WHITE PAPER

Floodplain Mapping in Washington State: Current Status, Alternatives for Improvement, and Recommendations

Submitted to

Washington State Department of Transportation

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Floodplain Mapping in Washington State: Current Status, Alternatives for Improvement, and Recommendations

Submitted to

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Abbreviations

BFE	base flood elevation
CTP	cooperating technical partners
1-D	one-dimensional
2-D	two-dimensional
3-D	three-dimensional
DEM	digital elevation model
DFIRM	digital flood insurance rate map
DHI	Danish Hydraulic Institute
Ecology	Washington Department of Ecology
ERM	elevation reference mark
FDPA	Flood Disaster Protection Act
FEMA	Federal Emergency Management Agency
FEQ	hydraulic model
FESWMS	hydraulic model
FHBM	flood hazard boundary map
FIRM	flood insurance rate map
FIS	flood insurance study
GIS	geographic information system
GPS	global positioning system
HEC	U.S. Army Corps of Engineers, Hydrologic Engineering Center
HEC-HMS	hydraulic model
HEC-RAS	hydraulic model
HSPF	Hydrologic Simulation Program – Fortran (hydrologic model)
IFSAR	interferometric synthetic aperture radar
LiDAR	light detection and ranging
LOMC	letter of map change
Mike11, -21	hydraulic models
MODFLOW	hydrogeologic model
NFIA	National Flood Insurance Act
NFIP	National Flood Insurance Program
NFIRA	National Flood Insurance Reform Act
NSSDA	National Standard for Spatial Data Accuracy
Q3 polygons	digitized flood insurance rate mapping data
RMSE	root mean square error
SFHA	special flood hazard area
TRIMR2D	hydraulic model
UNET	hydraulic model
USGS	U.S. Geological Survey
WSDOT	Washington State Department of Transportation
WSPRO	hydraulic model

Executive Summary

This report was developed at the direction of the Floodplain Management Task Force, an interagency group guiding cooperative and coordinated floodplain management decisions in Washington State. The task force was formed in 1998 as a result of the state legislature's passage of Substitute House Bill 3110, temporarily codified as Chapter 181, Laws of 1998.

The report describes shortcomings of floodplain maps and associated data currently used for floodplain management in Washington State; recommends a two-tier approach for state-wide improvements to floodplain maps; and provides information on data formats, data resolution, and hydraulic models necessary for the state-wide improvements. The recommended improvements could significantly reduce the extent of flood damage in Washington State, help avoid unnecessary impacts to critical habitat, provide better protection of transportation infrastructure and allow more accurate planning, engineering, and natural resource decisions.

The majority of floodplain maps used in Washington State are flood insurance rate maps (FIRMs) developed several decades ago by the Federal Emergency Management Agency (FEMA). In addition to use for flood insurance purposes, the maps are now used for land use and zoning decisions, natural resource management decisions, transportation planning, hazard management, and riparian habitat planning. FEMA has acknowledged that the maps are inaccurate and should be updated, but federal funding is limited. The maps are inaccurate for several reasons:

- They were based on outdated engineering methods and limited topographic data, vegetation data, planimetric information, and hydrologic data.

- Depicted features such as roads and buildings are now out of date, particularly in basins where significant development has occurred.

Flooding causes extensive damage in Washington State. Damage estimates for the floods of 1990 reached approximately $250 million, while region-wide (Washington, Oregon, Idaho) damage estimates from the February 1996 flood reached approximately $800 million. The FIRMs frequently under-represent the floodplain area and flood flow depths. Land use decisions based on the maps frequently result in development in flood-prone areas, increasing the likelihood of flood damages.

This report recommends that the Departments of Ecology, Transportation, Fish and Wildlife, and Natural Resources lead the state-wide effort to improve floodplain mapping accuracy. These lead agencies should form partnerships with local agencies, some of whom may already be involved in FEMA programs. These lead State agencies should also involve floodplain management stakeholders, including diking districts, Native American tribes, and other state and federal agencies, such as the U.S. Army Corps of Engineers. The State legislature should

support this multi-agency effort to the maximum extent possible by creating funding mechanisms and eliminating impediments to inter-agency coordination and information sharing.

Tier one improvements involve using readily available digital aerial photos and digital files of floodplain areas to enable computer rectification of stream alignments and approximate 100-and 500-year floodplain boundaries. This method would provide some improvement in the accuracy of floodplain information and floodplain management decisions during the interim period required to implement tier two improvements. Tier two improvements would involve thoroughly updating the floodplain maps, including data collection, hydraulic modeling, and generating new maps. The current goal for gathering topographic data should be to obtain 2-foot elevation contour data for the floodplains of the entire state using airborne light detection and ranging (LiDAR) technology or global positioning system (GPS) technology. A complete data-level assessment is being designed by the Floodplain Management Task Force, and is scheduled for piloting by 2002.

Introduction

This white paper summarizes the current status of floodplain mapping and management processes in Washington State, and outlines several shortcomings of those processes. The paper continues with a discussion of alternative methods for improving the accuracy of floodplain maps, including methods of expanding upon the existing maps and methods of generating completely new maps. Examples of floodplain mapping projects in Washington State and elsewhere in the United States are presented, as well as information on floodplain computer models. The paper concludes with a series of recommendations for improving floodplain mapping in Washington State on a systematic basis, and for maintaining consistency in the technical analyses and information produced in those mapping efforts.

This paper has been prepared to support the efforts of the Floodplain Management Task Force, which was formed in 1998 as a result of the state legislature's passage of House Bill 3110. The 1998 Legislature enacted Substitute House Bill 3110 (SHB 3110), temporarily codified as Chapter 181, Laws of 1998. SHB 3110 emphasized the need for interagency cooperation and coordinated floodplain management. It also marked the beginning of the state's effort to find innovative approaches to reducing flood hazards.

The committee that formed following the enactment of SHB 3110 was co-chaired by the Washington State Departments of Transportation and Ecology. Sitting on the committee were representatives from the Washington State Departments of Community, Trade, and Economic Development, Fish and Wildlife, Natural Resources, and the Emergency Management Division of the Military Department, along with representatives from the Federal Emergency Management Agency, Association of Washington Cities, Washington State Association of Counties, local government partners, and the Skokomish Tribe representing Tribal Governments. This group now continues as recommended by the original report as the Floodplain Management Task Force (FMTF).

The interagency and intergovernmental technical committee provided recommendations in a 1998 report to the State Legislature, encompassing the following topics:

<u>Administrative Recommendations</u>

- Improve access to information
- Identify a lead agency and establish a floodplain management task force
- Improve access to funding
- Establish environmental mitigation standards
- Increase technical assistance
- Review flood models
- Expand and update floodplain mapping

Legislative Recommendations

- Implement enhanced flood planning
- Improve land use planning

The ongoing mission of the Floodplain Management Task Force is to implement these recommendations, as well as develop new recommendations promoting sound floodplain management.

Background Information on Floodplains

Floods are natural processes where rising inland or tidal waters inundate otherwise dry land. Over a geologic time frame, the erosional and depositional processes that occur during floods create floodplains. Floodplains are valuable natural resource areas that play a major role in the ecological function of river and coastal ecosystems. For example, floodplains provide a storage area for floodwaters, which reduces downstream erosional forces and improves downstream water quality by removing pollutants from the water. In addition, floodplains allow infiltration and the recharge of ground water aquifers during flood events, and they provide critical habitat necessary for the survival of many invertebrate, fish, and wildlife species. An extensive review of the ecological importance of floodplains and associated riparian areas is provided in the Washington State Department of Transportation white paper titled *Ecological Issues in Floodplains and Riparian Corridors* (Bolton and Shellberg 2001).

A floodplain is defined in the most basic terms as "a nearly flat plain along the course of a stream that is naturally subject to flooding" (Webster's 1989). In undeveloped areas, floodplains are a natural extension of the streams, rivers, lakes, and wetlands that create them. It is only when human development encroaches on a floodplain that flooding damages are induced and that humans become concerned about controlling the flooding or questioning why development has been allowed within the floodplain. Damages that frequently result from the flooding of farms, roads, businesses, homes, and other infrastructure are on the rise in Washington State and elsewhere in the United States. Because of the dual concerns of protecting surface waters and protecting developed lands near those surface waters, floodplains are sensitive environmental areas that land use planners, natural resource agencies, and development projects struggle to manage appropriately in Washington state. As development pressure increases near surface waters throughout many areas of the state, and as many surface water bodies exhibit changes in their historically understood limits of flooding, accurate delineation of the floodplain becomes an even more critical issue.

Current floodplain management in Washington State is based primarily on relatively old floodplain maps developed by the Federal Emergency Management Agency (FEMA) for the purposes of implementing a flood insurance program. In many cases, these maps are no longer accurate because of changes in the floodplain or errors in the original floodplain modeling and mapping. Those maps are useful to a degree for non-insurance purposes, but serious adverse consequences can result from reliance on these outdated maps to effectively protect and manage floodplain areas. Due to limited funding, FEMA is unable to provide significant resources to local jurisdictions to update floodplain maps, let alone to attempt to do so on a statewide basis. To successfully protect the environmental functions of floodplains in the state, minimize flooding damages, and provide land use planners, natural resource agencies, and developers with a suitable basis for making important decisions, a new system of floodplain mapping and related information management is required.

In addition to flood prevention and damage assessment programs, other regulatory programs in Washington State would also benefit from a systematic process for updating and improving floodplain mapping. These programs include the Washington Department of Ecology's implementation of the state Growth Management Act and the state Watershed Planning Act. Threatened and endangered salmon recovery efforts at a variety of government levels are in need of additional data that could be provided in part by a program for significant floodplain mapping updates. Cities and counties throughout the state would benefit from improved floodplain definitions in implementing their sensitive areas codes and associated development permitting.

Methods of Analysis

This paper was produced using a variety of information sources, including the following:

- On March 7 and 8, 2001, the Washington State Department of Transportation (WSDOT) and Washington State Department of Ecology (Ecology) hosted a 2-day conference in Lacey, Washington focusing on floodplain mapping, modeling, and policy. Many of the oral presentations at the workshop are cited in this white paper. Issues raised in question and answer sessions following the presentations are also highlighted in this paper. The 120 attendees at the conference represented a cross-section of state and local agency floodplain managers, natural resource managers, hydrologists, hydraulic modelers, environmental scientists, consultants, and other interested parties involved in floodplain issues in this state.

- A workshop was hosted by WSDOT in Bellingham, Washington on April 5, 2001, bringing together several expert hydraulic modelers from around the Pacific Northwest to discuss modeling options for improved floodplain mapping, the strengths and weaknesses of some floodplain models, and the technical issues that must be understood before any major systematic modeling changes can occur in the state. The discussions in that workshop provided useful information for planning future floodplain modeling work, as detailed in the modeling section of this paper.

- An extensive literature search including internet resources was conducted to provide supporting information on the FEMA mapping process, recent floodplain mapping efforts in this state and elsewhere in the United States, ecological issues relevant to floodplain management, hydraulic modeling alternatives, and sources of data that may be applied to floodplain modeling.

- Information on computer models used for floodplain studies was obtained from Internet sites and a limited literature search. Reference databases searched included CASSI (publications from scientific and technical meetings), Civil Engineering, Compendex (engineering and scientific journals), Engineering E-Journals, Expanded Academic Index, and the University of Washington Library catalogue.

- Collaborative input was provided by individuals from various regulatory agencies in the state, including several attendees at the 2-day conference in Lacey.

- The 3110 Floodplain Management Task Force provided guidance on the relative importance of various issues discussed in this white paper and concurrence on the focus of the research conducted. Members of the committee provided several research papers, agency contacts, survey results, and other reference materials.

Chronology and Uses of Floodplain Mapping in Washington State

In the United States, floodplains have often been developed with little regard to the ecological impacts or to the potential loss of life and damage to private property and public facilities when flooding occurs. Development within the floodplain alters the natural floodplain processes, often resulting in degraded riparian habitat, and increased damage to communities located within the floodplain. In the past, government agencies used engineering solutions (dams, levees, seawalls and others) in an attempt to reduce flood damage to floodplain communities. However, these solutions often did not reduce flood damage costs and property loss, nor did they discourage continued development within the floodplain. In response to increasing flood damage costs and development within floodplains, the United States Congress acted in 1968 to establish the National Flood Insurance Program (NFIP).

History of the National Flood Insurance Program

The United States Congress passed the National Flood Insurance Act (NFIA) in 1968, establishing the NFIP. This program is administered by the Federal Emergency Management Agency (FEMA) and was created in response to increasing taxpayer costs for flood disaster relief and escalating flood damage to communities (FEMA 2001a). The intent of the program was to reduce flood costs and damage by allowing the federal government to assess flood hazard risks, map flood hazard areas, and make flood insurance available to communities that agree to participate in the program. Participation in the program requires a community to adopt and enforce floodplain management regulations that meet or exceed FEMA requirements, and to implement floodplain management ordinances to reduce future flood risks. There are two types of programs within the National Flood Insurance Program, the emergency program and the regular program.

The emergency program is for communities new to the National Flood Insurance Program. This program provides a general flood hazard map, termed a *flood hazard boundary m*ap (FHBM), and the community is required to adopt limited floodplain management requirements in exchange for lower levels of flood insurance. Communities in the emergency program are admitted to the regular program upon completion of a detailed engineering study, termed a *flood insurance study* (FIS), and production of a detailed flood hazard map, termed a *flood insurance rate map* (FIRM). For communities in the regular phase of the National Flood Insurance Program, more comprehensive floodplain management requirements are imposed on the community in exchange for higher amounts of flood insurance coverage (FEMA 2001a).

In 1973, Congress passed the Flood Disaster Protection Act (FDPA), which amended the 1968 National Flood Insurance Act. From 1968 to 1973, purchasing flood insurance was voluntary. However, the 1973 statute mandated purchasing flood insurance for insurable structures within flood prone areas as a condition of receiving federal or federally backed financing (Thompson et al. 2000). In addition, the 1973 statute required that FEMA notify flood-prone communities of their flood hazards in order to encourage greater participation in the National Flood Insurance Program (Magnotti et al. 1999). To satisfy this requirement, FEMA began performing hydrologic and hydraulic flood insurance studies and producing flood hazard maps for flood-prone communities (Thompson and Maune 2000).

