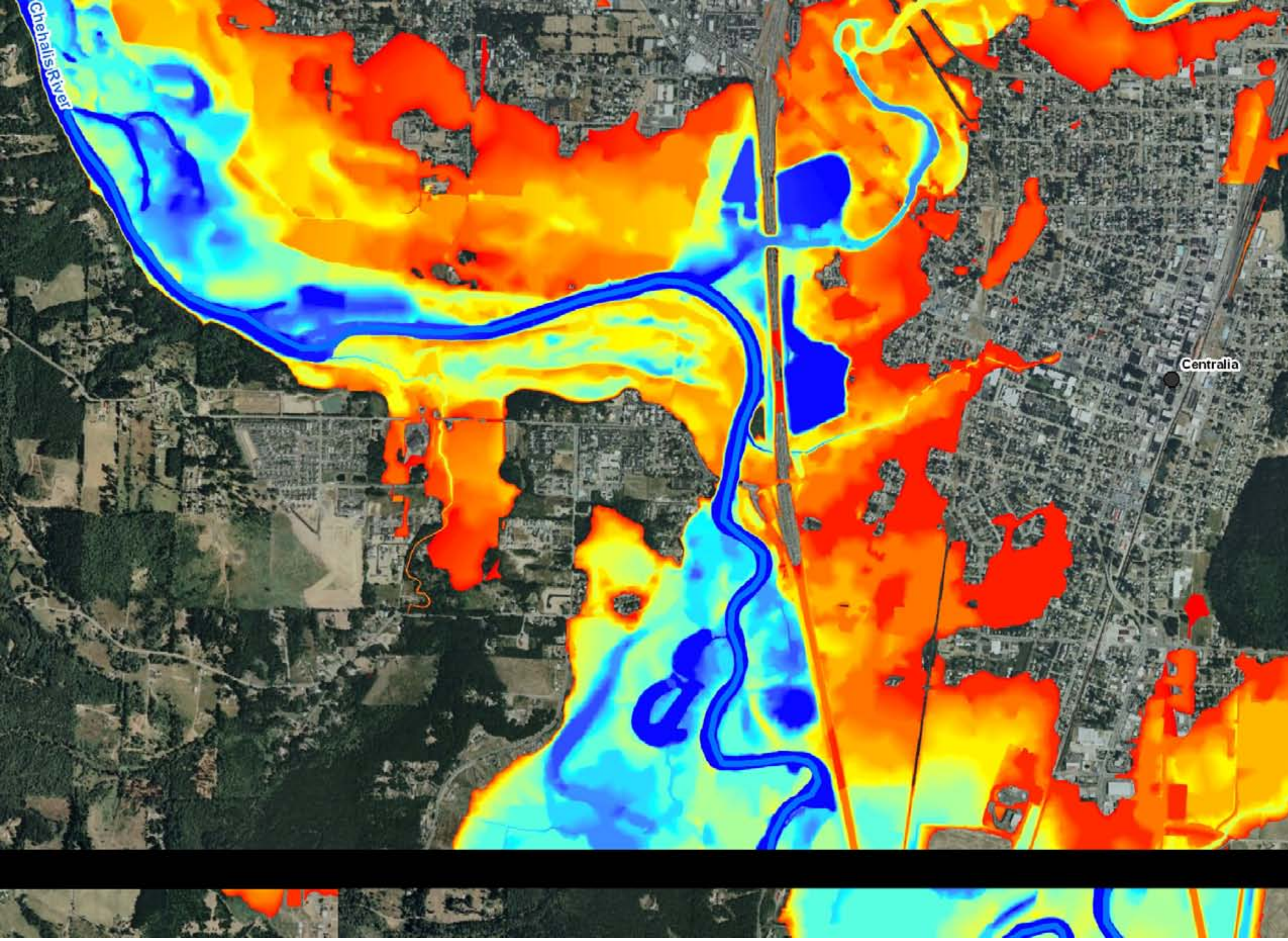


Regional Guidance for Hydrologic and Hydraulic Studies

In support of the Model Ordinance for Floodplain Management and the Endangered Species Act

2010

FEMA Region 10

Regional Guidance for
Hydrologic and Hydraulic Studies

in support of the

Model Ordinance for Floodplain Management under the National Flood Insurance Program

and the

Endangered Species Act

Produced by FEMA - Region 10
January 2010

FEMA
Region 10

For additional information or copies of this guidance:
Federal Emergency Management Agency
Attn: Mitigation Division
Federal Regional Center, Region 10
130 228th St. SW
Bothell, WA 98021-9796
(425) 487-4600
www.fema.gov/regionx/nfipesa.shtm

Contents

Acknowledgements

This guidance document was developed by Region X of the Federal Emergency Management Agency, as part of its continuing effort to improve floodplain management practices and assist communities in meeting the requirements of the Endangered Species Act.

It was prepared with the advice and assistance of a special advisory committee that included representatives from:

- City of Auburn
- City of Carnation
- City of Everett
- Jefferson County
- King County
- City of Lacey
- Lummi Nation
- City of Monroe
- Pierce County
- San Juan County
- Snohomish County
- City of Tukwila
- Washington State Department of Ecology
- Whatcom County
- The National Marine fisheries Service

While some comments were not incorporated, the reviews of each agency in a common endeavor to make this a useful guidance tool are appreciated.

This document was drafted by French & Associates, Ltd., Steilacoom, ESA Adolfson, Seattle, and PBS&J, Seattle, through an arrangement with the Insurance Services Office and the Community Rating System.

Introduction

Background

This Regional Guidance is written for communities in the Puget Sound Basin to assist them in meeting the requirements and criteria of the Endangered Species Act (ESA) as clarified in the Biological Opinion issued by the National Marine Fisheries Service on September 22, 2008. The primary audience for this guidance is engineers and other technical staff involved with mapping flood hazards.

This guidance was prepared with input from local officials, engineers, natural resources scientists, and planners. It will assist local officials and developers determine the most appropriate ways to prepare flood hazard data that meet the requirements of the National Flood Insurance Program (NFIP) and the ESA.

This document is designed to support the NFIP-ESA Model Ordinance, which was also prepared by FEMA Region X.

Hydrologic and Hydraulic Study Guidance

FEMA develops flood data and publishes flood hazard maps to support the NFIP. The data are summarized in Flood Insurance Studies and the maps are known as Flood Insurance Rate Maps (FIRMs). These products define the Special Flood Hazard Area (SFHA), which is the area predicted to be inundated by a flood having a 1-percent probability of being equaled or exceeded in any given year (also referred to as the 100-year flood or base flood). The SFHA designates the minimum area that a community in the NFIP must regulate. The "Regulatory Floodplain," as defined in the model ordinance, is the SFHA plus those areas of riparian habitat and channel migration areas that extend beyond the SFHA.

