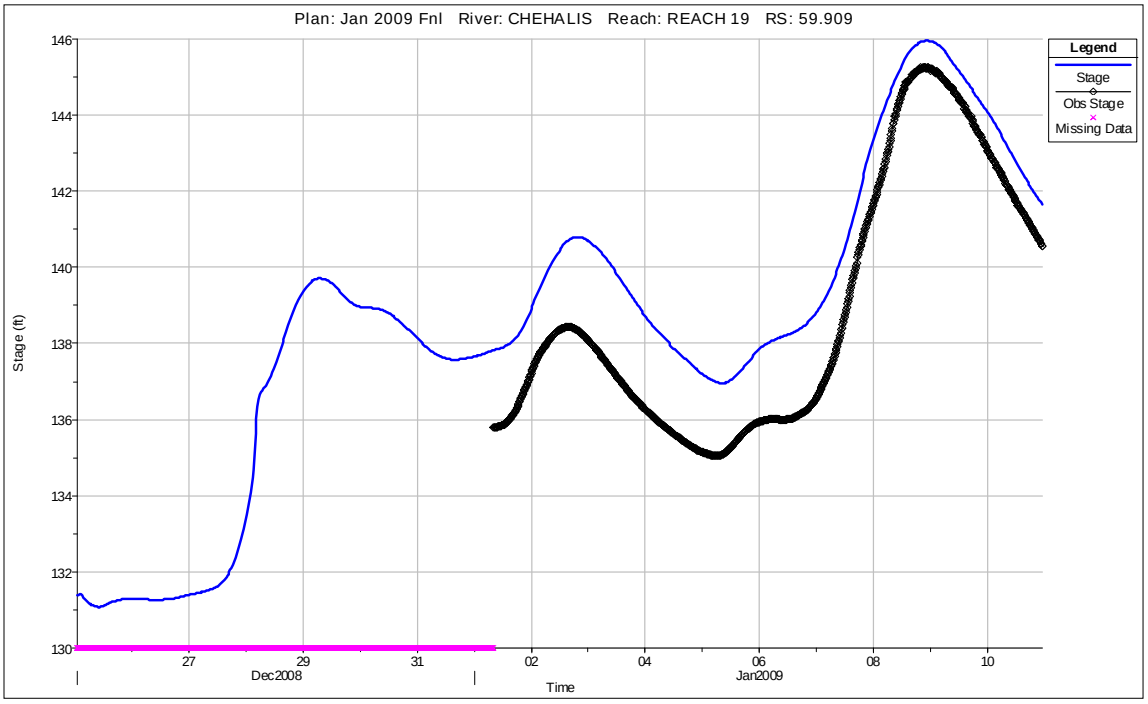


Figure 7. Stage hydrographs for Chehalis River at Grand Mound– January 2009

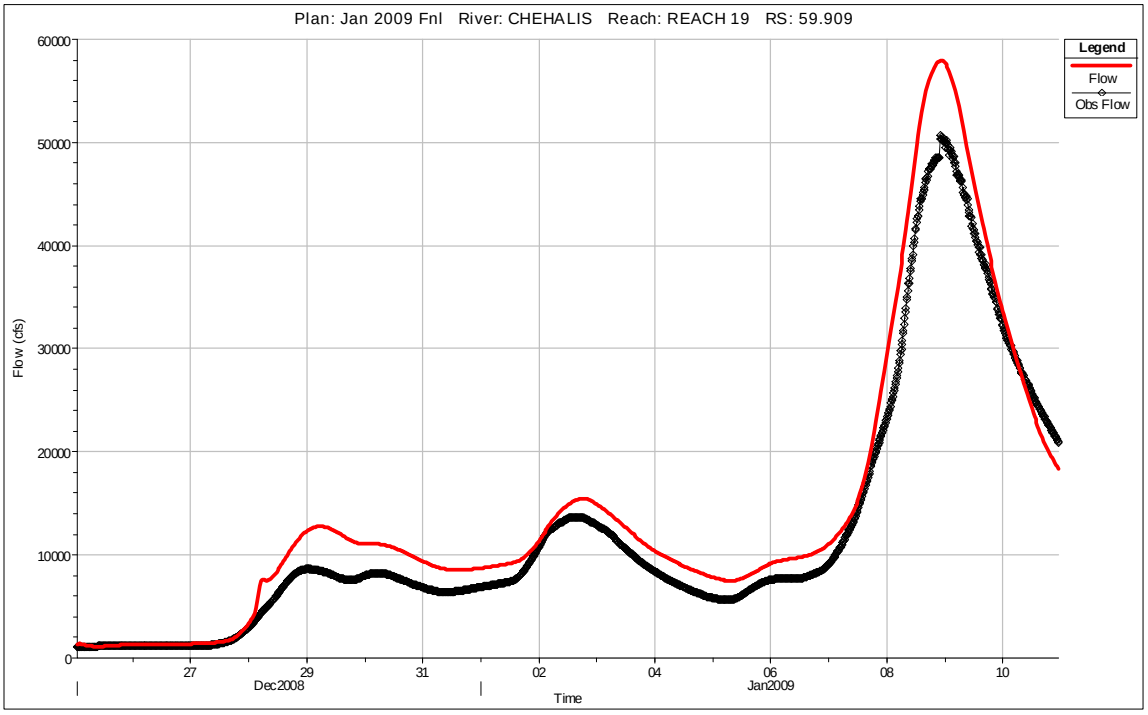


Figure 8. Flow hydrographs for Chehalis River at Grand Mound– January 2009

In addition to the stream gage data that were available for calibration, high water mark data are also available in specific locations throughout the basin. A comparison of simulated water surface elevations to recorded high water marks for the January 2009 event is shown in Table 5.

Table 5 Summary of high water mark data – January 2009

River	HEC-RAS River Station (RM)	Simulated Water Surface Elevation (feet NAVD88)	Observed High Water Mark (feet NAVD88)	Difference (feet NAVD88)
Chehalis River	85.99	213.22	211.1	2.12
Chehalis River	74.57	181.43	181.95	-0.52
Chehalis River	72.58	180.01	179.3	0.71
Chehalis River	64.25	161.51	163.11	-1.6
Chehalis River	64.2	161.33	163.11	-1.78
Dillenbaugh Creek	1	185.67	185.4	0.27
Dillenbaugh Creek	0.792	185.64	185.4	0.24
Dillenbaugh Creek	0.155	183.45	182.4	1.05
Dillenbaugh Creek	0.142	183.39	182.4	0.99
Newaukum River	1.3	185.26	185.4	-0.14
Salzer Creek	2.32	178.06	181.7	-3.64
Salzer Creek	2.25	177.98	181.7	-3.72
Salzer Creek	2.05	177.39	181.2	-3.81
Salzer Creek	1.15	177.26	176.4	0.86
Skookumchuck River	4	201.43	199.8	1.63
Skookumchuck River	2.41	190.54	190.46	0.08

December 2007 Event

Table 6 shows the comparison between modeled and observed peak flows at various locations on the Chehalis, Newaukum, and Skookumchuck Rivers for the January 2009 event. For illustration, a plot of simulated and observed stage and flow hydrographs at Grand Mound are included in Figures 9 and 10.

Table 6. Summary of model validation for flow for December 2007 event

Location	Computed Peak Flow (cfs)	Observed Peak Flow (cfs)	Difference in Peak Flow Magnitude (%)	Difference in Event Volume (%)	Peak Time Difference (hours)*
Chehalis River at Doty	62,215	63,100**	-1.4**	-0.1	0.0**
Chehalis River at Grand Mound	82,690	79,100	4.5	28.3	3.0
Chehalis River at Porter	84,790	102,000	-16.9	2.7	3.0
Newaukum River near Chehalis	12,458	12,900	-3.4	0.5	1.0
Skookumchuck River below Bloody Run	2,223	2,210	0.6	2.0	0.25
Skookumchuck River near Bucoda	3,494	3,600	2.9	0.9	-2.25

* A negative time difference denotes the simulated peak occurring before the observed peak

** Stream gage record ends near peak, values for comparison may be missing.

As seen in the table, most of the simulated and observed flow magnitude and volume differences are within 10 percent. The notable exceptions are the flow volume in the Chehalis River at Grand Mound and the peak flow magnitude in the Chehalis River at Porter. Similar to the 2009 calibration event, the simulated flow volume at Grand Mound is high compared to the observed volume. However, to "correct" this issue, the inflows upstream of Grand Mound would have to be dramatically reduced, and the inflows between Grand Mound and Porter would have to increase by about a multiple of three. We felt that this distribution of inflows would be unrealistic.

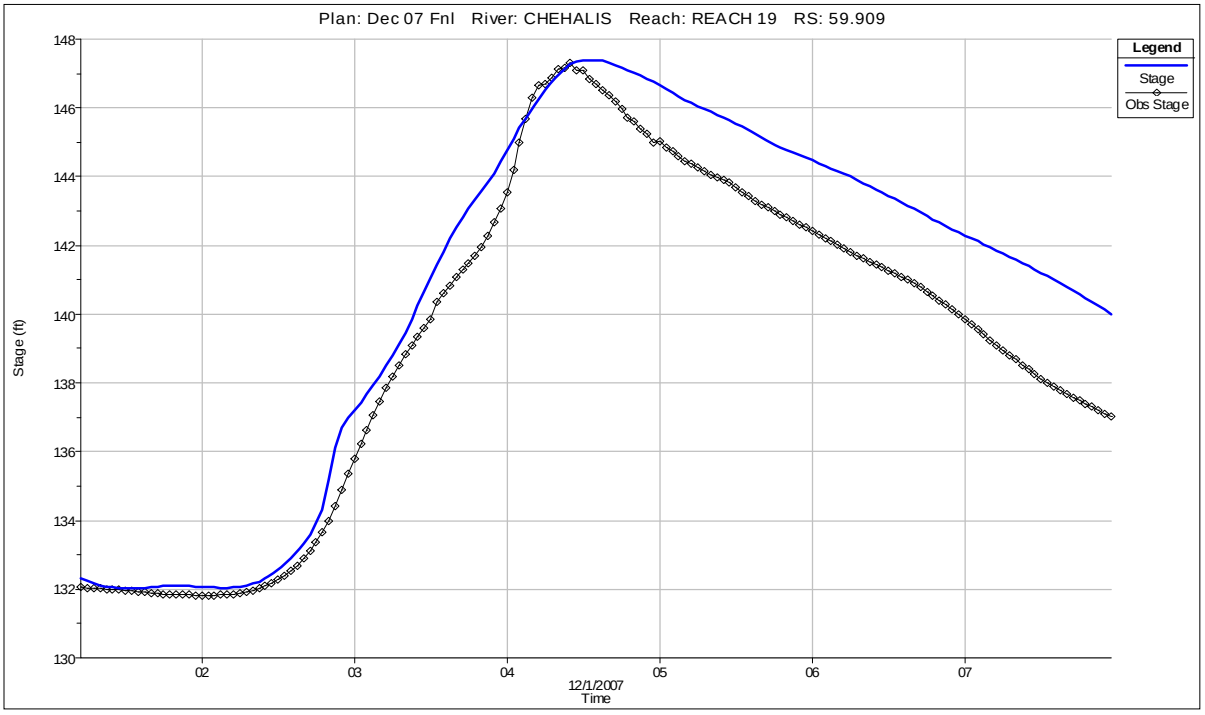


Figure 9. Stage hydrographs for Chehalis River at Grand Mound– December 2007

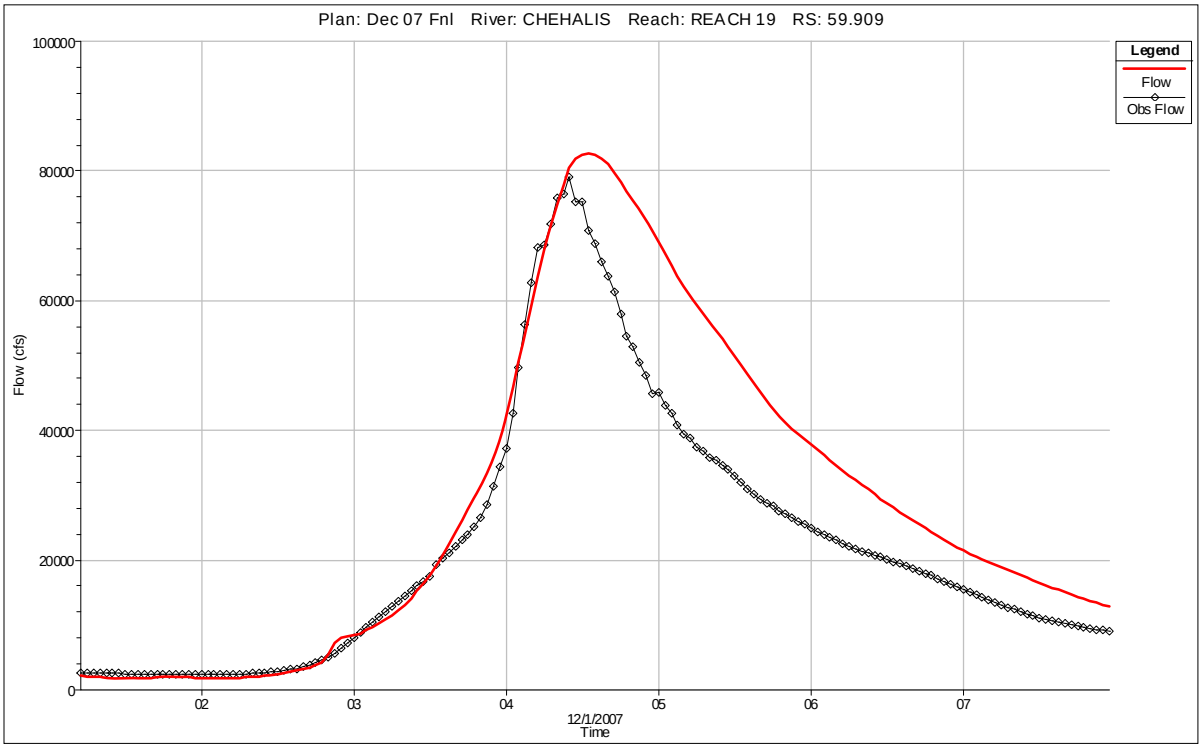


Figure 10. Flow hydrographs for Chehalis River at Grand Mound– December 2007

In addition to the stream gage data that were available for calibration, high water mark data are also available in specific locations throughout the basin. A comparison of simulated water surface elevations to recorded high water marks for the December 2007 event is shown in Table 7.

Table 7. Summary of high water mark data – December 2007

River	HEC-RAS River Station (RM)	Simulated Water Surface Elevation (feet NAVD88)	Observed High Water Mark (feet NAVD88)	Difference (feet NAVD88)
Black River	7.07	107.65	104.26	3.39
Black River	5.64	102.96	103.92	-0.96
Chehalis River	86.01	223.05	223.2	-0.15
Chehalis River	84.3	210.19	212.1	-1.91
Chehalis River	78.97	195.25	196.4	-1.15
Chehalis River	77.959	193.89	194	-0.11
Chehalis River	77.65	192.61	193.2	-0.59
Chehalis River	77.39	188.92	188.2	0.72
Chehalis River	75.2	186.62	187.65	-1.03
Chehalis River	74.73	185.03	185.48	-0.45
Chehalis River	74.25	183.9	184	-0.1
Chehalis River	74.02	183.65	184.1	-0.45
Chehalis River	73.73	183.37	183.1	0.27
Chehalis River	72.8	182.83	182.9	-0.07
Chehalis River	72.22	182.34	182.4	-0.06

Chehalis River	69.22	181.34	181.6	-0.26
Chehalis River	68.67	181.23	181.3	-0.07
Chehalis River	67.86	180.67	179.8	0.87
Chehalis River	66.95	176.5	175.5	1.00
Chehalis River	65.8	171.65	171.93	-0.28
Chehalis River	64.9	168.29	168.2	0.09
Chehalis River	61.96	155.75	157.9	-2.15
Chehalis River	61.7	155.75	153.13	2.62
Chehalis River	60.22	150.29	151.8	-1.51
Chehalis River	54.045	120.44	117.83	2.61
Chehalis River	53.264	115.33	115.42	-0.09
Chehalis River	52.947	113.98	114.72	-0.74
Chehalis River	51.499	106.03	111.34	-5.31
Dillenbaugh Creek	0.321	186.32	187	-0.68
Dillenbaugh Creek	0	185.03	185.48	-0.45
Newaukum River	0.1	186.97	187.65	-0.68
Salzer Creek	3.4	182.02	181.5	0.52
Salzer Creek	2.22	182.01	181.8	0.21
Salzer Creek	1.32	182.01	181.9	0.11
Salzer Creek	1.05	182.01	182.1	-0.09
Salzer Creek	0.65	182.01	181.8	0.21
Skookumchuck River	0.49	177.44	177.5	-0.06

Areas of concern

The development and calibration of the HEC-RAS hydraulic model developed for this project has followed the highest technical standards for a project such as this. The use of new channel and overbank topographic and bathymetric survey data to refine the model clearly improves the model's ability to capture physical conditions in the basin. Detailed calibration of the model to three large floods including numerous high water marks and flow and stage hydrographs improves our confidence in the model's ability to accurately simulate large flood events. Technical review of the model by three respected consulting firms, the Corps, WSDOT, WDFW, WADOE, and others helps ensure that the model is appropriately configured and well defined. However, despite all of these considerations, it must be remembered that any model is simply a representation of the actual system being investigated and any model is subject to uncertainty and error. In the case of the Chehalis River basin, the most significant issues leading to uncertainty in the results include the hydrologic data used to develop inputs to the model, potential anomalies during past flood events, and whether the hypothetical design flow events are adequately representative of the wide range of potential conditions. Each of these is discussed briefly below:

USGS Gage data

The USGS maintains a number of key streamflow gages in the Chehalis River basin. The USGS is the preeminent agency for streamflow gaging in the United States and data collected by the USGS is generally the best information available for gaining an understanding basin hydrology. Data from these gages is essential to

developing inputs to basin wide hydraulic modeling. However, it must be acknowledged that accurately estimating flows from extreme events is particularly difficult and the inherent uncertainties (errors) in gage data need to be considered when evaluating and using hydraulic model results. Several key streamflow gages in the Chehalis River basin, including the Chehalis River at Grand Mound, Chehalis River at Porter, and Newaukum River at Labree Road are subject to flows bypassing the gages during extreme flood events. Since the rating curves for these gages are generally developed using stage-discharge measurements made when flow is contained within the main channel (i.e. with no overbank bypass flows) it is unlikely that the extensions of these rating curves reflect the bypass flows. It is not clear, but discussions with the USGS and our review of the USGS data indicate that modifications to streamflow data to directly account for bypass flows are not made. As such, the data for periods when flows are bypassing the gage site are especially uncertain.

In addition to general difficulties in estimating high flows and particular concerns with gages that have bypass flows the data for several gages for the December 2007 flood are particularly difficult to use due to problems with the gages. The USGS gage at Doty was inoperable at the time of the peak of the December 2007 flood. The gage on the South Fork Chehalis River at Wildwood, while operable throughout the event had such large changes in bed level due to sediment movement during the event that the data is not felt to be useful at the peak of the flood. Because these gages measure runoff from the area where the storm was centered, and the mainstem and South Fork Chehalis were likely the source for 60% or more of the flow seen in the Twin Cities during the December flood, accurate modeling of that event is particularly problematic. However, considering the large number of calibration points throughout the basin, the availability of a continuous flow hydrograph at Grand Mound, and the work done by the USGS, the Corps, and FEMA/NHC to accurately re-create flood flow hydrographs for the upper basin for the December 2007 flood, we are confident that modeling and analysis of that flood is still appropriate for the current project. We would simply caveat the results that there is probably greater uncertainty in the flow values during that event than in other, less severe events.

Doty Flows – debris jams, volumes

Residents in the Upper Chehalis River, upstream of the South Fork confluence, have suggested that debris jams and or damming of the river caused by failed bridges during the December 2007 flood event were significant factors in the magnitude of the observed flows. The USGS has reviewed this issue and has determined that their estimate of the flood peak at Doty is reasonable. However there remains significant uncertainty in the flows reported for all gages in the upper basin during that flood event due to the fact that the discharges were higher than any previously seen and that there were significant debris and sediment issues throughout the watershed. The analyses documented herein include simulations of three extreme flood events, in addition to the December 2007 flood, and as such the conclusions reached regarding flood relief alternatives should hold regardless of the uncertainty in the hydrologic data for that particular flood.

“Representativeness” of 100-year flood

As discussed above, some reviewers felt that the Chehalis River Basin is too large and flood flows are too variable to model using only one or a few design storm events. Some reviewers suggested that the only way to adequately evaluate flood relief projects would be to develop a calibrated basin-wide hydrologic model and use that model to derive inputs to the hydraulic modeling and analysis. Unfortunately, there is neither time nor budget to undertake such an effort within this project. We concur that the basin hydrology is diverse and that no two storms will look the same. We also acknowledge that the approach of using one theoretical design

storm and three historic flood events is not perfect. For this reason it may be necessary to develop additional hydrologic data sets and make additional model runs to evaluate some projects, particularly projects on the tributaries. However, we feel that the approach taken in this study, as modified in consultation with the State tech team, is appropriate to meet the current needs of the Flood Authority. Future modeling efforts with different hydrologic data sets would be straightforward to model once the data were developed. These analyses could be conducted by any qualified hydraulic engineer on behalf of any stakeholder or agency using the HEC-RAS model. Again this highlights the benefit of a cooperatively developed and well vetted model.

Model Geometry versus Current Conditions

Although geometric (cross section) data used in the hydraulic model utilized the best available data sources, that data may not always accurately reflect current conditions. Notable data sets include topography from 1999 (in the Twin Cities floodplain area), 2002 (between Grand Mound and Montesano and along the Skookumchuck River), and 2005 and 2006 in Centralia and Chehalis. On the lower Satsop River, for example, significant channel adjustments have occurred since the 2002 LiDAR used in the current model. However, without updated overbank LiDAR, Satsop channel changes could not be reliably incorporated into the current model.

Although the current effort included new channel survey for a significant portion of the Lower Chehalis River, in-channel and bridge structure data for much of the upper basin and tributaries is from existing model cross sections, which are based on older, often sparse, cross section survey. The representativeness of model geometry should be carefully considered by a qualified hydraulic engineer before the model is utilized for other purposes or projects.

New topographic data will be available soon for much of the basin (Chehalis River corridor from Lewis County line to Montesano) or is already available (Thurston County and portions of Lewis County). The new topographic data could be used to update the hydraulic models thus improving the model's ability to simulate overbank flooding. This effort, however, was beyond the scope and schedule of the current project.

Modeling Tidal Flooding in the Lower Chehalis

Extension of the Lower Chehalis Model from Montesano (RM 12) to Grays Harbor was completed and calibrated for large flood events, and therefore may not provide a good representation of low flow conditions. The model was set up to handle significant riverine flow in conjunction with tidal exchange but it does not attempt to model the effects of solely (or principally) tidal flooding. As such the daily filling and flushing of the intertidal channels and surge plain downstream of Montesano would not be particularly well modeled during times when the river is not flooding. Extension of the Flood Authority model into Grays Harbor was done through the inclusion of a tidal boundary (using observed and/or predicted tide data) to provide a tool for the evaluation of the downstream impact/benefit of upstream flood relief alternatives. The estuary; however, is a dynamic system with a large tidal surge plain and numerous overflow paths and tidal sloughs that behave much differently under low flow conditions, and a different tool (possibly a 2-D model) may be more well suited for low-flow or ecological studies downstream of Montesano.