In 1994 Congress passed the National Flood Insurance Reform Act (NFRIA). This statute was developed in response to the large flooding disasters that occurred along the East Coast in 1992 and in the Midwest in 1993 (FEMA 1999). The major goals of the 1994 statute were to increase participation in the National Flood Insurance Program by creating more inducements to purchase flood insurance, to require that flood hazard maps be reviewed and assessed at least once every five years to determine map update needs, and to establish a technical mapping advisory council to provide recommendations to FEMA on how to improve the quality, accuracy, and use of flood hazard maps. To meet the last two goals, FEMA implemented the map modernization plan in 1997. The intent of the 1997 modernization plan is to use the best available technology to create more accurate, complete, usable, and accessible flood hazard maps for the public (FEMA 1997).

The National Flood Insurance Act of 1968, the Flood Disaster Protection Act of 1973, and the National Flood Insurance Reform Act of 1994 authorized FEMA through the National Flood Insurance Program to identify flood-prone communities in the United States, publish flood insurance studies and flood insurance rate maps for participating communities, and make flood insurance available to participating communities that agree to implement programs to reduce future flood risks. Currently, there are over 20,000 communities in the United States participating in the National Flood Insurance Program for which FEMA identifies flood hazards, and publishes and updates flood hazard maps. Of these 20,000 communities, 284 are located in the state of Washington (FEMA 2001b). Flood hazard maps are used for a variety of purposes including floodplain management, flood insurance rating, flood hazard prediction, floodplain habitat mapping, engineering of flood mitigation projects, bridges and roads, and other purposes. Therefore, having accurate up-to-date maps is a critical component to reducing future flood risks and flood damage costs across a wide spectrum of human activities.

Flood Hazard Maps

FEMA produces flood hazard maps primarily for determining flood insurance requirements and aiding in floodplain management decisions for communities participating in the National Flood Insurance Program. Flood hazard maps are the basis for floodplain management decisions, mitigation activities, and insurance activities of the program and participating communities (FEMA 2001a). Flood hazard maps also provide the information needed for the program to establish flood risk zones and determine flood insurance rates for a participating community. Currently, flood hazard maps have been published for more than 20,000 participating communities, resulting in over 80,000 individual flood hazard maps (FEMA 2001a). Two types of flood hazard maps are published by FEMA: flood hazard boundary maps and flood insurance rate maps.

FEMA has determined that the 100-year flood, also referred to as the base flood, shall be the standard flood size from which to delineate a Special Flood Hazard Areas (SFHA). The 100-year flood is a flood that has a 1-percent chance of occurring in any given year (FEMA 2001a). FEMA chose the 100-year flood as the level to manage floodplains because it represented a reasonable compromise between the need to restrict development in the floodplain to minimize damage to property and loss of lives, and an understanding of the economic benefits of floodplain development. Development may occur within the 100-year floodplain; however, that development must comply with floodplain management ordinances that meet the minimum federal standard (FEMA 2001a). Insurable structures located within the 100-year floodplain are required to obtain flood insurance.

Flood Hazard Boundary Maps

A flood hazard boundary map is based on approximate data and is used during the initial phase of National Flood Insurance Program participation to quickly provide a limited amount of data to a participating community for insurance purposes. Generally, a flood hazard boundary map identifies only the *special flood hazard area* (SFHA) within a community, which is defined as an area of land that would be inundated by a flood having a 1 percent chance of occurring in any given year (i.e., the 100-year flood). Only 1 percent of the 19,000 communities participating in the National Flood Insurance Program remain in the emergency phase and use flood hazard boundary maps (FEMA 2001a).

Flood Insurance Rate Maps

A flood insurance rate map is a more detailed flood hazard map that is issued following a detailed flood risk assessment conducted when a community begins participating in the regular phase of the National Flood Insurance Program (FEMA 2001a). Generally, FEMA performs detailed hydrologic and hydraulic flood insurance studies that identify flood-prone areas and provide flood risk data. Based on these flood insurance study results, FEMA prepares flood insurance rate maps that identify the location of the special flood hazard area within a community, base flood elevations, flood insurance risk zones, the 500-year floodplain boundary, and the regulatory floodway. FEMA describes the regulatory floodway as the river channel plus the adjacent floodplain that must be kept free from encroachment in order to discharge the 1 percent annual chance flood (i.e. the 100-year flood) without increasing flood levels by more than 1 foot. Local jurisdictions often place a more restrictive allowable flood level rise in the floodway when producing flood insurance rate maps. For example, King County (2001) specifies that no increase may occur within the floodway.

Several types of flood hazard areas are identified on flood insurance rate maps. All of these maps show the special flood hazard area, defined as the area that will be inundated by the flood event having a 1 percent chance of being equaled or exceeded in any given year (i.e. the 100-year flood). On a flood insurance rate map, special flood hazard areas are labeled as zones A, AO, A1-30, AE, A99, V, VE, and V1-30. Of particular importance are zones A and V. Zone A is an area subject to inundation by the 100-year flood event where a detailed hydraulic analysis has not been performed and flood elevations and depths are unknown. Similarly, zone V is an area along the coast that is subject to inundation by a storm wave hazard 100-year flood event, where hydraulic analysis has not been performed and flood elevation and depths are unknown. All other zones noted above are areas subject to inundation by the 100-year flood as determined by a detailed hydraulic analysis, where flood elevations and depths are known. Moderate flood hazard areas are labeled as zone B or X (shaded), and are areas between the limits of the 100-year flood and the 500-year flood. Minimal flood hazard zones are labeled zone C or X (unshaded). These areas are above the 500-year flood area. Areas labeled zone D are unstudied areas where the flood hazard is undetermined, but flooding is possible (FEMA 2001a).

A majority of the original flood insurance rate maps were produced in the mid- to late 1970s and early 1980s. In an attempt to rapidly produce these maps, FEMA prepared hand-drawn maps with poor vertical accuracy and limited elevation data, vegetation data, and planimetric information such as buildings, roads, and plats (Jones et al. 1998). Features such as roads and buildings that are identified are often out of date. In addition, the maps were produced using limited hydrologic data, inaccurate elevation data, and outdated engineering analysis methods (Jones et al. 1998). Many of the flood hazard studies used only 20 to 30 years worth of peak flow data to estimate the 100-year flood elevations, which is not enough data to estimate the 100-year flood with a high degree of accuracy. Current flood hazard studies can use an additional 10 to 20 years of peak flood flow data, resulting in a more accurate estimate of the 100-year flood.

The elevation data used for the original flood hazard studies were accurate to between 5 and 10 feet, which is substantially less accurate than the 1- to 2-foot accuracy of elevation data that can be generated today (FEMA 2001d). Watershed urbanization and associated land-use changes occurring over the past 10 to 20 years have effectively made many flood insurance rate maps nearly unusable. Moreover, the majority of these maps were originally produced for larger river systems; flood hazard areas for the smaller streams located in urbanizing watersheds were generally not mapped (FEMA 1997). Because watershed urbanization often results in land use changes that increase the volume of stormwater runoff entering urban streams, many of these unmapped streams now have flood hazards. Finally, flood insurance rate maps do not include areas subject to ground water flooding, or lands at risk from erosion within channel migration zones (Ecology 2001).

Washington State Flood Hazard Maps and National Flood Insurance Program Participation

Flooding occurs throughout Washington State on floodplains of rivers, streams, lakes, wetlands, closed depressions, and tidal areas. Flooding often results in considerable damage to personal property, loss of lives, and damage to public facilities such as roads, bridges and levees. Since 1971 there have been 24 federally declared major flooding disasters in Washington State, with 10 declared disasters since 1990 (WSDCD 1993, FEMA 2001b). Damages in Washington State from flooding are considerable. For example, damage estimates for the floods of 1990 have reached approximately $250 million, while region wide (Washington, Oregon, Idaho) damage estimates from the February 1996 flood have reached approximately $800 million (NWS 2000). Western Washington is particularly vulnerable to repetitive flooding events due to the geographic location, topography, and climate (WSDCD 1993). Major river systems are located in both western and eastern Washington, but those in western Washington are more prone to flooding. In addition, western Washington also has experienced the greatest watershed urbanization resulting in urban streams that are prone to flooding (Booth 2000).

Current, accurate flood hazard maps are a critical component in reducing flood damage and potential loss of life and property, and in protecting the beneficial ecological values of the floodplain. Updating flood hazard maps is important because changes in a watershed influence the hydrologic cycle and can affect flood levels. Watershed urbanization generally results in increased impervious surfaces (e.g. roads and roofs) and reduced forest cover, both of which can increase the volume of storm runoff, thereby increasing flood discharge volumes and the floodplain area (Booth 2000). Therefore, watersheds experiencing development need to update flood hazard maps to accurately show the extent of the floodplain to allow for accurate floodplain management decisions. A recent study in North Carolina determined that in counties experiencing watershed development, use of 1975-era flood insurance rate maps underestimated the current potential flood damage by over 50 percent (Reckhow 2001).

In Washington State, 284 communities currently participate in the National Flood Insurance Program, of which 274 are in the regular program and 10 are in the emergency program (FEMA 2001b). Of the communities in the regular program, FEMA has identified 21 communities as having no special flood hazard area and 33 as having only a minimal flood hazard. Of the communities in the emergency program, FEMA has identified four as having a special flood hazard area. There are 11 communities not in the National Flood Insurance Program where FEMA has identified a special flood hazard area. Flood hazard maps have been produced for 254 of the communities in the regular program. However, many flood hazard maps are 10 to 20 years old and need to be updated to accurately represent changing watershed conditions. According to FEMA (2001b), approximately 30 percent of Washington state flood insurance rate maps are greater than 20 years old, 70 percent are greater than 10 years old, and 75 percent are greater than 5 years old (FEMA 2001b).

Current Uses and Limitations of Flood Hazard Maps

Flood hazard maps were originally designed to provide information on the 100-year floodplain boundary and flood elevations, flood insurance risk zones, the 500-year floodplain boundary, and the regulatory floodway for the purpose of floodplain management and flood insurance rating. Over time, professionals and local and state agencies have used flood hazard maps for a variety of other uses for which the maps were not originally designed. For example, FEMA (1997) reports that flood insurance rate maps are being used by 1) real estate agents and property owners to determine the flood risk status of properties, 2) developers to design developments to be safe from flood hazards, 3) surveyors to prepare elevation certificates for structures, and 4) engineers to determine potential flood risks when designing mitigation projects, culvert replacements, bridge replacements, and road construction. In addition, many local governments use flood insurance rate maps in making land use decisions, permitting and development decisions; in identifying floodplains for critical habitat management; and in determining floodways (Ecology 2001).

FEMA flood insurance rate maps are currently used by many jurisdictions in the state as the sole basis for mapping 100-year floodplains. Local planning departments in these jurisdictions are basing permitting decisions for land development projects in the vicinity of floodplains on these maps, as there are no readily available alternatives. Similarly, those planning departments are basing zoning decisions on the presumed 100-year floodplain limits as indicated on the maps. Engineering designs for roads, bridges, levees, and other major infrastructure often rely on the FEMA-defined floodplain limits and flooding elevations to indicate where floodwater inundation will occur. Engineering calculations associated with flood storage mitigation requirements for projects that involve fill placed in the floodplain are based on the information displayed on flood insurance rate maps. Finally, there is increasing emphasis on managing floodplains for habitat enhancement and conservation, and the floodplain areas that receive this emphasis are often determined based on these maps.

The accuracy of the floodplain depths and areal limits displayed on the flood insurance rate maps produced by FEMA varies widely, but in general the accuracy is marginal. There are floodplains on stream systems that were mapped decades ago by FEMA, which are still illustrated accurately on the associated map panels. These floodplains tend to be in watersheds where developments such as roads, levees, bridges, and buildings have not altered the hydraulics of the stream, where land use practices have not changed significantly, and where the stream channel alignment is stable. Unfortunately, these conditions are uncommon in this state. More often the maps underrepresent the floodplain extent, and to a lesser degree they underrepresent the flood flow depths. There is an inherent connection between developed areas and inaccurate flood insurance rate maps that relates largely to the effects of land use change and development practices on hydrology and hydraulics. In many areas where development has occurred in and near a floodplain and upstream hydrology has changed, it is now apparent that the floodplains shown on the maps do not reflect current conditions.

Overview of the Current Floodplain Mapping Process

Modernizing the FEMA Flood Hazard Mapping Program

FEMA recognizes that flood hazard maps need to be periodically updated to accurately represent changing flood hazard conditions resulting from natural and human caused changes in the watershed and floodplain. To provide a system for updating flood hazard maps, FEMA initiated a map modernization plan in 1997. The three main objectives of this plan were to develop up-to-date flood hazard data for flood-prone areas; to convert base maps, elevation data, and engineering data to a digital format; and to involve local agencies (city, county, or state) in the implementation, development and ownership of the map updating process. To meet these objectives, FEMA developed the cooperating technical partners (CTP) agreement, through which FEMA provides technical assistance and partial funding for map updating programs administered by local agencies.

The Cooperating Technical Partners Agreement

FEMA designed the cooperating technical partners concept as the cornerstone of its 1997 map modernization program. FEMA cannot implement a complete nationwide updating program due to limited federal funding (FEMA 1997). The cooperating technical partners agreement allows FEMA to increase local agency involvement in the flood hazard mapping process and allows these agencies to become active partners with FEMA in the Flood Hazard Mapping Program. The cooperating technical partners process allows technically competent local communities, regional agencies, and state agencies to update their own flood hazard maps, while FEMA provides technical assistance and approval of all revised maps. Using this method, FEMA hopes to maximize the limited funding available for updating flood maps.