There are normally three major phases to a FEMA flood study of a stream or river:

1. Assess the flows (usually involving a hydrologic study)
2. Determine flood elevations and the floodway (via a hydraulic analysis)
3. Map the floodplain (SFHA) and floodway

Flood studies conducted for the NFIP are prepared by mapping partners, including state and regional agencies and local governments. FEMA's mapping criteria are spelled out in *Guidelines and Specifications for Flood Hazard Mapping Partners* (called *Guidelines and Specifications* in this document), which are available at http://www.fema.gov/plan/prevent/fhm/gs_main.shtm.

Guidelines and Specifications includes technical appendices which are updated as necessary. The primary technical appendix that relates to the issues discussed in this Regional Guidance is Appendix C: *Guidance for Riverine Flooding Analyses and Mapping* (FEMA, 2002).

This Regional Guidance is intended to supplement existing guidance for communities who wish to prepare studies in consideration of special ESA provisions for Washington State as explained in the Biological Opinion. The Biological Opinion identified three specific areas where study techniques need to be adjusted to provide better hazard data:

- Use foreseeable future land use changes to establish future base flood elevations,
- Use unsteady one-dimensional or two-dimensional hydraulic models to analyze complex riverine systems when applicable, and
- Include the channel migration area as part of the regulatory floodplain.

These three subjects are covered in the following three sections. Communities are not required to use this guidance and it does not define the only approaches to follow. However, communities that do follow this guidance will meet the ESA requirements as spelled out in the Biological Opinion, and have a more effective program to reduce the dangers and damage caused by floods and migrating stream channels.

NFIP/CRS

Each section also includes a discussion of how each of the three major elements of this guidance relate to potential Community Rating System (CRS) credits. More information on the CRS can be found in Appendix D of the NFIP-ESA Model Ordinance and at http://www.fema.gov/business/nfip/crs.shtm.

Future Conditions Floodplain Studies

Background

Flood Insurance Rate Maps serve several purposes:

- They guide local floodplain management programs,
- They establish insurance premium rates, and
- They are used to determine when a flood insurance policy is required under the mandatory purchase requirement.

After a review of the legal issues, FEMA's counsel concluded that FIRMs used for the last two purposes need to be based on the current conditions on the ground. In 2001, FEMA issued a report, *Modernizing FEMA's Flood Hazard Mapping Program: Recommendations for Using Future-Conditions Hydrology for the National Flood Insurance Program*. That report noted:

> As discussed in *Flood Insurance Study Guidelines and Specifications for Study Contractors"* (FEMA 37, January 1995), flood hazard determinations should be based on conditions that are planned to exist in the community within 12 months following completion of the draft Flood Insurance Study (FIS) report. Examples of future conditions to be considered in the context of FEMA 37 are public works projects in progress, including channel modifications, hydraulic control structures, storm-drainage systems, and other flood protection projects. These are changes that will be completed in the near future for which completion can be predicted with a reasonable degree of certainty and their completion can be confirmed prior to the NFIP map becoming effective….
>
> The current procedure for flood insurance rating is that structures shown within the existing conditions 1-percent-annual-chance (100-year) floodplain are subject to a mandatory purchase requirement. Due to statutory constraints at this time, FEMA can not use future-conditions data for flood insurance purposes. Therefore, there will be no change in the use of existing conditions data for establishing flood insurance rates. Through community participation in the CRS, reduced flood insurance rates are available for those communities that enforce more stringent regulatory standards than required by the NFIP. [pages 2 – 3, 5]

While the SFHA on a FIRM cannot be based on future conditions, local floodplain management programs are welcome to use future conditions maps, as long as the regulatory floodplain is at least as large as the currently effective SFHA. In fact, *Recommendations for Using Future-Conditions Hydrology* concludes with a recommendation that FIRMs display the future conditions floodplain for informational purposes. This has been done where requested by the community.

The 2008 Biological Opinion stated:

> The FEMA will also revise map modeling methods to consider future conditions and the cumulative effects from future land-use change, to the degree that such information is available (e.g. zoning, urban growth plans, USGS Climate study information). Future conditions considered should include changes in the watershed, its floodplain, and its hydrology; climate change, and other conditions that affect future flood risk. The FEMA shall ensure that jurisdictions use anticipated future land use changes when conducting hydrologic and hydraulic calculations to determine flood elevations. [page 158]

This section shows how the Biological Opinion requirements can be met within FEMA’s current mapping guidance.

Types of Future Conditions

The term “future conditions” has a number of possible meanings in the context of mapping flood hazards. From a flood study perspective, there are two general types of changes that can be expected to occur in the future:

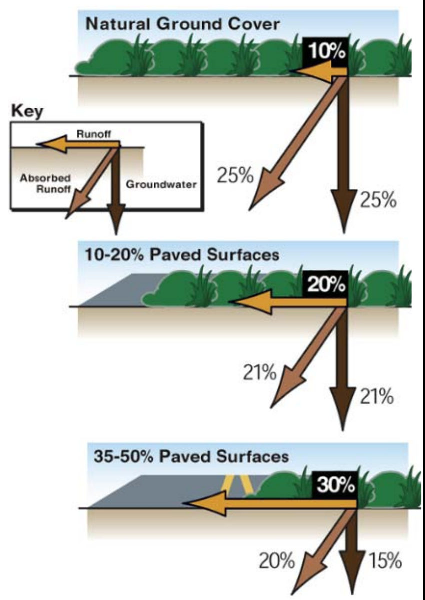
- Changes in the amount of rain and snow that feed floods (climate change), and
- Changes in the watersheds that absorb the rain and snowmelt (land-use changes).

Changes in precipitation: Changes in precipitation due to climate change are possible. Climate varies at many timescales, from daily cycles to the glacial-interglacial patterns that occur over many thousands of years. Changing climate patterns can be difficult to discern because of significant year to year variation and the short observational record.

Flood studies are necessarily dependent on past precipitation and flow records, which do not provide information on flows generated under different climatic conditions. Therefore, existing information is not clear as to how to alter peak flow predictions to account for a changing climate (see for example Brekke et al., 2009, Elsner et al., 2009, Rosenberg et al., 2009). Further, the magnitude of changes in peak flows due to changing climatic conditions is expected to be much smaller than changes resulting from alterations to land use, described below. Therefore, no specific consideration of changes in peak flow due to climate change is included in this guidance.

FEMA is currently developing a report that will assess how a changing climate will affect the NFIP. The report will include estimates of how climate change could impact inland floodplains and coastlands. The report’s findings will be incorporated into future versions of this guidance.