Alternatives Analysis

Definition of Alternatives

WSE updated the Flood Authority HEC-RAS model in order to examine a number of flood reduction scenarios, including the Dam and Levee alternatives detailed in Task 8, and an additional thirteen alternatives and ten combinations of those alternatives. Descriptions of each model scenario are included below.

Mainstem Chehalis River Dam

Following the severe flood in 2007, the Chehalis Basin Flood Authority began to evaluate whether flood retention structures in the Chehalis River Basin might be part of a solution to basin-wide flooding. This built on early work by the Corps of Engineers and the Lewis County Public Utilities District. After reviewing several sites, the flood retention project site still under consideration is a multi-purpose dam located upstream of Pe Ell on the Upper Chehalis River. The structure would have 80,000 ac-ft of dedicated flood control storage, a structural height of 288 feet, flow augmentation/hydropower storage capacity of 65,000 ac-ft, and an estimated construction cost of $245 million (Phase IIB).

Using the calibrated baseline geometry, WSE modeled the impacts of the dam above Pe Ell by altering model inflow to include the hydrologic effect of the upstream retention facility.

Corps Twin City Levee Project

Beginning in the 1980s the US Army Corps of Engineers began to evaluate a plan to build 11 miles of new levees in the Chehalis River floodway through Chehalis and Centralia. The Corps presented a design to build miles of new levees to the Centralia City Council in 1980. This basic plan was authorized for further analysis, but not funded for construction, by Congress as the Centralia Flood Damage Reduction Project ("Twin Cities project"). Work on the Twin City plan was largely shelved by the Corps in 2011 after the Corps determined that the proposed project would not have protected I-5 during the 2007 flood, would have increased flooding upstream and downstream and, at a cost of over $200 million, would not pass the Corps cost-benefit test.

The Twin Cities Levee project includes:

- Construction of a levee system designed to provide protection along the Chehalis River from approximately river mile (RM) 75 to RM 64 and along most of the lower 2 miles of both Dillenbaugh Creek and Salzer Creek.
- Construction of a levee along the lower approximately 2 miles of Skookumchuck River to the confluence with Coffee Creek that would provide 100-year level of protection.
- Raising the elevation of approximately eight structures that would incur induced damages from increased inundation as a result of the project, located near the Airport, Interstate-5, Skookumchuck River, and Salzer Creek.
- Modification of Skookumchuck Dam to provide for an additional 11,000 acre-feet of flood storage. The project would limit outflows from the dam and attempt to keep the flow in the Skookumchuck River Channel at the Pearl Street Bridge at or below 5,000 cfs.
- Total estimated cost of $205 million.

Mellen Street Bypass

Historically, the bridge at Mellen Street has been suggested by some as a significant cause of flood impacts in the Twin Cities area. However, the Chehalis HEC-RAS model predicts that there would be little benefit from

removing the bridge, in part because the natural topography, even without the bridge, acts as a constriction to flood waters. A different alternative would be to construct a high flow bypass from the left edge of the Chehalis River floodplain upstream of Mellen Street (RM 67.7) to downstream of the Skookumchuck River confluence (RM 66.16). The bypass channel would be approximately 700 feet wide and flow depths would be up to 10 feet deep in a flood such as December 2007.

Scheuber Bypass

The Chehalis River downstream of State Highway 603 flows parallel to Highway 6 for approximately 2.5 miles before turning north and flowing under the SR-6 highway bridge near the City of Chehalis. Water overtopping the highway upstream of the Newaukum River confluence enters the Scheuber Bypass reach that reconnects to the Chehalis River downstream of SR-6 near the Chehalis-Centralia Airport, effectively bypassing city of Chehalis. The Scheuber Bypass Alternative would provide culvert or bridge connections under the highway to pass additional flow downstream and into the bypass, with the goal of reducing peak flood levels within the City of Chehalis. A modeled connection was made by placing a large opening within a portion of the lateral structure representing Highway 6 near River mile 77.3.

Dredging/Channel Excavation

In the past, the Corps also evaluated a project to dredge or excavate the mainstem Chehalis River channel downstream of Mellen Street. WSE modeled a dredge/excavation project similar to the Corps investigated project, which would extend from just downstream of Mellen Street to just downstream of Lincoln Creek (RM 67.29 to RM 60.51). The modeled excavation had a 120-foot bottom width trapezoidal channel, and would lower the channel bottom by as much as 15 feet in some locations (tapering into the existing channel at the upstream and downstream ends). According to PIE's Chehalis River Basin Flood Reduction Report (1998), there is a natural rise in the river bottom in this area; the substrate is most likely bedrock that likely would require blasting for removal. Part of the area under consideration for dredging is fairly high quality riparian zone dominated by black cottonwood, red alder, Douglas fir, western red cedar, with an understory of salmonberry, snowberry, and other native shrubs and herbs. The portions of the area considered for dredging have good quality spawning habitat adjacent to it in the Chehalis River, and a high quality riparian zone with seasonally connected side channels. Habitat diversity, species diversity, wetlands and refugia are good quality (USACE 2012b).

Dredging of the Chehalis River would also require some dredging within the lower reaches of the Skookumchuck River. Model cross sections between the mouth of the Skookumchuck River and RM 3.32 were cut to create a 20 foot wide trapezoidal channel in order to tie the Skookumchuck River channel into the lowered Chehalis River channel and provide model stability.

Bridge Removal

Road and bridge restrictions throughout the Chehalis Basin can constrain the flow of the Chehalis River and its tributaries during flood events. Major floods have resulted in bridges overtopping and the inundation of access roads; damage has occurred in areas such as upstream of SR-6, Mellen Street, Galvin Road, the Sickman-Ford Bridge, Porter Creek Road, and Wakefield Road. Modifications of the SR-6 Bridge and Mellen St. Bridge were proposed in the PIE Chehalis River Basin Flood Reduction Report (1998), and projects involving modifications to Sickman-Ford Bridge and Galvin Road were referenced in the Comprehensive Flood Hazard Management Plan

for Confederated Tribes of the Chehalis Reservation. In fact, the Chehalis Tribe has evaluated options for changes to the Sickman-Ford Bridge and developed a scope for additional engineering design. Modifications to the Porter Creek Road and Wakefield Road (South Elma Bridge) were suggested as possible flood relief projects during lower basin stakeholder meetings in June 2012.

To better understand the potential for reduced flood impacts, various road and bridge removal projects were modeled using the Chehalis HEC-RAS model, including:

- Removing all bridges and approach fills in the entire model
- Removing the bridge and approach fill of SR-6 alone
- Removing the bridge and approach fills of Mellen Street
- Removing the Bridge and approach fills of Galvin Road
- Removing the bridge and approach fills of Sickman-Ford Bridge
- Removing the bridge and approach fills of Porter Creek Road Bridge
- Removing the bridge and approach fills of Wakefield Road (South Elma) Bridge

Due to time and budget constraints bridge removals were modeled by simply removing the bridge structure, approach fills, and upstream and downstream ineffective flow areas from the model. That is, the entire bridge and approach was removed rather than modified. Obviously, this could create significant concerns for transportation and new bridges and approach roads would likely be necessary in some or all locations to replace the existing structures. The purpose of the current modeling effort was to identify the maximum possible benefit that could be derived from bridge removals so that future analysis efforts could be prioritized to structures that showed some possibility of reducing flooding rather than simply to bridges that have been previously identified as concerns.

I-5 Protection

Flooding in the Chehalis Basin has affected access to I-5, closing it for four days in 1996, four days in 2007, and two days in 2009. The Washington Department of Transportation (DOT) estimated the total loss in economic output to the state economy due to the closure of I-5 in 2007 at $47 million (DOT). The major costs from I-5 closure are freight delays, but closures also impact private operating companies by affecting logistical and scheduling costs, as well as indirect market costs.

The Mellen Street to Blakeslee Junction (MTB) project now underway will provide access to the hospital in Centralia during flood events from downtown Centralia. In addition, the 2011 Washington State Legislature and the Washington State Office of Finance Management (OFM) directed WSDOT to evaluate alternative projects that could protect I-5 and the municipal airport at Centralia and Chehalis. OFM contracted with WSDOT to perform the work on I-5 alternatives. Project alternatives evaluated include raising I-5 using fill material, raising I-5 using a viaduct, relocating I-5 outside the flood area, and protecting I-5 with walls and levees. The fill, viaduct, and relocation projects had cost estimates ranging from $350 million - $2 billion.

The option modeled by WSE would protect I-5 with walls and levees, which has a projected cost of $80-100 million. This project would involve building earthen levees and structural walls, replacing bridges with bottomless arches at Dillenbaugh and Salzer Creek, and providing stormwater treatment systems.

Localized I-5 Protection and Airport Levee Improvements

The Chehalis HEC-RAS model predicts that even if a water retention project in the upper watershed were constructed, it alone would not protect I-5 from flooding during the 2007 and 2009 flood events. Improvements near the south end of Centralia-Chehalis Airport, north of Salzer Creek and north of the 13th Street interchange would also need to be implemented to protect I-5 from flooding. Over the past few years the Chehalis-Centralia Airport has been working on a project for enhancing the Airport Levee. The airport levee enhancement project is designed to provide protection for the Airport and to a lesser degree I-5.

The airport levee project would involve raising the existing 2.3 miles of earthen levee to an elevation three feet above the 100 year flood level as recently identified by FEMA. This is accomplished by widening the base of the levee and constructing it higher in a way that maintains existing side slopes. In addition to the improvements to the existing levee, the project would elevate Airport Road along the south side of the Airport and replace all utility infrastructure. The cost estimate for this project is approximately $3.2 million, with the roadway improvements responsible for the majority of the cost.

However, to achieve protection of the airport area in a 100-year event, some additional localized flood protection improvements would be needed along I-5 north of Salzer Creek and south by Dillenbaugh Creek. This alternative would include those improvements, designed to a level to eliminate I-5 flooding in an event such as the December 2007 Flood.

Skookumchuck Levees

The Corps Twin Cities Levee Project described previously includes levee segments throughout the Twin Cities area in addition to modifications to operations at Skookumchuck Dam. As documented in the Corps Project Closeout Report (2012b) the Corps has determined that the Twin Cities Project is not viable given federal benefit cost criteria. A modified proposal was developed which would include only the levees along the Skookumchuck River (Corps Levee Reaches 12 through 16) and the levee downstream of the Skookumchuck River confluence (Corps Reach 1). This proposal would not include any modifications to Skookumchuck Dam but would assume that the levees were constructed sufficiently high to prevent overtopping in any of the simulated flood events.

Potential Combinations of Alternatives

Following the initial run of flood reduction projects, WSE was asked to model a number of projects in combination to determine the additive impact on flood levels. The following alternatives were simulated in an initial phase of this work:

1) with mainstem dam and airport levee improvements
2) with WSDOT floodwalls/berms and airport levee improvements
3) with Scheuber bypass, Mellen Street bypass, and airport levee improvements
4) with dam, airport levee improvements, WSDOT floodwalls/berms
5) with dam, airport levee improvements, WSDOT floodwalls/berms, downstream bridge removals
6) with Scheuber bypass, Mellen Street bypass, airport levee improvements, WSDOT floodwalls/berms, downstream bridge removals

7) with Scheuber bypass, Mellen Street bypass, airport levee improvements, small floodwall along I-5 near Dillenbaugh Creek

The results of these alternatives were presented at a workshop held in early June in Grand Mound. The participants at that workshop reviewed the results of the preliminary modeling of the combination alternatives and provided feedback on which of these should be developed and evaluated further. The following alternatives were selected for additional modeling and analysis:

A. Mainstem Dam on the Chehalis River, Airport levee improvements, small floodwall along I-5 near Dillenbaugh Creek, Skookumchuck Levees, Sickman Ford Bridge modification, and Wakefield Road (South Elma) Bridge Modification.

B. Same as Alternative "A" with the addition of WSDOT's proposed I-5 berms and floodwall protection project.

C. WSDOT's I-5 berms and floodwalls, Airport levee improvements, Mellen Street and Scheuber Road Bypasses, Skookumchuck Levees, Sickman Ford Bridge modification, and Wakefield Road (South Elma) Bridge Modification.

Results

Results of the simulation of basin wide flood relief alternatives are presented below. Tabular results are included for every alternative and combination of alternatives listed above. Additional, more detailed analyses have also been prepared for some alternatives. These include inundation mapping for the Twin Cities area, detailed evaluation of flooding of I-5, and bar charts comparing the results at various locations throughout the basin for the December 2007 and 100-year events. These more detailed analyses were completed for several of the individual alternatives and each of the groupings described above. While only the results for combination alternatives A, B, and C are presented herein, many others were presented at workshops or Flood Authority meetings over the course of this project. The additional interim results will be included in the final products submitted by WSE to the Flood Authority.

Tabular Summary

Tables 8, 9, and 10 compare the simulated water surface elevations under each of the modeled alternatives with baseline conditions. Comparisons are made at 26 representative locations distributed throughout the basin. These were focused primarily along the main stem Chehalis River but include points along the South Fork Chehalis, Newaukum, and Skookumchuck Rivers. Table 8 includes data for the December 2007 and 100-year flood events for the individual project elements while Table 9 shows the same alternatives for the February 1996 and January 2009 events. Table 10 compares the effect on water surface elevations of combinations of flood relief elements for all four modeled events. The broad distribution of points provides a basin-wide picture of the effects of each alternative and the data for the four simulated floods allows evaluation of the effects under different types of floods.

Table 8: Comparison of Water Surface Elevation Changes with Flood Relief Alternatives – December 2007 and 100-year Storm Events

Alternatives Analysis Summary for December 2007 Flood Event

Location		Max Water Surface Elevation (feet NAVD) or Change in Flood Water Surface (feet)														
Description	X-section	Dec 07 (ft NAVD)	Dec w/Dam (ft NAVD)	Change (ft NAVD)	Dec w/Lev (ft NAVD)	Change (ft NAVD)	Dec w/Dam&Lev (ft NAVD)	Change (ft NAVD)	Dec MellenBP (ft NAVD)	Change (ft NAVD)	Dec Dredge (ft NAVD)	Change (ft NAVD)	Dec ScheuberBP (ft NAVD)	Change (ft NAVD)	Dec Sc-AP-Mel (ft NAVD)	Change (ft NAVD)
Near Doty	100.95	328.1	315.8	-12.3	328.1	0.0	315.8	-12.3	328.1	0.0	328.1	0.0	328.1	0.0	328.1	0.0
Curtis Store (on S Fork Chehalis)	1.81	238.9	232.8	-6.1	238.9	0.0	232.8	-6.1	238.9	0.0	238.9	0.0	238.9	0.0	238.9	0.0
Downstream of South Fork	86.42	227.7	222.1	-5.6	227.7	0.0	222.1	-5.6	227.7	0.0	227.7	0.0	227.7	0.0	227.7	0.0
Near Adna	80.23	197.9	196.3	-1.6	197.9	0.0	196.3	-1.6	197.9	0.0	197.9	0.0	197.9	0.0	197.9	0.0
Labree Road (on Newaukum R)	4.11	204.7	204.7	0.0	204.7	0.0	204.7	0.0	204.7	0.0	204.7	0.0	204.7	0.0	204.7	0.0
Newaukum Confluence	75.2	186.6	184.4	-2.2	187.1	0.5	184.5	-2.2	186.6	0.0	186.6	0.0	185.1	-1.5	185.6	-1.0
Along Airport Levee	71.49	182.1	179.2	-2.9	183.4	1.3	179.7	-2.4	180.4	-1.7	181.5	-0.7	182.1	-0.1	181.3	-0.9
Dillenbaugh Storage Area	SA #301	186.6	184.2	-2.3	187.0	0.5	184.4	-2.2	186.6	0.0	186.6	0.0	185.2	-1.4	185.7	-0.9
Airport Storage Area	SA #2	182.2	178.4	-3.7	168.6	-13.5	159.4	-22.8	180.6	-1.6	181.5	-0.7	182.1	-0.1	159.4	-22.8
Long Road Storage Area	SA #5	179.1	169.4	-9.7	178.0	-1.1	169.4	-9.7	177.7	-1.4	178.5	-0.6	179.1	-0.1	169.4	-9.7
Centralia Storage Area	SA #610	178.5	174.5	-4.0	176.8	-1.7	174.5	-3.9	175.8	-2.7	177.2	-1.3	178.4	-0.1	174.7	-3.8
Mellen St	67.43	178.6	175.7	-2.9	178.9	0.3	176.0	-2.6	175.4	-3.2	176.9	-1.7	178.6	-0.1	175.5	-3.1
Bucoda (Skookumchuck R)	11.1	244.3	244.3	0.0	244.3	0.0	244.3	0.0	244.3	0.0	244.3	0.0	244.3	0.0	244.3	0.0
Pearl Street (Skookumchuck R)	2.43	186.6	186.6	0.0	186.6	0.0	186.6	0.0	186.6	0.0	179.6	-7.0	186.6	0.0	186.6	0.0
Skookumchuck Confluence	66.88	176.4	173.4	-3.0	176.4	0.0	173.7	-2.7	174.5	-1.9	174.5	-2.0	176.4	-0.1	174.5	-1.9
Upstream of Galvin Road	64.9	168.2	164.6	-3.6	168.2	0.0	164.9	-3.3	168.5	0.3	166.6	-1.6	168.1	-0.1	168.6	0.3
Grand Mound (Prather Road)	59.909	147.4	145.7	-1.7	147.4	0.0	145.8	-1.5	147.5	0.2	147.4	0.0	147.3	0.0	147.6	0.2
Near Rochester	54.476	124.2	122.0	-2.2	124.2	0.0	122.2	-2.0	124.4	0.2	124.2	0.0	124.2	0.0	124.5	0.3
Anderson Road	51.499	106.0	105.3	-0.7	106.0	0.0	105.4	-0.6	106.1	0.1	106.0	0.0	106.0	0.0	106.1	0.1
Black River Confluence	46.937	92.9	90.9	-2.0	92.9	0.0	91.1	-1.9	93.1	0.2	92.9	0.0	92.9	0.0	93.2	0.3
Sickman Ford Bridge	44.175	85.5	83.0	-2.5	85.5	0.0	83.2	-2.3	85.7	0.2	85.5	0.0	85.5	0.0	85.8	0.3
Porter Creek Road	34.497	57.0	54.7	-2.3	57.0	0.0	54.9	-2.1	57.2	0.2	57.0	0.0	57.0	0.0	57.3	0.3
Wakefield Road	24.52	40.2	37.7	-2.5	40.3	0.0	37.9	-2.3	40.4	0.2	40.2	0.0	40.2	0.0	40.6	0.4
Satsop Confluence	19.89	34.5	33.1	-1.4	34.5	0.0	33.2	-1.3	34.6	0.1	34.5	0.0	34.5	0.0	34.7	0.2
Montesano	12.5	17.3	15.6	-1.7	17.4	0.1	15.7	-1.6	17.5	0.2	17.2	-0.1	17.4	0.1	17.7	0.4
Cosmopolis	1.99	10.9	10.9	0.0	10.9	0.0	10.9	0.0	10.9	0.0	11.0	0.1	10.9	0.0	10.9	0.0

Note: Negative change means that the alternative has lower simulated water levels, positive change indicates the alternative raises water levels.

Alternatives Analysis Summary for 100-year Design Event

Location		Max Water Surface Elevation (feet NAVD) or Change in Flood Water Surface (feet)														
Description	X-section	100 Year (ft NAVD)	100 w/Dam (ft NAVD)	Change (ft NAVD)	100 w/Lev (ft NAVD)	Change (ft NAVD)	100 w/Dam&Lev (ft NAVD)	Change (ft NAVD)	100 w/MellenBP (ft NAVD)	Change (ft NAVD)	100 w/Dredge (ft NAVD)	Change (ft NAVD)	100 w/ScheuberBP (ft NAVD)	Change (ft NAVD)	100 w/Sc-AP-Mel (ft NAVD)	Change (ft NAVD)
Near Doty	100.95	323.2	313.0	-10.3	323.2	0.0	313.0	-10.3	323.2	0.0	323.2	0.0	323.2	0.0	323.2	0.0
Curtis Store (on S Fork Chehalis)	1.81	233.6	230.2	-3.3	233.6	0.0	230.2	-3.3	233.6	0.0	233.6	0.0	233.6	0.0	233.6	0.0
Downstream of South Fork	86.42	223.2	219.1	-4.1	223.2	0.0	219.1	-4.1	223.2	0.0	223.2	0.0	223.2	0.0	223.2	0.0
Near Adna	80.23	197.1	195.5	-1.6	197.1	0.0	195.5	-1.6	197.1	0.0	197.1	0.0	197.1	-0.1	197.1	-0.1
Labree Road (on Newaukum R)	4.11	204.9	204.9	0.0	204.9	0.0	204.9	0.0	204.9	0.0	204.9	0.0	204.9	0.0	204.9	0.0
Newaukum Confluence	75.2	185.7	184.1	-1.6	186.0	0.3	184.1	-1.6	185.7	0.0	185.6	-0.1	183.8	-1.9	184.0	-1.7
Along Airport Levee	71.49	180.8	179.1	-1.7	181.7	0.9	179.3	-1.4	179.4	-1.4	180.0	-0.8	180.8	0.0	179.9	-0.9
Dillenbaugh Storage Area	SA #301	185.8	184.3	-1.5	186.1	0.2	184.3	-1.5	185.8	0.0	185.8	0.0	184.2	-1.6	184.4	-1.4
Airport Storage Area	SA #2	180.8	177.2	-3.6	159.4	-21.4	159.4	-21.4	179.4	-1.3	179.9	-0.9	180.8	0.0	159.4	-21.4
Long Road Storage Area	SA #5	177.9	169.4	-8.5	176.7	-1.3	169.4	-8.5	169.4	-8.5	176.7	-1.2	177.9	0.0	169.4	-8.5
Centralia Storage Area	SA #610	176.7	174.8	-1.9	176.1	-0.5	174.9	-1.8	174.3	-2.3	175.1	-1.6	176.6	0.0	174.3	-2.3
Mellen St	67.43	177.6	175.8	-1.8	177.8	0.2	176.0	-1.6	174.3	-3.3	175.5	-2.1	177.6	0.0	174.5	-3.1
Bucoda (Skookumchuck R)	11.1	252.0	252.0	0.0	252.0	0.0	252.0	0.0	252.0	0.0	252.0	0.0	252.0	0.0	252.0	0.0
Pearl Street (Skookumchuck R)	2.43	191.7	191.7	0.0	191.7	0.0	191.7	0.0	191.7	0.0	189.4	-2.3	191.7	0.0	191.7	0.0
Skookumchuck Confluence	66.88	175.7	174.0	-1.7	175.8	0.1	174.2	-1.5	173.8	-1.9	173.5	-2.2	175.7	0.0	173.9	-1.8
Upstream of Galvin Road	64.9	167.3	165.2	-2.1	167.4	0.1	165.4	-2.0	167.6	0.2	165.5	-1.8	167.3	0.0	167.8	0.4
Grand Mound (Prather Road)	59.909	147.1	146.2	-0.9	147.1	0.0	146.3	-0.8	147.2	0.1	147.1	0.0	147.1	0.0	147.3	0.2
Near Rochester	54.476	124.0	122.8	-1.2	124.1	0.1	122.9	-1.1	124.2	0.2	124.0	0.0	124.0	0.0	124.4	0.4
Anderson Road	51.499	106.1	105.7	-0.3	106.1	0.0	105.8	-0.3	106.1	0.1	106.1	0.0	106.1	0.0	106.2	0.1
Black River Confluence	46.937	93.0	92.0	-1.1	93.1	0.1	92.1	-0.9	93.2	0.2	93.0	0.0	93.0	0.0	93.4	0.4
Sickman Ford Bridge	44.175	85.6	84.3	-1.3	85.7	0.1	84.4	-1.2	85.8	0.2	85.6	0.0	85.7	0.0	86.1	0.4
Porter Creek Road	34.497	57.4	56.2	-1.2	57.5	0.1	56.3	-1.1	57.5	0.2	57.4	0.0	57.4	0.0	57.8	0.5
Wakefield Road	24.52	41.6	40.1	-1.5	41.7	0.1	40.2	-1.4	41.8	0.2	41.6	0.0	41.7	0.1	42.1	0.5
Satsop Confluence	19.89	35.4	34.8	-0.6	35.5	0.1	34.9	-0.6	35.5	0.1	35.4	0.0	35.5	0.1	35.7	0.2
Montesano	12.5	18.8	18.1	-0.7	18.9	0.1	18.2	-0.7	19.0	0.1	18.9	0.0	18.9	0.1	19.2	0.3
Cosmopolis	1.99	11.0	10.6	-0.4	10.6	-0.4	10.6	-0.4	11.1	0.1	11.0	0.0	11.1	0.1	11.2	0.2

Note: Negative change means that the alternative has lower simulated water levels, positive change indicates the alternative raises water levels.