In the past, a community that needed revisions to its flood insurance rate maps would have to request FEMA to perform a new flood hazard mapping study. Through a cooperating technical partners agreement, a community can be proactive in developing solutions to its mapping needs. By working as a partner with FEMA, a community can revise its flood maps using local information and data, then submit the maps to FEMA for approval. FEMA believes that having local communities produce their own flood hazard maps will generally result in more accurate flood hazard maps because local information, data, and base maps are often more accurate than FEMA can produce (FEMA 1997).

There are several benefits of joining the cooperating technical partners program. First, FEMA provides training, technical assistance, and mentoring to local communities on how to produce high-quality floodplain maps. Second, locally produced maps are often more accurate because local resources, data, information, and knowledge are often of better quality than can be obtained by FEMA. Third, a community can obtain grants from FEMA to fund part of the map updating process. Fourth, highly accurate maps in a digital format will allow local authorities to make more informed floodplain management and growth management decisions. In addition, other local agencies will also benefit from updated floodplain maps. For example, when accurate floodplain maps are placed in a digital format, geographic information system (GIS) technologies can be used to overlay these maps with data such as critical wildlife habitat areas or riparian habitat zones, to allow for better-informed growth management decisions.

There are many mapping activities that can be accomplished when a local agency enters into a cooperating technical partners agreement. These activities include collecting highly accurate digital elevation data, producing accurate base maps using digital orthophoto quadrangles, redelineating flood hazard areas using accurate digital elevation data and existing flood insurance engineering analysis data, and redelineating flood hazard areas using new hydrologic and hydraulic analysis. A major benefit of entering into a cooperating technical partners agreement is that the new elevation data, base maps, and flood hazard areas will be produced in a digital format that allows for easier map updating and data sharing with other digital data (e.g. locations of roads, buildings, critical habitat areas) using GIS technologies. For example, the Unified Sewerage Agency of Washington County, Oregon entered into a cooperating technical partners agreement with FEMA to revise floodplain maps along the Tualatin River. According to FEMA (2001c), the new digital floodplain maps will not only be used to make floodplain management decisions, but will also be used to identify stream and floodplain enhancement needs, locate stream migration barriers, and map the ecological condition of the river using GIS technologies.

Examples of Remapping Efforts

In the state of Washington, several local communities and local government agencies are in the process of updating flood hazard maps. These jurisdictions are taking several different approaches to revising their flood hazard maps. Descriptions of these different methods, as well as descriptions of methods taken by local and state governments in Oregon and North Carolina, are briefly described below.

King County, Washington

Extensive flooding that occurred in King County in 1990 revealed numerous inaccuracies with the flood insurance rate maps being used by the county. In general, the maps were underestimating the flood levels with flood damage occurring to property and public facilities located outside the 100-year flood boundary. In 1993, King County implemented a program to update flood hazard maps. The county prioritized river basins needing map revisions based on whether the floodplains were unstudied, contained no 100-year flood elevations, or contained substantial zone A areas. Currently, King County has revised floodplain maps for over 60 miles of the Tolt River, the Raging River, three forks of the Snoqualmie River, the middle Green River, and the south fork of the Skykomish River. The county attempts to revise floodplain maps using full river coverage within the county and hence does not stop mapping at city boundaries (Stypula 2001 personal communication).

King County updates its flood hazard maps by performing detailed hydrologic and hydraulic studies to prepare revised floodplain and floodway maps. Accurate base maps are developed using digital elevation data at the 2-foot contour interval, and show all roads, buildings, structures, houses, and vegetation data. The county is currently using the interferometric synthetic aperture radar (IFSAR) technology to obtain terrain and elevation data (Stypula 2001 personal communication). Updated hydrologic information is obtained from King County and USGS gauging stations, and flood frequency analyses are performed using historical flow data. River cross-sections are resurveyed using narrower linear spacing than required by FEMA, to produce more accurate data for use in the hydraulic model. Hydraulic modeling is then performed using the latest version of the HEC-RAS model. The resulting product is the accurate delineation of the floodplain and floodway produced on a detailed digital base map that contains accurate elevation and planimetric data. Using GIS technologies, these detailed maps can be used by other county departments and communities for a variety of purposes such as identifying critical riparian habitat zones, showing areas in need of instream and floodplain habitat improvement, and identifying aquatic species migration barriers (Stypula 2001 personal communication).

Pierce County, Washington

On September 22, 1999, Pierce County entered into a cooperating technical partners agreement with FEMA to redelineate flood hazard maps along approximately 13 miles of the Puyallup River and 30 associated tributaries using updated topographic data. The county received a $40,000 grant from FEMA to perform the remapping. The total cost of the project is unknown, but was greater than the $40,000 provided by FEMA (Brake 2001 personal communication).

Pierce County determined that flood insurance rate maps for the Puyallup River and tributaries were inaccurate after the February 1996 flood that caused extensive damage to private property and public facilities located outside the 100-year floodplain boundary. The county speculated that river channel reconfigurations and watershed land-use changes were likely responsible for the inaccuracy of the maps. The county determined that it would update its flood insurance rate maps using a stepped approach. The first step was to rapidly redelineate floodplain boundaries and update the maps using the method of Jones et al. (1998). Briefly, this method involves no new hydrologic and hydraulic analysis; instead, updated high-accuracy digital elevation data and detailed digital base maps are combined with existing flood insurance elevation data to redelineate the floodplain boundary and determine new base flood elevations. The second step is to perform detailed hydrologic and hydraulic analysis at a later date when funding is available.

Use of the Jones et al. (1998) method appears to be one way to rapidly update flood insurance rate maps without the cost of performing a detailed hydraulic study. The benefits of this method are 1) it is relatively inexpensive (estimated cost is approximately 10 to 20 percent of the cost of performing new hydrologic and hydraulic analysis [Jones et al. 1998]), 2) it provides digital maps that can be combined with other digital data such as roads, buildings, vegetative cover, land-use using GIS technologies, and 3) it provides digital maps that are more accurate than existing flood insurance rate maps. This technique would be useful for situations where the existing flood insurance engineering analysis is adequate but the base maps and elevation data used to delineate the floodplain boundaries are not sufficiently detailed nor up-to-date, or for situations where the existing maps are very inaccurate and an agency needs to rapidly redelineate floodplain boundaries for floodplain management and growth management decisions. Although the method appears to be sound, Pierce County noted that it worked better on low-gradient river areas than on high-gradient river areas (Brake 2001 personal communication).

City of Issaquah, Washington

On March 15, 2000, the City of Issaquah entered into a cooperating technical partners agreement with FEMA to update flood hazard maps on Issaquah Creek and Tibbetts Creek using updated topographic data, updated flood probability data, and new hydraulic modeling results (Ritland 2001 personal communication). The agreement states that the City of Issaquah would perform flood hazard map updating under the guidance and oversight of FEMA. The estimated total cost of the project is $180,000 dollars, with all funding from the city.

The City of Issaquah determined that the original 1979 FEMA flood hazard study and flood insurance rate maps for Issaquah Creek and Tibbetts Creek were inaccurate after flood levels occurring in 1986, 1990, and 1996 exceeded the predicted 100-year flood level in certain areas of the city. During these flood events, properties, businesses, and public facilities located outside of the mapped 100-year floodplain were damaged and building foundations undermined. The city determined that the original 1979 FEMA study used outdated and inaccurate base mapping data as well as inaccurate modeling methods to produce the flood insurance rate maps (Ritland 2001 personal communication). In 1998, Issaquah initiated a remapping program to provide accurate base map and elevation data from which future floodplain delineations could occur.

The City of Issaquah hired a consultant to update its FEMA flood hazard maps using detailed study methods. The methods used consisted of 1) collecting highly accurate digital elevation data, 2) developing new base maps that show all planimetric data including roads, buildings, houses and vegetation, 3) using updated high-flow data collected by the U.S. Geological Survey (USGS) and King County, 4) collecting extensive high water elevations during flooding events, 5) using an updated flood frequency analysis performed by the USGS, and 6) performing new hydraulic analyses using Boss RMS for AutoCAD version 4.0 with HEC-RAS as the analysis engine. This information is being used to produce detailed digital flood insurance rate maps to allow the City of Issaquah to make sound floodplain management and growth management decisions. In addition, the new digital maps will be available for use by other communities and agencies to perform other studies such as critical floodplain habitat mapping and stream survey mapping.

City of North Bend, Washington

The City of North Bend is situated within the floodplain of the middle fork and south fork of the Snoqualmie River. In the 1960s, King County constructed levees at various locations along the south fork to protect the city from flooding, resulting in North Bend being included in the King County flood hazard protection program. In the early 1980s, the City of North Bend entered into the National Flood Insurance Program, and FEMA conducted a flood insurance engineering analysis and produced flood insurance rate maps. However, in 1997, the U.S. Army Corps of Engineers decertified the levees, which resulted in FEMA requesting the Corps to update the flood hazard study and flood insurance rate maps for North Bend (Heiden 2001 personal communication).

The Corps of Engineers produced preliminary updated flood insurance rate maps in August 2000. However, the city and King County appealed the validity of these maps, stating that several inaccuracies existed with the delineation of the 100-year flood boundary. Because the City of North Bend does not have the technical capability to perform flood mapping studies, the city requested that King County evaluate the updated maps and complete the floodplain mapping update if necessary. To meet this request, King County entered into a cooperating technical partners agreement with FEMA to take the lead in completing the City of North Bend floodplain mapping study initiated by FEMA and conducted by the Corps of Engineers. The agreement provides King County with grant funding to support the technical reevaluation of the FEMA study and update the City of North Bend flood insurance rate maps (King County 2000).

Yakima County, Washington

Yakima County does not have a program to update flood hazard maps and relies on FEMA to update these maps within the county. Flooding occurs beyond the 100-year floodplain limits depicted on the existing flood insurance rate maps for the lower Naches River and Yakima River. Many of the existing maps in Yakima County are inaccurate because of 1) land-use changes in the watersheds, and 2) use of inaccurate elevation data and poor vertical resolution in creating the maps (Knuteson 2001 personal communication). The county has several programs to improve its existing maps without performing new engineering studies. For example, on the lower Naches River, the county is using GIS technologies to digitize existing flood insurance rate maps and to overlay them onto WSDOT 1996 flood flyover aerial photos. The county will note differences in the mapped floodplain boundary and the actual 1996 floodplain boundary, and will revise flood hazard maps using the most restrictive boundaries (Knuteson 2001 personal communication). The county may extend this map overlay program to include the Yakima River valley.

Yakima County is also considering updating flood insurance rate maps using the method of Jones et al. (1998), as described above for Pierce County (Knuteson 2001 personal communication). Currently, Yakima County has access to accurate airborne light detection and ranging (LiDAR) elevation data and digital orthophoto quadrangle base maps for the Yakima and Naches river valleys. Because the county has GIS capabilities, using the method of Jones et al. (1998) is feasible.

Walla Walla County, Washington

Walla Walla County does not have a program to update floodplain maps, and relies on FEMA to revise flood insurance rate maps within the county. FEMA funds all map updates that occur in the county, and the Corps of Engineers performs all remapping studies. Because many of the existing maps appear inaccurate, and FEMA has been slow to update these maps, the county is considering updating these maps using existing information with no new analysis or floodplain mapping. This method consists of digitizing existing flood insurance rate maps and fitting them to updated digital orthophoto quadrangle base maps (Krueger 2001 personal communication). Once the map is digitized, county floodplain managers can redelineate the floodplain boundary as needed based on high water mark levels recorded during recent flooding events. Although this method does not truly update the floodplain boundary, it allows for improved floodplain management decisions, because the existing floodplain is then more accurately represented on a high-quality base map.

Washington County, Oregon

On May 12, 2000 the Unified Sewerage Agency of Washington County, Oregon entered into a cooperating technical partners agreement with FEMA to revise flood hazard information for a 166 square mile area of the Tualatin River. Under the agreement, the sewerage agency will perform detailed hydraulic and hydrologic analysis and prepare revised floodplain and floodway mapping for the Tualatin River and its tributaries. Hydrologic modeling will be performed using historical flow data and the Corps of Engineers HEC-HMS model, which determines where critical low flow and flooding events will occur along the river system. Hydraulic modeling will be performed using the latest version of the HEC-RAS model from flows derived with HEC-HMS model (FEMA 2001c).

The new digital topographic, hydrologic, and hydraulic data will be used to prepare new digital flood insurance rate maps (DFIRMs) for Washington County, Oregon. These up-to-date, accurate maps are anticipated to improve future floodplain management and growth management decisions, which will reduce future flood damage costs. In addition, the new digital maps will be used by other agencies within Washington County in their efforts to improve the physical and biological quality of the river. For example, Washington County expects to overlay these digital flood insurance rate maps with natural resource data using GIS technology to produce maps to identify stream/floodplain enhancement needs, to show the location of aquatic species migration barriers, and for conducting an ecological inventory and stream ranking of the river and its tributaries (FEMA 2001c).

North Carolina

Since 1989 there have been 14 federally declared major flooding disasters in North Carolina. In 1992, hurricane Floyd caused $3.5 billion in damages and resulted in 4,117 uninsured and under-insured homes being destroyed (Thompson and Maune 2000). As a result of the flood damage caused by hurricane Floyd, North Carolina initiated a program to update flood hazard data and maps throughout the state. On September 15, 2000, the state of North Carolina, FEMA, and several other federal, state, and local agencies entered into a historic cooperating technical partners agreement whereby the state assumed primary responsibility for updating all National Flood Insurance Program flood hazard maps in North Carolina (Thompson and Maune 2000). This statewide flood hazard map updating is anticipated to save lives and reduce future private and public damage costs by providing accurate, up-to-date information about flood hazards from which future floodplain management and growth management decisions can be made. The statewide remapping program will be conducted in a series of phases over a 5-year time period. The total estimated cost to update flood maps in North Carolina is $60 million. To date, the North Carolina general assembly has allocated $23 million to the flood mapping project, while FEMA has contributed $6 million, and other federal agencies are anticipated to contribute $4 million (Thompson and Maune 2000).