Changes in the watershed: Changes in land use and land cover (e.g., conversion of forest or agricultural land to urban land uses) can have significant impacts on the volume of surface water runoff resulting from a given precipitation event. Changes in land cover typically increase peak flows by greater than 50 percent in small Puget Sound watersheds, and change the timing of peak flows (see the graphic, Booth et al., 2002, Grant et al., 2008).



These graphics show the relative increase in runoff from a watershed as it is urbanized and the amount of impervious surfaces increase.

– *NAI Toolkit*, ASFPM, 2003

Forest harvest patterns in managed forest land can also influence runoff patterns. Harvest patterns include re-growth, so it is assumed that future change from these processes is limited, since the bulk of these impacts are already accounted for in past flow measurements.

Land-use and land-cover changes in the watershed are anticipated to have the most significant impacts on peak flows. Therefore, the technical aspects of this guidance are focused on anticipating and planning for flows generated from a more developed landscape.

Other physical changes in the floodplain include infrastructure changes, such as bridge replacement, or land use conversion. If such changes are happening or scheduled within 12 months of a flood insurance study being undertaken, FEMA already requires their inclusion in a new flood study.

Development in the floodplain also has the potential to result in cumulative affects on flood storage. For example, if the fringe is filled, the base flood elevation could rise by up to one foot. To comply with the Biological Opinion, communities will need to prevent filling of the floodplain or include mitigation measures such as compensatory storage so that man-made changes in the floodplain do not affect future flows. In addition low impact development techniques are required for any development allowed within the floodplain. Therefore, development within the floodplain should not have an impact on downstream flood peaks.

On the other hand, there could be natural changes in the floodplain that are not necessarily addressed in *Guidelines and Specifications.* Local critical area regulations encourage preserving the natural and beneficial functions of the floodplain. As riparian plant communities develop, they may provide greater roughness along the channel banks and overbank areas, increasing flood elevations in those areas.

Restoration projects, including levee setback projects, have the potential to change flooding patterns. If an analysis finds that they do affect base flood elevations or the floodway or SFHA boundaries, a CLOMR from FEMA is required. As more projects are completed, they may have a cumulative impact on flood elevations. However, due to their expense, the few restoration projects that have been completed cover relatively short reaches. The distribution and effects of such future projects are difficult to predict. This Regional Guidance does not provide a mechanism to capture this type of future condition.

Conclusion: Development in the watershed has a predictable and measurable impact on the flow regime. This guidance recommends that communities evaluate changes to the base flood from expected future watershed development based on the development patterns laid out in their local long range land use plans. At the request of the community, FEMA will reflect the results of the community-initiated future conditions study on FIRMs when they are revised. The flooding extent determined by future conditions analysis and mapping can be depicted as a shaded X Zone on the FIRM, instead of the 500-year floodplain.

When to Analyze Future Conditions

There are two situations where it is *not* necessary to analyze and map future conditions:

1. Larger rivers: In general terms, the larger the river system, the less potential impact there will be from changing land cover (see for example Grant et al., 2008, Herrera, 2004). These larger systems where future conditions analysis is not required are the "flow control-exempt" water bodies listed in the Washington State Department of Ecology's *Stormwater Management Manual for Western Washington.* The list of these waters is in Appendix I-E of the Ecology manual and Appendix B of this Regional Guidance. The list should be updated in future versions of the Ecology manual.

2. No change expected: Future conditions do not need to be investigated in areas where the contributing basin has already been developed and these conditions are reflected in existing floodplain mapping. For instance, if the contributing watershed is in, and is expected to remain in agriculture or managed forest, these basins do not need to be analyzed for future conditions.

It is most important to capture future conditions for smaller streams that are located in or near areas that are likely to urbanize, such as in or near a city or its urban growth area. For smaller watersheds that are currently undeveloped or only partially developed, it is important to investigate potential changes in peak flows when more than four percent of the overall watershed will become effective impervious surface (Booth et al., 2002). As a general rule, future conditions hydrology should be determined for all cases where over ten percent of a stream's contributing basin is converted from existing forest lands or has an increase in impervious surface.

These criteria are summarized in Table 1.

Situation	Analyze future conditions hydrology?
Study is for a large, flow control-exempt, water body	No
The watershed is developed up to the levels shown in the land use or comprehensive plan	No
The watershed is managed forest or agriculture with *no* potential for conversion	No
> 4% of the watershed will become effective impervious surface, or a >10 % increase is likely if existing condition is >4%	Yes
All other situations	Yes

Table 1. When to analyze for future conditions

Future Conditions Hydrologic Analysis

To develop a reasonable estimate of the future conditions 1 percent annual chance flow, it is necessary to rely on rainfall runoff simulations with altered land use conditions. Gauge analysis has the benefit of using measured data, but the data only reflect past land use, not the future.

All of the currently accepted hydrology models for peak flow determination (available at http://www.fema.gov/plan/prevent/fhm/en_hydro.shtm) can be used to estimate future conditions by changing land cover/use parameters. Some models, such as HSPF and SWMM, will be more amenable to this type of analysis than others. All runoff models should be calibrated to past flood events before they are used for base flood determination.

Future land use conditions can be developed using comprehensive plans developed by communities to comply with the Washington Growth Management Act. These plans specify the type of land uses and, sometimes, percentage of lot coverage allowed during a foreseeable planning horizon, such as 20 years.

It is recommended that a conservative assumption be used that all of the areas in the watershed will be developed as planned. This information can be used in the hydrologic model's land use-to-land cover relationships to describe a build-out condition within the watershed.

Stormwater management regulations usually require stormwater management facilities that will minimize the impact of development on runoff. The 2005 Ecology manual requires that post-development flow quantities be managed using flow frequencies ranging from 50 percent of the 2-year recurrence interval flow to the 50-year recurrence interval flow.

The influence of stormwater management facilities on the 1 percent annual chance flood is considered to be negligible for the following reasons:

- They are required to have overflows sufficient to pass the post-development 100-year flow,
- They can fail due to extreme flood conditions or deficiencies in design, installation, or maintenance,
- Basic retention and detention regulations don't address timing, so there's no assurance that future flooding will not be increased by the facilities, and
- The basic analytical technique is to ignore all private facilities because of long-term maintenance issues.

Future Conditions Hydraulic Analysis

No changes to the existing hydraulic analyses techniques are necessary to develop future conditions floodplain mapping based on land use changes as described above. The same models and approach used for existing conditions can continue to be used with different flows developed in the hydrologic analysis, with the exception of anticipating development of vegetation.