Table 8 (continued): Comparison of Water Surface Elevation Changes with Flood Relief Alternatives – December 2007 and 100-year Storm Events

Alternatives Analysis Summary for December 2007 Flood Event

Location			Max Water Surface Elevation (feet NAVD) or Change in Flood Water Surface (feet)													
Description	X-section	Dec 07 (ft NAVD)	Dec WSDOT I5 (ft NAVD)	Change (ft NAVD)	Dec WSDOT-AP (ft NAVD)	Change (ft NAVD)	Dec I5-Dam (ft NAVD)	Change (ft NAVD)	Dec I5-Dam-Br (ft NAVD)	Change (ft NAVD)	Dec I5-2BP-Br (ft NAVD)	Change (ft NAVD)	Dec Twin Cities (ft NAVD)	Change (ft NAVD)	Dec No Bridges (ft NAVD)	Change (ft NAVD)
Near Doty	100.95	328.1	328.1	0.0	328.1	0.0	315.8	-12.3	315.8	-12.3	328.1	0.0	328.1	0.0	327.7	-0.4
Curtis Store (on S Fork Chehalis)	1.81	238.9	238.9	0.0	238.9	0.0	232.8	-6.1	232.8	-6.1	238.9	0.0	238.9	0.0	239.0	0.1
Downstream of South Fork	86.42	227.7	227.7	0.0	227.7	0.0	222.1	-5.6	222.1	-5.6	227.7	0.0	227.7	0.0	227.7	0.0
Near Adna	80.23	197.9	197.9	0.0	197.9	0.0	196.3	-1.6	196.3	-1.6	197.9	0.0	197.9	0.0	197.9	0.0
Labree Road (on Newaukum R)	4.11	204.7	204.7	0.0	204.7	0.0	204.7	0.0	204.7	0.0	204.7	0.0	204.7	0.0	204.7	0.0
Newaukum Confluence	75.2	186.6	186.7	0.1	187.2	0.6	184.5	-2.1	184.5	-2.1	185.6	-1.0	187.7	1.1	186.1	-0.5
Along Airport Levee	71.49	182.1	183.0	0.8	183.4	1.2	179.7	-2.4	179.7	-2.4	181.3	-0.8	184.1	2.0	182.1	0.0
Dillenbaugh Storage Area	SA #301	186.6	186.8	0.3	187.3	0.8	184.4	-2.2	184.4	-2.2	185.8	-0.8	173.4	-13.2	185.5	-1.0
Airport Storage Area	SA #2	182.2	183.1	0.9	159.4	-22.8	159.4	-22.8	159.4	-22.8	159.4	-22.8	174.9	-7.3	182.1	0.0
Long Road Storage Area	SA #5	179.1	177.9	-1.2	177.9	-1.2	169.4	-9.7	169.4	-9.7	169.4	-9.7	181.9	2.7	179.1	0.0
Centralia Storage Area	SA #610	178.5	176.6	-1.9	176.7	-1.8	174.6	-3.9	174.5	-3.9	174.6	-3.8	181.9	3.4	178.5	0.0
Mellen St	67.43	178.6	178.9	0.2	178.9	0.2	176.0	-2.6	176.0	-2.6	175.5	-3.2	179.4	0.8	178.7	0.1
Bucoda (Skookumchuck R)	11.1	244.3	244.3	0.0	244.3	0.0	244.3	0.0	244.3	0.0	244.3	0.0	245.5	1.3	244.2	-0.1
Pearl Street (Skookumchuck R)	2.43	186.6	186.6	0.0	186.6	0.0	186.6	0.0	186.6	0.0	186.6	0.0	187.1	0.5	186.6	0.0
Skookumchuck Confluence	66.88	176.4	176.4	-0.1	176.4	-0.1	173.7	-2.7	173.7	-2.7	174.5	-2.0	177.1	0.7	176.5	0.0
Upstream of Galvin Road	64.9	168.2	168.2	-0.1	168.2	-0.1	164.9	-3.3	164.8	-3.5	168.1	-0.1	168.5	0.3	167.9	-0.3
Grand Mound (Prather Road)	59.909	147.4	147.3	-0.1	147.3	0.0	145.9	-1.5	146.7	-0.7	148.4	1.0	147.6	0.2	148.2	0.8
Near Rochester	54.476	124.2	124.1	-0.1	124.2	0.0	122.2	-2.0	122.2	-2.1	124.4	0.2	124.5	0.3	124.2	0.0
Anderson Road	51.499	106.0	106.0	0.0	106.0	0.0	105.4	-0.6	105.4	-0.6	106.1	0.1	106.1	0.1	106.0	0.0
Black River Confluence	46.937	92.9	92.9	0.0	92.9	0.0	91.1	-1.8	90.9	-2.0	92.9	0.0	93.2	0.3	92.7	-0.2
Sickman Ford Bridge	44.175	85.5	85.4	0.0	85.5	0.0	83.2	-2.3	82.1	-3.4	84.4	-1.1	85.9	0.4	84.2	-1.3
Porter Creek Road	34.497	57.0	56.9	0.0	57.0	0.0	54.9	-2.1	54.8	-2.2	57.2	0.2	57.4	0.4	56.9	-0.1
Wakefield Road	24.52	40.2	40.2	0.0	40.2	0.0	37.9	-2.3	37.8	-2.4	40.7	0.5	40.7	0.5	40.3	0.1
Satsop Confluence	19.89	34.5	34.5	0.0	34.5	0.0	33.2	-1.3	33.2	-1.3	34.7	0.2	34.7	0.2	34.5	0.0
Montesano	12.5	17.3	17.3	0.0	17.3	0.1	15.7	-1.6	15.7	-1.6	17.7	0.4	17.5	0.2	17.4	0.1
Cosmopolis	1.99	10.9	10.9	0.0	10.9	0.0	10.9	0.0	10.9	0.0	10.9	0.0	11.0	0.1	10.9	0.0

Note: Negative change means that the alternative has lower simulated water levels, positive change indicates the alternative raises water levels.

Alternatives Analysis Summary for 100-year Design Event

Location			Max Water Surface Elevation (feet NAVD) or Change in Flood Water Surface (feet)													
Description	X-section	100 Year (ft NAVD)	100 WSDOT I5 (ft NAVD)	Change (ft NAVD)	100 WSDOT-AP (ft NAVD)	Change (ft NAVD)	100 I5-Dam (ft NAVD)	Change (ft NAVD)	100 I5-Dam-Br (ft NAVD)	Change (ft NAVD)	100 I5-2BP-Br (ft NAVD)	Change (ft NAVD)	100 Twin Cities (ft NAVD)	Change (ft NAVD)	100 No Bridges (ft NAVD)	Change (ft NAVD)
Near Doty	100.95	323.2	323.2	0.0	323.2	0.0	313.0	-10.3	313.0	-10.3	323.2	0.0	323.2	0.0	323.1	-0.1
Curtis Store (on S Fork Chehalis)	1.81	233.6	233.6	0.0	233.6	0.0	230.2	-3.3	230.2	-3.3	233.6	0.0	233.6	0.0	233.6	0.1
Downstream of South Fork	86.42	223.2	223.2	0.0	223.2	0.0	219.1	-4.1	219.1	-4.1	223.2	0.0	223.2	0.0	223.2	0.0
Near Adna	80.23	197.1	197.1	0.0	197.1	0.0	195.5	-1.6	195.5	-1.6	197.1	-0.1	197.1	0.0	197.1	0.0
Labree Road (on Newaukum R)	4.11	204.9	204.9	0.0	204.9	0.0	204.9	0.0	204.9	0.0	204.9	0.0	204.9	0.0	204.9	0.0
Newaukum Confluence	75.2	185.7	185.7	0.1	186.0	0.3	184.1	-1.6	184.1	-1.6	184.0	-1.7	186.2	0.5	185.3	-0.4
Along Airport Levee	71.49	180.8	181.3	0.5	181.6	0.9	179.4	-1.4	179.4	-1.4	179.9	-0.9	182.5	1.7	180.9	0.1
Dillenbaugh Storage Area	SA #301	185.8	185.9	0.1	186.2	0.4	184.3	-1.5	184.3	-1.5	184.4	-1.4	173.7	-12.2	184.7	-1.1
Airport Storage Area	SA #2	180.8	181.4	0.6	159.4	-21.4	159.4	-21.4	159.4	-21.4	159.4	-21.4	159.4	-21.4	180.9	0.1
Long Road Storage Area	SA #5	177.9	176.0	-2.0	176.6	-1.3	169.4	-8.5	169.4	-8.5	169.4	-8.5	177.6	-0.3	178.0	0.1
Centralia Storage Area	SA #610	176.7	176.1	-0.6	176.1	-0.6	174.9	-1.8	174.9	-1.8	174.3	-2.3	177.6	0.9	176.8	0.2
Mellen St	67.43	177.6	177.7	0.2	177.8	0.2	176.0	-1.6	176.0	-1.6	174.5	-3.1	178.5	0.9	177.7	0.1
Bucoda (Skookumchuck R)	11.1	252.0	252.0	0.0	252.0	0.0	252.0	0.0	252.0	0.0	252.0	0.0	250.6	-1.4	251.9	0.0
Pearl Street (Skookumchuck R)	2.43	191.7	191.7	0.0	191.7	0.0	191.7	0.0	191.7	0.0	191.7	0.0	190.2	-1.4	191.4	-0.3
Skookumchuck Confluence	66.88	175.7	175.7	0.0	175.8	0.1	174.2	-1.5	174.2	-1.5	173.9	-1.8	176.5	0.8	175.8	0.1
Upstream of Galvin Road	64.9	167.3	167.4	0.0	167.4	0.1	165.4	-2.0	165.2	-2.1	167.5	0.1	167.8	0.5	167.3	-0.1
Grand Mound (Prather Road)	59.909	147.1	147.1	0.0	147.1	0.0	146.3	-0.8	147.1	0.0	148.1	1.0	147.4	0.3	148.0	0.9
Near Rochester	54.476	124.0	124.0	0.0	124.1	0.1	122.9	-1.1	122.9	-1.1	124.3	0.3	124.4	0.4	124.0	0.0
Anderson Road	51.499	106.1	106.1	0.0	106.1	0.0	105.8	-0.3	105.8	-0.3	106.2	0.1	106.2	0.1	106.1	0.0
Black River Confluence	46.937	93.0	93.0	0.0	93.1	0.1	92.1	-0.9	91.9	-1.1	93.1	0.1	93.4	0.4	92.9	-0.2
Sickman Ford Bridge	44.175	85.6	85.7	0.0	85.7	0.1	84.5	-1.2	83.2	-2.4	84.7	-0.9	86.1	0.4	84.4	-1.2
Porter Creek Road	34.497	57.4	57.4	0.0	57.5	0.1	56.3	-1.1	56.2	-1.2	57.7	0.4	57.8	0.4	57.4	0.0
Wakefield Road	24.52	41.6	41.6	0.0	41.7	0.1	40.2	-1.4	40.2	-1.3	42.0	0.4	41.9	0.4	41.6	0.1
Satsop Confluence	19.89	35.4	35.4	0.0	35.5	0.1	34.9	-0.5	34.9	-0.5	35.7	0.3	35.6	0.2	35.5	0.1
Montesano	12.5	18.8	18.9	0.0	18.9	0.1	18.2	-0.7	18.2	-0.7	19.2	0.3	19.0	0.2	18.9	0.1
Cosmopolis	1.99	11.0	11.0	0.0	11.0	0.0	10.6	-0.4	10.6	-0.4	11.2	0.2	11.1	0.1	11.0	0.0

Note: Negative change means that the alternative has lower simulated water levels, positive change indicates the alternative raises water levels.

Table 9: Comparison of Water Surface Elevation Changes with Flood Relief Alternatives – February 1996 and January 2009 Storm Events

Alternatives Analysis Summary for February 1996 Flood Event

Location		Max Water Surface Elevation (feet NAVD) or Change in Flood Water Surface (feet)														
		Feb 96	Feb w/Dam	Change	Feb w/Lev	Change	Feb w/Dam&Lev	Change	Feb MellenBP	Change	Feb Dredge	Change	Feb ScheuberBP	Change	Feb Sc-AP-Mel	Change
Description	X-section	(ft NAVD)	(ft NAVD)	(ft NAVD)	(ft NAVD)	(ft NAVD)	(ft NAVD)	(ft NAVD)	(ft NAVD)	(ft NAVD)	(ft NAVD)	(ft NAVD)	(ft NAVD)	(ft NAVD)	(ft NAVD)	(ft NAVD)
Near Doty	100.95	318.1	307.2	-11.0	318.1	0.0	307.2	-11.0	318.1	0.0	318.1	0.0	318.1	0.0	318.1	0.0
Curtis Store (on S Fork Chehalis)	1.81	233.2	231.1	-2.1	233.2	0.0	231.1	-2.1	233.2	0.0	233.2	0.0	233.2	0.0	233.2	0.0
Downstream of South Fork	86.42	222.4	219.0	-3.5	222.4	0.0	219.0	-3.5	222.4	0.0	222.4	0.0	222.4	0.0	222.4	0.0
Near Adna	80.23	196.6	195.0	-1.6	196.6	0.0	195.0	-1.6	196.6	0.0	196.6	0.0	196.4	-0.2	196.4	-0.2
Labree Road (on Newaukum R)	4.11	204.6	204.6	0.0	204.6	0.0	204.6	0.0	204.6	0.0	204.6	0.0	204.6	0.0	204.6	0.0
Newaukum Confluence	75.2	185.1	183.8	-1.3	185.3	0.2	183.9	-1.3	185.1	-0.1	185.1	-0.1	183.2	-1.9	183.3	-1.8
Along Airport Levee	71.49	180.3	179.0	-1.3	181.0	0.7	179.2	-1.1	179.0	-1.3	179.5	-0.8	180.4	0.0	179.4	-0.9
Dillenbaugh Storage Area	SA #301	185.1	183.8	-1.4	185.4	0.3	183.8	-1.3	185.1	-0.1	185.1	-0.1	183.4	-1.8	183.5	-1.7
Airport Storage Area	SA #2	180.3	175.9	-4.4	159.4	-20.9	159.4	-20.9	178.9	-1.4	179.3	-1.1	180.4	0.0	159.4	-20.9
Long Road Storage Area	SA #5	177.5	169.4	-8.1	175.2	-2.3	169.4	-8.1	169.4	-8.1	169.5	-8.1	177.6	0.0	169.4	-8.1
Centralia Storage Area	SA #610	176.2	174.9	-1.3	176.1	-0.1	175.0	-1.2	174.2	-2.0	174.7	-1.5	176.3	0.1	174.4	-1.8
Mellen St	67.43	177.3	175.9	-1.4	177.5	0.2	176.1	-1.2	174.0	-3.3	175.2	-2.0	177.3	0.0	174.3	-3.0
Bucoda (Skookumchuck R)	11.1	251.4	251.4	0.0	251.4	0.0	251.4	0.0	251.4	0.0	251.4	0.0	251.4	0.0	251.4	0.0
Pearl Street (Skookumchuck R)	2.43	191.3	191.3	0.0	191.3	0.0	191.3	0.0	191.3	0.0	188.8	-2.5	191.3	0.0	191.3	0.0
Skookumchuck Confluence	66.88	175.5	174.2	-1.3	175.6	0.1	174.4	-1.1	173.6	-1.9	173.3	-2.2	175.6	0.1	173.8	-1.7
Upstream of Galvin Road	64.9	167.2	165.4	-1.7	167.3	0.1	165.6	-1.6	167.4	0.2	165.3	-1.8	167.2	0.0	167.6	0.5
Grand Mound (Prather Road)	59.909	146.9	146.2	-0.7	147.0	0.1	146.3	-0.6	147.0	0.1	146.9	0.0	146.9	0.0	147.2	0.3
Near Rochester	54.476	123.7	122.8	-0.9	123.8	0.1	122.9	-0.8	123.8	0.2	123.7	0.0	123.7	0.0	124.0	0.4
Anderson Road	51.499	105.9	105.6	-0.3	105.9	0.0	105.7	-0.2	106.0	0.0	105.9	0.0	105.9	0.0	106.0	0.1
Black River Confluence	46.937	92.6	91.8	-0.8	92.7	0.1	91.9	-0.7	92.7	0.2	92.6	0.0	92.6	0.0	92.9	0.3
Sickman Ford Bridge	44.175	85.0	84.1	-1.0	85.2	0.2	84.2	-0.9	85.2	0.2	85.0	0.0	85.1	0.1	85.5	0.4
Porter Creek Road	34.497	56.7	55.8	-0.9	56.8	0.2	55.9	-0.8	56.9	0.2	56.7	0.0	56.7	0.1	57.1	0.4
Wakefield Road	24.52	40.1	39.2	-0.9	40.3	0.2	39.3	-0.8	40.3	0.2	40.1	0.0	40.2	0.1	40.7	0.5
Satsop Confluence	19.89	34.7	34.5	-0.2	34.7	0.0	34.5	-0.2	34.8	0.1	34.8	0.1	34.8	0.1	34.9	0.2
Montesano	12.5	17.6	17.3	-0.3	17.6	0.0	17.3	-0.3	17.8	0.1	17.8	0.2	17.7	0.1	17.9	0.3
Cosmopolis	1.99	9.3	9.2	-0.1	9.3	0.0	9.2	-0.1	9.4	0.1	9.4	0.0	9.4	0.1	9.5	0.1

Note: Negative change means that the alternative has lower simulated water levels, positive change indicates the alternative raises water levels.

Alternatives Analysis Summary for January 2009 Flood Event

Location		Max Water Surface Elevation (feet NAVD) or Change in Flood Water Surface (feet)														
		Jan 09	Jan w/Dam	Change	Jan w/Lev	Change	Jan w/Dam&Lev	Change	Jan w/MellenBP	Change	Jan w/Dredge	Change	Jan w/ScheuberBP	Change	Jan w/Sc-AP-Mel	Change
Description	X-section	(ft NAVD)	(ft NAVD)	(ft NAVD)	(ft NAVD)	(ft NAVD)	(ft NAVD)	(ft NAVD)	(ft NAVD)	(ft NAVD)	(ft NAVD)	(ft NAVD)	(ft NAVD)	(ft NAVD)	(ft NAVD)	(ft NAVD)
Near Doty	100.95	314.4	306.7	-7.7	314.4	0.0	306.7	-7.7	314.4	0.0	314.4	0.0	314.4	0.0	314.4	0.0
Curtis Store (on S Fork Chehalis)	1.81	228.1	227.7	-0.5	228.1	0.0	227.7	-0.5	228.1	0.0	228.2	0.0	228.1	0.0	228.1	0.0
Downstream of South Fork	86.42	216.9	213.3	-3.7	216.9	0.0	213.3	-3.7	216.9	0.0	216.9	0.0	216.9	0.0	216.9	0.0
Near Adna	80.23	193.9	191.7	-2.2	193.9	0.0	191.7	-2.2	193.9	0.0	193.9	0.0	193.6	-0.3	193.6	-0.3
Labree Road (on Newaukum R)	4.11	204.7	204.7	0.0	204.7	0.0	204.7	0.0	204.7	0.0	204.7	0.0	204.7	0.0	204.7	0.0
Newaukum Confluence	75.2	183.5	182.1	-1.4	183.5	0.0	182.1	-1.4	183.4	-0.1	183.4	-0.1	181.8	-1.7	181.5	-2.0
Along Airport Levee	71.49	178.8	177.4	-1.3	178.8	0.1	177.4	-1.3	177.7	-1.1	178.1	-0.7	178.9	0.2	177.9	-0.8
Dillenbaugh Storage Area	SA #301	184.1	183.7	-0.4	184.1	0.0	183.7	-0.4	184.1	0.0	184.0	0.0	183.7	-0.3	183.7	-0.4
Airport Storage Area	SA #2	172.0	159.4	-12.6	159.4	-12.6	159.4	-12.6	167.3	-4.7	169.1	-2.8	174.5	2.5	159.4	-12.6
Long Road Storage Area	SA #5	169.4	169.4	0.0	169.4	0.0	169.4	0.0	169.4	0.0	169.4	0.0	169.4	0.0	169.4	0.0
Centralia Storage Area	SA #610	174.5	174.0	-0.6	174.6	0.1	174.0	-0.6	172.4	-2.1	172.9	-1.7	174.6	0.1	172.7	-1.9
Mellen St	67.43	175.6	174.5	-1.2	175.7	0.1	174.5	-1.2	172.4	-3.2	173.2	-2.5	175.7	0.1	172.6	-3.0
Bucoda (Skookumchuck R)	11.1	250.9	250.9	0.0	250.9	0.0	250.9	0.0	250.9	0.0	250.9	0.0	250.9	0.0	250.9	0.0
Pearl Street (Skookumchuck R)	2.43	190.5	190.5	0.0	190.5	0.0	190.5	0.0	190.5	0.0	188.1	-2.4	190.5	0.0	190.5	0.0
Skookumchuck Confluence	66.88	173.9	172.9	-1.0	174.0	0.1	172.9	-1.0	172.0	-1.9	171.3	-2.6	174.0	0.1	172.2	-1.7
Upstream of Galvin Road	64.9	165.1	164.1	-1.0	165.1	0.1	164.1	-1.0	165.3	0.2	163.6	-1.5	165.2	0.1	165.5	0.4
Grand Mound (Prather Road)	59.909	146.0	145.5	-0.5	146.0	0.0	145.5	-0.5	146.1	0.1	146.0	0.0	146.1	0.1	146.2	0.2
Near Rochester	54.476	122.5	121.8	-0.7	122.5	0.0	121.8	-0.7	122.7	0.2	122.5	0.0	122.6	0.1	122.8	0.3
Anderson Road	51.499	105.5	105.3	-0.3	105.6	0.0	105.3	-0.3	105.6	0.0	105.5	0.0	105.6	0.0	105.6	0.1
Black River Confluence	46.937	91.6	91.0	-0.7	91.7	0.0	91.0	-0.7	91.8	0.1	91.6	0.0	91.8	0.1	92.0	0.3
Sickman Ford Bridge	44.175	83.8	83.0	-0.9	83.9	0.0	83.0	-0.9	84.0	0.2	83.8	0.0	84.0	0.2	84.3	0.4
Porter Creek Road	34.497	55.6	54.8	-0.8	55.7	0.0	54.8	-0.8	55.8	0.2	55.6	0.0	55.8	0.2	56.0	0.4
Wakefield Road	24.52	38.8	37.9	-0.9	38.8	0.0	37.9	-0.9	39.0	0.2	38.8	0.0	39.0	0.2	39.3	0.5
Satsop Confluence	19.89	33.7	33.4	-0.3	33.7	0.0	33.4	-0.3	33.8	0.1	33.7	0.0	33.8	0.2	34.0	0.4
Montesano	12.5	17.7	17.6	-0.1	17.7	0.0	17.6	-0.1	17.8	0.0	17.8	0.1	17.7	0.0	17.8	0.0
Cosmopolis	1.99	11.7	11.7	0.0	10.6	-0.4	11.7	0.0	11.7	0.0	11.7	0.0	11.7	0.0	11.7	0.0

Note: Negative change means that the alternative has lower simulated water levels, positive change indicates the alternative raises water levels.