The North Carolina flood mapping update program consists of several components, each designed to improve the quality of flood hazard maps. The overall goal of the program is to produce seamless digital map coverage statewide by creating digital flood insurance rate maps on a countywide basis rather than on a community basis. Thus, floodplain boundaries will be shown for incorporated and unincorporated county areas on the same set of flood insurance rate maps. A major goal of the flood mapping program will be the acquisition of high-resolution digital elevation data for the entire state using airborne light detection and ranging (LiDAR) methods and the production of statewide base maps using digital orthophoto quadrangles, unless a local agency has more accurate and current digital base map information available (Dewberry & Davis 2000). After elevation and base map data are collected and digital base maps are produced for the entire state, floodplain mapping will occur using a phased approach outlined below.

Prior to any revision of flood hazard maps, all existing flood insurance rate maps will be assessed for accuracy and adequacy of the data to determine the best available technology to use for the remapping process. Where the existing data are found to be adequate, no new analysis or floodplain mapping will occur; rather, the existing map data will be digitized and fitted onto the updated base maps. Where the existing flood insurance engineering analysis is adequate but the topographic data used to delineate the floodplain boundaries are found to be inaccurate, no new analysis will occur; however the new elevation data will be used with the existing flood insurance elevations to redelineate the flood hazard areas. Where existing flood insurance rate maps and the flood insurance engineering analysis are determined to be inaccurate, a detailed hydrologic and hydraulic analysis will be conducted. The extent of detail for the hydraulic analysis can range from approximate (where no channel cross-sections are surveyed and bridge/culvert openings are not included) to detailed (supplementing the digital elevation data with field surveys for channel cross-sections, bridge/culvert opening geometry, and floodplain characteristics) (Dewberry & Davis 2000).

The cooperating technical partners program anticipates that the updated flood hazard data will provide accurate information for local agencies, communities, and property owners to make informed floodplain management and growth management decisions. In addition, the high-quality topographic information and accurate base maps produced for the program will be useful to other state, local, and community agencies for engineering and planning applications through the use of ARCinfo software and GIS technologies. For example, the accurate elevation data and base maps will be useful for engineering and planning applications, such as transportation planning and design, mapping critical habitat areas, and performing stormwater management modeling (North Carolina 2001).

The Utility of Flood Insurance Rate Maps for the Purposes They Support

Land Use Planning and Development Review

Every local land use planning and development permitting agency in the state of Washington that has jurisdiction over lands with surface water bodies must understand and manage floodplains to some degree. There are two basic purposes that local governments use floodplain maps for 1) zoning decisions, and 2) land development permitting. In newly developing areas, zoning designations near surface waters are typically influenced by the location of the floodplain. For example, areas within the floodplain may be zoned for purposes that do not invite major flood damages, such as agricultural use or light industrial use. Zoning for commercial and residential land uses may seek to locate those types of development beyond the floodplain. In areas that are already developed, floodplain mapping has less of an effect on zoning.

Local development review agencies regulate development in the floodplain based on their understanding of where and how often it floods. That understanding is often directly tied to the information shown on FEMA-produced flood insurance rate maps. Planning areas that are covered by the state Growth Management Act, that is, areas of the state where urban growth is occurring, are required to write, adopt, and implement sensitive areas codes that regulate activities in floodplains. Even those jurisdictions that are not covered by the Growth Management Act are concerned about flood-prone areas and what occurs in them. When local planning and development review agencies rely upon the local flood insurance rate map panels, they are essentially accepting the accuracy of the floodplain limits delineated on those maps and making land use and zoning decisions accordingly.

Where the flood insurance rate maps under-represent flooding conditions, either because the mapped floodplain area underestimates the extent of inundation or because the mapped flooding elevations are too low compared to reality, local planning agencies often allow development to occur in areas that will experience flooding. When that flooding occurs, the local planning agency is faced with irate landowners wondering why they were allowed to build in the actual floodplain. The cost of the damage is generally not covered by FEMA, and the landowners are forced to recover damage costs on their own. Conversely, there are likely instances where a river or stream has altered its course and flooding will no longer occur, yet the flood insurance rate map shows it to be within the floodplain. The local planning agency may therefore deny a landowner's application for grading or structural construction where there is no threat of flood damage. The planning agency may be sympathetic to the landowner in this scenario but is unable to make an exception to a rule stemming from reliance on the flood insurance rate map for all other applications.

Another example of how local planning agencies are handicapped by relying upon the flood insurance rate maps relates to low-lying areas where rising ground water causes flooding. These flood-prone areas are often not captured in the FEMA floodplain mapping process, or the flooding areas are underestimated on the maps, and therefore the local planning agency assumes flooding is not an issue in that location. This phenomenon has occurred in numerous areas of western Washington in recent years, particularly in Pierce and Thurston counties. Prolonged periods of abnormally wet weather typically result in high ground water tables in the geologic formations that characterize much of western Washington. The water surface elevation in many lakes and wetlands is actually an expression of the ground water table in a low-lying area. If there is development surrounding the water body, as is often the case, the rising ground water floods the homes and roads adjacent to the normally benign water body. Again, the local planning agency is confronted with irate property owners wondering why their homes were allowed to be built in a flood-prone area, or why flood protection mechanisms such as pump stations are not in place. The planning agency is often helpless in this situation because there was never any previous evidence of potentially damaging flood levels, or because the flood insurance rate map indicated a much lower flood elevation.

Engineering Design

Engineering design projects near surface waters often require knowledge of flood elevations. Examples include bridges, culverts, roads, and commercial and residential structures. The estimated 100-year (and sometimes higher) flood elevation translates into finished floor elevations, bridge decks, culvert diameters, and road surface elevations that are slightly higher to avoid costly flooding damage. Construction cost constraints usually preclude designers from adding a few extra feet of elevation to the design as a safety factor. Designing to a near-wet but presumed safe elevation is common. Where the estimated 100-year water surface elevation is lower than reality, the engineering designers are effectively inviting damage to eventually occur. For many areas of the state there is no better source of flood elevation data available than the local flood insurance rate map. Thus, reliance upon flood insurance rate maps that inaccurately portray flood elevations in design events results in damages to public infrastructure and private businesses and residences.

One example of this is the Skokomish River floodplain, where changes in watershed conditions have reduced channel carrying capacity, resulting in repetitive damaging floods inundating State Route 101. While the Skokomish River floodplain conditions have changed considerably, the available floodplain maps have not been updated to adequately support engineering designs (or other uses). Another example can be found in the Chehalis River basin where degraded watershed conditions have combined with floodplain development to result in floods of increasing magnitude and increasing economic damage. The disastrous Chehalis Basin flood of 1996 was originally described as a 400-year event based on the old floodplain maps. Later analysis of the data resulted in the flood being downgraded to a 100-year event (Park personal communication 2001). Engineering design projects that were relying on the old Chehalis River floodplain maps were obviously under-estimating the extent of flooding that would occur in a 100-year event.

Engineering designs for roads, levees, and other structures are also predicated on the assumed lateral extent of flooding for a nearby surface water body. For instance, the alignment of a road may be designed to skirt the area of flooding expected in a 100-year event. In these scenarios the road elevation may not be closely scrutinized as noted above because there is less of a fear of inundation. However, if the mapped floodplain limits underestimate the areal extent of flooding, the resultant road embankment may be damaged or overtopped by floodwaters in an event where it was unexpected. Again, reliance upon a local flood insurance rate map that under-represents actual flooding conditions can inadvertently result in flooding damages in a location presumed to be otherwise safe during the course of engineering design.

Riparian Ecosystem Management

As noted previously, natural resource managers are increasingly concerned about the ecological health of floodplains and increased protection of natural (undeveloped) floodplain areas because of the connection to the health of the associated water body (Bolton and Shellberg 2001). The floodplain land areas and associated habitat are the focus of riparian ecosystem management. Appropriate management of these areas is dependent on available maps indicating floodplain limits. As with other uses of floodplain limits discussed previously, the available reference information is often embodied in the flood insurance rate map panels for the area. For areas immediately adjacent to the water body, there are probably no problems inherent in reliance upon the maps, because stream and wetland buffers regulated separate from floodplains provide a basis for ecological studies and for protection of those floodplain areas. However, floodplain areas further removed from the water body, beyond conventional buffer areas, are also contributors to the ecological condition of the water body. If those areas are underestimated, riparian ecosystem interests are not focusing on many important areas. While this does not pose as critical a problem as underestimated floodplains do for engineering design and land use planning, this is nonetheless an important problem. We are only beginning to understand many of the complex floodplain phenomena that affect the health of our streams and rivers. Underestimating the extent of land area that should be studied and protected in this context reduces the potential for ecological improvements that can be made in the years to come.

Flood Insurance

Flood insurance ratings are based on the location of an insurable structure in relation to the 100-year floodplain shown on a flood insurance rate map. The map shows a community's flood hazard areas and the degree of risk in those areas, which is used to determine the flood insurance rate for an area. The National Flood Insurance Program requires all insurable structures located within the 100-year floodplain to have flood insurance, which is made available at reduced rates if the local government enforces floodplain management measures that meet FEMA requirements. Flood insurance is also available, but not required, at reduced rates for structures located outside the flood insurance rate map 100-year floodplain. For nearly every mortgage transaction and building permit issued in the United States, the lender reviews the current flood insurance rate map to determine the location of the property in relation to the 100-year floodplain. Flood insurance rate maps are also used during mortgage transactions by insurance companies, real estate agents, and property owners.

Current, accurate, and easy to use flood insurance rate maps are needed to reduce flood damage and to allow for appropriate floodplain management and growth management decisions. When a map underestimates the flood hazard area, flooding can occur in areas located outside the 100-year floodplain where flood insurance is not required and floodplain management measures are not taken. This consequence can result in increased property damage and potential loss of life during floods. Conversely, when a river system alters its course and the floodplain boundary shifts, an outdated flood insurance rate map may overestimate the flood hazard area, resulting in property owners located within the mapped 100-year floodplain boundary being required to purchase flood insurance when there is no longer a flood hazard.

Alternatives and Improvements to Flood Insurance Rate Maps

An important question with significant cost implications is whether the current flood insurance rate maps can be expanded or extended to improve the accuracy of the floodplain boundary using readily available information. If there are mechanisms by which the maps could be improved while not requiring extensive data acquisition and hydraulic modeling efforts, then those cost-effective alternatives should be pursued. The following paragraphs describe available information that might be used to improve the accuracy of the maps in many locations. Some additional examples of how various jurisdictions in Washington State are updating their floodplain maps using the flood insurance rate maps in combination with newer information are provided in an earlier section of this white paper, Overview of the Current Floodplain Mapping Process.

In many flood-prone areas of the state inundation in recent flood events exceeded the predicted 100-year flood elevation or floodplain boundary indicated on the applicable flood insurance rate map, yet the hydrologic data for the associated stream or river indicate that less than a 100-year flow event occurred. In these instances it is obvious that the map underestimates the flooding that will occur in extreme events. When floods occur it is common for aerial photographs (and ground-level photographs and notes) to be taken, documenting the extent of flooding (Park 2001 personal communication). These photographs can then be used to ground-truth the actual extent of flooding that can be expected for the given hydrologic characteristics that occurred in that flood. This empirical information can be used by local planning authorities to redraw the floodplain boundary and recalculate the estimated flooding depths for the corresponding hydrologic event. The modified flood limits can then be extrapolated for an approximation of what can be expected in a 100-year hydrologic event. While this is a crude method of extending the flood insurance rate map definition of the floodplain, it provides a practical basis for improved floodplain management decisions.

It is expected that digital aerial photography will be available for the entire state of Washington before the end of 2001. The Washington Department of Ecology is currently geo-referencing digital aerial photography data provided by the U.S. Geological Survey so that users can readily key these photographs to the same coordinate system in other digital files, such as local maps (Franklin 2001 personal communication). These digital orthophoto quarter-quadrangle maps will provide many local planning departments with a significant advancement in information to use in managing floodplains and other concerns. The map scale is 1 to 12,000, or 1 inch to 1,000 feet. While that scale does not enable users to see many smaller features that could be of importance, it enables the viewing of major physical features that lie in and adjacent to floodplains. As discussed in the preceding paragraph, improvements to the floodplain limits provided on paper flood insurance rate maps can be accomplished using photographs. The digital orthophoto quarter-quadrangles can assist greatly in that process.

Another relatively simple method for improving the definition of floodplain limits involves use of digital flood insurance rate map information overlain with local mapping features. FEMA has now produced computer files for nearly all delineated floodplains for which paper maps were produced in the past. These files, known as Q3 data, contain the outlines, or irregular polygons as digital mapping experts know them, of the 100- and 500-year floodplain boundaries in plan view. Other information that is typically included on the paper copies of the flood insurance rate maps, such as major road locations and estimated flooding elevations, are not included in the digital files. The digital information in these files is keyed to a geographic coordinate system so that a computer operator can overlay the flooded area polygons with other maps or aerial photos (perhaps digital orthophoto quarter-quadrangle maps as described above) in the same coordinate system. The computer operator can then view discrepancies between the flood insurance rate maps and other maps or photos.

For example, the Q3 data may show the 100-year floodplain boundary at a distance of 100 feet from a road embankment that is known to act as a containment berm for floodwaters, in conditions at least up to the 100-year flood event. The computer operator can see the discrepancy between the edge of the Q3 polygon and the mapped or photographed road alignment, then manually adjust the Q3 boundary to meet the road embankment. The result is improved accuracy of a computer map of the floodplain. Local planning officials can then use the adjusted and improved digital maps to guide their floodplain management decisions. This method relies heavily upon the floodplain modeling results that are indicated on the flood insurance rate maps (Q3 polygons), and that modeling may very well be in need of major refinement. Thus, this method is not likely to result in the best possible accuracy for mapping of floodplain limits, but it will enable improvements in comparison to the paper copies of the flood insurance rate maps. This method also requires local jurisdictions to have the attendant computer resources, though a moderate level of computer proficiency and digital data storage capacity is all that is needed.