Future conditions discharges are input into the hydraulic model to determine the future-conditions flood hazards. Certain hydraulic parameters may also need to be adjusted based on expected land-use and land-cover changes, as determined by the community.

Vegetation: It is a good floodplain management practice to consider the continuing establishment of riparian vegetation along channel banks and in the floodplain. This development could have significant influence on the study's roughness coefficient. For example, using values from Chow, 1959, a central roughness coefficient (Manning's n) for cultivated land with no crops is 0.030, and a central value for medium to dense brush in winter is 0.070 (in Sturm, 2001). The influence of the roughness coefficient on velocity calculations is linear, so doubling this value will certainly influence the hydraulic calculations, the resulting base flood elevation, and the extent of flooding.

Future conditions hydraulic modeling should consider the potential for riparian and floodplain vegetation to establish and continue to develop. Therefore, future conditions can assume a full riparian forest community (e.g., >50 years old). Agricultural areas can be considered to remain in production and do not require adjustments.

Not all areas will be allowed to develop to full riparian forest. If a community has an operations and maintenance plan (or similar) that includes vegetation maintenance (e.g., to comply with PL84-99), then future vegetation development needs to be as prescribed in the plan.

Future Conditions Summary

Communities should analyze the future conditions flood hazards by using the rainfall runoff models and hydraulic models described in *Guidelines and Specifications*. Future conditions are generally impacted by changes to the land cover conditions. These estimates should be predicted by local land use or comprehensive plans. In summary;

- The use of standard rainfall runoff models with changed land cover conditions to simulate future watershed development should be encouraged to predict future peak flows and base flood elevations. These estimates should assume full build out as predicted by local land use plans.

- Modelers should also consider increasing roughness coefficients within the hydraulic analysis to simulate the continued growth of vegetation within the study area.

CRS Credit for Future Conditions Mapping

The Community Rating System (CRS) is summarized in the separate publication, *CRS Credit for Habitat Protection* and explained in more detail in the *CRS Coordinator's Manual*. Credit toward reducing flood insurance premiums is provided in communities that implement floodplain management measures that are above and beyond the minimum require-ments of the National Flood Insurance Program.

As discussed above, floodplain management regulations using a floodplain map based on future conditions is above and beyond the guidance in FEMA's *Guidelines and Specifications for Flood Hazard Mapping Partners*. This can be credited by the CRS, provided:

- The hydrologic and hydraulic study techniques used are recognized in *Guidelines and Specifications.* A technique that is not discussed there may be submitted to the FEMA Regional Office for consideration for CRS credit.
- The study and floodplain map is adopted for use in the community's development regulations. New buildings constructed in the regulatory floodplain must be protected to the future condition's base flood elevation.
- A community may submit the study to FEMA for incorporation into the next scheduled DFIRM update for that community.
- At each CRS cycle verification visit (generally every five years), the community must document whether its regulatory floodplain data still reflect future conditions. For example, a study based on a 20-year land use plan prepared in 1995 will no longer reflect future conditions in 2015.

Regulatory floodplain maps based on future conditions hydrology are credited under Section 411.c. "Future conditions hydrology" is defined in the *CRS Coordinator's Manual* as changes in watershed land use as discussed in the previous pages. If another technique is used to reflect future conditions, an appropriate explanation can be submitted for consideration.

The amount of credit is based on the type of FIRM zone and the amount of the Special Flood Hazard Area shown on the FIRM that is affected by the new study.

Hydraulic Models

Several elements of the Biological Opinion address the selection of appropriate hydraulic analysis techniques. This section reviews how this can be done.

Current Models

FEMA maintains a list of currently accepted hydraulic models for use in floodplain delineation on its website at: http://www.fema.gov/plan/prevent/fhm/en_hydra.shtm. The currently accepted hydraulic models for floodplain mapping fall into one of three general categories: steady one-dimensional (1D), unsteady 1D, or unsteady two-dimensional (2D). Key features of each type of model are shown in Table 2.

The importance of proper engineering judgment in determining the most appropriate hydraulic model is underscored throughout Appendix C to *Guidelines and Specifications*. This judgment should continue to be the primary factor driving model selection.

Model Type	Description	Geometry	Advantages	Disadvantages
Steady 1D	Unchanging flow assumed to travel entirely in the downstream direction	Cross section	• Easiest to set up and run • Efficient mapping tool	• Simplifies flow processes to 1D unchanging in time • Does not capture complex overbank flow processes • Does not address overbank storage
Unsteady 1D	Changing flow (e.g., inflow hydrograph) assumed to travel entirely in the down-stream direction	Cross section	• More accurate timing of peak, especially where multiple sources of water converge • Overbank and structure flows can be simulated using approximations at locations entered by the user • Takes floodplain storage into account	• Simplified flow processes to 1D • Requires specific data input to represent significant water flux into and out of overbank storage areas • Less stable than steady models • Requires additional data development, hydrographs
Unsteady and steady 2D	Changing flow assumed to travel both downstream and laterally across the channel/floodplain	3D Digital elevation model (DEM)	• More realistic simulation of complex flow patterns (e.g., strongly meandering streams, overbank flows, flow compression at bridge piers)	• More data intensive to build DEM • More prone to instability • Needs hydrograph for all major tributaries