Table 9 (continued): Comparison of Water Surface Elevation Changes with Flood Relief Alternatives – February 1996 and January 2009 Storm Events

Alternatives Analysis Summary for February 1996 Flood Event

Location			Max Water Surface Elevation (feet NAVD) or Change in Flood Water Surface (feet)													
		Feb 96	Feb WSDOT I5	Change	Feb WSDOT-AP	Change	Feb I5-Dam	Change	Feb I5-Dam-Br	Change	Feb I5-2BP-Br	Change	Feb Twin Cities	Change	Feb No Bridges	Change
Description	X-section	(ft NAVD)	(ft NAVD)	(ft NAVD)	(ft NAVD)	(ft NAVD)	(ft NAVD)	(ft NAVD)	(ft NAVD)	(ft NAVD)	(ft NAVD)	(ft NAVD)	(ft NAVD)	(ft NAVD)	(ft NAVD)	(ft NAVD)
Near Doty	100.95	318.1	318.1	0.0	318.1	0.0	307.2	-11.0	307.2	-11.0	318.1	0.0	318.1	0.0	318.0	-0.2
Curtis Store (on S Fork Chehalis)	1.81	233.2	233.2	0.0	233.2	0.0	231.1	-2.1	231.1	-2.1	233.2	0.0	233.2	0.0	233.1	0.0
Downstream of South Fork	86.42	222.4	222.4	0.0	222.4	0.0	219.0	-3.5	219.0	-3.5	222.4	0.0	222.4	0.0	222.4	0.0
Near Adna	80.23	196.6	196.6	0.0	196.6	0.0	195.0	-1.6	195.0	-1.6	196.4	-0.2	196.6	0.0	196.6	0.0
Labree Road (on Newaukum R)	4.11	204.6	204.6	0.0	204.6	0.0	204.6	0.0	204.6	0.0	204.6	0.0	204.6	0.0	204.6	0.0
Newaukum Confluence	75.2	185.1	185.1	0.0	185.4	0.3	183.9	-1.3	183.9	-1.3	183.4	-1.8	185.4	0.3	184.7	-0.4
Along Airport Levee	71.49	180.3	180.7	0.4	181.0	0.7	179.2	-1.1	179.2	-1.1	179.4	-0.9	181.3	1.0	180.4	0.1
Dillenbaugh Storage Area	SA #301	185.1	185.2	0.1	185.5	0.4	183.8	-1.3	183.8	-1.3	183.5	-1.7	173.4	-11.7	183.9	-1.3
Airport Storage Area	SA #2	180.3	180.8	0.5	159.4	-20.9	159.4	-20.9	159.4	-20.9	159.4	-20.9	159.4	-20.9	180.4	0.1
Long Road Storage Area	SA #5	177.5	174.3	-3.2	175.4	-2.2	169.4	-8.1	169.4	-8.1	169.4	-8.1	176.4	-1.1	177.6	0.0
Centralia Storage Area	SA #610	176.2	176.1	-0.1	176.1	-0.1	175.0	-1.2	175.0	-1.2	174.4	-1.8	177.2	1.0	176.2	0.0
Mellen St	67.43	177.3	177.4	0.1	177.5	0.2	176.1	-1.2	176.1	-1.2	174.2	-3.0	177.7	0.4	177.3	0.1
Bucoda (Skookumchuck R)	11.1	251.4	251.4	0.0	251.4	0.0	251.4	0.0	251.4	0.0	251.4	0.0	249.0	-2.4	251.3	-0.1
Pearl Street (Skookumchuck R)	2.43	191.3	191.3	0.0	191.3	0.0	191.3	0.0	191.3	0.0	191.3	0.0	190.1	-1.2	191.2	-0.1
Skookumchuck Confluence	66.88	175.5	175.6	0.1	175.7	0.2	174.4	-1.1	174.4	-1.1	173.8	-1.7	175.6	0.1	175.6	0.1
Upstream of Galvin Road	64.9	167.2	167.2	0.1	167.3	0.1	165.6	-1.6	165.4	-1.7	167.4	0.2	166.9	-0.3	166.9	-0.2
Grand Mound (Prather Road)	59.909	146.9	146.9	0.0	147.0	0.1	146.3	-0.6	147.1	0.2	148.0	1.1	146.9	-0.1	147.8	0.9
Near Rochester	54.476	123.7	123.7	0.0	123.8	0.1	122.9	-0.8	122.8	-0.8	124.0	0.3	123.6	-0.1	123.7	0.0
Anderson Road	51.499	105.9	105.9	0.0	105.9	0.0	105.7	-0.2	105.7	-0.2	106.0	0.1	105.9	0.0	105.9	0.0
Black River Confluence	46.937	92.6	92.6	0.0	92.7	0.1	91.9	-0.7	91.7	-0.9	92.7	0.1	92.5	0.0	92.4	-0.1
Sickman Ford Bridge	44.175	85.0	85.1	0.1	85.2	0.2	84.2	-0.8	83.0	-2.0	84.2	-0.9	85.0	0.0	83.9	-1.2
Porter Creek Road	34.497	56.7	56.7	0.1	56.8	0.2	55.9	-0.8	55.8	-0.9	57.0	0.3	56.7	0.0	56.7	0.0
Wakefield Road	24.52	40.1	40.2	0.1	40.3	0.2	39.3	-0.8	39.2	-0.9	40.7	0.6	40.1	0.0	40.3	0.2
Satsop Confluence	19.89	34.7	34.7	0.0	34.7	0.0	34.5	-0.2	34.5	-0.2	34.9	0.2	34.7	0.0	34.8	0.1
Montesano	12.5	17.6	17.6	0.0	17.6	0.0	17.3	-0.3	17.3	-0.3	17.9	0.3	17.7	0.1	17.7	0.1
Cosmopolis	1.99	9.3	9.3	0.0	9.3	0.0	9.2	-0.1	9.2	-0.1	9.5	0.1	9.3	0.0	9.4	0.0

Note: Negative change means that the alternative has lower simulated water levels, positive change indicates the alternative raises water levels.

Alternatives Analysis Summary for January 2009 Flood Event

Location			Max Water Surface Elevation (feet NAVD) or Change in Flood Water Surface (feet)													
		Jan 09	Jan WSDOT I5	Change	Jan WSDOT-AP	Change	Jan I5-Dam	Change	Jan I5-Dam-Br	Change	Jan I5-2BP-Br	Change	Jan Twin Cities	Change	Jan No Bridges	Change
Description	X-section	(ft NAVD)	(ft NAVD)	(ft NAVD)	(ft NAVD)	(ft NAVD)	(ft NAVD)	(ft NAVD)	(ft NAVD)	(ft NAVD)	(ft NAVD)	(ft NAVD)	(ft NAVD)	(ft NAVD)	(ft NAVD)	(ft NAVD)
Near Doty	100.95	314.4	314.4	0.0	314.4	0.0	306.7	-7.7	306.7	-7.7	314.4	0.0	314.4	0.0	314.3	-0.1
Curtis Store (on S Fork Chehalis)	1.81	228.1	228.1	0.0	228.1	0.0	227.7	-0.5	227.7	-0.5	228.1	0.0	228.1	0.0	228.1	0.0
Downstream of South Fork	86.42	216.9	216.9	0.0	216.9	0.0	213.3	-3.6	213.3	-3.7	216.9	0.0	216.9	0.0	216.9	0.0
Near Adna	80.23	193.9	193.9	0.0	193.9	0.0	191.7	-2.2	191.7	-2.2	193.6	-0.3	193.9	0.0	193.9	0.0
Labree Road (on Newaukum R)	4.11	204.7	204.7	0.0	204.7	0.0	204.7	0.0	204.7	0.0	204.7	0.0	204.7	0.0	204.7	0.0
Newaukum Confluence	75.2	183.5	183.5	0.0	183.5	0.0	182.1	-1.4	182.1	-1.4	181.6	-1.9	183.4	-0.1	183.3	-0.2
Along Airport Levee	71.49	178.8	178.8	0.0	178.9	0.1	177.5	-1.3	177.4	-1.3	177.9	-0.8	178.8	0.1	178.8	0.1
Dillenbaugh Storage Area	SA #301	184.1	184.1	0.0	184.1	0.0	183.7	-0.3	183.7	-0.3	183.7	-0.3	173.4	-10.7	183.3	-0.7
Airport Storage Area	SA #2	172.0	172.2	0.2	159.4	-12.6	159.4	-12.6	159.4	-12.6	159.4	-12.6	159.4	-12.6	173.3	1.4
Long Road Storage Area	SA #5	169.4	169.4	0.0	169.4	0.0	169.4	0.0	169.4	0.0	169.4	0.0	169.4	0.0	169.4	0.0
Centralia Storage Area	SA #610	174.5	174.6	0.0	174.6	0.1	174.0	-0.6	174.0	-0.6	172.7	-1.9	175.4	0.8	174.5	0.0
Mellen St	67.43	175.6	175.6	0.0	175.7	0.1	174.5	-1.2	174.5	-1.2	172.6	-3.0	175.6	0.0	175.7	0.0
Bucoda (Skookumchuck R)	11.1	250.9	250.9	0.0	250.9	0.0	250.9	0.0	250.9	0.0	250.9	0.0	247.5	-3.3	250.8	-0.1
Pearl Street (Skookumchuck R)	2.43	190.5	190.5	0.0	190.5	0.0	190.5	0.0	190.5	0.0	190.5	0.0	188.9	-1.6	190.4	0.0
Skookumchuck Confluence	66.88	173.9	173.9	0.0	174.0	0.1	172.9	-1.0	172.9	-1.0	172.2	-1.7	173.7	-0.2	174.0	0.0
Upstream of Galvin Road	64.9	165.1	165.1	0.0	165.2	0.1	164.1	-1.0	164.0	-1.1	165.4	0.3	164.8	-0.3	165.0	-0.1
Grand Mound (Prather Road)	59.909	146.0	146.0	0.0	146.0	0.0	145.5	-0.5	146.3	0.3	147.1	1.1	145.8	-0.2	146.9	0.9
Near Rochester	54.476	122.5	122.5	0.0	122.5	0.0	121.8	-0.7	121.8	-0.7	122.8	0.3	122.3	-0.2	122.5	0.0
Anderson Road	51.499	105.5	105.5	0.0	105.6	0.0	105.3	-0.2	105.3	-0.2	105.7	0.1	105.5	-0.1	105.6	0.0
Black River Confluence	46.937	91.6	91.6	0.0	91.7	0.0	91.0	-0.7	90.8	-0.8	91.8	0.2	91.4	-0.2	91.5	-0.1
Sickman Ford Bridge	44.175	83.8	83.8	0.0	83.9	0.0	83.0	-0.9	82.0	-1.9	83.1	-0.8	83.6	-0.2	82.8	-1.1
Porter Creek Road	34.497	55.6	55.6	0.0	55.7	0.0	54.8	-0.8	54.8	-0.9	55.9	0.3	55.4	-0.2	55.6	0.0
Wakefield Road	24.52	38.8	38.8	0.0	38.8	0.0	37.9	-0.9	37.8	-0.9	39.2	0.5	38.6	-0.2	38.8	0.0
Satsop Confluence	19.89	33.7	33.7	0.0	33.7	0.0	33.4	-0.3	33.4	-0.2	34.0	0.4	33.6	0.0	33.7	0.1
Montesano	12.5	17.7	17.7	0.0	17.7	0.0	17.6	-0.1	17.6	-0.1	17.8	0.0	17.8	0.0	17.8	0.0
Cosmopolis	1.99	11.7	11.7	0.0	11.7	0.0	11.7	0.0	11.7	0.0	11.7	0.0	11.7	0.0	11.7	0.0

Note: Negative change means that the alternative has lower simulated water levels, positive change indicates the alternative raises water levels.

Table 10: Comparison of Water Surface Elevation Changes with Flood Relief Alternatives A, B, and C – February 1996, December 2007, January 2009 and 100-year Design Storm Events

		Max Water Surface Elevation (feet NAVD) or Change in Flood Water Surface (feet)													
		February 1996 Flood Event							December 2007 Flood Event						
Location		Baseline	Alt A	Change	Alt B	Change	Alt C	Change	Baseline	Alt A	Change	Alt B	Change	Alt C	Change
Description	X-section	(ft NAVD)	(ft NAVD)	(ft)	(ft NAVD)	(ft)	(ft NAVD)	(ft)	(ft NAVD)	(ft NAVD)	(ft)	(ft NAVD)	(ft)	(ft NAVD)	(ft)
Near Doty	100.95	318.1	307.2	-11.0	307.2	-11.0	318.1	0.0	328.1	315.8	-12.3	315.8	-12.3	328.1	0.0
Curtis Store (on S Fork Chehalis)	1.81	233.2	231.1	-2.1	231.1	-2.1	233.2	0.0	238.9	232.8	-6.1	232.8	-6.1	238.9	0.0
Downstream of South Fork	86.42	222.4	219.0	-3.5	219.0	-3.5	222.4	0.0	227.7	222.1	-5.6	222.1	-5.6	227.6	0.0
Near Adna	80.23	196.6	195.0	-1.6	195.0	-1.6	196.4	-0.2	197.9	196.3	-1.6	196.3	-1.6	197.9	0.0
Labree Road (on Newaukum R)	4.11	204.6	204.6	0.0	204.6	0.0	204.6	0.0	204.7	204.7	0.0	204.7	0.0	204.7	0.0
Newaukum Confluence	75.2	185.1	183.9	-1.3	183.9	-1.2	183.4	-1.8	186.6	184.5	-2.2	184.5	-2.1	185.6	-1.0
Along Airport Levee	71.49	180.3	179.3	-1.1	179.3	-1.0	179.5	-0.8	182.1	179.7	-2.4	179.7	-2.4	181.3	-0.8
Dillenbaugh Storage Area	SA #301	185.1	183.8	-1.3	183.8	-1.3	183.5	-1.7	186.6	184.4	-2.2	184.4	-2.2	185.8	-0.8
Airport Storage Area	SA #2	180.3	159.4	-20.9	159.4	-20.9	159.4	-20.9	182.2	159.4	-22.8	159.4	-22.8	159.4	-22.8
Long Road Storage Area	SA #5	177.5	169.4	-8.1	169.4	-8.1	169.4	-8.1	179.1	169.4	-9.7	169.4	-9.7	169.4	-9.7
Centralia Storage Area	SA #610	176.2	175.9	-0.3	176.0	-0.2	174.6	-1.6	178.5	175.8	-2.7	175.9	-2.6	175.8	-2.7
Mellen St	67.43	177.3	176.2	-1.1	176.2	-1.1	174.6	-2.6	178.6	176.1	-2.5	176.1	-2.5	175.8	-2.8
Bucoda (Skookumchuck R)	11.1	251.4	251.4	0.0	251.4	0.0	251.4	0.0	244.3	244.3	0.0	244.3	0.0	244.3	0.0
Pearl Street (Skookumchuck R)	2.43	191.3	191.4	0.1	191.4	0.1	191.4	0.1	186.6	186.6	0.0	186.6	0.0	186.6	0.0
Skookumchuck Confluence	66.88	175.5	174.5	-1.1	174.5	-1.0	174.2	-1.3	176.4	173.8	-2.7	173.8	-2.6	175.0	-1.4
Upstream of Galvin Road	64.9	167.2	165.5	-1.7	165.5	-1.7	167.5	0.3	168.2	164.8	-3.4	164.9	-3.4	168.4	0.2
Grand Mound (Prather Road)	59.909	146.9	146.3	-0.7	146.3	-0.6	147.1	0.2	147.4	145.8	-1.6	145.8	-1.5	147.5	0.1
Near Rochester	54.476	123.7	122.8	-0.9	122.9	-0.8	124.0	0.3	124.2	122.1	-2.1	122.2	-2.1	124.4	0.2
Anderson Road	51.499	105.9	105.7	-0.2	105.7	-0.2	106.0	0.1	106.0	105.4	-0.7	105.4	-0.6	106.1	0.1
Black River Confluence	46.937	92.6	91.7	-0.9	91.7	-0.9	92.6	0.0	92.9	90.9	-2.0	90.9	-2.0	92.8	-0.1
Sickman Ford Bridge	44.175	85.0	83.0	-2.1	83.0	-2.1	84.1	-0.9	85.5	82.1	-3.4	82.1	-3.4	84.3	-1.1
Porter Creek Road	34.497	56.7	55.9	-0.8	55.9	-0.8	57.1	0.4	57.0	54.8	-2.1	54.9	-2.1	57.2	0.3
Wakefield Road	24.52	40.1	38.4	-1.7	38.4	-1.7	39.6	-0.5	40.2	37.2	-3.0	37.2	-3.0	39.6	-0.6
Satsop Confluence	19.89	34.7	34.5	-0.2	34.5	-0.2	35.0	0.3	34.5	33.2	-1.3	33.2	-1.3	34.7	0.3
Montesano	12.5	17.6	17.4	-0.2	17.4	-0.2	18.0	0.4	17.3	15.7	-1.6	15.7	-1.6	17.7	0.4
Cosmopolis	1.99	9.3	9.2	-0.1	9.2	-0.1	9.5	0.2	10.9	10.9	0.0	10.9	0.0	10.9	0.0

Note: Negative change means that the alternative has lower simulated water levels, positive change indicates the alternative raises water levels.

		Max Water Surface Elevation (feet NAVD) or Change in Flood Water Surface (feet)													
		January 2009 Flood Event							100-Year Design Flood Event						
Location		Jan 09	Alt A	Change	Alt B	Change	Alt C	Change	100-year	Alt A	Change	Alt B	Change	Alt C	Change
Description	X-section	(ft NAVD)	(ft NAVD)	(ft)	(ft NAVD)	(ft)	(ft NAVD)	(ft)	(ft NAVD)	(ft NAVD)	(ft)	(ft NAVD)	(ft)	(ft NAVD)	(ft)
Near Doty	100.95	314.4	306.7	-7.7	306.7	-7.7	314.4	0.0	323.2	313.0	-10.3	313.0	-10.3	323.2	0.0
Curtis Store (on S Fork Chehalis)	1.81	228.1	227.7	-0.5	227.7	-0.5	228.1	0.0	233.6	230.2	-3.3	230.2	-3.4	233.6	0.0
Downstream of South Fork	86.42	216.9	213.3	-3.7	213.3	-3.7	216.9	0.0	223.2	219.1	-4.1	219.0	-4.2	223.2	0.0
Near Adna	80.23	193.9	191.7	-2.2	191.7	-2.2	193.6	-0.3	197.1	195.5	-1.6	195.5	-1.6	197.1	-0.1
Labree Road (on Newaukum R)	4.11	204.7	204.7	0.0	204.7	0.0	204.7	0.0	204.9	204.9	0.0	204.9	0.0	204.9	0.0
Newaukum Confluence	75.2	183.5	182.1	-1.4	182.1	-1.4	181.6	-1.9	185.7	184.1	-1.6	184.1	-1.6	184.0	-1.7
Along Airport Levee	71.49	178.8	177.4	-1.3	177.4	-1.3	178.0	-0.8	180.8	179.4	-1.4	179.4	-1.4	179.9	-0.8
Dillenbaugh Storage Area	SA #301	184.1	183.7	-0.4	183.7	-0.3	183.7	-0.3	185.8	184.3	-1.5	184.3	-1.5	184.4	-1.4
Airport Storage Area	SA #2	172.0	159.4	-12.6	159.4	-12.6	159.4	-12.6	180.8	159.4	-21.4	159.4	-21.4	159.4	-21.4
Long Road Storage Area	SA #5	169.4	169.4	0.0	169.4	0.0	169.4	0.0	177.9	169.4	-8.5	169.4	-8.5	169.4	-8.5
Centralia Storage Area	SA #610	174.5	174.3	-0.2	174.3	-0.2	172.8	-1.8	176.7	175.9	-0.8	176.1	-0.6	175.0	-1.7
Mellen St	67.43	175.6	174.5	-1.1	174.5	-1.1	172.8	-2.8	177.6	176.1	-1.5	176.1	-1.5	174.9	-2.7
Bucoda (Skookumchuck R)	11.1	250.9	250.9	0.0	250.9	0.0	250.9	0.0	252.0	251.9	-0.1	251.9	-0.1	251.9	-0.1
Pearl Street (Skookumchuck R)	2.43	190.5	190.6	0.1	190.6	0.1	190.6	0.1	191.7	192.4	0.7	192.4	0.7	192.4	0.7
Skookumchuck Confluence	66.88	173.9	173.0	-0.9	173.0	-0.9	172.5	-1.5	175.7	174.3	-1.4	174.3	-1.4	174.4	-1.3
Upstream of Galvin Road	64.9	165.1	164.1	-1.0	164.1	-1.0	165.5	0.4	167.3	165.3	-2.0	165.3	-2.0	167.6	0.3
Grand Mound (Prather Road)	59.909	146.0	145.5	-0.5	145.5	-0.5	146.2	0.2	147.1	146.2	-0.9	146.2	-0.8	147.3	0.2
Near Rochester	54.476	122.5	121.8	-0.7	121.8	-0.7	122.8	0.3	124.0	122.9	-1.1	122.9	-1.1	124.3	0.3
Anderson Road	51.499	105.5	105.3	-0.3	105.3	-0.3	105.6	0.1	106.1	105.8	-0.3	105.8	-0.3	106.2	0.1
Black River Confluence	46.937	91.6	90.8	-0.8	90.8	-0.8	91.8	0.1	93.0	91.9	-1.2	91.9	-1.2	93.1	0.0
Sickman Ford Bridge	44.175	83.8	81.9	-1.9	81.9	-1.9	83.1	-0.8	85.6	83.2	-2.4	83.2	-2.4	84.6	-1.0
Porter Creek Road	34.497	55.6	54.8	-0.8	54.8	-0.8	56.0	0.4	57.4	56.2	-1.1	56.3	-1.1	57.8	0.5
Wakefield Road	24.52	38.8	37.2	-1.5	37.2	-1.5	38.5	-0.3	41.6	39.3	-2.3	39.3	-2.3	40.8	-0.7
Satsop Confluence	19.89	33.7	33.4	-0.2	33.4	-0.2	34.1	0.4	35.4	34.9	-0.5	34.9	-0.5	35.7	0.2
Montesano	12.5	17.7	17.7	-0.1	17.7	-0.1	17.8	0.1	18.8	18.2	-0.7	18.2	-0.7	19.2	0.3
Cosmopolis	1.99	11.7	11.7	0.0	10.6	-0.4	11.7	0.0	11.0	10.6	-0.4	10.6	-0.4	11.2	0.2