As noted previously, in the state of Washington approximately 30 percent of flood insurance rate maps are more than 20 years old, 70 percent are more than 10 years old, and 75 percent are more than 5 years old (FEMA 2001b). In general, older flood hazard studies used flood frequency analysis based on only a few decades worth of high-flow data. For many of these studies there are now 10 to 20 years worth of additional data available that would greatly improve the accuracy of the flood hazard study and corresponding flood insurance rate map (Jones et al. 1998). The USGS recently determined the magnitude and frequency of floods in Washington using annual maximum instantaneous discharges from 527 stations that have 10 or more years worth of peak discharge data (Sumioka et al. 1997). These data include flood peaks recorded during 1990 and 1996, years in which very high flood levels were recorded. Indeed, the USGS reports that flood peaks that occurred during the February 1996 floods exceeded previous historic peak discharges recorded at many gauging stations in Washington. Performing flood hazard studies using additional peak flow data, including in some instances the highest recorded flows, would greatly improve the accuracy of the flood analysis.

Additionally, during the past 10 to 20 years many local governments, such as King County, have been monitoring flow levels in urban streams, rivers, and tributaries. These local gauging stations are either located on streams and tributaries not previously gauged by the USGS, or are located in river sections that are lacking USGS gauging data. The addition of local peak flow data would be invaluable in improving the accuracy of flood hazard studies and flood insurance rate maps. Moreover, urban streams that were not included in flood hazard studies in the past due to limited peak flow data can now be included on the maps. This fact is important because many unmapped urban streams are experiencing greater flood hazard risks as land uses change in urbanizing watersheds.

A significant advantage of using digital floodplain maps in combination with other digital maps and digital photographic information is the ability to visually reference flood-prone areas to roads, structures, and other physical features. The paper copies of the flood insurance rate maps, and the associated Q3 files themselves, do not provide users with suitable mapping of these physical features. Therefore, the user of a paper flood insurance rate map often has difficulty determining where the floodplain limit lies on the ground. Because the limits of the floodplain are a major consideration in local planning decisions, improved knowledge of the floodplain with respect to well understood physical features should always engender more informed decision-making on floodplain management issues.

In summary, there are ways that the existing flood insurance rate maps can be combined with other readily available information sources to enhance the accuracy of estimated floodplain limits. There may be other methods in addition to those discussed in the preceding paragraphs. For locations in the state where the currently available maps are all that can be relied upon, the aforementioned methods of adjusting the floodplain boundaries shown on the maps should be explored. These adjustments will result in greater accuracy for defining floodplain boundaries until such time that improved maps based on updated hydrologic and hydraulic modeling information are available. Reliance upon the adjusted floodplain maps is justified for land use planning, development permitting, engineering, and other uses as the "best available information."

There are several known instances where local map update efforts are being used in support of regulating floodplains while FEMA has not approved the latest updated flood insurance rate maps. These instances are briefly described below.

City of North Bend

Flood insurance rate maps for the City of North Bend are out of date, and the Corps of Engineers produced updated draft maps in August 2000. However, because of concerns regarding floodplain delineation accuracy, the city and King County appealed the draft maps and FEMA is reviewing the appeal. Moreover, King County has entered into a cooperating technical partners agreement with FEMA to take the lead in completing the revised floodplain mapping process and producing new draft flood insurance rate maps. Until an official FEMA map is produced, the City of North Bend will use the most restrictive floodplain boundary shown on a flood insurance rate map as the best available information when regulating development activities (Heiden 2001 personal communication).

City of Issaquah

The City of Issaquah determined that the original 1979 FEMA flood hazard study and flood insurance rate maps for Issaquah Creek and Tibbetts Creek were inaccurate and has undertaken the process of updating these maps. During the map updating process, the city uses new information as soon as draft maps are prepared. The city believes that new information, even if in a draft form and pending approval by FEMA, represents the best available information for regulating development in the floodplain (Ritland 2001 personal communication).

Walla Walla County

FEMA updates flood insurance rate maps for Walla Walla County. During the map updating process, the county regulates development in the floodplain based on the old map until FEMA produces a final updated map. Walla Walla County believes that flood insurance rate maps in draft form are not acceptable for making floodplain management decisions (Krueger 2001 personal communication).

King County

King County uses an approach similar to that used by the City of Issaquah. The county will use preliminary data and draft flood insurance rate maps as the best available information for making floodplain management decisions. The county believes that it is better to rely on updated preliminary data for regulating the floodplain than on information from an outdated and inaccurate flood insurance rate map (Stypula 2001 personal communication).

Creating Better Maps — Hydraulic Models and Data Needs

This section describes the hydraulic models used for floodplain mapping. A brief summary of the most common model classifications and floodplain models is presented first. Important factors in selecting a model class and a specific model are then generally discussed. A table summarizing many of these factors for the floodplain models most commonly used in Washington is included.

Hydraulic Model Options

Hydraulic models can be classified in several ways. One classification is 1-dimension (1-D), 2-dimensional (2-D), or 3-dimensional (3-D). A 1-D model is organized in a linear fashion. Cross-section geometries along a linear flow path are entered sequentially in the model. Multiple flow paths can typically be analyzed, but all data are organized along linear flow paths. Some 2-D information can also be captured by a looped 1-D model, sometimes called a 1-D+ model. For example, multiple channels can be handled this way without moving to the complexity of a complete 2-D model. Data in a 2-D model are organized in an x-y grid overlaid on the floodplain. Elevations and other data for each coordinate in the grid are entered in the model. A 3-D model extends the grid concept to a third dimension. The complexity progression from a 1-D, to a 2-D, to a 3-D model involves increases in data required; computational power required; and time required to develop, calibrate, and verify the model.

Another classification criterion involves whether flow varies with time. In a steady flow model, each computational run includes only the peak flow rate. Water surface profiles based on the peak flow rate are calculated for the floodplain. In an unsteady flow model, also called a hydrodynamic model, each computational run is based on a hydrograph that represents varying flow rates over time. Unsteady models require more complete flow data and are more complex than steady flow models. This increased complexity increases the ability of the model to accurately represent more complex physical processes. Unsteady models offer many benefits for floodplain management. They can simulate a system with downstream water levels controlled by tides and confluences of tributary flow; they allow storage routing; they can simulate the effects of dike breaches and overtopping, adding and removing dikes, and the effects of road works and elevation changes; and they can simulate combinations of these phenomena (Shumuk 2001).

Until recently, almost all floodplain modeling was conducted with 1-D steady flow models. The increases in affordable computing power in recent years make 1-D and 2-D unsteady flow models feasible for many more studies than in the past. The 3-D models are currently too computationally intensive to be seriously considered a floodplain mapping option. This increase in computing power makes possible a significant improvement in accuracy over the old flood insurance rate maps that were all calculated using 1-D steady flow models. Mapping studies conducted to update these can use unsteady flow models or 1-D+ or 2-D models in situations where this will increase accuracy.

Hydraulic models must be approved by FEMA for use in the National Flood Insurance Program. Currently, FEMA has approved ten 1-D steady flow models, nine 1-D unsteady flow models, and four 2-D steady/unsteady models. However, some of the models approved are being phased out because a later version of the model has also been approved, some are only used in limited geographic areas that do not include Washington, some can only be used for limited parts of a floodplain analysis, and some are not to be used for new studies. Therefore, this white paper discussion focuses on only the FEMA-approved models that are the most appropriate for Washington. Two 2-D models that are not yet approved by FEMA are also introduced. The models included in the following discussion are HEC-RAS 3.0, WSPRO, FEQ 8.92, UNET 2.1, Mike11, FESWMMS, Mike21, and TRIMR2D.

1-D Steady Flow

HEC-RAS 2.2 is a 1-D steady flow model developed by the U.S. Army Corps of Engineers Hydrologic Engineering Center (HEC). This model has recently been upgraded to HEC-RAS 3.0, which includes 1-D steady or unsteady flow analysis. Because HEC-RAS 3.0 has only recently been released, little experience exists with using the unsteady flow analysis. It is therefore listed by FEMA with the 1-D steady models. The unsteady flow portion is heavily based on the UNET model, and is expected to have the same capabilities as UNET. Historically, HEC-RAS and its predecessor, HEC-2, have been the most common industry standard for floodplain modeling work.

WSPRO is a 1-D steady flow model developed by the U.S. Geological Survey and the Federal Highway Administration that uses standard step backwater computational techniques. It was developed to provide bridge designers with a highly flexible tool for analysis of alternative bridge openings and embankment configurations. It can also be used to analyze existing stream crossings, and is generally applicable to water-surface profile analyses for highway design as well as for problems related to floodplain mapping, flood insurance studies, and estimating stage-discharge relationships (USGS 2001).

1-D Unsteady Flow

The FEQ 8.92 model is a 1-D unsteady flow model that solves the full, dynamic equations of motion for flow in open channels and control structures. This model was developed by the U.S. Geological Survey.

UNET 2.1 is a 1-D unsteady flow model that solves the full, dynamic equations of motion for flow in open channels and control structures. It was developed by the Corps of Engineers Hydrologic Engineering Center and has recently been incorporated into HEC-RAS 3.0.

Mike11 is a 1-D unsteady flow model that solves the full, dynamic equations of motion for flow open channels and control structures. It was developed by the Danish Hydraulic Institute and is marketed commercially.

2-D Unsteady Flow

FESWMS is a 2-D unsteady flow model developed by the U.S. Geological Survey.

Mike21 is the 2-D version of the Mike model series developed by the Danish Hydraulic Institute. It is marketed commercially but is not currently approved by FEMA for National Flood Insurance Program use.

TRIMR2D is a 2D model developed in Italy that solves shallow water equations. It uses a semi-implicit, semi-Lagrangian, finite difference solution scheme. Information obtained on this model is limited to a presentation from the floodplain modeling and mapping conference hosted by the 3110 Floodplain Management Task Force in Lacey (Jones 2001). According to the presentation, the model is more robust than many models and is capable of modeling longer reaches than other 2-D models. A Nisqually River reach of more than 20 miles has been successfully modeled, and the USGS plans to begin modeling a reach more than 20 miles long on the Snoqualmie River. The model handles wetting and drying cycles, but does not include culvert flow. TRIMR2D can feasibly handle a grid size of five meters. It is not currently approved by FEMA for National Flood Insurance Program use.

Model Selection

Numerous factors, including the physical complexity of the system to be modeled and budget realities affect model selection for a floodplain mapping project. The following section briefly discusses some of these factors in the context of a general model selection method.

In general, the differences in cost and complexity are greater between model classes than they are between specific models in a similar class. For example, the data requirements and modeling cost involved in a situation that is suitable for a 1-D steady-state model are similar for HEC-RAS and WSPRO. However, the data requirements and modeling cost involved could be significantly greater for an unsteady flow application of HEC-RAS than for a steady flow application of HEC-RAS.

Therefore, one way to approach model selection is to divide the process into two phases: model class selection, and specific model selection.

Model Class Selection

Model class selection involves determining whether a steady or unsteady model is most appropriate and determining whether the situation can be adequately represented by a 1-D model. The accuracy required helps make this determination. More complex models provide a more accurate mathematical representation of a physical system, but in some situations, the additional accuracy provided may not be necessary for the objectives of the floodplain study. Or, improved accuracy may be required only in certain local areas of a floodplain.

In order to make the most appropriate model selection, a good understanding of the physical situation to be modeled is required. If time-based phenomena are critical to accurately represent the hydraulic situation, an unsteady flow model will provide more accurate results. Time-based phenomena that might drive the selection of an unsteady flow model over a steady flow model include:

- Travel time and attenuation of the peak flow within the watershed
- Off-channel storage
- Lateral weirs and high flow short-circuiting
- Tidal influences
- Variable upstream or downstream flow control
- Eddies
- Superelevation around bends
- Flooding and drying cycles
- Sedimentation and scour effects
- Channel migration
- Roughness coefficients that vary with time
- Portable dikes or levees, such as sandbagging during a flood event
- Variable-rate pumps.

Two other factors that are important in selecting a model class are the size of the system to be modeled, and the calibration and verification data available. More complex models can result in large, unstable files for large areas. If a long reach is to be modeled, it may be most appropriate to use a less complex model for the overall reach and a more complex model for isolated areas. If limited calibration and verification data are available, the added expense and time required for a more complex model may not be warranted. It is critical to understand that the model is only as good as the data on which it is based.

Budget realities are also important in selecting a model class. The overall budget available for the project must include the cost of the model itself; model development, calibration and verification; and data collection or ground-truthing of existing data. If limited accurate data are available, more budget must be devoted to data collection, and a more complex model may not be feasible. The more complex models typically have more complex data requirements. For example, an unsteady model requires complete hydrographs for all inflows, as opposed to a steady flow model that only requires a peak flow rate for all inflows. A 2-D model requires elevation and channel/floodplain roughness data at many points on a grid, whereas a 1-D model may require data at fewer points.

It is difficult to provide standard cost estimates for the different model classes, because a modeling study is very situation dependent. However, King County experience indicates that 1-D steady flow modeling with HEC-RAS is expected to cost approximately $14,000 per river mile, including new data collection (Stypula 2001 personal communication). Costs will depend to a certain extent on the marketplace, assuming consultants do a portion of the work. Some consultants have found that if they are extremely familiar with an unsteady model, the costs are only slightly higher than for a steady model.

The final selection of a model class, then, is an iterative process of considering the objective of the study, which determines the accuracy required; the physical situation to be modeled and which aspects of that situation must be modeled to achieve the desired accuracy; and the budget and data available. Some current studies are finding that a 1-D unsteady model provides the best current trade-off between modeling capabilities and cost and data availability issues. Some current studies find the 1-D steady model still the most appropriate and cost-effective model for their floodplains.

Specific Model Selection

Once a feasible model class has been determined, a specific model can be selected within that class. Once again, a number of factors may affect this decision. Some of these factors are specific capabilities that are not included in all models. Depending on the situation to be modeled, these factors might or might not be important. Examples include:

- Supercritical flow
- Floodplain formulation
- Floodplain structures included
- Roughness coefficient varying across cross-section
- Roughness coefficient varying with depth.

