Stormwater Management FOR EASTERN WASHINGTON

FINAL DRAFT

Stormwater Management Manual for Eastern Washington

Foreword, Chapter 1 – Introduction
Chapter 2 – Core Elements for New Development and Redevelopment
Chapter 3 – Preparation of Stormwater Site Plans
Chapter 4 – Hydrologic Analysis and Design

WASHINGTON STATE DEPARTMENT OF ECOLOGY

June 2003
Publication Number 03-10-038A

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Foreword

Objective of the Manual

Urban development causes significant changes in patterns of stormwater flow from land into receiving waters. Water quality can be affected when runoff carries sediment or other pollutants into streams, wetlands, lakes, and marine waters or into groundwater. Stormwater management can help to reduce these effects. Stormwater management involves careful application of site design principles; construction techniques and source controls to prevent sediment and other pollutants from entering surface or groundwater; treatment of runoff to reduce pollutants; and flow controls to reduce the impact of altered hydrology.

The objective of this Manual is to provide guidance in stormwater design and management for eastern Washington. The Manual aims to provide a commonly accepted set of technical standards, in addition to presenting new design information and new approaches to stormwater management. The Department of Ecology believes that when the standards and recommendations of this Manual are properly applied, stormwater runoff should generally comply with water quality standards and protect beneficial uses of the receiving waters. Ecology recognizes that individual circumstances vary greatly, and in some instances compliance with the Manual may not ensure compliance with water quality standards.

Background and Development of the *Stormwater Management Manual for Eastern Washington*

Many guidance manuals for stormwater have been written to address national, regional and local characteristics and management needs. In Washington, several guidance manuals have been prepared, used, and updated to address regional and local requirements. The Department of Ecology published the *Stormwater Management Manual for Western Washington* in August 2001 as an update to a predecessor manual prepared in 1992. Ecology initially proposed that the Manual could be updated to cover the entire state of Washington. Eastern Washington representatives requested that Ecology instead create a separate manual for the eastern portion of the state. Based upon these requests and upon recognition of the significantly different hydrology and geology of eastern Washington, Ecology agreed to create a separate manual.

Discussions continued at various conferences, meetings and forums to determine the best method to accomplish this effort. A chartering meeting was held in June 2001 to formalize the structure and process for preparing the Manual for eastern Washington. The meeting was attended by more than 70 representatives of 17 cities, 11 counties and five Federal and State agencies with interests in stormwater management in eastern Washington.

The chartering meeting established a ten-person Steering Committee with several alternate members to lead the overall effort; it also created two Subcommittees: one for leading the preparation of the Technical Stormwater Manual, and another for leading the preparation of a Model Municipal Stormwater Program. Ecology agreed to fund the hiring of a consultant team to support the development and preparation of the documents and to assist the Steering Committee and Subcommittees with meeting coordination, public involvement and related project tasks. Proposals were received by four consultant teams in October 2001; the Steering Committee selected the team lead by Tetra Tech/KCM of Spokane.

A project kick-off meeting was held on November 7, 2001 with members of the Steering Committee, Ecology, and the consultant team. The scope of work for the project and a proposed production schedule were prepared; a corresponding budget was prepared and the work began. A stakeholder workshop was held on November 29, 2001 to inform interested parties about the project efforts, the regulatory requirements, the schedule for meetings, and the document production format. After the introductory sessions, concurrent meetings of the Subcommittees were held to begin the development of the Manual and the Model Program. Meetings were held at least once per month to review drafts and updates for each chapter of each document. Periodic presentations were made to address special stormwater management issues. These efforts resulted in draft documents being submitted for public review in fall 2002.

Following the public comment period, the subcommittees reviewed all of the comments received on both of the documents and agreed to minor revisions to the Model Program and substantive revisions to the Manual. The final Model Program will be published in summer 2003. The public comment period on the Final Draft Manual is from early June through mid August 2003.

Acknowledgement of the Eastern Washington Stormwater Management Steering Committee and Manual Subcommittee

Ecology would like to thank the members of the Eastern Washington Stormwater Management Steering Committee for their valuable commitment of time and leadership in leading the process to develop this Manual and the *Model Municipal Stormwater Program for Eastern Washington*.

Ecology would also like to thank the Eastern Washington Stormwater Manual Subcommittee participants for their valuable commitment of time and energy in helping develop, review and shape the contents of this document.

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Gary Beeman, Wash. St. Dept. of Transportation South Central Region, *Steering Committee Co-Chair*
Steve Worley, Spokane County, *Manual Subcommittee Chair*
Nancy Aldrich, City of Richland, *Manual Subcommittee Co-Chair*
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Jim St. John, David Evans and Associates
Steve Worley, Spokane County, *Subcommittee Chair*

Organization of this Manual

Chapter 1: Introduction The first chapter explains the need for a technical stormwater management manual; what the Manual is; and how the Manual is intended to be used. It provides the regulatory framework for the Manual.