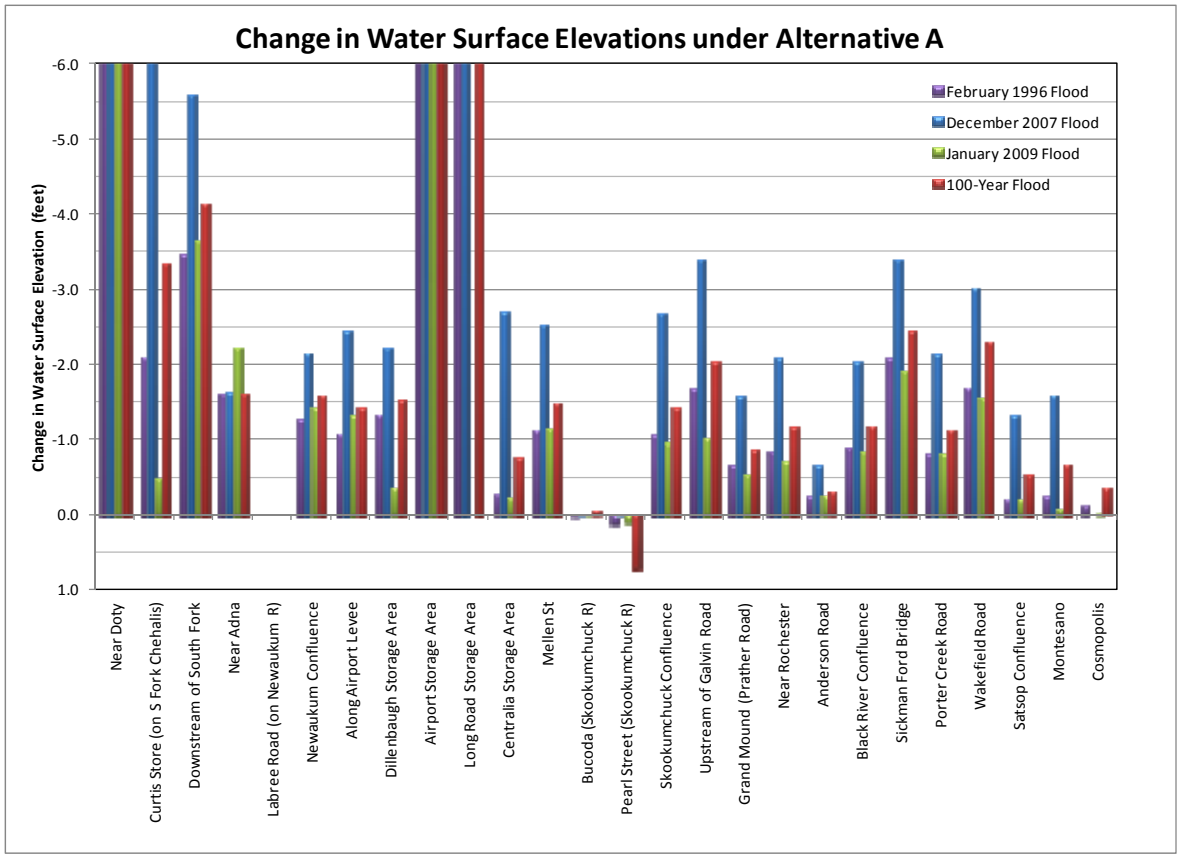
Note: Negative change means that the alternative has lower simulated water levels, positive change indicates the alternative raises water levels.

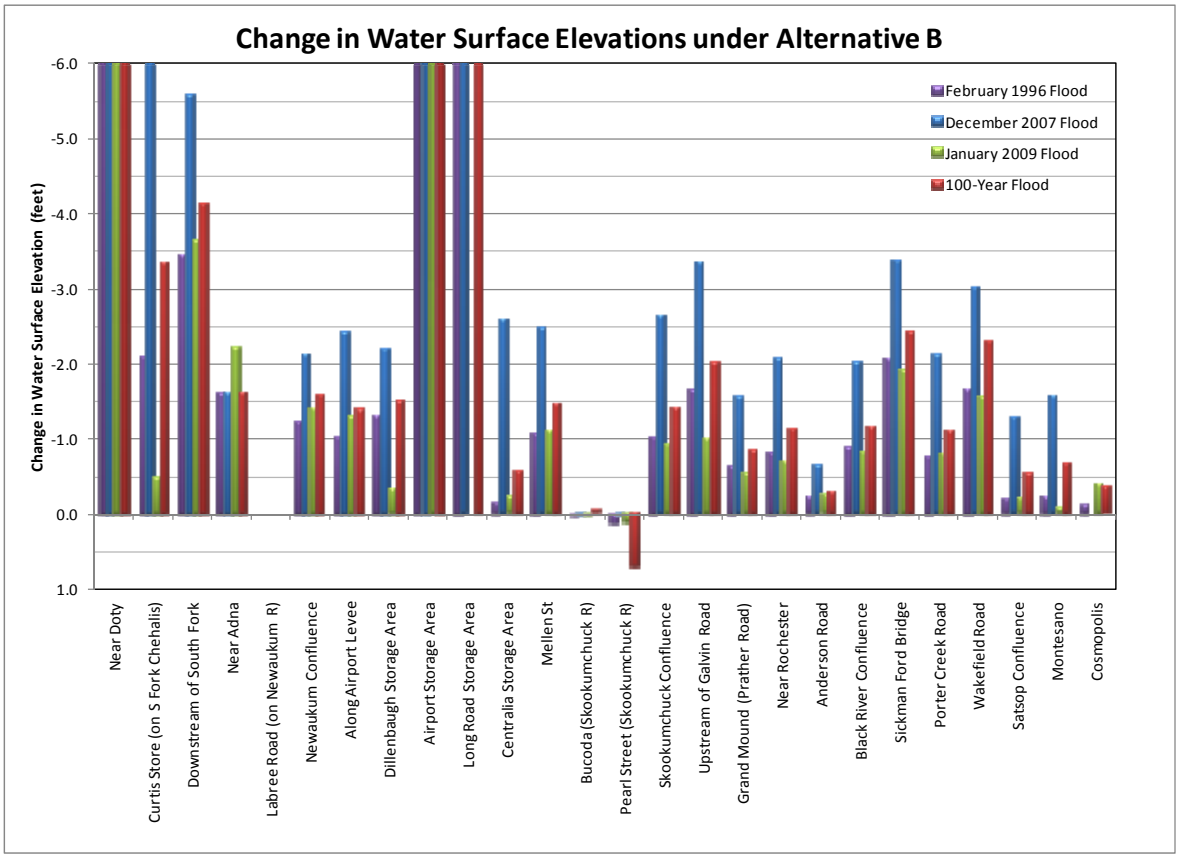
Basin-wide bar charts

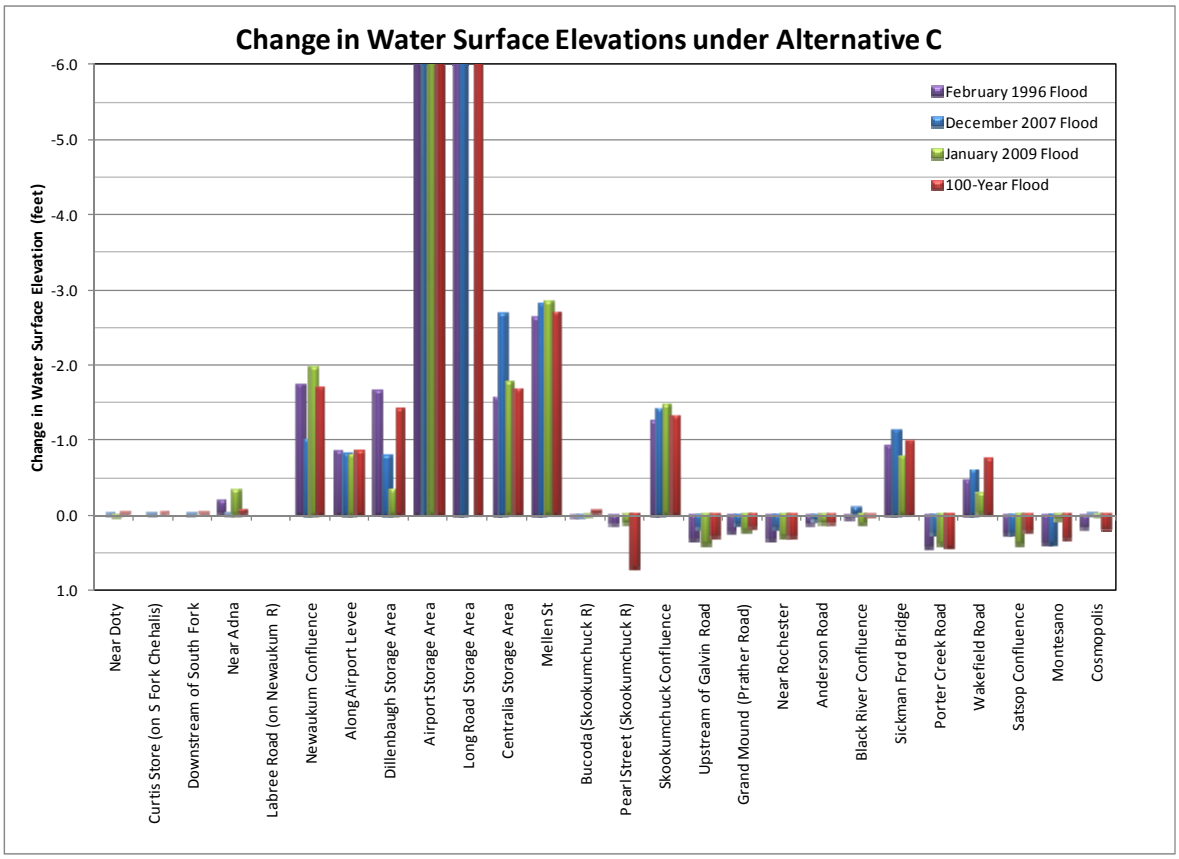
Figures 11 through 13 show the effects on water surface elevations of the combination alternatives at the same locations as shown in Table 10. This graphical presentation of results for the four simulated floods facilitates quick comparisons between the alternatives. As can be seen in the bar charts, Alternatives A and B, which include the mainstem dam, result in lower flood water levels throughout the basin for all of the floods. Other proposed elements of these flood relief alternatives have more localized effects. Alternative C, which does not include the main stem dam, would have no effect on water levels upstream of Highway 603 and would have less overall benefit on reaches within the Twin Cities. Downstream water levels would also be generally increased under this alternative with the exception of near the downstream bridge replacement projects.

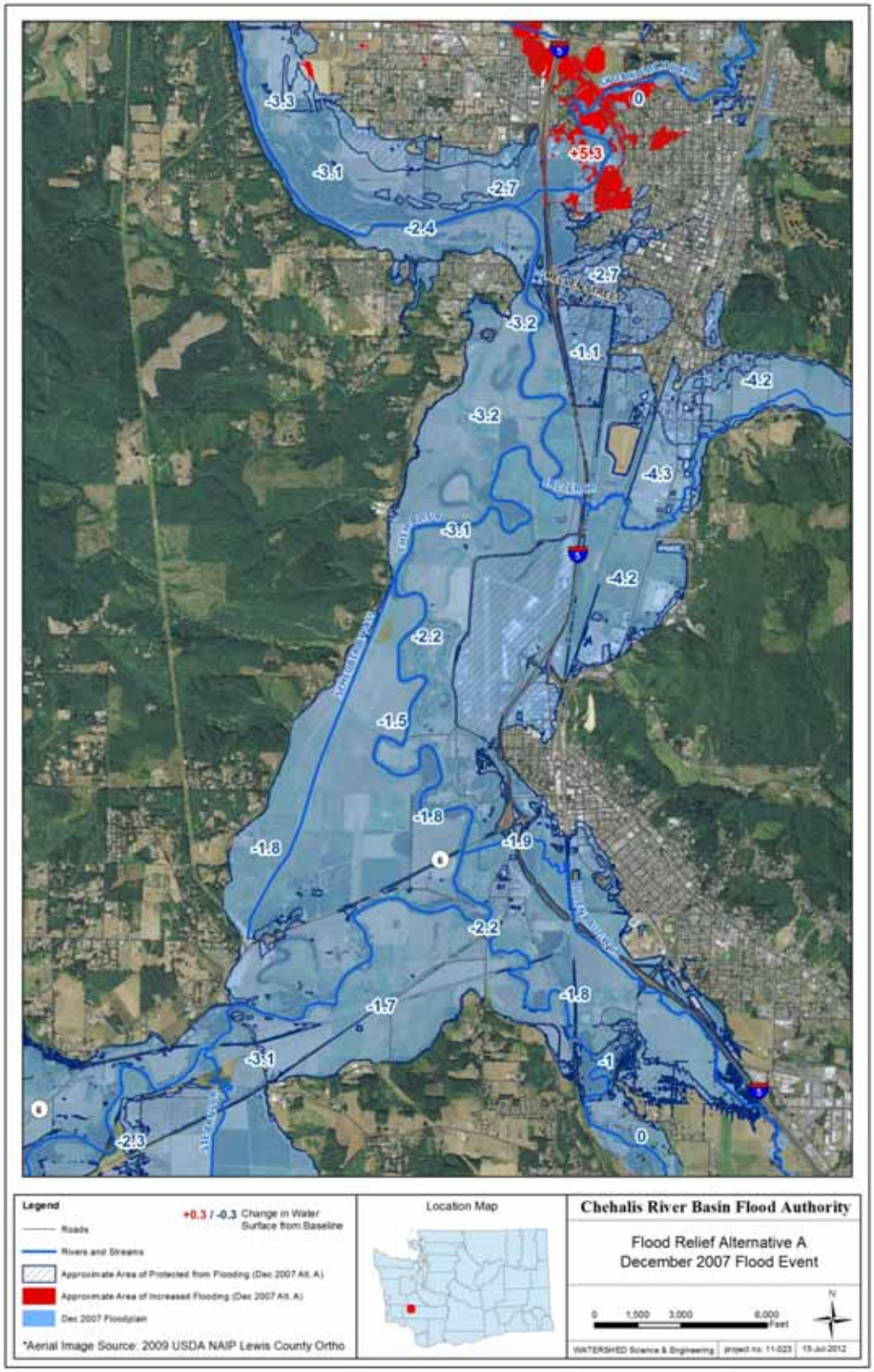
Twin Cities Inundation Mapping

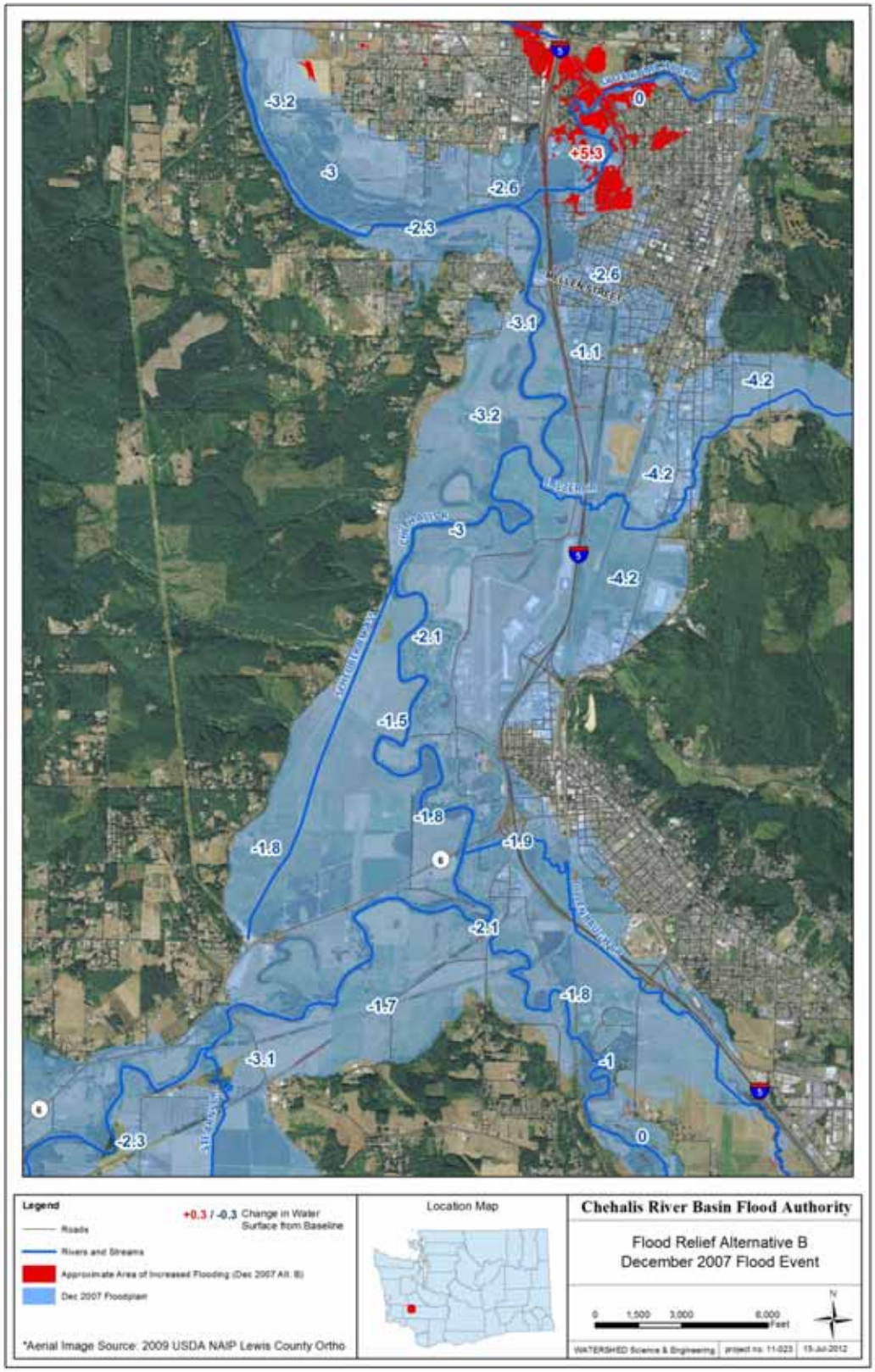
Figures 14 through 16 show inundation maps for the three basin wide flood relief alternatives (A, B, and C) for the December 2007 flood event. As shown in these figures, the inundated area would be reduced significantly under Alternatives A and B (with the main stem dam). Alternative C, without the dam, tends to increase water levels in some locations while lowering water levels at other locations within the Twin Cities.

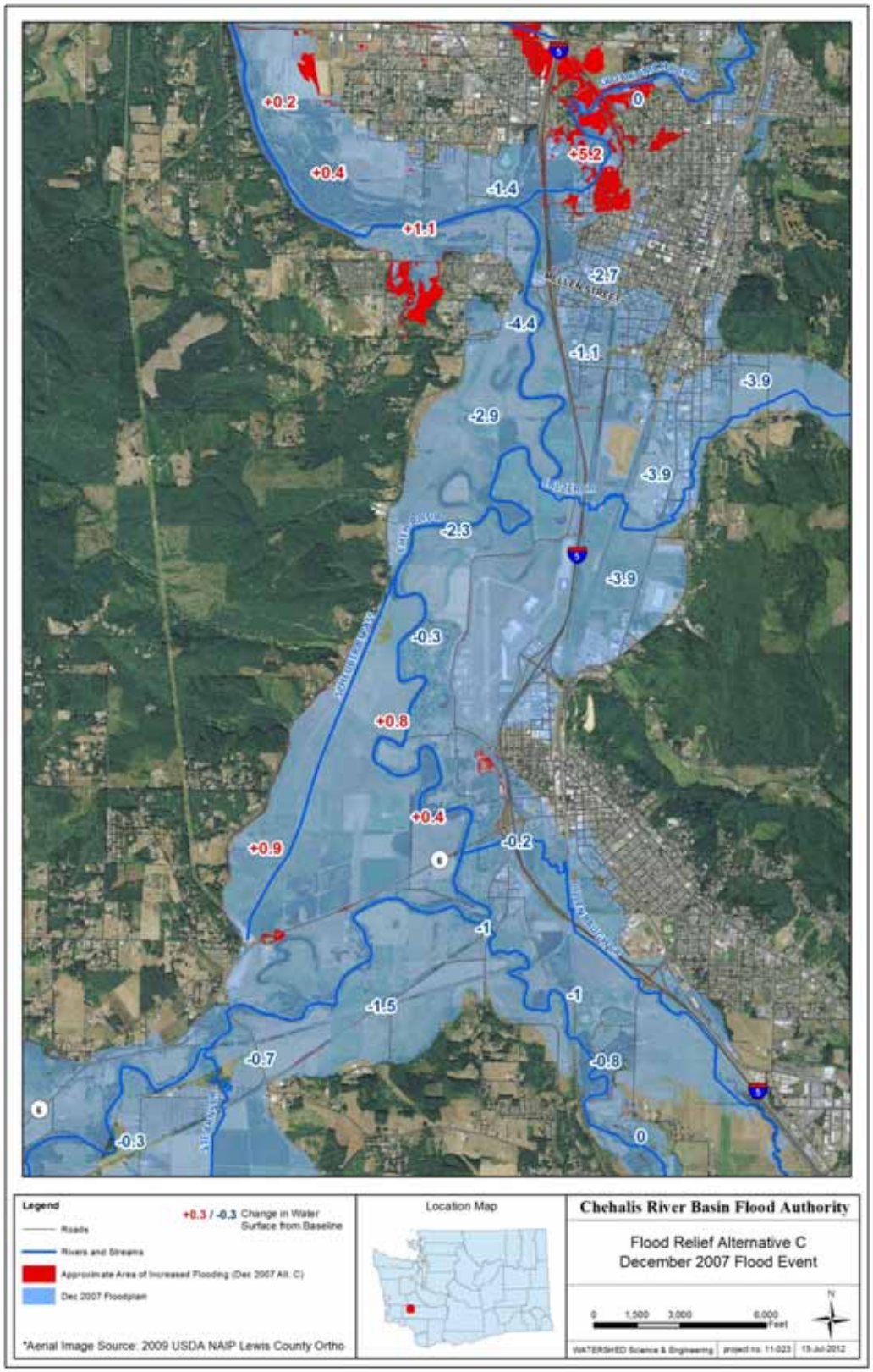



Change in Water Surface Elevations under Alternative B
Change in Water Surface Elevation (feet)
-6.0
-5.0
-4.0
-3.0
-2.0
-1.0
0.0
1.0
February 1996 Flood
December 2007 Flood
January 2009 Flood
100-Year Flood
Near Doty
Curtis Store (on S Fork Chehalis)
Downstream of South Fork
Near Adna
Labree Road (on Newaukum R)
Newaukum Confluence
Along Airport Levee
Dillenbaugh Storage Area
Airport Storage Area
Long Road Storage Area
Centralia Storage Area
Mellen St
Bucoda (Skookumchuck R)
Pearl Street (Skookumchuck R)
Skookumchuck Confluence
Upstream of Galvin Road
Grand Mound (Prather Road)
Near Rochester
Anderson Road
Black River Confluence
Sickman Ford Bridge
Porter Creek Road
Wakefield Road
Satsop Confluence
Montesano
Cosmopolis