Budget issues are also important. For choosing a specific model within a model class, the following factors can have a large influence on the budget:

- Cost of model
- Modeler experience available
- Pre/post processor capability
- GIS interface.

Some expert modelers believe that the expertise and insight of the modeler is as important as model selection within a model class. They believe that experienced modelers have ways to get around many of the perceived shortcomings of a particular model, and that choosing a modeler experienced with a particular model is more important than selecting a model with one or two particular features (consensus of discussions at April 5, 2001 floodplain modeling workshop in Bellingham, Washington sponsored by WSDOT).

Other factors that may be important for final model selection include:

- Ease of use and learning curve, particularly if the model will be used in-house
- Model support and support life
- Model robustness
- Source code availability.

Table 1 summarizes the capabilities of the primary FEMA-approved models with regard to the factors discussed in this section.

Table 1. Hydraulic model capabilities[1].

Floodplain Model Characteristics	HEC-RAS 2.2 (steady)[2]	WSPRO	FEQ	UNET	MIKE11	FESWMS 2DH
General Information						
developer	US Army Corps of Engineers	US Geological Survey, Federal Highway Administration	US Geological Survey	US Army Corps of Engineers	Danish Hydraulic Institute	US Geological Survey
flow equation/numerical solution scheme	energy equation/ standard step backwater	energy equation/ standard step backwater	full dynamic - finite difference	full dynamic – de St. Venant / finite difference	full dynamic – de St. Venant / finite difference	full dynamic/finite element
steady/unsteady	steady	steady	unsteady	unsteady	unsteady	steady or unsteady
1-D, 2-D	1-D	1-D	1-D	1-D	1-D	2-D
Model capabilities affecting model class selection						
supercritical flow	yes	yes	approximated	approximated	yes	yes
tidal influences	no	no	yes	yes	yes	yes
superelevation at bends/eddies	no	no	no	no	no	yes
feasible for large systems	yes	yes	most	most	most	generally no
flooding and drying	no	no	yes	yes	yes	yes
sedimentation/scour	no	no	no	to be incorporated in HEC-RAS 3.0 UNET routines	yes – sediment transport & scour for reach-scale assessments	yes – sediment transport and deposition on localized scale
channel migration	no	no	no	no	yes – morphological model	no
roughness coefficient varies with time	no	no	no	no	yes	yes
portable dikes/levees	yes	no	yes	yes	yes	yes
pumps	Constant	constant	variable	variable	variable	variable
upstream flow control	Constant	constant	variable	variable	variable	variable
flow constrictions	no – use WSPRO	yes	yes	no	yes	yes
braided/branching channel	some	some	yes	yes	yes	yes
direction/velocity	no	no	pseudo	pseudo	pseudo	yes
water surface variation across floodplain	no	no	no	no	no	yes
floodway formulation available	yes	no	no	no	no	no
off-channel storage	no	no	simple level-pool reservoirs	simple level-pool reservoirs	simple level-pool reservoirs	yes, but often unstable
levee/embankment failure	no	no	user-defined sequence	user-defined sequence	user-defined sequence	user-defined sequence

Table 1. Hydraulic model capabilities (continued).

Floodplain Model Characteristics	HEC-RAS 2.2 (steady)[2]	WSPRO	FEQ	UNET	MIKE11	FESWMS 2DH
Budget issues affecting model class selection						
platform/computer requirements (recommended)	Pentium 2, 64 MB RAM	Pentium, 64 MB RAM	Pentium, 64 MB RAM	Pentium, 64+ MB RAM	Pentium, 64+ MB RAM	Pentium, 64++ MB RAM
animated graphical output	no (use HEC-GeoRAS for graphical output)	no	no	yes (with HEC-RAS 3.0 interface)	yes	yes (with SMS interface)
topographic resolution	variable	variable	variable	variable	variable	variable
Model capabilities affecting specific model selection						
supercritical flow	yes	yes	approximated	approximated	yes	yes
floodway formulation	yes	yes	no	under review	no	no
encroachment options	yes	no	no	no	yes	no
floodplain structures	bridges, culverts, ice flow	single opening bridges, culverts, embankment, multiple-opening stream crossings	control structures, culvert, bridges	bridges, culverts, embankment, multiple-opening stream crossings	bridges (requires outside verification), culverts, embankment, multiple-opening stream crossings	bridges, culverts, embankment, multiple-opening stream crossings
roughness coefficient varies across cross section	yes	yes	yes	yes	yes	yes
roughness coefficient varies with depth	yes	no	yes	yes	yes	yes
lateral weirs/high flow short-circuiting	yes	yes	yes	yes	yes	yes
Budget issues affecting specific model selection						
cost of model	Public domain	public domain	public domain	public domain	approx. $15,000	approx. $3,000 (for SMS interface)
modeler experience available	high	medium	medium	medium	medium	medium
pre/post processor capability	good	limited	good	see HEC-RAS	excellent	SMS interface
GIS interface	HEC Geo-RAS, ArcView 3.1 extension; requires 3D Analyst	no	yes	see HEC-RAS	yes	yes– with SMS interface
Other issues affecting specific model selection						
ease of use/learning curve	user-friendly interface, reasonable level of hydraulics expertise	reasonable level of hydraulics expertise	higher level of hydraulics expertise	higher level of hydraulics expertise	user-friendly interface, higher level of hydraulics expertise	advanced level of hydraulics expertise
model support life	public domain	public domain	public domain	public domain	good	good
model robustness	good	good	good	good	excellent	good
source code available	no	no	yes	no	no	yes

[1] Based on published information; actual modeling experience may vary
[2] HEC-RAS 3.0 includes most features of HEC-RAS 2.2 and UNET

Recommendations for Improving Floodplain Mapping in Washington State

As discussed in this white paper, the current system of floodplain mapping in Washington State is inadequate. Widespread reliance upon flood insurance rate maps based on sketchy topographic data and hydraulic modeling work performed years ago is contributing to the extent of flooding damages in Washington State. Inaccurate maps are constraining the accuracy of many critical decisions made at the local, state, and federal levels. Improving the accuracy of the floodplain maps that are used in this state would allow more accurate decision-making and cost effective floodplain management. The remainder of this paper is devoted to a discussion of the steps that should be considered in charting this course of action.

Who Should Lead the Way?

The problems of inaccurate floodplain mapping usually extend across political boundaries. Many streams in Washington State flow in unincorporated county lands, through multiple cities, across county lines, through federal lands, tribal lands, and private property. The floodplains that parallel these streams likewise affect numerous interests. Given the multitude of stakeholders for a given stream system, it would be difficult for all stakeholders to come together in a timely and constructive manner to accomplish cost-effective mapping improvements. Further, many of the stakeholders are financially unable to contribute to improved mapping efforts. Federal agencies such as FEMA, the Corps of Engineers, and the USGS do not have the funding or the vested interests to be feasible candidates to lead the way in a major statewide remapping effort.

The state of Washington is therefore the most logical entity that has the technical, financial, and political resources to enact significant statewide floodplain mapping improvements on a consistent basis. The state agencies best suited to lead the effort include the Departments of Ecology, Transportation, Fish and Wildlife, and Natural Resources, because they have the technical knowledge and information management capacity to collectively manage the data needs, modeling, map production, and stakeholder coordination that must occur. In addition, these agencies manage much of the land and infrastructure that is affected by flooding.

Local government agencies and other local stakeholders, as well as other state departments, need to participate in this process to define priorities and enable meaningful and accurate improvements to Washington's floodplain maps. The state agencies should engage all interested parties at the local, state, and federal level in a collaborative process of data gathering, hydraulic modeling, floodplain map production, floodplain map maintenance, and floodplain regulation and associated decision-making. In locations where recent modeling and mapping efforts are already underway, the stage agencies can partner with the local agencies to complete the effort. These areas represent a relatively small fraction of the flood prone areas in the state.

High Priority Geographic Areas

There are valid, yet contradictory arguments for prioritizing the areas of the state that have the greatest need for updated flood maps. On the one hand, urban areas tend to have better funding, and much of the most current data has been gathered for those areas. In addition, the larger population in urban areas means that more people would directly benefit from the superior accuracy that the new maps would provide. On the other hand, rural areas often lack the funding to update maps on their own. Many rural counties in this state have the fastest growing populations, and much of that growth is occurring in or near floodplains. Furthermore, these counties often contain key transportation corridors, hydroelectric dams, power plants and other infrastructure that is critical not only to the immediate area, but to the entire state.

To provide the greatest benefit to the most geographic areas, the most cost-effective strategy would concentrate the State's efforts on helping those local jurisdictions that lack the funding and expertise that the State can contribute. Because it is the local jurisdiction (usually county government) and not the State that enters into the National Flood Insurance Program, the State can enter into partnerships that focus on gathering the critical topographic and hydrographic data and carrying out the flood modeling that are needed as the preliminary steps for updating the flood maps. This strategy would also focus on the engineering and watershed management associated data needs of many State agencies, while simultaneously helping local communities prepare the necessary tools for flood insurance rate map updates, should they choose to become partners in that effort.

Local Agency Concerns and Needs

Local jurisdictions where floodplain maps need revision must be partners in the process, regardless of whether they are contributing funds to a modeling and mapping effort. In order for local agencies to abide by the results of new floodplain maps in their ongoing floodplain management work, they will need to understand how the maps were created, what data were used, and specifically where the accuracy of the maps is approximate. Local agencies should be engaged in the process from the beginning stages of data gathering through review of updated mapping documentation, prior to FEMA initiating its review (i.e., at a point where their comments can make a difference). Local agencies will likely be attuned to information sources that may not be evident to others involved in modeling work. These agencies can also play an important role in communicating the intent, progress, and results of remapping efforts to their constituents.

An important consideration in the involvement of local agencies is availability of computer resources. To take full advantage of new floodplain maps, and to efficiently participate in their development, local agencies must have sufficient computer capabilities and resources to efficiently work with data files, display and plot maps, and communicate with those preparing and maintaining the maps. Local agency staff or their consultants must be trained in the use of these computer systems.

Tiered Approach to Improving Floodplain Maps

A state-sponsored effort to create new floodplain maps in many flood-prone areas will take several years. While this process unfolds, there are relatively simple methods for improving on the information presented in the flood insurance rate maps that many jurisdictions in the state could pursue. Those jurisdictions engaged in their own processes for updating floodplain maps may not need to take these steps. These actions are considered the first tier of floodplain map improvement. To eventually reach the best feasible (and necessary) accuracy of statewide floodplain maps, new modeling and mapping work will be required in many areas where it has not otherwise been undertaken by local jurisdictions. This is considered the second tier of floodplain map improvement.

Tier 1: Floodplain Map Improvements with Available Information

As discussed earlier in this paper, there are several methods that can be used to improve the accuracy of the flood insurance rate maps as published by FEMA. These methods involve use of readily available digital aerial photos and digital files of floodplain areas (such as Q3 data or digitized outlines of floodplain limits from the flood insurance rate maps) to enable computer rectification of stream alignments and approximate 100- and 500-year floodplain boundaries. Floodplain boundaries defined by FEMA can be overlain with the aerial photos to determine locations where the flood insurance rate map definition of the floodplain is noticeably inaccurate, based on local knowledge of flooding extent and associated physical features. The ability of a map user to see roads, vegetation, and other physical features on an aerial photo while simultaneously viewing a floodplain boundary is a definite improvement over viewing a paper copy of the map that does not indicate those features clearly.

While the adjusted maps would not be reviewed by FEMA for concurrence on the revised floodplain boundaries, they would serve to give the local jurisdiction the best available information with which to manage the floodplain(s) and conduct development permitting activities. The aerial photography data that should serve as a baseline for these map improvements are the digital orthophoto quarter-quadrangle maps that Ecology is currently producing at 1 to 12,000 scale. If more detailed aerial photography is available from another source, the other source should be used in lieu of the digital orthophoto quadrangle maps.

Tier 2: New Modeling and Mapping

The second tier of effort for improving the accuracy of floodplain maps will involve developing new hydraulic models, gathering the supporting data, calibrating those models to observed data, modeling extreme flood events, plotting associated areas of floodwater inundation, and coordinating implementation of the new maps. In general the accuracy of floodplain maps should improve considerably in this process. Therefore, it is recommended that the State, in partnership with all local jurisdictions concerned with flooding, set a goal and funding schedule for accomplishing this second tier of mapping improvements

Future Hydraulic Modeling of Floodplain Areas

The following discussion focuses primarily on modeling of flood flows in streams and rivers. Modeling of low-lying areas that are inundated by rising ground water is discussed at the end of this section.

Models to Use

As discussed earlier in this paper, there are numerous FEMA-endorsed models for preparing estimates of floodplain boundaries and flood flow elevations. Many of the available models are frequently used in Washington State, and there is extensive expertise available in the region to knowledgeably use and manipulate these models. There is no single model that fits all situations. HEC-RAS remains a standard for many applications where the hydraulic properties to be modeled are not complex, i.e., where a 1-D steady flow model is sufficient. However, no study should preclude the use of other models, particularly where the hydraulic characteristics are complex and a 1-D model will produce marginally accurate results. Table 1 provides guidance on the capabilities of various models that realistically could be used. Prior to launching a floodplain modeling study, any jurisdiction that is uncertain in choosing appropriate models should consult expert assistance from other agencies or consultants who have the knowledge to make this critical decision. Related issues such as model data needs, cost, and selection of the lead modeler are decisions that are dependent on model selection.

Based on current studies and information, it is expected that HEC-RAS will continue to be used for many floodplain modeling studies. It is public domain software with a wide user base and significant modeler experience available in both the private and public sector. The addition of unsteady flow regime capability by incorporating UNET routines provides the opportunity to apply steady or unsteady flow regimes, depending on the situation.