Chapter 2: Core Elements for New Development and Redevelopment This chapter describes the components of a successful stormwater management program. It provides the technical basis for eight specific elements that are required for most projects and describes the conditions under which one or more elements may or may not apply to a particular project.

Chapter 3: Preparation of Stormwater Site Plans This chapter provides guidance for preparing the individual site plans upon which each project activity's success in managing stormwater will depend.

Chapter 4: Hydrologic Analysis and Design This chapter identifies and describes the recommended methodologies for sizing and designing water quality treatment and flow control facilities.

Chapter 5: Runoff Treatment Facility Design This chapter provides specific design information for runoff treatment systems, including infiltration treatment facilities and pre-treatment facilities required for UIC rule-authorized subsurface infiltration systems such as drywells.

Chapter 6: Flow Control Facility Design This chapter provides specific design information for flow control facilities including detention, retention, evaporation and infiltration systems.

Chapter 7: Construction Stormwater Pollution Prevention This chapter identifies and describes best management practices for preventing pollution, particularly from erosion and sediment runoff, during the construction phase of a project.

Chapter 8: Source Control The final chapter identifies and describes best management practices to prevent contamination of stormwater runoff.

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Chapter 1 - Introduction

1.1 Purpose and Scope

The objective of this Manual is to provide guidance in stormwater design and management for eastern Washington. The Manual aims to provide a commonly accepted set of technical standards, in addition to presenting new design information and new approaches to stormwater management. These stormwater management practices, if properly applied at a project site, should protect water quality in the receiving waters (both surface and ground waters). Improperly managed stormwater runoff is one of the principal sources of water quality and habitat degradation in urban areas. A number of existing laws and regulations require that project proponents properly manage stormwater runoff to avoid adverse impacts to water quality and aquatic resources. This Manual is intended to provide technically sound and realistic guidance on how to properly manage stormwater runoff from individual project sites.

This Manual identifies eight Core Elements for managing stormwater runoff from new development and redevelopment projects of all sizes. The Manual also provides guidance for preparation and implementation of stormwater site plans. The requirements of the Core Elements are generally satisfied by the application of Best Management Practices (BMPs) selected from Chapters 5 through 8 of this Manual. Projects that follow this approach will apply reasonable, technology-based BMPs and water quality-based BMPs to reduce the adverse impacts of stormwater.

This Manual is applicable to all types of land development including residential, commercial and industrial development and roads. A Manual with a more specific focus – such as a Highway Runoff Manual or a stormwater manual adopted by a local jurisdiction – may provide more appropriate guidance to the project proponent.

The Manual is limited in scope for addressing environmental problems caused by urbanization. The Manual does not include site development standards or limit where development should be allowed. Project by project management of stormwater runoff from new development and redevelopment alone will not correct existing water quality and instream habitat problems. The engineered runoff treatment and flow control facilities recommended in this Manual can reduce the adverse impacts of development, but such facilities cannot remove sufficient pollutants to replicate the pre-development water quality, nor can they replicate the natural functions of the watershed that existed before development.

This Manual is applicable to all of eastern Washington, including the area bounded on the west by the Cascade Mountains crest; on the north by the Canadian border; on the east by the Idaho border; and on the south by the Oregon border. At the southern end of Washington’s Cascade Mountain range where the crest does not follow county borders this Manual is applicable to all of Yakima and Klickitat Counties.

1.1.1 The Manual's Role as Technical Guidance

The *Stormwater Management Manual for Eastern Washington* is not a regulation. The Manual does not have any independent regulatory authority and it does not establish new environmental regulatory requirements. Current law and regulations require project proponents to design, construct, operate and maintain stormwater treatment systems that prevent pollution of State waters. The Manual is a guidance document which provides local governments, State and Federal agencies, developers and project proponents with a set of stormwater management practices. If these practices are implemented correctly, they should result in compliance with existing regulatory requirements for stormwater – including compliance with the Federal Clean Water Act, Federal Safe Drinking Water Act and State Water Pollution Control Act.

The purpose of this Manual is to provide technical guidance on measures to control the quantity and quality of stormwater runoff from new development and redevelopment projects. These measures are considered to be necessary to achieve compliance with State water quality standards and to contribute to the protection of the beneficial uses of the receiving waters (both surface and ground waters). Stormwater management techniques applied in accordance with this Manual are presumed to meet the technology-based treatment requirement of State law to provide all known available and reasonable methods of treatment, prevention and control (AKART; RCW 90.52.040 and RCW 90.48.010).