Change in Water Surface Elevations under Alternative C
Change in Water Surface Elevation (feet)
-6.0
-5.0
-4.0
-3.0
-2.0
-1.0
0.0
1.0
February 1996 Flood
December 2007 Flood
January 2009 Flood
100-Year Flood
Near Doty
Curtis Store (on S Fork Chehalis)
Downstream of South Fork
Near Adna
Labree Road (on Newaukum R)
Newaukum Confluence
Along Airport Levee
Dillenbaugh Storage Area
Airport Storage Area
Long Road Storage Area
Centralia Storage Area
Mellen St
Bucoda (Skookumchuck R)
Pearl Street (Skookumchuck R)
Skookumchuck Confluence
Upstream of Galvin Road
Grand Mound (Prather Road)
Near Rochester
Anderson Road
Black River Confluence
Sickman Ford Bridge
Porter Creek Road
Wakefield Road
Satsop Confluence
Montesano
Cosmopolis


-3.3
-3.1
-2.7
-2.4
0
+5.3
-2.7
-3.2
-1.1
-4.2
-3.2
-4.3
-3.1
-4.2
-2.2
-1.5
-1.8
-1.8
-1.9
-2.2
-1.7
-1.8
-3.1
-1
-2.3
0
Legend
+0.3 / -0.3 Change in Water Surface from Baseline
Roads
Rivers and Streams
Approximate Area of Protected from Flooding (Dec 2007 Alt. A)
Approximate Area of Increased Flooding (Dec 2007 Alt. A)
Dec 2007 Floodplain
*Aerial Image Source: 2009 USDA NAIP Lewis County Ortho
Location Map
Chehalis River Basin Flood Authority
Flood Relief Alternative A
December 2007 Flood Event
0 1,500 3,000 6,000 Feet
N
WATERSHED Science & Engineering
project no. 11-023
13-Jul-2012


-3.2
0
+5.3
-3
-2.6
-2.3
-2.6
-3.1
-1.1
-4.2
-3.2
-4.2
-3
-4.2
-2.1
-1.5
-1.8
-1.9
-1.8
-2.1
-1.8
-1.7
-3.1
-1
-2.3
0
Legend
+0.3 / -0.3 Change in Water Surface from Baseline
Roads
Rivers and Streams
Approximate Area of Increased Flooding (Dec 2007 Alt. B)
Dec 2007 Floodplain
*Aerial Image Source: 2009 USDA NAIP Lewis County Ortho
Location Map
Chehalis River Basin Flood Authority
Flood Relief Alternative B
December 2007 Flood Event
0 1,500 3,000 6,000 Feet
N
WATERSHED Science & Engineering
project no. 11-023
13-Jul-2012


+0.2
0
+5.2
+0.4
-1.4
+1.1
-2.7
-4.4
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-0.3
+0.8
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-0.2
-1
-1
-1.5
-0.7
-0.8
-0.3
0
Legend
+0.3 / -0.3 Change in Water Surface from Baseline
Roads
Rivers and Streams
Approximate Area of Increased Flooding (Dec 2007 Alt. C)
Dec 2007 Floodplain
*Aerial Image Source: 2009 USDA NAIP Lewis County Ortho
Location Map
Chehalis River Basin Flood Authority
Flood Relief Alternative C
December 2007 Flood Event
0 1,500 3,000 6,000 Feet
N
WATERSHED Science & Engineering
project no. 11-023
13-Jul-2012

I-5 Protection Summary

Table 11 compares the simulated water surface elevations and minimum roadway elevations for 33 locations along I-5. These locations include each cross section that contacts the interstate as well as the major modeled storage areas. Some of the points are on the west side of the freeway along the main stem Chehalis River, the Newaukum River, and/or Dillenbaugh Creek. Other points are along the east side of the freeway on Dillenbaugh Creek near Chehalis. The road surface elevations for I-5 were taken from the April 2012 field survey by WSDOT, where available, or from LiDAR data where field survey were not available. These data are intended to represent the lowest elevation of the roadway surface, which in many cases is on the shoulder outside the traffic lanes. In some locations the elevations of I-5 are significantly higher than the floodplain because the freeway is elevated where it approaches an overpass.

Table 11: Comparison of Effects on I-5 Flooding for Flood Relief Alternatives for December 2007 Event

River	Reach	River Sta	I-5 Elev WSDOT		Description	December 2007 Flood											
							Baseline			Alternative A			Alternative B			Alternative C	
			(NGVD 29)	NAVD 88		WSEL	Change	Result	WSEL	Change	Result	WSEL	Change	Result	WSEL	Change	Result
CHEHALIS	REACH 13	68.98	174.62	178.02	1600 feet N of Salzer Creek culvert	181.4	3.4	Floods	178.2	0.2	Floods	178.3	0.3	Wall	178.6	0.6	Wall
CHEHALIS	REACH 13	69.22	175.65	179.05	280 feet N of Salzer Creek culvert	181.5	2.4	Floods	178.3	-0.8		178.3	-0.7		178.8	-0.3	
CHEHALIS	REACH 11	69.9	175.65	179.05	at Salzer Creek culvert	181.5	2.5	Floods	178.4	-0.7		178.4	-0.6		179.0	-0.1	
CHEHALIS	REACH 11	70.18	175.8	179.2	Between airport levee and Salzer Cr	181.6	2.4	Floods	178.4	-0.8		178.5	-0.8		179.0	-0.2	
Airport Storage Area	SA #2	SA #2		176.3	Low Point From RM 70.25 to RM 73.73	182.2	5.9	Floods	159.4	-16.9		159.4	-16.9		159.4	-16.9	
CHEHALIS	REACH 9	73.73	179.7	183.1	near NW West Street	183.4	0.3	Floods	181.8	-1.3		181.8	-1.3		184.1	1.0	Wall
CHEHALIS	REACH 9	74.02	179.9	183.3	just north of SR6 Interchange	183.7	0.4	Floods	181.9	-1.4		181.9	-1.4		184.2	0.9	Wall
CHEHALIS	REACH 9	74.25	179.5	182.9		183.9	1.0	Floods	182.1	-0.8		182.1	-0.8		184.3	1.4	Wall
CHEHALIS	REACH 9	74.57	183.8	187.2	On southbound off ramp	184.2	-3.0		182.4	-4.8		182.4	-4.8		184.4	-2.8	
DILLENBAUGH CR	REACH 8	0.094	180.46	183.86	dillenbaugh I-5 Weir	185.2	1.3	Floods	183.3	-0.6		183.3	-0.6		184.9	1.1	Wall
DILLENBAUGH CR	REACH 8	0.122	180.46	183.86	dillenbaugh I-5 Weir	186.1	2.2	Floods	183.9	0.1	Floods	184.0	0.1	Wall	185.4	1.6	Wall
DILLENBAUGH CR	REACH 8	0.142	178.16	181.56	low point on I-5 N on-ramp	186.2	4.7	Floods	184.1	2.5	Floods	184.1	2.5	Wall	185.6	4.0	Wall
CHEHALIS	REACH 7	74.95	187.4	190.8	On Chehalis (west) side of I-5. Road superelevated, sloping to low of 186.4 (NAVD) on East side of I-5	185.7	-5.1		183.6	-7.2		183.6	-7.2		185.1	-5.7	
DILLENBAUGH CR	REACH 8	0.155	194.7	198.1	East side of I-5	186.3	-11.8		184.1	-14.0		184.1	-14.0		185.6	-12.5	
CHEHALIS	REACH 7	75.08	204.1	207.5	West side of I-5	186.3	-21.2		184.1	-23.4		184.1	-23.4		185.4	-22.1	
DILLENBAUGH CR	REACH 8	0.219	204.2	207.6	East side of I-5	186.3	-21.3		184.1	-23.5		184.1	-23.5		185.6	-22.0	
CHEHALIS	REACH 7	75.085	204.7	208.1	West side of I-5	186.3	-21.8		184.1	-24.0		184.1	-24.0		185.4	-22.7	
DILLENBAUGH CR	REACH 8	0.239	205.5	208.9	East side of I-5	186.3	-22.6		184.1	-24.8		184.2	-24.8		185.6	-23.3	
NEWAUKUM	REACH 6	0.1	206.07	209.47	West side of I-5	187.0	-22.5		184.7	-24.7		184.8	-24.7		185.9	-23.6	
DILLENBAUGH CR	REACH 8	0.321	208	211.4	East side of I-5	186.3	-25.1		184.2	-27.3		184.2	-27.2		185.6	-25.8	
DILLENBAUGH CR	REACH 8	0.385	209.1	212.5	East side of I-5	186.3	-26.2		184.2	-28.4		184.2	-28.3		185.6	-26.9	
NEWAUKUM	REACH 6	0.553	211.45	214.85	West side of I-5	187.2	-27.6		184.9	-29.9		184.9	-29.9		186.1	-28.8	
DILLENBAUGH CR	REACH 8	0.478	211.4	214.8	East side of I-5	186.4	-28.4		184.2	-30.6		184.2	-30.6		185.7	-29.1	
DILLENBAUGH CR	REACH 8	0.495	211	214.4	East side of I-5	186.4	-28.0		184.3	-30.1		184.3	-30.1		185.7	-28.7	
DILLENBAUGH CR	REACH 8	0.511	211	214.4	East side of I-5	186.5	-27.9		184.3	-30.1		184.3	-30.1		185.8	-28.7	
DILLENBAUGH CR	REACH 8	0.583	207.8	211.2	West side of I-5	186.6	-24.6		184.4	-26.8		184.4	-26.8		185.8	-25.4	
DILLENBAUGH CR	REACH 8	0.623	205.8	209.2	West side of I-5	186.7	-22.5		184.5	-24.8		184.5	-24.7		185.9	-23.3	
DILLENBAUGH CR	REACH 8	0.792	182.4	185.8	West side of I-5	187.6	1.8	Floods	184.9	-0.9		184.9	-0.9		186.3	0.5	Wall
DILLENBAUGH CR	REACH 8	1.00001	181.65	185.05	West side of I-5	187.6	2.6	Floods	184.9	-0.2		184.9	-0.2		186.3	1.3	Wall
DILLENBAUGH CR	REACH 8	1.25	183.2	186.6	West side of I-5	187.6	1.0	Floods	184.9	-1.7		184.9	-1.7		186.3	-0.3	
DILLENBAUGH CR	REACH 8	1.29	183.4	186.8	West side of I-5	187.6	0.8	Floods	184.9	-1.9		184.9	-1.9		186.3	-0.5	
DILLENBAUGH CR	REACH 8	1.32	183.5	186.9	West side of I-5	187.6	0.7	Floods	185.0	-2.0		185.0	-2.0		186.3	-0.6	
DILLENBAUGH CR	REACH 8	1.5	184.8	188.2	West side of I-5	187.6	-0.6		185.0	-3.3		185.0	-3.2		186.3	-1.9	

Discussion of Results

The results presented above show the level of flood water level reduction that can be achieved through individual flood relief projects and combinations of those projects. Data are presented for four flood events to show how each project or alternative performs in each different types of storm events. The data show benefits and potential water surface elevation impact of each project. Given this information, projects can be refined and alternatives can be configured to address specific flood damage problem areas. The data presented herein is limited to water surface elevation comparisons. Information on depths of flooding can be generated using the model output but this level of analysis was beyond the scope of this study. Ultimately, conclusions regarding flood impacts would need to consider changes in water surface elevation in conjunction with actual depths of flooding. In some cases, a small decrease in flood depth could have significant benefits while in other cases even large reductions might not have much effect. The same is true for water level increases – some locations may not be particularly sensitive to increases (for example areas where flooding is already very deep) while other areas might be particularly problematic. That level of analysis and evaluation of the results will need to be

undertaken in combination with information on project costs to define a preferred package of flood relief projects for the basin. The model developed for this study will be helpful to generate the hydraulic data needed to inform that effort.

Caveats and further work required

The results and data described herein were developed using the Chehalis River Basin HEC-RAS hydraulic model. As discussed above there are always uncertainties involved in modeling extreme flood events, and the large floods on the Chehalis River are particularly difficult to model accurately due to problems with some flow gages during these events. Significant efforts were made to calibrate the model to all available high water marks and anecdotal information on past flooding. While the modeling is felt to be entirely appropriate for the analyses described herein, use of the model for other purposes should be done with caution.

Furthermore, inundation maps prepared to document changes in the extent and depths of flooding under the alternatives were developed using automated mapping techniques, which are appropriate for preliminary evaluations. The maps were also based on the best available topographic data, which in some cases is more than 10 years old. As such, the maps may not be entirely accurate in some locations and should be used with caution. These inundation maps were not intended to replace other flood hazard maps such as those available from FEMA since the preparation of those maps requires significant manual post-processing of the data that is well beyond the scope of this study. Detailed inundation mapping for flood hazard evaluation could be done using the new modeling but that would require additional efforts not currently scoped.

It should also be noted that the geometric (cross section) data used in the hydraulic model used available topographic data sources and that these included data sources from 1999 (in the Twin Cities floodplain area), 2002 (between Grand Mound and Montesano and along the Skookumchuck River), and 2005 and 2006 in Centralia and Chehalis. New topographic data will be available soon for much of the basin (Chehalis River corridor from Lewis County line to Montesano) or is already available (Thurston County and portions of Lewis County). The new topographic data could be used to update the hydraulic models thus improving the model's ability to simulate overbank flooding. This effort, however, is beyond the scope and schedule of the current project.

Summary and Recommendations

The Chehalis River Basin Flood Authority recognized the need for detailed hydraulic modeling and analysis of potential flood relief alternatives in the Chehalis River basin. In particular extending the existing hydraulic modeling downstream to the mouth of the river and using the model to evaluate a broad range of possible flood relief projects. Through a budget proviso in Engrossed Substitute House Bill (ESHB) 2020 the Washington State Legislature provided funding to "complete the hydraulic model for the Chehalis River to calculate flood levels, flood damages, and benefits of proposed flood mitigation projects for the lower portions of the river." WATERSHED Science & Engineering, together with subconsultant WEST Consultants, was retained by the Flood Authority to develop the hydraulic model and apply it to the evaluation of more than 25 potential flood relief projects or combinations of projects. The results of those evaluations are presented above.

Concurrent with the Flood Authority's efforts to evaluate basin wide flood relief alternatives the Corps is conducting hydraulic analyses related to ecosystem restoration planning and WSDOT is designing and evaluating several alternatives to mitigate the effects of flooding to Interstate 5. WSE and WEST worked with those agencies to ensure that the model development work for the Flood Authority leveraged those agencies work and resulted in single baseline hydraulic model that was accepted by all. The comprehensive basin wide model described above has been provided to the Corps for review and is being used by WSDOT for their analyses. The use of a consistent hydraulic analysis tool by all three groups should facilitate agreement on the potential benefits and impacts of various alternatives and as such should improve collaborative efforts to address basin flood problems.

The hydraulic model developed for this study extends from the mouth of the Chehalis River to upstream of Pe Ell, a distance of more than 108 miles. The model also includes significant portions of key tributaries including the following: Wynoochee River (54 miles), Satsop River (2 miles), Black River (10 miles), Lincoln Creek (4 miles), Skookumchuck River (21 miles), Hanford Creek (6 miles), Salzer Creek (5 miles), Newaukum River (10 miles), Dillenbaugh Creek (3.5 miles), and South Fork Chehalis River (5.8 miles). While the model was developed primarily to evaluate the effects on the main stem Chehalis River of large-scale flood relief projects it can also serve as a tool for the evaluation of hydraulic conditions and flooding on these tributaries. In fact, the model has already been used by WSE to evaluate the effects of potential modifications to the railroad bridge downstream of Bucoda on the Skookumchuck River.

The baseline hydraulic model developed for this study represents the best available information on hydraulic conditions in the modeled reaches. However, it must be recognized that the model includes both newly modeled reaches (e.g. Chehalis River between Porter and Aberdeen) and reaches where existing models were incorporated. In some of the older model reaches new cross sections surveys were collected and used (e.g. Skookumchuck River at Bucoda, Chehalis River between Grand Mound and Porter) while in other reaches (e.g. the Chehalis River between Grand Doty and Grand Mound, South Fork Chehalis) the model is using cross sections collected as long ago as 2001, or in some cases 1989. Similarly, in some portions of the model (e.g. Newaukum River) floodplain topographic data were updated to reflect more recently available LiDAR data while in other reaches (e.g. Satsop River, Black River) the topographic data dates back to 2002, or in some cases earlier. Obviously, it would have been preferable to update the entire model with new field surveyed cross sections and up to date overbank topographic data. Furthermore, it would have been preferable to be able to thoroughly review, refine, and validate all of the exiting model reaches that were incorporated into the final model. However, the efforts are simply beyond the scope and resources of the current project. That said the

model is still a significant improvement over any tool that has been previously available and its availability should enhance flood relief investigations throughout the basin.

As time and resources allow it is recommended that the model be updated to use new topographic and survey data, that the updated model be refined to address any new infrastructure that has been built since the original model development, and that the updated model be calibrated to available flood information. It is further recommended that any future application of the model be preceded by an assessment by a qualified hydraulic engineer to see if the model as developed herein is appropriate for the intended use.

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WATERSHED Science & Engineering (2012c). “Newaukum River Model Extension and Refinement” Technical Memorandum, March 13, 2012.

WATERSHED Science & Engineering (2012d). “Response to State team comments on Chehalis River Hydraulic Model” Technical Memorandum, April 11, 2012.

Appendices

Appendix A

WSE Responses to State Tech Team Comments on Work Plan (Oct 21, 2011)

Reviewer	Comment	Response	Task
Guy Hoyle-Dodson, DOE	The assumption that this tidally influenced flood plain can be even marginally modeled with HEC-RAS is highly optimistic. The matrix solutions in HEC-RAS within the unsteady-state flow simulation is highly unstable in these situations and has difficulty forming a solution.	Both WSE and WEST staff have significant experience applying HEC-RAS in a tidal environment and we do not believe that it's application is as "optimistic" as the reviewer suggests. We can point to numerous instances of HEC-RAS being successfully applied to hydraulic modeling in tidal environments including significant modeling applications on the Green and Snohomish Rivers and Tillamook Bay. We can also cite literature supporting the appropriateness of HEC-RAS in these situations including the FHWA website at http://www.fhwa.dot.gov/engineering/hydraulics/hydrology/hec25c4.cfm and the attached draft paper submitted to the Journal of Hydraulic Engineering (I don't have access to the final version).	Task 5c
Guy Hoyle-Dodson, DOE	The inclusion of tidal influences would require a downstream boundary hydrograph , and measurements.	It is the intent of this study to develop a downstream boundary condition using the NOAA tide gage data available for the Aberdeen station.	Task 5c
Guy Hoyle-Dodson, DOE	Theta Weighting Factor. Theta is a weighting applied to the finite difference approximations when solving the unsteady flow equations. Theoretically Theta can vary from 0.5 to 1.0. However, as practical limit is from 0.6 to 1.0 Theta of 1.0 provides the most stability, but less numerical accuracy. Theta of 0.6 provides the most accuracy, but less numerical stability. The default in HEC-RAS is 1.0. Once you have your model developed, reduce theta towards 0.6, as long as the model stays stable. For rivers with tidal boundaries, in which the rising tide will propagate upstream, the user should always try to use a theta value as close to 0.6 as possible. Tidal waves are very dynamic. In order for the solution to be able to accurately model a tidal surge, theta must be close to 0.6. Thus accuracy is sacrificed for stability.	We don't envision Theta being a big concern The reviewer cites a "textbook" concern but practically speaking we've never had much issue with it nor have we seen it have a tremendous effect on results (except possibly for dam break or other flash flooding type simulations). Usually we are also looking at peak results, whereas Theta is more likely to have an effect on the shape of computed stage/flow hydrographs. But we feel other inputs and uncertainties -- geometry, roughness, boundary conditions -- have a greater effect. The current Twin Cities model already has Theta set to unity, which is the default. For a model this large, plus extended all the way to Grays Harbor, it might be difficult to reduce that down to 0.6 without some instability arising somewhere. Also, if the present model is already calibrated, we probably don't want to change this parameter if it might compromise (however minor) the upstream calibration. Our suggestion would be to initially build a truncated version of the model, from Monteseno downstream, that is both more manageable to run (using inflows taken from the larger model) but can also be used for some sensitivity tests to the lower tidal region of the study. We can modify Theta just for the lower end see if we observe significant change, and do some other sensitivity tests just related to the tidal area. We assume the reviewer is not talking about surface tidal waves, as neither RAS nor any other typical 2D model for rivers simulates those. More likely storm surges, as reflected in the downstream stage hydrograph boundary. HEC-RAS should be able to handle these OK, they don't rise THAT fast or dynamically. And the diffusive effects of using the fully implicit solution (Theta=1) should be minimal.	Task 5c

Reviewer	Comment	Response	Task
Guy Hoyle-Dodson, DOE	It might be easier and more cost effective just to use a 2-D model.	Notwithstanding our opinion that a useful HEC-RAS model can be developed for this reach I share Guy's opinion that a well developed 2-D model would provide a more robust tool for a wide range of purposes. One problem, however, is that we don't have adequate time or budget to do the detailed bathymetric data collection that would be required to support a robust 2-D model. Furthermore, model development costs and run times would also be significantly greater for a detailed 2-D model, pushing them beyond the time and budget resources of the current project. Finally, since the preeminent task in our current work plan is to provide a tool that can be used to evaluate the downstream impact/benefit of upstream flood relief alternatives we need to recognize that modeling for the remainder of the system, from Pe Ell to Montesano, is being performed in HEC-RAS. The intent here is to append the downstream reach to the Corps model to allow the Flood Authority to evaluate basin wide flood relief alternatives in a single tool.	Task 5c
Guy Hoyle-Dodson, DOE	They should ensure that modeling for all tributaries has the QA/QC and level of detail and accuracy that is commensurate with the other modeling being performed for the Corp, otherwise the continuity across the entire model will suffer.	Modeling of the tributaries will be scoped in detail in coordination with the Flood Authority and Stakeholders to ensure their needs are met. There may be benefit in modeling the tributaries at a lower level of detail than the main stem, simply to allow more miles of trib to be modeled. This is still to be determined.	Task 6b
Guy Hoyle-Dodson, DOE	This may require more resources that currently allocated.	The work plan will be tailored to the available funds	Task 5d
Guy Hoyle-Dodson, DOE	Consultant should consider 2-D modeling on the lower reach	See previous response	None
Paul Pickett, DOE	The work plan states that they will be using the hydrologic statistical events developed by the Corps and not adding any more. How will hydrologic statistical events and boundary conditions be developed for the tributary modeling?	WEST's work for the Corps is developing hydrologic data for all major tributaries in the Chehalis basin at up to 78 locations including more than 50 ungaged sites. WEST is also developing flows for the major tributaries for use in the modeling of the main stem Chehalis River. These data will be used for tributary modeling either independently of the main stem or using the main stem model to provide a downstream boundary condition. More detail on WEST's work for the Corps is available in their scope for that project.	Task 6a