Mike11 and FEQ are expected to be used in more floodplain studies in the future. As a commercially marketed model, the cost of the Mike11 model is higher than public domain models, but it offers excellent user interface, support, and graphical presentation abilities. Several consultants in the United States and Canada are beginning to use Mike11 extensively in floodplain studies.

2-D models are expected to be necessary only in extremely complex floodplain situations where a large budget is available for modeling and data collection. However, as computational requirements decrease and available data increase, use of these models will become feasible for more studies.

Data to Support Hydraulic Modeling

High-quality data are essential for new floodplain modeling and mapping efforts. While the cost of those data will directly affect the speed with which statewide map improvements are made, it is critical that each floodplain modeling effort meets a degree of accuracy that enables reliable mapping for the long term. Shortcutting accurate data needs will result in marginal improvements in map accuracy, and will not result in cost-effective allocation of the available funding. By using high-quality and accurate data sources, the obligation to use "best available science" for management of floodplain areas under the state Growth Management Act will be met. The basic standards that should apply to data used in future floodplain modeling and mapping efforts are as follows:

- Topographic data with 2-foot or less contour resolution for the area of the floodplain to be modeled, and for a conservative distance beyond the floodplain (the entire watershed if possible)
- Topographic data with the best available contour resolution for all other areas in the watershed to be modeled
- Peak flood stage elevation and flow hydrograph data for at least one major flood event, at one or more locations
- Survey data for all bridges, culverts, dikes, and other structures within the modeled area that affect conveyance of flow
- Land use and soil data for the entire land area within and slightly beyond the estimated floodplain to be modeled.

The issue of suitable flow hydrograph data is complex, and there is no rule of thumb that can be applied in all cases. The frequency of the flow data is also important. The minimum frequency of flow measurements that will support accurate hydraulic modeling is hourly, with no significant gaps in the record.

At a minimum, thirty years of record is an acceptable hydrograph length. However, given that the modeling will be performed to estimate flooding in the 100-year, and in some cases the 500-year event, longer hydrograph records provide greater confidence in the model results. It is also critical that the flow record be relatively current, so that it reflects current precipitation and runoff characteristics in the watershed. If a watershed has multiple flow gauging sites, all of the data should be used in hydraulic modeling for that system. Similarly, the more flood events captured in the gauge record the greater the achievable modeling accuracy.

However, for watersheds where few if any gauges exist, it will be important to determine whether additional gauges can be installed to obtain baseline data in a timely manner, or whether the limits of the model must be reduced to match the availability of flow data. In general, there is at least one streamflow gauge on the main stem of each major river in Washington where flooding is problematic, but gauges on major tributaries are limited. This poses a problem for accurate modeling of peak flood events, as the timing of flow delivery to the main stem is uncertain. If there are tributaries that constitute a significant proportion of the drainage area of a river's watershed, and no flow data are available downstream of the confluence before another such tributary confluence, it will be necessary to simulate the runoff from the drainage area for that tributary using a hydrologic model. The accuracy of the associated hydrologic model will directly affect the accuracy of the main stem flood model.

Thus, case-by-case decisions on selection of the hydrologic model in concert with the approach to the floodplain model will have to be made. The variety of scenarios that will occur and the associated modeling decisions that will be required are beyond the scope of this white paper. It is likely that the Hydrologic Simulation Program – Fortran (HSPF) model will be used extensively in these scenarios. HSPF is used widely in the region for accurate modeling of basin runoff processes, and does not require excessively expensive data gathering.

In addition to the above information, land use data, soil data, precipitation data, and potentially snowpack data will be needed for areas of the watershed beyond the floodplain if hydrologic modeling of basin runoff is necessary to support the hydraulic model. The precipitation data must correspond to the timing of the flood events that are being simulated in the hydraulic model. If the watershed experiences flood events typically associated with snowmelt, the snowpack data will be crucial to achieving accurate runoff hydrograph results.

Modeling of flood stages in low-lying areas where rising ground water causes flooding will require a different approach. Flow data are not applicable, but recorded or estimated flood stage (elevation) data are critical. In these situations, hydrologic modeling of basin runoff may be necessary, and ground water flow modeling will likely be necessary. As discussed above, the hydrologic modeling of overland runoff will likely entail use of the HSPF model and the associated land use, soil, precipitation, and possibly snowpack data. As with modeling of overland runoff, there are many options available for simulation of ground water movement.

One example of a study that evaluated peak flood stages in a lake with no outlet is the *Horseshoe Lake Site Characterization and Flooding Analysis* (Herrera and Robinson & Noble 1996). That study used the HSPF model in combination with MODFLOW, which simulated the ground water table fluctuation. The MODFLOW model required static water elevation data from several wells in surrounding areas, geologic data for the underground aquifer system, and inflows derived from the HSPF model output (i.e., the water estimated to infiltrate the ground by the HSPF model). The combination of peak water table elevations simulated with MODFLOW and corresponding peak overland runoff flows simulated with HSPF enabled the estimation of peak lake surface elevations over a long-term sequence of precipitation data. Statistical evaluation of the resulting annual peak water levels enabled relatively accurate estimation of the 100-year flood level in the lake. Similar studies have been conducted in many other locations in western Washington in recent years, and those study results should be considered in determining an appropriate modeling plan for lakes and depressions plagued by ground water-induced flooding.

Inundation Areas to Model and Map

Government agencies use the 100-year floodplain mapped by FEMA to make floodplain management decisions, land-use decisions, and flood-mitigation plans. However, in order for an agency to make optimum growth management decisions, flooding events with a higher probability than the 1-percent flood should also be drawn on the flood hazard map. For example, Jones et al. (1998) suggest showing the 25-year flood limits to better identify flood-prone areas where greater restrictions on development should occur. Similarly, North Carolina is updating many FIRM maps to show the 10-percent (10-year), 2-percent (50-year), 1-percent (100-year), and 0.2-percent (500-year) annual chance flood hazard zones (Dewberry & Davis 2000). The additional information provided by identifying the 10-year or 25-year flood hazard areas will allow for more informed floodplain management decisions in the future that may reduce property damage and loss of lives in future floods.

Sources of Data

Topographic Data

The preferred method for obtaining 2-foot contour data for future floodplain modeling work (among other purposes) uses a newly developing technology called light detection and ranging, or LiDAR. This technology has been used in recent years in western Washington and is literally exploding in popularity throughout the United States. This breakthrough technology allows removing the effects of vegetation, specifically the tree canopy and dense understory vegetation, on the accuracy of the mapped ground surface. Conventional aerial surveys and global positioning systems (GPS) are handicapped by their inability to penetrate the tree canopy, whereas LiDAR incorporates estimation of the tree/vegetation canopy height and computer software that strips away the vegetation, resulting in accurate mapping of forest floors and all other land areas. A consortium of government agencies and private interests has been created in western Washington to promote pooling of resources to prioritize, gather, share, and manage LiDAR data. This consortium was initially spearheaded by Kitsap County, and has gained momentum as more are produced via LiDAR. The State of Washington should become an active participant in this consortium to expedite the mapping coverage for all flood-prone areas. FEMA has endorsed the use of LiDAR for flood hazard mapping studies nationwide.

The approximate cost for developing topographic data with LiDAR is on the order of $370 to $500 per square mile, depending on a number of factors (Plaster 2001 personal communication). As this technology becomes more widely used, it will be cost competitive with other viable alternatives for large-scale topographic mapping.

Streamflow and Stage Data

Streamflow and peak stage data are readily available for many stream systems in Washington State from the USGS and from county governments. Additional stream gauges need to be added to the existing networks of gauges. However, funding to operate existing gauges has been dwindling in recent years, and the outlook for more federal funding in the immediate future is not good.

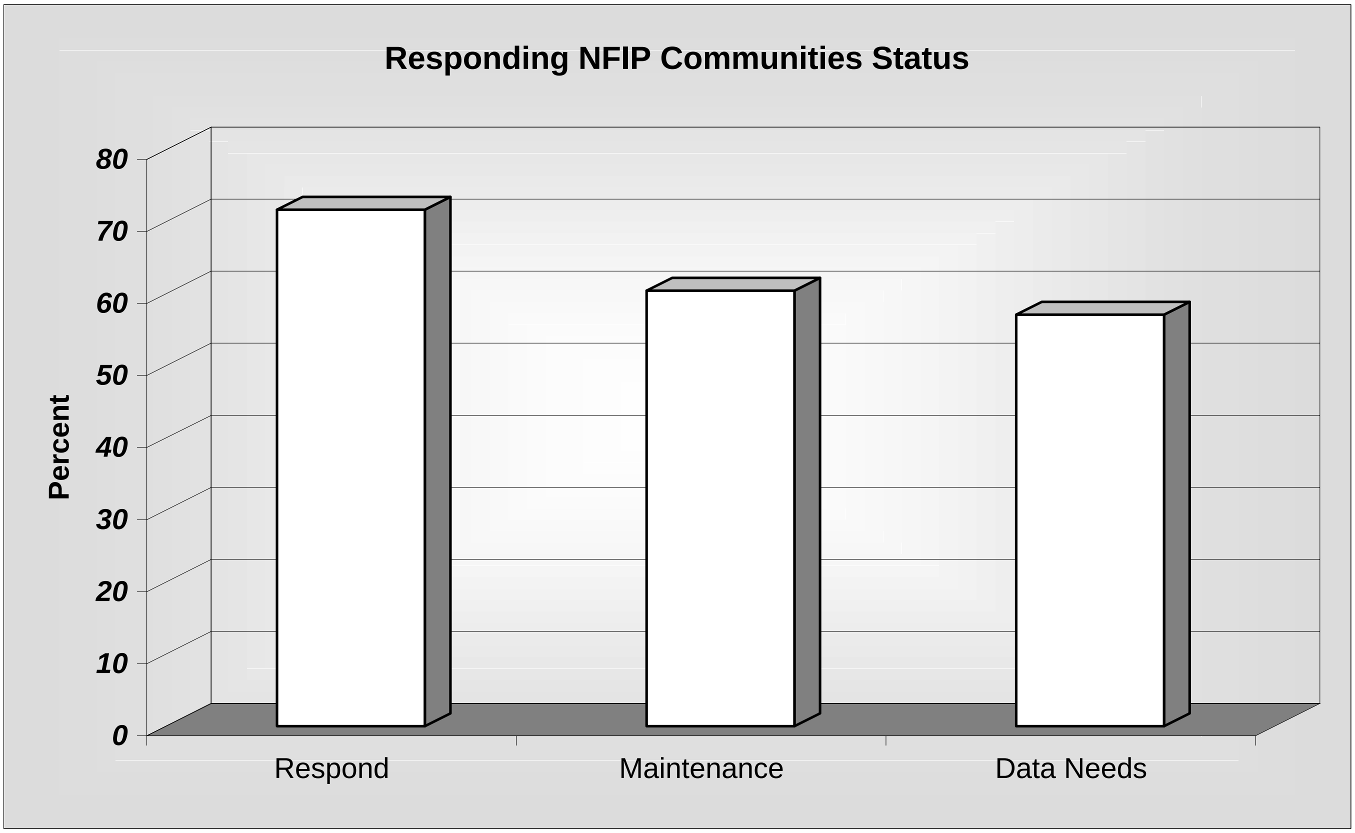
Despite the increasing need to gather data that characterizes changing hydrographs, particularly in watersheds that are experiencing rapid development, gauges in Washington State are being shut down for lack of funding. More partnerships are needed between watershed stakeholders to fund the ongoing operation of the existing stream gauge network as well as its expansion.

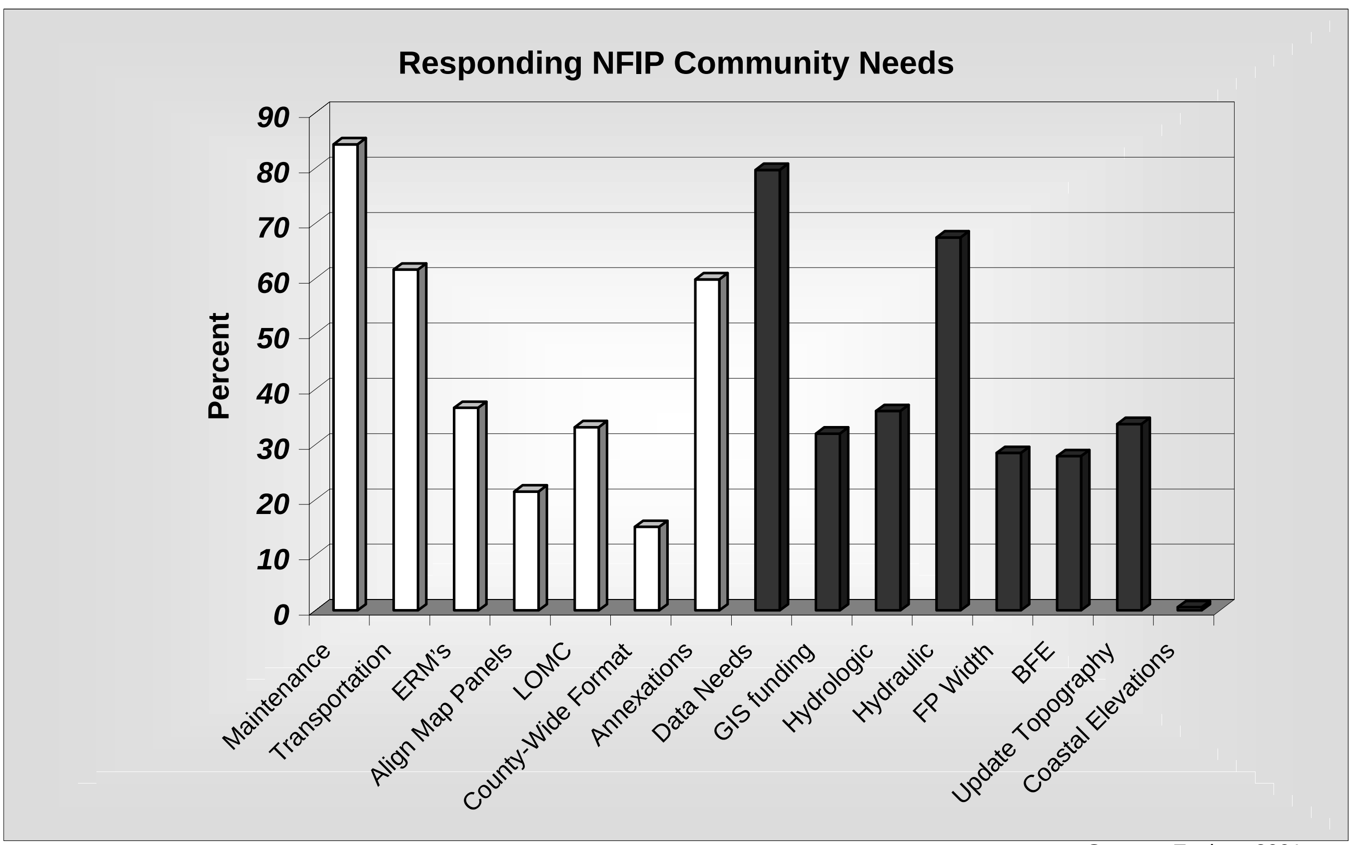
Community-Supplied Data

The Washington Department of Ecology recently conducted a supplemental survey of communities throughout Washington State that are participants in the National Flood Insurance Program, soliciting feedback on the types of information and assistance those communities need for floodplain map development, updating, and maintenance. This current survey amended a five-year ongoing FEMA nation-wide survey. Figure 1 presents the results of this survey (Ecology 2001). The upper portion of Figure 1 depicts the percentage of National Flood Insurance Program communities that responded to some or all of the survey, the percentage of respondents who provided information on maintenance needs, and the percentage of respondents who provided information on mapping data needs. Approximately 70 percent of the participating communities in the state responded, an excellent rate of return on the survey. It is likely that the 30 percent who did not respond are in general not experiencing major problems with the current floodplain maps. Given this high rate of response to the survey, the information is quite useful in the process of planning for a systematic floodplain mapping update program on a statewide basis.