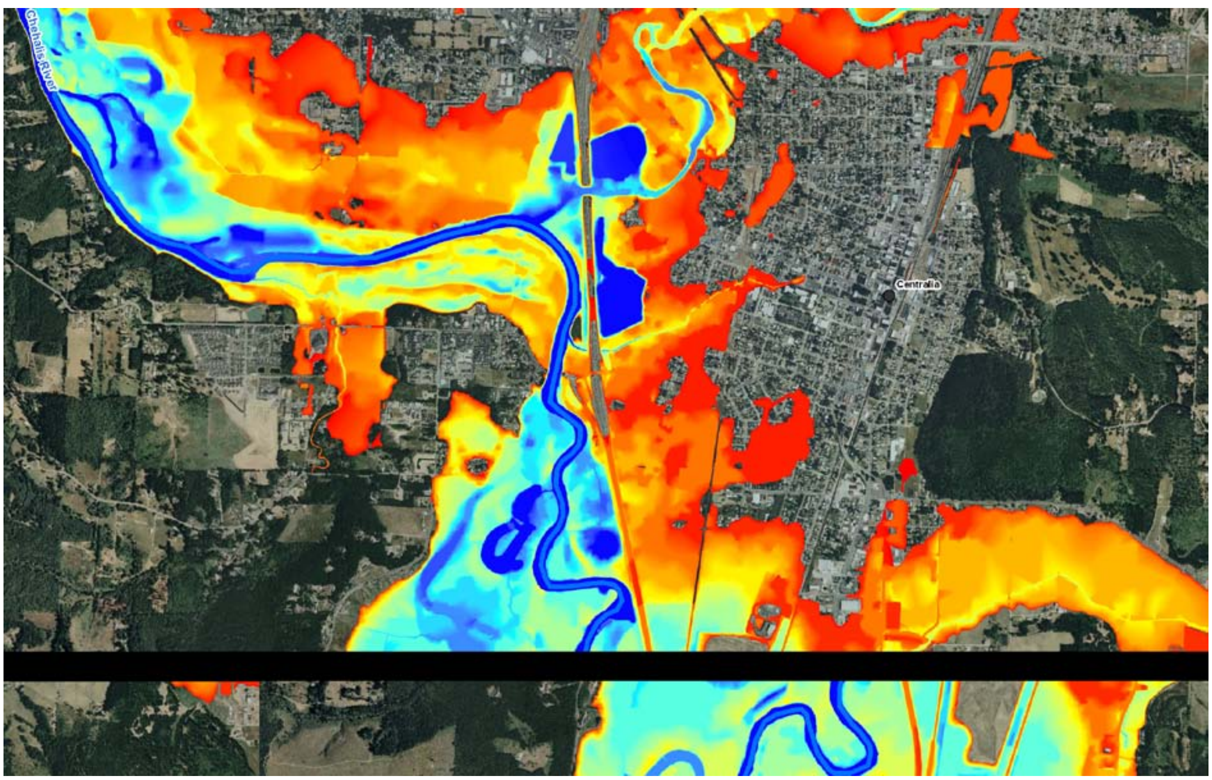
Table 2. General characteristics of the three common types of hydraulic models

Another consideration for the selection of models is the level of precision that is required for the results. In many instances, a less precise hydraulic method will still provide sufficient detail for mapping floodplains, especially if appropriately conservative assumptions are made during the modeling and mapping steps.

Regional Guidance

Guidelines and Specifications suggests the use of steady 1D models, except when conditions are too complex for these models to provide satisfactory answers. More complex hydraulic approaches are used when there is reason to believe that a steady 1D model will not produce a reasonable estimate of the base flood elevation. This guidance can be found in Section C.3.4 of *Guidelines and Specifications.*

This Regional Guidance provides more specific advice for applying different models, but is not intended to supersede the technical requirements for applying a specific model provided in the revised Appendix C to *Guidelines and Specifications*.



An unsteady 1D model was used by the Corps of Engineers to develop flood mapping for the Upper Chehalis River. The Chehalis valley near Chehalis and Centralia is a hydraulically complex area that includes the confluences of several major tributaries and significant floodplain storage volume. One product is this map showing flood depths. The use of an unsteady 1D approach in this location has additional benefits in terms of supporting the design and analysis of potential flood mitigation measures.

− NHC

Assessing the hydraulic aspects of the channel and floodplain: Several elements of the Biological Opinion focus on requiring that the NFIP include measures to avoid, minimize, and mitigate potential impacts to floodplain storage and physical habitat provided within the channel and floodplain system. It calls for more complex hydraulic analyses to support the identification of impacts and the determination of appropriate mitigation. Unlike steady-state hydraulic models, unsteady-state models account for floodplain storage. In situations where storage is a concern, unsteady-state models should be considered. The application of an unsteady 1D model will assist in:

- The identification of upstream and downstream impacts (e.g., stage, velocity, duration) of floodplain alterations, and
- The development of appropriate and effective mitigation measures.

Some hydraulic systems are best represented by a 2D model. These instances include:

- Locations with uncertain and potentially changeable flow paths
- Bridges or other locations where flows experience significant lateral flow compression
- Estuaries with flow reversals

For example, the use of a 2D model is common for scour analyses at bridge piers and for the design of fish habitat improvement projects. Flow surrounding bridge piers has a strong lateral component which cannot be captured with a 1D approach. Similarly, a 2D model will be the more appropriate choice to capture post-project conditions for habitat restoration projects that include the use of engineered log jams to create more complex flow processes.

NFIP/CRS

CRS Credit for Hydraulic Modeling

CRS credit is available for some higher study standards. However, this credit is not provided where it is standard practice to use appropriate hydraulic analysis techniques for a given situation, as specified in *Guidelines and Specifications*.

Channel Migration Zones

Background

Dynamic physical stream processes can cause channels to move or “migrate” over time. The area within which a river channel is likely to move over a period of time is referred to as the channel migration zone (CMZ). Channel migration is a severe hazard that converts normally dry ground to a river bed, often by undercutting and destroying buildings, roads, and infrastructure. The hydraulic models approved in *Guidelines and Specifications* do not reflect possible changes in the channel bed during floods.

Keeping inappropriate development out of the CMZ will prevent flood-related damage such as this. − Packwood, Washington, January 2007

The NFIP-ESA Model Ordinance uses the term “channel migration area,” which is defined as the mapped CMZ plus 50 feet. That is the area subject to the regulatory requirements of the ordinance. This *Regional Guidance* deals with the hydrologic and hydraulic aspects of mapping the CMZ. Once the CMZ is mapped, the area subject to regulations can be quickly delineated.

While a CMZ does not account for dynamic changes in the channel bed during floods, it does delineate areas subject to the hazard. The CMZ is not mapped as part of a Flood Insurance Study and is not included on FIRMs, but it is appropriate to regulate and include within a community’s mapping database.

Biological Opinion Requirements

Identifying the extent of the CMZ is referenced in several parts of the 2008 Biological Opinion:

> The FEMA will ensure that effects from habitat alterations that are reasonably certain to occur but might occur later in time, such as changes in storm water quantity, quality, and treatment, decreased riparian vegetation, lost large woody debris, increased bank armoring, and impaired channel migration, are also mitigated. [page 152]
>
> Bank stabilization measures along salmonid bearing streams, channel migration zones, and along estuarine and marine shorelines must be minimized to the maximum extent possible. [page 224]
>
> No activity is allowed that limits the natural meandering pattern of the channel migration zone, however, natural channel migration patterns may be enhanced or restored [page 224]

The Biological Opinion calls for higher regulatory standards within the Regulatory Floodplain, which includes the CMZ (page 154). Special rules apply in the Protected Area, which includes the channel migration area (CMZ plus 50 feet). FEMA does not require the development of CMZ mapping, but if mapping has been completed and adopted for local regulatory purposes before September 22, 2008, then this designation shall be used to define the channel migration area.

If a community chooses to map and regulate the CMZ, the mapping should be developed consistent with this Regional Guidance.