Reviewer	Comment	Response	Task
Paul Pickett, DOE	One of the issues that has come up in the past has been the timing of storm events and the orientation of the storm events to the basin. Peak flow events from the tributaries won't occur at the same time. Different scenarios based on historical events would have a sequencing of peak events across the basin and maximum intensity hitting in different locations. How will this be addressed in the modeling?	Assumptions about coincidence of tributary flows, as necessary for modeling the main stem Chehalis River will be implicit in the WEST work for the Corps. Analysis of the fall range of possible spatial precipitation patterns is beyond the scope of either the Corps study or this study and will not be investigated in either study.	Task 6a
Paul Pickett, DOE	I think Guy is correct that using the HEC-RAS 1-D model could result in significant uncertainty in the results and a 2-D model would be more reliable. I also agree with Hal that it is acceptable, at least as a first-cut analysis. But as part of the study report, the success of using HEC-RAS at the downstream end should be evaluated to determine the limitations and uncertainty of the 1-D model and the benefits of using a 2-D model for an improved analysis in the future. On the other hand, if a 2-D model could be developed with a reasonable amount of additional effort, that would be preferable. Greg Pelletier (Department of Ecology) developed a 2-D hydrodynamic model of Grays Harbor and the Chehalis River from Montesano downstream. He used the "Wetland Dynamic Water Budget Model", which is an Army Corps of Engineers model similar to DYNHYD. Ray Walton is very familiar with it - he "wrote the book" on it, literally. Greg Pelletier says the model input information is available, possibly on the Ecology website. Could the existing WDWBM model be upgraded to serve the purposes of this study? Here are links to Greg's work: • Project page: http://www.ecy.wa.gov/programs/wq/tmdl/ChehalisBasin/GraysHbrTMDL.html • Computer simulation information: http://www.ecy.wa.gov/programs/eap/wrias/tmdl/ghfc/results.html	See previous discussion of 2-D model in response to comments from Guy Hoyle-Dodson. Note that the WDWBM model is not actually a 2-D model. It is a pseudo 2-D link-node model with the 2-D effect gained by branching flows off of and one node in multiple directions. This is structurally the same as the network branching available within HEC-RAS and considering the more sophisticated hydraulic routing available in RAS the RAS model would actually be a better option. Note also that the model developed by Greg Pelletier only has a single branch up the Chehalis River and thus the pseudo 2-D effect is limited to Grays Harbor in an area outside the current project boundary.	Task 5c
Paul Pickett, DOE	Does the workplan include time and funding for review by the state agencies and addressing any comments received?	The work plan will allow time for the Consultant team to discuss technical issues with agency reviewers at key milestones.	none

Reviewer	Comment	Response	Task
Paul Pickett, DOE	It would be better to brief state agency technical staff at regular intervals and incorporate their comments during the course of the project (rather than waiting until the draft report is out to brief state agencies and solicit comments)? Is this approach incorporated in the work plan, or could it be?	The work plan will allow time for the Consultant team to discuss technical issues with agency reviewers at key milestones. Note however that the tight timeframe for this project will require great flexibility and responsiveness on the part of the agencies if coordination is to be successful.	none
Hal Beecher, WDFW	If new channel survey data are obtained, they are presumed to be superior to 2001 data for cross sections. It would be useful to assess how the two data sets compare in maximal conveyance, width, difference between adjacent floodplain elevation and relevant channel bed elevations (probably not pool bottoms) to determine if conveyance in the river is changing or if the two data sets are complementary (two samples from the same population). Such information may shed some light on processes affecting channel conveyance (dynamic equilibrium or not).	The data will be available for these comparisons.	Task 5a
Hal Beecher, WDFW	The plan briefly discusses use of HEC-RAS vs. 2-dimensional modeling. Annear et al. (2002: 265) discussed HEC-RAS and their discussion is supportive of using HEC-RAS: "The model's purpose is to provide information on river stages over a range of flows, particularly for floods." "These situations include mixed flow regime calculations (i.e., hydraulic jumps), bridge hydraulics, and evaluation profiles at river confluences. … It has culvert and bridge routines. The program can model a single river reach, a dendritic system, or a full network (looped systems)." Thus, use of HEC-RAS appears reasonable.	Agreed	Task 5c
Hal Beecher, WDFW	This optional task includes developing hydrographs for "ecologically significant flows at up to 50 locations." Natural resource agencies and interests should be consulted to determine what those flows are and what locations are modeled. A major consideration is stranding of fish as flows recede from a flood. Rate of stage decline should be addressed over the range of flows where overbank flows drop to within the channel.	See previous responses regarding the hydrology. At this point no additional hydrologic data development is planned under this contract.	Task 6a
Casey Kramer, WSDOT	Explain why deferred. Would like a brief discussion summarizing other previous and on-going LiDAR efforts within the project area.	Preliminary checks of the LIDAR data can be made using the area between Montesano and Aberdeen for which both 2009 and 2002 LiDAR data are available. Additional checks can be made using the topographic data collected during the cross section surveys. These checks should suffice for now given that FEMA is planning on collecting new LiDAR data in fall 2011.	Task 3

Reviewer	Comment	Response	Task
Casey Kramer, WSDOT	Last sentence in Task 5a seems to support Task 3.	The draft work plan was written prior to the collection of the data discussed above.	Task 5a
Casey Kramer, WSDOT	Refer to which Task you are referring to "topographic data described above".	Task 5a	Task 5b
Casey Kramer, WSDOT	What are the 50 locations West is looking at?	WEST has a map showing the hydrologic data development locations. This map can be provided upon request.	Task 6a
Casey Kramer, WSDOT	Also interested in China, Salzer, Dillenbaugh, etc. This may be upstream of the proposed work plan.	The available budget is not adequate to allow detailed modeling of the four tributaries already defined in the scope. It is understood that many more tributaries could benefit from hydraulic modeling and analysis. IF additional funds become available additional modeling may be conducted.	Task 6b
Casey Kramer, WSDOT	Explain why deferred.	At the request of the Flood Authority, to make the best use of available funds.	Task 6d
Casey Kramer, WSDOT	Seems like a minimal cost for an important task. Topography/bathymetry is the foundation for a accurate hydraulic model, not knowing the quality of the data could be viewed as a flaw in the modeling results.	See previous comment on checks that will be preformed.	Optional Task 3

Appendix B

WSE Response to State Tech Team Comments on Hydraulic Model (4/17/2012)

WATERSHED

Science & Engineering

110 Prefontaine Place South, Suite 508
Seattle, WA 98104
206-521-3000

Memorandum

To: Chehalis River Basin Flood Authority and State Technical Review Team

From: WATERSHED Science & Engineering (WSE) and WEST Consultants (WEST)

Date: 04/17/2012

Re: **Response to State team comments on Chehalis River Hydraulic Model**

Watershed Science & Engineering (WSE) and WEST Consultants (WEST) have developed an HEC-RAS hydraulic model of the Chehalis River, including portions of several significant tributaries (e.g. the Wynoochee, Satsop, Black, Skookumchuck, and Newaukum Rivers). Following a meeting on February 23rd, the model and available documentation were provided to a group of State technical staff for review and comment. Three State reviewers provided detailed written comments on the model: Paul Pickett (DOE), Casey Kramer (WSDOT), and Guy Hoyle-Dodson (DOE). These comments were well formed and generally helpful in identifying areas in the hydraulic model that required additional consideration and/or refinement. The three comment letters (attached) were reviewed and discussed by the WSE-WEST team and a number of modifications were made to the model to address significant concerns. In some cases, no changes to the model were necessary, either because the model was already configured appropriately or because the comment raised questions beyond the scope of the current study. Our general responses to the reviewer's comments are provided below. These responses will also be discussed further with the individual reviewers to ensure that we are all comfortable moving ahead with the Chehalis River Basin alternatives analysis using the resulting (refined) model.

RE: Paul Pickett comment letter of 3/30/2012:

Mr. Pickett's comments focused primarily on the hydrologic data proposed for use in the evaluation of flood relief alternatives. He noted that flood events in a basin as large and complex as the Chehalis Basin can come in many different forms and that a comprehensive analysis of flood relief alternatives would require a range of design events to be simulated. However, in our response below we provide data showing that the largest flood events (i.e. the top 10 floods) observed in the Chehalis basin in the past 80 years have similar enough characteristics to make the proposed design event modeling approach reasonable for the current effort. Furthermore, we note that the hydrology for the current study was done and widely reviewed as part of the concurrent Corps project and using the same hydrologic methodology as that study will maintain consistency between the modeling efforts. However, in an effort to provide a more robust and useful analysis, we offer a

recommendation to use hydrologic data for the calibration events (1996, 2007, and 2009) to augment the design event evaluation.

In addition to comments on the proposed hydrologic data, Mr. Pickett offered a number of suggestions for improving the evaluation and presentation of "Model Quality" metrics. We have reviewed these comments and find them to be well stated and helpful. We will endeavor to provide additional information on model quality including expanded reporting of model uncertainties, as suggested, when reporting the results of the alternatives analysis.

Detailed Response to "Sensitivity to Hydrology"

Mr. Pickett presented a very useful analysis of the high variability in flood coincidence of contributions from major tributaries in the Upper Chehalis River (above the flow gage near Grand Mound). We agree that multiple hydrologic scenarios of inflows from the major tributaries are possible that would result in a similar magnitude of high flow event for the Chehalis River near Grand Mound.

The hydrologic methodology that WEST used to develop the synthetic flood events for their current U.S. Army Corps of Engineers (USACE) study is similar to the one used by the USACE in the 2003 General Reevaluation Study (updated in 2010). The essential feature of the approach was to develop synthetic flood hydrographs at various locations throughout the basin that together would generate 1.5- to 500-year flood events for the Chehalis River near Grand Mound. The flood magnitude (recurrence frequency) of the basin-wide synthetic events is evaluated using the flow gage site on the Chehalis River near Grand Mound. The coincident relationships for peak flows between the Grand Mound gage and upstream gages were determined using all concurrent annual peaks, which provide a systematic and objective method to define the long-term average coincidence between a synthetic peak discharge near Grand Mound and the coincident inflow from an upstream tributary or from the headwaters of the Upper Chehalis River.

In Mr. Pickett's comment letter he plots the correlation between the annual peak discharges near Grand Mound and near Doty with and without inclusion of the December 2007 event. The figure shows that for flows in the Chehalis River near Grand Mound less than about 45,000 cfs, roughly the peak discharge of a 10-year event (Table 1), the two regression curves are relatively close to each other. For flows that exceed about 45,000 cfs, the regression curves depart significantly. Mr. Pickett expressed concern that the higher ratio of flows near Doty to flows near Grand Mound might result in unreasonably large contributions from the upper watershed (above Doty), even though this is only seen in some of the observed flood events.

To evaluate and respond to Mr. Pickett's concern we analyzed data from the top 10 annual peaks at the Grand Mound gage and the corresponding peaks at major upstream gages. Our key finding is that a large flood event near Grand Mound cannot occur if a large event does not occur in the headwaters above Doty. Table 2 summarizes available USGS peak flow data for the Chehalis River basin. This table shows the top 10 flood events recorded by the USGS at the Grand Mound. Of these, two occurred in the 1930s when none of these other major USGS gages in the basin was in operation. Of the remaining eight largest flood events at Grand Mound:

1) All eight had a corresponding flood on the Chehalis at Doty that was in the top 10 of all time at that location.
2) Seven of the eight had a flood on the South Fork Chehalis River that was in the top 10 at that location.

3) Seven of the eight had a flood on the Newaukum River that was in the top 10 at that location.
4) Only four of the eight had a flood on the Skookumchuck River that was in the top 10 at that location.

Furthermore, review of the concurrent USGS gage records for Doty and Grand Mound shows that of the top 10 historical flood events at Doty, eight were also in the top 10 events of all time at Grand Mound. Similarly, of the top 10 events on the South Fork Chehalis River and the Newaukum River 7 were also among the top 10 events at Grand Mound. However, it can be seen that of the top 10 flood events on the Skookumchuck River only four were in the top 10 flood events at Grand Mound. Looking in more detail at the Skookumchuck gage records it can also be seen that the 2nd highest flow of all time on the Skookumchuck was only the 24th highest flow at Grand Mound and the 4th highest flow on the Skookumchuck was only the 23rd highest flow in the USGS record at Grand Mound.

From these data, we can make the following observations:

6) A large flow (herein defined as among the top 10 highest peaks recorded) on the Chehalis at Grand Mound has never happened without a correspondingly large flow on the Chehalis River at Doty.
7) A large flow at Doty is a reliable (although not perfect) indicator of a large flow at Grand Mound.
8) A large flow on the Chehalis at Grand Mound can happen with or without a significant flow contribution from the Skookumchuck River.
9) A large flow on the Skookumchuck is not a very good indicator of large flows at Grand Mound.
10) Peak flows on the Newaukum and South Fork are similarly correlated to the flows at Grand Mound, less so than the Doty flows but more so than the Skookumchuck flows.

Using the top 10 flows at Grand Mound as a representative and sufficiently large sample of basin wide flood events, we see that the average contributions from Doty, South Fork, Newaukum, and Skookumchuck during these events are 45%, 17%, 19%, and 14% of the Grand Mound peak. In his comments Mr. Pickett noted that the preliminary proposed design flow hydrology had ratios of 44%, xx% (South Fork is under review), 17%, and 14%, respectively, for these locations. The proposed design flow ratios appear to be very reasonable given the data in Table 2 and the observations listed above. Figure through Figure show the distributions of flood return periods across the entire basin for the February 1996, December 2007, and January 2009 events. For the January 2009 event, a flood event greater than the 100-year peak discharges occurred in the Skookumchuck and Newaukum Rivers. However, the corresponding flows near Doty and near Grand Mound are only a 12-, and 15-year event, respectively. Thus, while this event is a good example that portions of the basin can see extreme floods while other portions see smaller flood events it also supports the conclusion that a basin-wide extreme flood (as determined using the gage at Grand Mound) is only possible with a large contribution from the Upper Chehalis basin.

We feel that these additional analyses indicate that the coincident relationships determined from all concurrent annual peaks between the Grand Mound gage and the upstream gages provide a reasonable representation of the large flood events in the Upper Chehalis River basin. However, we agree with Mr. Pickett that a high variability in storm timing and magnitude exists in the Chehalis River basin. To evaluate the sensitivity of storm variability, we recommend that the hydraulic model evaluations of flood relief alternatives be run for both the synthetic hydrographs and for the observed February 1996, December 2007, and January 2009 flood events. While we believe that the design event does a reasonable job of characterizing large, basin wide, floods the

addition of the historical flood events provides a range of alternative hydrologic conditions that have been seen in the recent past and are useful for a more robust evaluation of flood relief alternatives.

Table 1. Expected Probability Flood Frequency Natural or Unregulated Peak Discharges (in cfs) at Fully Gaged Active Sites

Recurrence Interval (yrs)		Chehalis River nr Doty	Newaukum River nr Chehalis	Skook. River nr Centralia	Chehalis River nr Grand Mound	Chehalis River at Porter	Satsop River nr Satsop	Wyn. River above Save Ck nr Aberdeen	Wyn. River above Black Ck nr Montesano
		12020000	**12025000**	**12026000***	**12027500**	**12031000**	**12035000**	**12036000**	**12037400**
Annual Peak Recurrence (yrs)	**1.5**	8,155	5,160	3,400	21,519	25,109	21,751	11,300	15,100
	2	9,900	6,206	4,230	25,659	29,651	25,936	13,000	17,700
	5	15,110	8,674	6,390	36,917	42,160	35,644	17,500	23,900
	10	19,412	10,253	7,920	45,352	51,678	41,742	20,700	28,000
	20	24,281	11,732	9,450	54,239	61,840	47,382	24,000	31,900
	50	31,906	13,607	11,500	67,091	76,794	54,432	28,400	37,000
	100	38,775	14,995	13,200	77,844	89,514	59,588	32,100	40,800
	200	46,828	16,370	15,000	89,674	103,733	64,642	36,000	44,800
	500	59,627	18,187	17,400	107,184	125,153	71,242	41,600	50,100

*A substitute for Station 12026150 for unregulated flood flow statistics only

Table 2: Comparison of USGS Recorded Peak Flows for Key Gages in the Chehalis River Basin

Chehalis at Porter				Chehalis near Grand Mound			Skookumchuck at Bucoda				Newaukum				SF Combined (extended w Doty)				Chehalis near Doty			
Date	Flow (cfs)	Rank [1]	% [2]	Date	Flow (cfs)	Rank [1]	Date	Flow (cfs)	Rank [1]	% [2]	Date	Flow (cfs)	Rank [1]	% [2]	Date	Flow (cfs)	Rank [1]	% [2]	Date	Flow (cfs)	Rank [1]	% [2]
12/05/2007	102000	1	129%	12/04/2007	79100	1	12/03/2007	3600	55	5%	12/03/2007	12900	3	16%	12/03/2007	20710	1	26%	12/03/2007	63100	1	80%
02/09/1996	80700	2	108%	02/09/1996	74800	2	02/08/1996	11300	1	15%	02/08/1996	13300	1	18%	02/08/1996	9540	4	13%	02/08/1996	28900	2	39%
01/11/1990	60400	4	88%	01/10/1990	68700	3	01/10/1990	8540	8	12%	01/09/1990	10400	6	15%	01/09/1990	9880	3	14%	01/09/1990	27500	3	40%
11/25/1986	45900	9	89%	11/25/1986	51600	4	02/01/1987	6470	22	13%	11/24/1986	10700	5	21%	11/24/1986	6430	12	12%	11/24/1986	17900	9	35%
01/09/2009	68100	3	134%	01/08/2009	50700	5	01/08/2009	10500	3	21%	01/07/2009	13000	2	26%	01/08/2009	11660	2	23%	01/08/2009	20100	7	40%
01/22/1972	55600	5	113%	01/21/1972	49200	6	01/21/1972	8190	11	17%	01/21/1972	9770	10	20%	01/20/1972	6540	10	13%	01/20/1972	22800	4	46%
Data not available				12/29/1937	48400	7									Data not available							
11/26/1990	43000	11	90%	11/25/1990	48000	8	11/25/1990	8400	9	18%	11/24/1990	10300	7	21%	11/24/1990	7400	7	15%	11/24/1990	20600	6	43%
Data not available				12/21/1933	45700	9									Data not available							
12/05/1975	48100	7	107%	12/05/1975	44800	10	12/04/1975	6110	27	14%	12/04/1975	8020	17	18%	12/04/1975	6590	9	15%	12/04/1975	17400	10	39%
		42	**107%**			**39**			**136**	**14%**			**51**	**19%**			**48**	**17%**			**42**	**45%**
01/27/1971	49600	6	11	01/26/1971	40800	11	12/09/1953	10930	2	24	11/07/2006	11200	4	26	11/06/2006	8130	5	26	02/07/1945	21400	5	32
01/02/1997	46000	8	12	12/30/1996	38700	12	12/11/1955	10150	4	23	12/02/1977	10300	7	17	11/25/1998	7420	6	17	01/18/1986	18100	8	27
01/13/2006	43200	10	15	01/23/1935	38000	13	01/25/1964	9760	5	22	11/26/1998	10000	9	17	01/30/2006	7080	8	15	12/16/2001	16600	11	
02/26/1999	42000	12		02/10/1951	38000	13	02/17/1949	9400	6	17	12/29/1996	9700	11		01/18/1986	6500	11		02/24/1999	16300	12	
12/19/2001	41200	13		01/31/2006	37900	15	12/28/1949	8710	7	36	01/31/2003	8940	12		12/15/1999	6350	13		01/30/2006	16000	13	
01/07/1954	40800	14		01/17/1974	37400	16	12/30/1996	8380	10	12	01/30/2006	8720	13		02/07/1945	5700	14		02/09/1951	15700	14	
01/17/1974	39100	15		02/18/1949	36500	17	12/13/1966	7270	12		01/15/1974	8440	14		12/16/2001	5620	15		12/20/1994	15300	15	
12/23/1955	38900	16		12/03/1977	36500	17	12/22/1964	7200	13		01/26/1971	8390	15		12/20/1994	5500	16		12/03/1982	15200	16	
12/15/1977	38900	16		11/26/1998	36500	17	12/02/1977	7170	14		12/16/1999	8100	16		12/03/1982	5460	17		12/15/1939	15100	17	
01/27/1964	38500	18		01/15/1936	36300	20	11/12/1958	6940	15		01/25/1964	7970	18		12/15/1939	5430	18		11/06/2006	14500	18	
12/17/1999	38100	19		12/21/1994	35900	21	11/20/1960	6680	16		02/23/1986	7960	19		12/09/1987	4960	19		12/09/1987	13800	19	
02/11/1951	36100	20		01/26/1964	35700	22	01/30/2006	6640	17		12/17/2001	7920	20		02/17/1949	4920	20		12/13/1966	13400	20	
12/15/1966	35700	21		12/22/1955	35100	23	01/26/1971	6630	18		12/09/1953	7880	21		12/13/1966	4650	21		02/22/1949	12800	21	
12/22/1994	35600	22		01/06/1954	34700	24	02/08/1955	6530	19		12/04/1982	7820	22		03/19/1997	4530	22		12/09/1956	12600	22	
01/31/1965	34000	23		12/14/1966	34400	25	11/20/1962	6520	20		01/18/2005	7740	23		01/25/1964	4330	23		03/19/1997	12600	22	
02/24/1949	33500	24		11/08/2006	32700	26	02/09/1951	6480	21		01/30/2004	7460	24		12/26/1980	4310	24		11/25/1962	12400	24	
01/26/1982	33300	25		01/20/1986	32100	27	12/11/1946	6320	23		01/14/1975	7400	25		12/30/1970	4250	25		12/15/1999	12400	24	
02/27/1950	32500	26		12/18/2001	31900	28	03/22/1948	6320	23		02/07/1979	7280	26		01/31/2003	4240	26		12/26/1980	12000	26	
01/16/1975	32100	27		12/17/1999	31000	29	11/22/1959	6290	25		12/12/1955	7200	27		11/27/1949	4040	27		12/07/1970	11700	27	
02/23/1961	32000	28		11/21/1962	29800	30	12/19/1941	6190	26		11/20/1962	6960	28		12/09/1956	3940	28		11/27/1949	11400	28	
12/28/1980	32000	28		01/25/1982	27300	31	12/17/2001	6060	28		02/17/1949	6950	29		12/23/1964	3780	29		02/04/1968	11200	29	
11/28/1962	31600	30		02/09/1945	27000	32	02/01/2003	5990	29		01/25/1984	6760	30		12/11/1955	3720	30		12/11/1955	11000	30	
11/23/1959	30100	31		02/22/1961	27000	32	01/16/1974	5950	30		04/01/1931	6750	31		02/09/1951	3690	31		02/02/1947	9980	31	
11/09/2006	29400	32		12/20/1941	26900	34	12/09/1956	5520	31		01/14/1998	6580	32		01/18/2005	3650	32		10/30/1997	9920	32	
01/28/1970	29200	33		01/15/1975	26900	34	01/24/1982	5250	32		12/23/1964	6500	33		10/30/1997	3560	33		11/17/2009	9460	33	
12/19/1979	28600	34		02/26/1950	26300	36	01/08/2007	5240	33		11/20/1960	6460	34		02/03/1963	3460	34		01/25/1964	9450	34	
12/28/1972	28100	35		12/24/1964	26200	37	03/09/1966	5160	34		12/11/1946	6350	35		02/04/1968	3450	35		02/04/1952	9320	35	