The bottom portion of Figure 1 summarizes the survey responses for specific categories of map maintenance needs and data needs. The lighter bars on the figure relate to map maintenance needs and the darker bars relate to map data needs. A brief explanation of each of these categories follows:

- Maintenance – percent of survey respondents who have map maintenance needs
- Transportation – roads, bridges, culverts, etc. need to be added or updated on the maps
- Elevation reference marks (ERM) need to be added or updated on the maps
- Align map panels – individual map panels need to be aligned with each other and within a county-wide format
- LOMC – information presented in letters of map change need to be added
- Countywide format – the maps need to be converted to a countywide format
- Annexations – changes need to be made to the corporate city limits shown on the maps





Source: Ecology 2001

Figure 1. Community needs for developing and maintaining floodplain maps.

- Data needs – percentage of survey respondents who have mapping data needs
- GIS funding – the community needs funding for GIS hardware, software, and technical staff to operate the GIS
- Hydrology – updated hydrologic information needs to be used in the process of updating the maps
- Hydraulics – updated hydraulic analysis is required in support of improved floodplain maps
- Floodplain width – changes to the floodplain width are needed on the maps
- Changes to base flood elevations (BFE) are needed on the maps
- Update topography – updated topographic information is needed in support of improved floodplain maps
- Coastal elevations – accurate mapping of coastal floodwater elevations is needed. The survey results depicted in Figure 1 are 'as responded', however the need for better coastal elevation data is underestimated.

As shown in Figure 1, the responding communities have a variety of data needs and map maintenance needs, and many communities share the same needs. Of most importance in this figure, almost 80 percent of the responding communities indicate that they need additional data to support improved floodplain maps.

The land use data needed in hydrologic and hydraulic modeling efforts will ideally come from local GIS sources but may also be determined from aerial photos, ground-truthing reconnaissance, or other reliable sources. The soil data used in hydrologic and hydraulic modeling can be obtained from soil surveys published by the U.S. Department of Agriculture, and the Natural Resource Conservation Service (formerly the Soil Conservation Service), if there is no local source of more accurate data. Precipitation data are available from a number of gauging sites throughout the state. These gauges should have sufficient records and geographic spacing to support the accuracy needed for hydrologic and hydraulic modeling of floodplains.

Coordination should occur among state and local programs to share data. Doing so will reduce costs of data gathering and data management for all involved. Watershed planning on a statewide basis, salmon recovery planning, and a myriad of local basin planning efforts focusing on control of high runoff flows, water quality problems, and protection and enhancement of riparian areas create a variety of opportunities for sharing costs for collection and management of flow data, topographic data, culvert and bridge data, and other information that serves multiple interests. Development of a data clearinghouse at the state level would make this data sharing as convenient and efficient as possible.

Standardization and Management of Data

Three key factors in successful mapping of floodplain areas throughout the state will be standardization of the data used in modeling work, managing the data that are collected to support modeling work, and managing the resultant digital maps. Washington State currently adopts the FEMA Federal Standard under RCW 86.16, and cannot exceed those standards without the request of the local jurisdiction. However, the State is currently discussing state-wide standards and will propose such standards to the Floodplain Management Task Force (the 3110 committee) for adoption by local governments. The following paragraphs outline the standards that should be implemented for data formats and data management.

Minimum Standards for Community Supplied Base Map Data

Resolution - The minimum resolution requirement for raster data files is 1 meter ground distance between data points. Higher resolution data will be acceptable.

Horizontal Accuracy - The base map data used to prepare digital flood maps should employ the National Standard for Spatial Data Accuracy (NSSDA). The NSSDA uses root mean square error reported in ground distances at the 95-percent confidence level. This means that 95 percent of the positions in the dataset will have an error with respect to true ground position that is equal to or smaller than the reported accuracy value. The minimum horizontal positional accuracy for new digital flood data will be that of the default base map - the USGS digital orthophoto quadrangles, that have NSSDA accuracy of 38 feet. Data that meet higher standards are also acceptable.

Vertical Accuracy - NSSDA uses root mean square error (RMSE) to estimate both horizontal and vertical accuracy. The vertical accuracy of any digital elevation model (DEM) is defined as 1.96 times the RMSE of linearly-interpolated elevations in the DEM, as compared with known elevations.

Horizontal Reference System - The digital files must be geo-referenced to a known projection and datum and be accompanied by information that describes those parameters. The accepted projection and datum for the State of Washington is Stateplane South (Zone 5626) and the North American Datum of 1927 (NAD27).

Data Sources - Community-supplied data may be in the form of digital orthophotos or vector data files. Locally produced digital orthophotos should meet USGS digital orthophoto quadrangle standards at a minimum. Aerial images that are not ortho-rectified should not be acceptable. Vector files may be photogrammetrically compiled or digitized from orthophotos.

Unacceptable vector file sources include "TIGER" files or other files compiled at scales smaller than 1:20,000.

Age - The data should have been created or reviewed for update needs within the last seven years.

Coverage - Data should be complete and contiguous throughout the entire geographic area of concern. If only portions of a geographic area are available, only those sub-areas which are completely covered by the base data should be used.

Availability - The data should be made available at the time of the initial coordination contact. Distribution of the data should be made only after a formal request has been submitted to the coordinating body.

Restrictions on Use - FEMA, the Washington Department of Ecology, and WSDOT must be able to print and distribute an unlimited number of hard copy maps using the data. FEMA, the Washington Department of Ecology, and WSDOT should also be able to freely distribute the base map data in raster format, along with the floodplain information, to the public.

Contents - The data files must contain all transportation features (roads, railroads, and airports) for the community. If digital orthophotos are supplied, these features must be clearly visible. If vector files are supplied, they also should contain transportation features. Roads are considered to be those travel ways intended and maintained for use by motorized vehicles. In vector format, roads may be portrayed as road centerlines, edge of pavement, or right-of-ways.

New/Improved Topography - Although there are several methods for updating topography, the primary method in Washington State incorporates airborne light detection and ranging (LiDAR) to create digital elevation models (DEMs). Once processed, LiDAR data requires a large electronic storage system, and a somewhat sophisticated GIS program is needed to analyze and display the data. However, because topography is one of the most critical components of any floodplain mapping activity, these computer resources are critical. The elevations derived from cross sections are the primary input to all hydrologic and hydraulic models that delineate flood scenarios, and therefore are of the most importance.

There are two primary factors to consider when attempting to update topographic data using LiDAR, quality control and "bald-earthing." Although both factors are primarily the responsibility of the LiDAR contractor, the deliverables should be well documented prior to any contraction. The DEMs produced from LiDAR data should have a maximum root mean square error (RMSE) of 15 centimeters, which is roughly equivalent to 1-foot accuracy. As described previously, the models used to delineate the 100-year floodplain should be based on minimum 2-foot contour topography, at least in the floodplain. The data post-processing procedure for "bald-earthing", or stripping away the masking effects of vegetation cover on the ground surface, is also important. Depending on the time of the year, density of the vegetation canopy, and the slope of the topography, the bald-earthing process can be tenuous.

Thematic Separation of Data - Thematic data must be separated by level, layer, or attribute in the same electronic file, or stored in different files. For example, the roads should be separated from the streams or corporate limits by one of the listed methods.

File Format - The files must be submitted in one of the following file formats:

- Raster Data - Digital orthophoto files may be submitted in TIF (preferred), BIP, or JPEG format
- Vector Data - ARC/INFO export file (.E00 file extension)
- ArcView shapefile - .SHP file extension
- Microstation design file .DGN file extension
- MapInfo interchange format .MIF file extension
- MapInfo native table format .TAB file extension
- AutoCAD drawing exchange format - .DXF file extension
- Digital Line Graph - .DLG file extension
- Spatial Data Transfer Standard - SDTS

Transfer Media - The files should be submitted in one of the following electronic media:

- CD-ROM (preferred);
- Zip disk;
- 8 mm tape;
- 4 mm tape;
- 3.5-inch diskette
- Electronic transfer to FTP site; or
- Electronic transfer by E-mail (for files under 2 megabytes in size)

Tiling - Data should be in one single file or a series of thematic files that cover the entire geographic area of the community instead of individual small tiles that each cover a limited geographic area.

Data Structure - Vector data files must meet the following data structure requirements:

- Line features must be contiguous (no dashes, dots, patterns, or hatching)
- Files must not contain curves or B-splines
- Files must not contain nested cells
- CADD files must not contain annotation generated from a database; the annotation must be placed as text
- There should be no gaps or overshoots between features that should close with each other.

Metadata - The files must be accompanied by metadata that complies with the Federal Geographic Data Committee metadata standards.

Combining Data from Multiple Sources - Complete and integrated data files for an entire county are desired. However, if only portions of a county are available, a decision may be made to combine data from multiple base map sources. This may entail piecing together data provided by adjoining communities or digital orthophoto quarter-quadrangles.

Coordination with FEMA

While it is not necessary for FEMA to approve updated floodplain maps prior to their use in floodplain decisions for non-insurance purposes, FEMA input is important in developing the maps. The technical expertise that FEMA can provide, in addition to cost sharing, are desirable contributions. Once new floodplain maps have been finalized by the modelers, and stakeholders are involved on the state and local levels, the new maps should be used immediately as the best available information to support land use, engineering, and other uses while the FEMA approval process occurs.

FEMA's website (www.fema.gov) currently offers the best avenue for obtaining information and contact information. The State of Washington is in FEMA Region X.

Funding Sources

A large-scale effort to modernize floodplain maps in Washington state will require funding. Securing funding will involve cost sharing among a number of parties and environmental objectives. When a particular flood relief, floodplain mapping, or similar project can support multiple objectives, the number of funding options and potential for securing those funds increases. An example is provided by recent floodplain land acquisition efforts in Snohomish County. Agricultural lands have been purchased along the Snohomish River floodplain to enable removal of flood control dikes to support wetland restoration and fish habitat restoration, as well as to enable reestablishment of off-channel flood flow storage areas. The multiple objectives have provided for greater funding opportunities and expedited the appropriation of those funds (Miller 2001).

Most of the funding that will be needed for updating floodplain maps and creating new floodplain maps in this state will not be available from federal sources. The FEMA Region X office currently appropriates only $500,000 per year for floodplain mapping grants in the states of Washington, Oregon, Idaho, and Alaska combined (Park 2001 personal communication). That amount is minimal in light of the large number of floodplain map updates needed. The potential for using federal funding associated with salmon recovery under the Endangered Species Act for the purposes of mapping floodplains should be explored. Declining fish stocks have created a slow-paced emergency in the context of allocating federal monies for emergency purposes, and that may offer promise for obtaining floodplain mapping monies through FEMA for studies that will also support salmon recovery efforts (D’Acci 2001 personal communication). As federal funding is directed into Washington State for salmon recovery, every effort should be made to coordinate studies where data collection is needed for floodplain mapping in addition to salmon recovery. There are many possibilities for coordinating the protection of habitat, removal of fish passage barriers, and the protection of the floodplain from flood prone development. Funding may be provided by natural resource agencies for the protection of endangered species and their habitat; by emergency planning agencies to reduce the damage done by flooding; by land use agencies and governments protecting critical areas; or by state agencies protecting critical infrastructure around the state (e.g. highways and bridges). The goals of these organizations are related and intertwined with one another. It is the goal of the Floodplain Management Task Force to guide the coordination and use of these many different funding sources and targeted actions towards the greatest common good, which includes protecting the floodplain and the habitat it provides as well as protecting society's investments in infrastructure and land use.

Local jurisdictions that will benefit from updated or new flood floodplain mapping projects should contribute funding to the maximum extent possible. This will expedite the rate at which the State is able to provide mapping improvements in all flood-prone areas. Local areas that are plagued by frequent and expensive flooding should consider establishing utility rate structures that allow for accumulation of funds to go toward floodplain map improvements and modeling studies. State agencies should partner with these local jurisdictions to offer advice and resources that expedite the ability of local jurisdictions to accomplish the improvements. The money spent in floodplain map improvements will promote land use planning and other efforts that reduce flood damages in future years.

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