Regional Guidance

There are several methods of delineating a CMZ, ranging from approximate to more rigorous technical methods. The Washington State Department of Ecology released a CMZ delineation method in 2003, *A Framework for Delineating Channel Migration Zones* (Rapp and Abbe, 2003) (referenced here as the 2003 Framework). The 2003 Framework was devised to provide a technical framework for delineating the likely CMZ and is intended to be implemented by experienced fluvial geomorphologists.

The 2003 Framework is the method cited in the Biological Opinion as the basis for determining the location of the CMZ. It is also the method recommended for use by this Regional Guidance. Key elements of the method are described here, but this discussion is not intended to provide all of the detail offered in Rapp and Abbe 2003.

The 'design life' (how long into the future the CMZ mapping is intended to capture) of the CMZ mapping is an important consideration that will influence the applicability and use of the study for use as the Regulatory Floodplain. The Biological Opinion specifies that a 100 year timeframe be used. This 100 year time frame should be considered differently than the "100-year" terminology typically used in floodplain management. In floodplain terminology "100-year" is shorthand for an event with a one percent chance of occurring in any given year.

In CMZ delineation, a 100 year design life would establish the area the channel could occupy assuming that current climatic conditions and channel processes continue to occur for the next 100 years. The 100 year design life can be expressed as the potential valley area that the channel can migrate within over 100 years. It is recognized that the relative hazards of migration can significantly vary within the overall CMZ. Communities have, and will, implement variable regulations within the CMZ.

The 2003 Framework identifies four generalized components of CMZ delineation. This approach allows for a more detailed description of physical processes and provides a method to build on each data collection step. In most cases, all of these components will need to be accounted for to establish a CMZ delineation . These components are described in Table 3 on page 15 and shown graphically on page 16.

A number of data sources are available to support this work, as shown in Appendix D of Rapp and Abbe 2003 and Appendix A of this Regional Guidance. The 2003 Framework assumes that these sources will be used in conjunction with some level of field data collection. There is a significant amount of interpretation necessary to accomplish mapping of the various components of the CMZ. Judgments need to be made about data quality at each step, as the resolution of the mapping will always be limited by a finite amount of data.

Element	Description	Notes	Include in the mapped CMZ?
Historical Migration Zone (HMZ) Also referred to as the Historical Channel Occupation Tract (HCOT) see for example GeoEngineers, 2003	The collective area the channel occupied in the historical record	Dependent on extent and quality of past records, including Government Land Office maps, and past aerial photographs	Yes
Avulsion Hazard Zone (AHZ)	The area not included in the HMZ that is at risk of avulsion over the timeline of the CMZ	Dependent on field measurements and identification of vertical channel variation, bank stratigraphy, and the presence and location of relict channels and secondary flowpaths on the floodplain	Yes
Erosion Hazard Area (EHA)	The area not included in the HMZ or the AHZ that is at risk of bank erosion from stream flow or mass wasting over the timeline of the CMZ	The EHA can result from either erosion of the stream bank, or slope failures of the bank that occur after erosion of the toe	Yes
Disconnected Migration Area (DMA)	The portion of the CMZ where man-made structures, such as major levees and Interstate highways, physically eliminate channel migration. In some cases, a levee protects an area that is so important, it will warrant restoring a migrated channel to its earlier location.	Care needs to be taken to assess (1) whether the man-made structures will actually prevent channel movement (e.g., are levees sufficiently engineered?) and (2) whether the structure, highway, or protected area is so important that there is no doubt that after a flood, the channel would be restored to its previous location. Clear evidence of the presence of a DMA would include: Corps certified levees and a local adopted maintenance agreement that states that flood fighting would occur and any damage repaired to prevent channel migration.	Case-by-case

Table 3. Elements of the overall CMZ (Rapp and Abbe, 2003).

Note 1 – In the case where there are features of aquatic habitat existing landward of the levee footprint, the study should show how the habitat would not be impacted by the selection of the levee as a boundary to CMZ hazards.

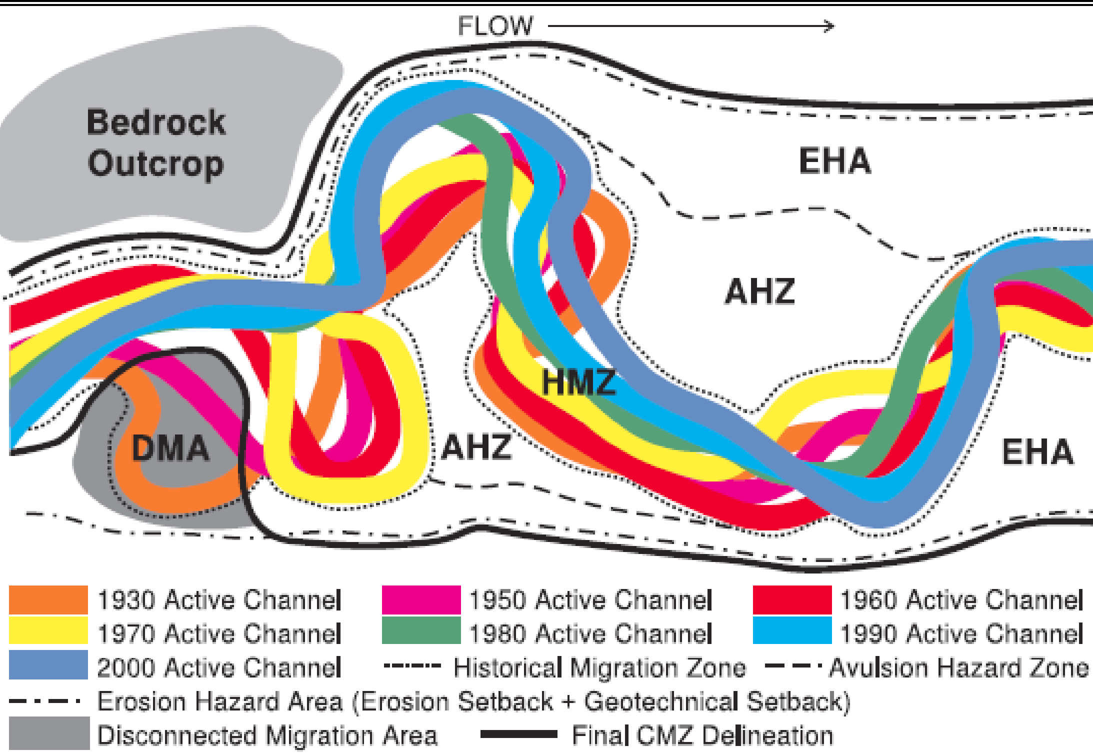
The resultant mapping can include a hazard-based treatment of likely CMZ areas. The approach allows for a ranking of, for example, severe, high, moderate, and low hazard areas throughout the CMZ. This ranking is allowed to be subjective, depending on the mapper's experience and confidence after working through all of the delineation steps. The use of these designations is optional and the criteria used to establish them can be determined by each community.