Notes: [1] Rank is the rank among the events at each individual gage, highlighted cells show events that were in the top 10 at Grand Mound but not in the top 10 at another gage

[2] % refers to percent of corresponding flow at Grand Mound seen at each of the other gages

[3] The table was truncated to show only events above a 2-year flow at Grand Mound

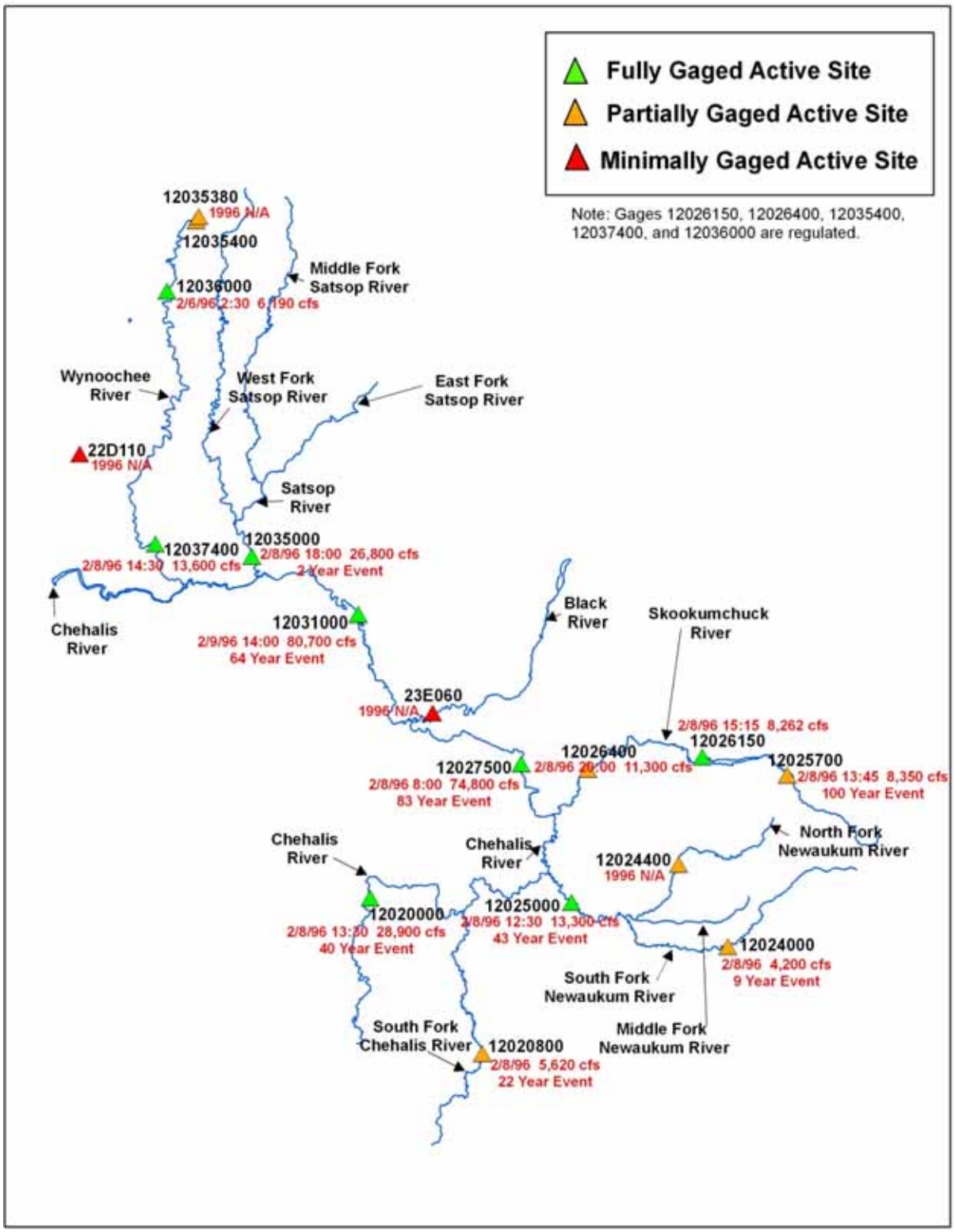

Figure 1. Flood Return Periods at Various Gaged Sites for the February 1996 Event

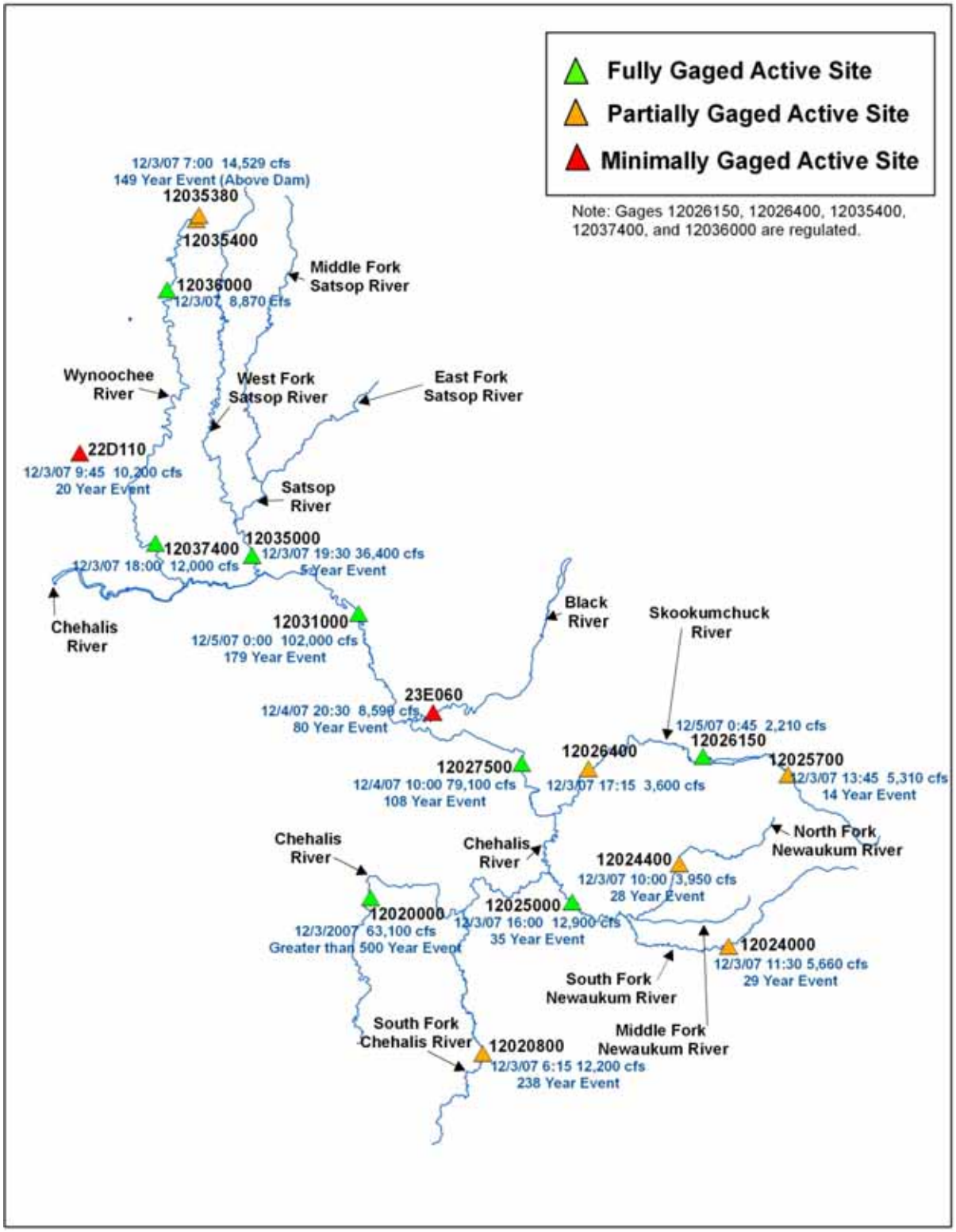

Figure 2. Flood Return Periods at Various Gaged Sites for the December 2007 Event

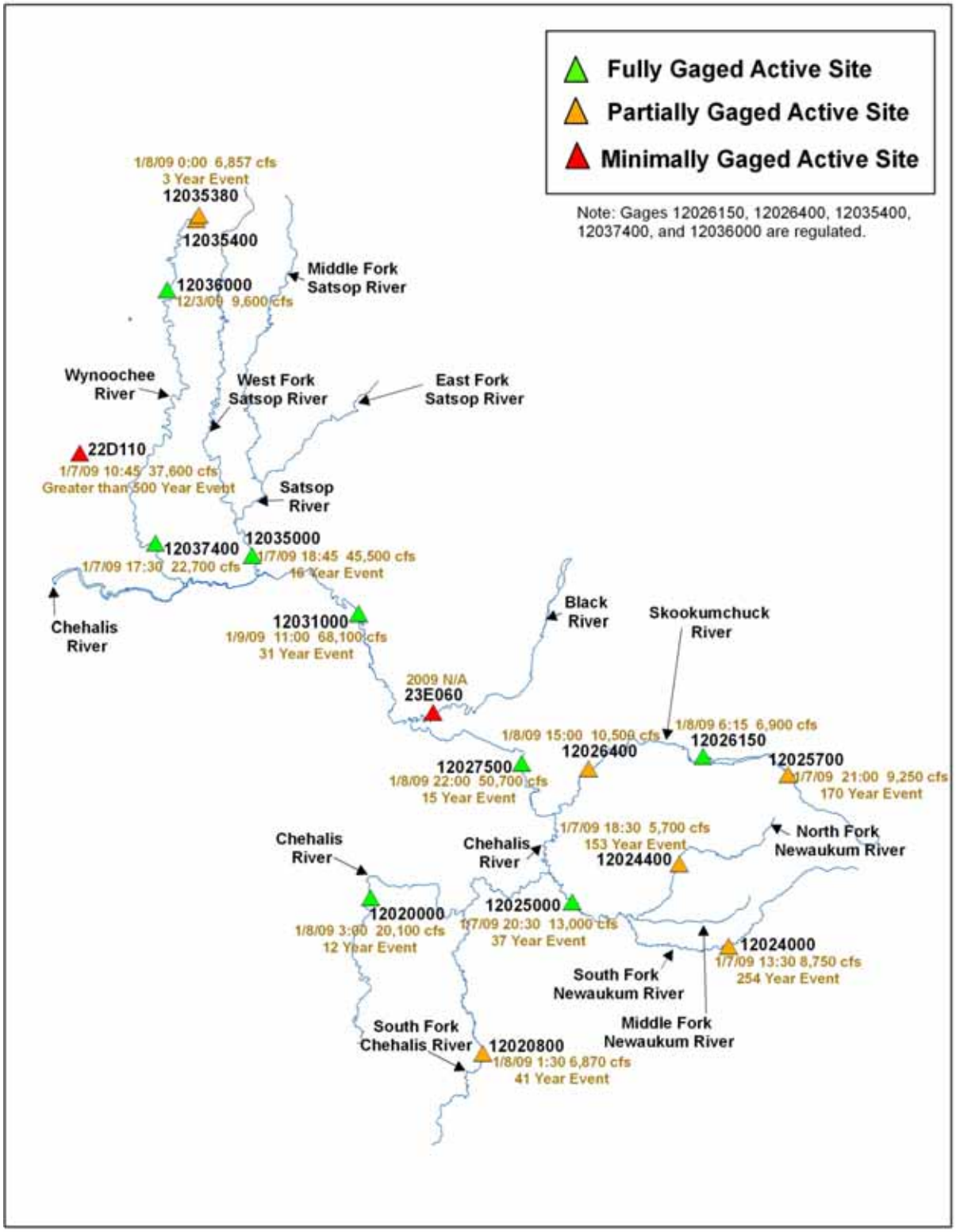

Figure 3. Flood Return Periods at Various Gaged Sites for the January 2009 Event

RE: Guy Hoyle-Dodson comment letter of 4/1/2012:

Mr. Hoyle Dodson's comments on the HEC-RAS model were particularly comprehensive including comments on general modeling approaches as well as a number of specific areas of concern or question. While many of these related to the new portions of the model being developed for this study, a large number were specifically related to the "Twin Cities" portion of the model previously developed by others. That said, and in an effort to make the model as robust and useful as possible, we have reviewed all of the comments and will attempt to address all of them as appropriate in refining the model. In addition to refinements to the model configuration we offer the following responses to key comments made by Guy:

- Regarding contraction and expansion losses, at bridges and elsewhere, note that the momentum equation which is solved under unsteady flow implicitly accounts for losses due to flow transitions. The original modeling by PIE and then by NHC, was carried out using unsteady-flow versions of UNET and HEC-RAS, that did not allow inputs of additional contraction and expansion losses. With the current HEC-RAS version 4.1, the USACE has now added a table to allow modeling of additional losses, for example at bridges with a particularly sharp contraction or expansion zone. For typical bridges, however, these losses are already accounted for in the unsteady (momentum) equation of motion. See HEC-RAS version 4.1 release notes, page 4: http://www.hec.usace.army.mil/software/hec-ras/documents/HEC-RAS_4.1_Release_Notes.pdf
- Regarding reach lengths, it should be noted that this model was developed (by PIE) generally following the 6 cross-section bridge modeling approach commonly called the Normal Bridge methodology in HEC-2 parlance. The two middle cross-sections were cut typically along the top of the roadway. The immediate upstream and downstream cross-sections were then cut close to the roadway but along natural ground (sometimes referred to as full valley sections). These are not intended to be the fully expanded or contracted sections, but are included so that floodplain storage is properly accounted for in the unsteady model. These should have appropriate ineffective areas to keep the majority of the floodplain from conveying flow, and have been checked accordingly. The fully expanded/contracted sections are generally the next downstream/upstream sections from the "full valley" sections, i.e. sections 1 and 6. These are further away from the bridge at a more acceptable distance for the flow transition.
- Regarding divided flow, it was generally assumed that this issue was dealt with appropriately in the original Twin Cities model. The current project did not include scope or budget to review or revise these in the existing FEMA model. That said, we took a quick look at the sections identified, and in some instances examined the amount of flow simulated on the floodplain to see if it would make any significant difference in the simulation results. Revisions were made to ineffective areas at some locations, as noted further below.
- On the Lower Chehalis tidal portion, the divided flow is more complex due to the tidal nature of this reach. Water does not have to exceed the channel bank elevation for flow to be in the side channels, as it comes up the channels from downstream due to the tide. Regarding the two bridges in the tidal reach, the Monte Bridge does not really have any flow contraction or expansion, in part because the upstream reach parallels the highway and does not overtop. The Hwy 101 bridge could have some ineffective areas added upstream and downstream, but it is not going to change the results any this close to the Aberdeen tidal boundary.
- Interpolated cross-sections on the Newaukum River were removed. These were added to reduce reach length and improve model stability, but HEC-RAS is unable to interpolate the blocked ineffective areas. Upon further review, the interpolations are not necessary for stability.

- Ineffective area limits (station, elevation) were revised at Newaukum cross-sections 9.84, 5.01, 2.97 and 1.03, as suggested. At other locations on the Newaukum, review of topography indicates ineffective area limits are appropriately set; i.e., divided flow would exist based upon upstream conditions.
- Regarding divided flow and ineffective limits on the main stem Chehalis in Reaches 19, 21, 23, and 24: These reaches downstream of Grand Mound tend to have significant remnant channels in some overbank areas. In addition to the general adjustments to ineffective limits discussed previously, in the areas where divided flow was noted and remnant channels are picked up in the cross section geometry, blocked, permanent ineffective areas were used where appropriate to make cut-off remnant channels ineffective.
- Regarding Right Overbank Manning's n values at cross sections 82.61 through 82.57: The overbank n values of 0.08 were a carryover from the Corps modeling. Although the aerial imagery shows what appear to be fields in the overbanks, there are also rows of trees in the right overbank at these cross sections. A Mannings n value of 0.08 does not seem to be overly conservative in this area.
- Regarding lateral structures where bounding channel cross sections have been recommended: HEC-RAS uses a linear interpolation of water surfaces between modeled cross sections to calculate flows over lateral structures. We believe the cross sections currently in the model appropriately estimate the overflows at the level of detail warranted in a regional model and that the addition of cross sections to refine the overflow estimates would not create large changes in water surface elevations in the modeled storage areas and the Chehalis River.
- Regarding Rainbow Falls Inline Weir (Reach 1): We will add a cross section closer to the upstream face of the weir to more accurately model the upstream head on the weir.
- Regarding comments related to the Skookumchuck River: Under the original Flood Authority contract, non-georeferenced areas of the Skookumchuck River model (Reach 14 of the PIE model above RS 6.44) were georeferenced by West, and 2002 LiDAR was used to update overbank geometry. The contract did not include time to investigate (or refine) modeling assumptions made during the original model development. The subsequent tributaries modeling amendment included budget for WSE to update cross section data and refine the model near the town of Bucoda (RS 9.69 to 11.8) While we agree that additional refinement to the remainder of the model would be beneficial, such refinement is generally outside the scope and budget of the current project. That said, the following summarizes the changes made to the Skookumchuck reach of the model to address Mr. Hoyle-Dodson's comments:
    - NHC Reach (River Mile 0.0 to River Mile 6.44) – this reach was refined by Northwest Hydraulic Consultants as part of the Lewis County FEMA study (2010). As such we did not feel that additional model changes, without detailed supporting investigations, were advisable.
    - Intermediate Reach (River Mile 6.44 to 9.39) – this reach, between the NHC reach and the Bucoda reach had some unusual ineffective flow and levee limits in the original PIE model (as georeferenced by WEST). In response to Mr. Hoyle-Dodson's comments and our own review of the topographic information for this reach we adjusted several ineffective and levee boundaries to better simulate expected conditions in this reach.
    - Bucoda Reach (River Mile 9.69 to 11.8) – The HEC-RAS configuration in this reach was developed and calibrated by WSE using new cross section surveys and available high water marks. Comments on this reach were reviewed and minor changes were made to levee and ineffective flow limits.
    - Upstream Reach (River mile 11.92 to 21.77) – We agree with Mr. Hoyle-Dodson that some of the ineffective limits in the PIE model of this reach appear unusual. However, the hydraulic conditions in this reach are fairly complex with shallow overbank flow in many locations. Without additional high water mark data or detailed field investigations to verify existing

conditions we did not feel it was appropriate to make adjustments to the existing model at this time.

RE: Casey Kramer comment letter of 4/2/2012:

Mr. Kramer's comments were discussed between Mr. Kramer, WSE, WEST, and NHC staff in a meeting at WSE's office on March 27, 2012. As a group we agreed upon a plan of action for updating the model to address the comments. It is noted that Mr. Kramer's model comments focused on the Twin Cities portion of the model constructed by others and not actually part of the current model development effort. However, in an effort to ensure that all future analyses conducted with the model are as useful as possible the following modifications were made:

1) USGS Chehalis River Near Grand Mound, WA Gage 12027500

No model modifications were necessary to address questions with the USGS gage. WSE confirmed with the USGS that the Grand Mound gage rating curve was extrapolated from the available discharge measurements, none of which were made at a time when there was any overbank flow or flow over Prather Road. An excel plot of the available USGS discharge measurements was prepared by WSE and discussed at the meeting on March 27th. As concurred by the group, the lack of high flow discharge measurements from which to develop the high flow rating means that the upper end of the current rating curve is subject to greater uncertainty than if actual discharge measurements were available. In our opinion, discharges at higher stages (e.g. near the 100-year event) should only be considered accurate to within plus or minus 15% or so. Thus, the "observed" flow in the December 2007 flood event (79,100 cfs) could actually range between about 67,000 and 91,000 cfs.

2) Chehalis River along I-5 Upstream of Mellen Street

As discussed during the March 27th meeting, several changes were made to the model geometry near the Mellen Street Bridge. The small section of Long Road Dike immediately adjacent to I-5 was lowered and a connection was added between SA501 and SA5. Ineffective limits were added in the left overbank upstream of Mellen Street, at RS 67.86 through 67.59. Ineffective limits through the bridge itself were also modified to further constrict the upstream and downstream cross sections.

These changes had only limited effect on simulated water surface elevations upstream of Mellen Street Bridge. When constrictions were added to the Chehalis River, in the form of ineffective limits (changes to Manning's n and contraction/expansion coefficients were also briefly tested), water surface elevations in the vicinity of Mellen Street increased only about one tenth of a foot. However, more flow did overtop the lateral structures in the right overbank, which resulted in less flow in the Chehalis River.

WSDOT also provided new topographic survey data for I-5 and the airport levee. The lateral structure elevations in the model were revised to reflect the new survey data. The revision to the lateral structures resulted in minor changes to the simulated water levels in the main stem of the Chehalis River.

Considering the results of the model investigations in this area it appears that we would either need to make atypical changes to the modeling of the Mellen Street Bridge (such as arbitrary additional head losses) or increase the flows reaching the bridge in order to "hit" the higher of the high water marks upstream of the bridge. Increasing the flows would lead to problems with matching high water marks at other locations in the model so we do not feel that is a reasonable alternative. Similarly, we don't feel it is wise to insert arbitrary losses into the model simply to meet a few high water marks (bearing in mind that there are other, lower high water marks in the same area that we are already overshooting). Thus, we feel that the modeling in this area has been improved as much as possible and do not propose to make any additional changes.

3) Dillenbaugh Creek and Chehalis River Connections near Main Street and I-5

To better approximate December 2007 flood conditions near the Dillenbaugh Creek/Chehalis Junction, two lateral weirs (0.120 and 0.092) were added along Dillenbaugh to model flow entering the north- and southbound lanes of I-5 and flowing under the Highway 6 overpass. Weir elevations were based on 2012 survey completed by WSDOT. Additionally, the weir coefficient (C_d) for Main Street was reduced from 2.0 to 1.5 to approximate losses as water exiting Dillenbaugh flows through vegetation and around buildings on its path to Storage Area #303.

With these changes the model showed peak flow values of:

- 1870 cfs flowing over the Main Street weir (LS 0.187) between Dillenbaugh Creek and Storage Area #303
- 1710 cfs overtopping of the I-5 weir returning to the Chehalis River (LS 74.41, Chehalis Reach 9) and 30 cfs flowing through the culvert under I-5
- 165 cfs flowing from SA #303 to Dillenbaugh Creek via the northbound lanes of I-5
- 145 cfs flowing from Dillenbaugh Creek to the Chehalis River via the southbound lanes of I-5

A section of the I-5 weir (LS 74.41) was then lowered (as discussed during the March 27th meeting) to simulate the portion of I-5 that does not have a jersey barrier along its east side, and the failure of the centerline jersey barrier that occurred during the Dec 2007 flood event. This resulted in peak flow values of:

- 2378 cfs flowing over the Main Street weir
- 2552 cfs flowing over the I-5 weir or through the culvert back into the Chehalis River
- 176 cfs flowing from Dillenbaugh to SA #303 via the northbound lanes of I-5
- 87 cfs flowing from Dillenbaugh to the Chehalis via the southbound lanes of I-5

The maximum simulated depth of flow over I-5 in between SR-6 and NW West Street was about 2.0 ft, which may be somewhat high based on photographs we have seen from the 2007 flood. Additional model refinement might reduce the peak stages over the freeway in this area but it is not clear that there is enough information to definitively state how high the flow may have gotten and/or the direction and magnitude of breakout flows from Dillenbaugh Creek during the event. As such, no additional refinement to the model calibration was attempted.

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Appendix G: Bibliography

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