While the map should show the 100-year design life channel migration zone, the community may adopt only the high hazard portion for its channel migration development regulations. For the purposes of the NFIP-ESA Model Ordinance, the Regulatory Floodplain is based on the channel migration area, which is the channel migration zone adopted by the community for its development regulations, plus 50 feet.

CRS Credit for Mapping Channel Migration Zones

Mapping channel migration zones is covered under the CRS credit for uncertain flow path hazards, found in the *Special Hazards Supplement to the CRS Coordinator's Manual*. A stream subject to channel migration is considered a movable bed stream. A separate supplement is scheduled to be published in 2010.

Credit points for mapping a CMZ are provided if the community also has special development regulations that protect new development from migrating stream channels. The NFIP-ESA Model Ordinance does not include such regulations, as the CMZ is only used to help delineate the Protected Area. Therefore, for CRS credit, the community must have additional CMZ regulatory standards as well as a map prepared in accordance with these guidelines.



Example figure of CMZ elements (Rapp and Abbe, 2003)

The credit for CMZ mapping is provided if the local history of migration is "reflected in the mapping process. For full credit, mapping must be based upon floodplain soils and historic channel migration that indicate the probable extent of future migration." (*Special Hazards* Supplement, page 30.) Any mapping that implements the 2003 Framework or similarly credible methods will receive full credit under this element of the CRS.

Half the CMZ mapping credit can be provided when there are no studies that meet the criteria above. Half credit is provided if a community uses a locally developed standard building setback for unstudied streams in lieu of a detailed study by a developer. Such a locally developed setback standard must be based upon data from the general area regulated.

Appendix A. References

Booth, D.B., D. Hartley, and C. R. Jackson. 2002. "Forest Cover, Impervious-Surface Area, and the Mitigation of Stormwater Impacts." *Journal of the American Water Resources Association*. Vol. 38: 835-845.

Brekke, L.D., Kiang, J.E., Olsen, J.R., Pulwarty, R.S., Raff, D.A., Turnipseed, D.P., Webb, R.S.S., and White, K.D. 2009. *Climate Change and Water Resources Management- A Federal Perspective.* U.S. Geological Survey Circular 1331. http://pubs.ugsg.gov/circ/1331/

Elsner, M.M., Cuo, L., Voisin, N., Deems, J.S., Hamlet, A.F., Vano, J.A., Mickelson, K.E.B., Lee, S-Y., and D.P. Lettenmaier. 2009. "Implications of 21st Century Climate Change for the Hydrology of Washington State." *Washington Climate Change Impacts Assessment Report.*

FEMA. 2003. *Guidelines and Specifications for Flood Hazard Mapping Partners.* Volume 1: Flood Studies and Mapping.

FEMA. 2002. *Guidelines and Specifications for Flood Hazard Mapping Partners.* Appendix C. *Guidance for Riverine Flooding Analyses and Mapping*.

FEMA. 2008. Draft *Guidelines and Specifications for Flood Hazard Mapping Partners.* Appendix C. *Guidance for Riverine Flooding Analyses and Mapping*.

Federal Emergency Management Agency (FEMA). 2001. *Modernizing FEMA's Flood Hazard Mapping Program: Recommendations for Using Future-Conditions Hydrology for the National Flood Insurance Program.*

FEMA. 2007. *National Flood Insurance Program Community Rating System Coordinator's Manual*. FIA-15/2007. http://www.fema.gov/library/viewRecord.do?id=2434

FEMA 2006. *Special Hazards Supplement to the CRS Coordinator's Manual*. http://training.fema.gov/emiweb/CRS/index.htm

FEMA, 2010, *CRS Credit for Habitat Protection,* http://training.fema.gov/EMIWeb/CRS/

FEMA 2010. *Model Ordinance for Floodplain Management Under the National Flood Insurance Program and the Endangered Species Act*

GeoEngineers, 2003. "Geomorphic Evaluation and Channel Migration Zone Analysis Puyallup, Carbon, and White Rivers." Prepared for Pierce County Public Worka and Utilities Environmental Services, Water Progams Division. June 19, 2003.

Grant, G.E., Lewis, S.L., Swanson, F.J., Cissel, J.H., McDonnell, J.J. 2008. *Effects of Forest Practices on Peak Flows and Consequent Channel Response: A State-of-Science Report for Western Oregon and Washington.* Gen. Tech. Rep. PNW.GTR-760, Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Herrera Environmental Consultants, Inc. Northwest Hydraulic Consultants, 2004. “Discharge of Stormwater to High Order Streams: Determining Exempt Reaches.” Prepared for Washington State Department of Transportation. April 13, 2004.

Mote, P., Petersen, A., Reeder, S., Shipman, H., and L.W. Binder. 2008. *Sea Level Rise in the Coastal Waters of Washington State.* University of Washington Climate Impacts Group and the Washington State Department of Ecology. January 2008.

NMFS (National Marine Fisheries Service). 2008. *Endangered Species Act – Section 7 Consultation Final Biological Opinion and Magnuson-Stevens Fishery Conservation and Management Act Essential Fish Habitat Consultation.* Implementation of the National Flood Insurance Program in the State of Washington Phase One Document – Puget Sound Region. September 22, 2008.

Rapp, C.F and T.B. Abbe. 2003. *A Framework for Delineating channel migration zones.* Ecology Final Draft Publication #03-06-027. http://www.ecy.wa.gov/biblio/0306027.html

Rosenberg, E.A., Keys, P.W., Booth, D.B., Hartley, D., Burkey, J., Steinemann, A.C., and Lettenmaier, D.P. 2009. *Precipitation Extremes and the Impacts of Climate Change on Stormwater Infrastructure in Washington State.* Implications of 21st century climate change for the hydrology of Washington State. Washington Climate Change Impacts Assessment Report. March 2009.

Sturm, T.W. 2001. *Open Channel Hydraulics*. McGraw Hill, New York, NY.

Washington State Department of Ecology 2004. *Stormwater Management Manual for Eastern Washington*. Publication Number 04-10-076.

Washington State Department of Ecology 2005. *Stormwater Management Manual for Western Washington*. Publication Numbers 05-10-029 through 05-10-033.

Appendix B. Flow Control-Exempt Surface Waters

(Appendix I-E to *Stormwater Management Manual for Western Washington)*

Stormwater discharges that are otherwise subject to Minimum Requirement #7 – Flow Control, to waters on this list must meet the following restrictions to be exempt from Minimum Requirement #7.

- Direct discharge to the exempt receiving water does not result in the diversion of drainage from any perennial stream classified as Types 1, 2, 3, or 4 in the State of Washington Interim Water Typing System, or Types “S”, “F”, or “Np” in the Permanent Water Typing System, or from any category I, II, or III wetland; and
- Flow splitting devices or drainage BMP’s are applied to route natural runoff volumes from the project site to any downstream Type 5 stream or category IV wetland:
  - Design of flow splitting devices or drainage BMP’s will be based on continuous hydrologic modeling analysis. The design will assure that flows delivered to Type 5 stream reaches will approximate, but in no case exceed, durations ranging from 50% of the 2-year to the 50-year peak flow.
  - Flow splitting devices or drainage BMP’s that deliver flow to category IV wetlands will also be designed using continuous hydrologic modeling to preserve pre-project wetland hydrologic conditions unless specifically waived or exempted by regulatory agencies with permitting jurisdiction; and
- The project site must be drained by a conveyance system that is comprised entirely of manmade conveyance elements (e.g., pipes, ditches, outfall protection, etc.) and extends to the ordinary high water line of the exempt receiving water; and
- The conveyance system between the project site and the exempt receiving water shall have a hydraulic capacity sufficient to convey discharges from future build-out conditions (under current zoning) of the site, and the existing condition from non-project areas from which runoff is or will be collected; and
- Any erodible elements of the manmade conveyance system must be adequately stabilized to prevent erosion under the conditions noted above.

Exempt Surface Waters List

Alder Lake	
Aston Creek	Downstream of confluence with George Creek
Baker Lake	
Baker River	Baker River/Baker Lake downstream of the confluence with Noisy Creek
Bogachiel River	0.4 miles downstream of Dowans Creek
Calawah River	Downstream of confluence with South Fork Calawah River
Carbon River	Downstream of confluence with South Prairie Creek
Cascade River	Downstream of Found Creek
Cedar River	Downstream of confluence with Taylor Creek
Chehalis River	1,500 feet downstream of confluence with Stowe Creek
Chehalis River, South Fork	1,000 feet upstream of confluence with Lake Creek
Cispus River	Downstream of confluence with Cat Creek
Clearwater River	Downstream of confluence with Christmas Creek
Columbia River	Downstream of Canadian border
Coweman River	Downstream of confluence with Gobble Creek
Cowlitz River	Downstream of confluence of Ohanapecosh River and Clear Fork Cowlitz River
Crescent Lake	
Dickey River	Downstream of confluence with Coal Creek
Dosewallips River	Downstream of confluence with Rocky Brook
Dungeness River	Downstream of confluence with Gray Wolf River
Elwha River	Downstream of confluence with Goldie River
Grays River	Downstream of confluence with Hull Creek
Green River (WRIA 26 – Cowlitz)	3.5 miles upstream of Devils Creek
Hoh River	1.2 miles downstream of Jackson Creek
Humptulips River	Downstream of confluence with West and East Forks
Kalama River	2.0 miles downstream of Jacks Creek
Lake Cushman	
Lake Quinault	
Lake Shannon	
Lake Sammamish	
Lake Union & Union Bay	King County
Lake Washington, Ship Canal, & Salmon Bay	
Lake Whatcom	
Lewis River	Downstream of confluence with Quartz Creek
Lewis River, East Fork	Downstream of confluence with Big Tree Creek
Lightning Creek	Downstream of confluence with Three Fools Creek
Little White Salmon River	Downstream of confluence with Lava Creek
Mayfield Lake	
Muddy River	Downstream of confluence with Clear Creek
Naselle River	Downstream of confluence with Johnson Creek
Newaukum River	Downstream of confluence with South Fork Newaukum River
Nisqually River	Downstream of confluence with Big Creek
Nooksack River	Downstream of confluence of North Fork and Middle Forks

Nooksack River, North Fork	Downstream of confluence with Glacier Creek, at USGS gauge 12205000
Nooksack River, South Fork	0.1 miles upstream of confluence with Skookum Creek
North River	Downstream of confluence with Vesta Creek
Ohanapecosh River	Downstream of confluence with Summit Creek
Puyallup River	Half-mile downstream of confluence with Kellog Creek
Queets River	Downstream of confluence with Tshletshy Creek
Quillayute River	Downstream of Bogachiel River
Quinault River	Downstream of confluence with North Fork Quinault River
Riffe Lake	
Ruby Creek	Ruby Creek at SR-20 crossing downstream of Granite and Canyon Creeks
Satsop River	Downstream of confluence of Middle and East Forks
Satsop River, East Fork	Downstream of confluence with Decker Creek
Sauk River	Downstream of confluence of South Fork and North Fork
Sauk River, North Fork	North Fork Sauk River at Bedal Campground
Silver Lake	Cowlitz County
Skagit River	Downstream of Canadian border
Skokomish River	Downstream of confluence of North and South Fork
Skokomish River, South Fork	Downstream of confluence with Vance Creek
Skokomish River, North Fork	Downstream of confluence with McTaggert Creek
Skookumchuck River	1 mile upstream of Bucoda at SR 507 mile post 11.0
Skykomish River	Downstream of South Fork
Skykomish River, South Fork	Downstream of confluence of Tye and Foss Rivers
Snohomish River	Down stream of confluence of Snoqualmie and Skykomish Rivers
Snoqualmie River	Downstream of confluence of the Middle Fork
Snoqualmie River, Middle Fork	Downstream of confluence with Rainy Creek
Sol Duc River	Downstream of confluence of North and South Fork Soleduck River
Stillaguamish River	Downstream of confluence of North and South Fork
Stillaguamish River, North Fork	7.7 highway miles west of Darrington on SR 530, downstream of confluence with French Creek.
Stillaguamish River, South Fork	Downstream of confluence of Cranberry Creek and South Fork
Suiattle River	Downstream of confluence with Milk Creek
Sultan River	0.4 miles upstream of SR2
Swift Creek Reservoir	
Thunder Creek	Downstream of the confluence with Neve Creek
Tilton River	Downstream of confluence with North Fork Tilton River
Toutle River	North and South Fork Confluence
Toutle River, North Fork	Downstream of confluence with Hoffstadt Creek
Toutle River, South Fork	Downstream of confluence with Thirteen Creek
White River	Downstream of confluence with Huckleberry Creek
Willapa River	Downstream of confluence with Mill Creek
Wind River	Downstream of confluence with Cold Creek
Wynoochee Lake	
Wynoochee River	Downstream of confluence with Schafer Creek