This technology-based treatment requirement does not excuse any discharge from the obligation to apply additional stormwater management practices as necessary to comply with State water quality standards. The State water quality standards include: Chapter 173-200 WAC, Water Quality Standards for Ground Waters of the State of Washington; Chapter 173-201A, Water Quality Standards for Surface Waters of the State of Washington; and Chapter 173-204, Sediment Management Standards. Additional treatment to meet those standards may be required by federal, state, or local governments.

Following this Manual is not the only way to properly manage stormwater runoff. A project proponent may choose to implement other practices to protect water quality; but in this case the project proponent assumes the responsibility of providing technical justification that the chosen practices will protect water quality (see Section 1.1.3, Presumptive versus Demonstrative Approaches to Protecting Water Quality below).

1.1.2 More Stringent Measures and Retrofitting

Federal, State, and local government agencies with jurisdiction can require more stringent measures that are deemed necessary to meet locally established goals, State water quality standards, or other established natural resource or drainage objectives. Water cleanup plans or Total Maximum Daily Loads (TMDLs) may identify more stringent measures needed to restore water quality in an impaired water body.

This Manual is not a retrofit manual, but it can be helpful in identifying options for retrofitting BMPs to existing development. Retrofitting stormwater BMPs into existing developed areas may be necessary to meet federal Clean Water Act and state Water Pollution Control Act (Chapter 90.48 RCW) requirements. In retrofit situations there frequently are site constraints that make the strict application of these BMPs difficult. In these instances, the BMPs presented here can be modified using best professional judgment to provide reasonable improvements in stormwater management.

1.1.3 Presumptive versus Demonstrative Approaches to Protecting Water Quality

Wherever a discharge permit or other water-quality-based project approval is required, project proponents may be required to document the technical basis for the design criteria used to design their stormwater management BMPs. This includes: how stormwater BMPs were selected; the pollutant removal performance expected from the selected BMPs; the scientific basis, technical studies, and(or) modeling which supports the performance claims for the selected BMPs; and an assessment of how the selected BMP will comply with State water quality standards and satisfy State AKART requirements and Federal technology-based treatment requirements.

The Manual is intended to provide project proponents, regulatory agencies and others with technically sound stormwater management practices which are *presumed* to protect water quality and instream habitat – and meet the stated environmental objectives of the regulations described in this chapter. Project proponents always have the option of not following the stormwater management practices in this Manual. However, if a project proponent chooses not to follow the practices in the Manual then the project proponent may be required to individually *demonstrate* that the project will not adversely impact water quality by collecting and providing appropriate supporting data to show that the alternative approach is protective of water quality and satisfies State and federal water quality laws.

Figure 1.1 graphically depicts the relation between the *presumptive approach* (the use of this Manual) and the *demonstrative approach* for achieving the environmental objectives of the standards. Both the presumptive and demonstrative approaches are based on best available

Figure 1.1 – Relation between environmental science and standards in stormwater regulations. Both the presumptive and demonstrative approaches are based on using best available science to protect water quality. See the glossary for definitions.

STANDARDS

Water Pollution Control Act

(Chapter 90.48 RCW)

Discharges to state waters shall not cause pollution, which is defined as an alteration of the physical, chemical or biological properties of State waters which would impair beneficial uses. Requires the use of AKART and BMPs approved by Ecology.

Federal Clean Water Act

Restore and maintain the chemical, physical, and biological integrity of the Nation's waters.

- State water quality standards (water-quality based treatment requirements)
- Federal technology-based treatment requirements
- NPDES permits
- 303(d) impaired water body list and water clean-up plans

Others

Endangered Species Act

- Properly functioning conditions

Hydraulics Code (HPA)
Safe Drinking Water Act (UIC)

Presumptive Approach

The Stormwater Management Manual for Eastern Washington provides a default set of stormwater practices based on current science which satisfy State and Federal stormwater requirements.

Considerations:

- More predictable, practices are approved across jurisdictions
- Costly studies, etc. are not required as they may be under the demonstration approach

Demonstrative Approach

Project sponsor and approval agency individually review and condition proposed projects to meet federal and state stormwater standards based on current science.

Considerations:

- Lacks predictability and can be very time consuming
- For large, complex projects may reduce costs and/or improve environmental protection

Hydrology

- When native vegetation is removed and replaced with impervious surfaces (roads or buildings) there is an increase in stormwater runoff and a decrease in summer base flows.
- Increased flows lead to increased flooding and stream bank and stream bed erosion.
- Unless mitigated, adverse high flow impacts occur at even low levels of urban development: 4% to 10% total impervious area.
- Transportation infrastructure (including parking areas) represents between 50% and 75% of the impervious surface area within any single watershed.

Water Quality

- More than a third of the State's urban streams, creeks and embayments are impaired due to stormwater runoff.
- Stormwater runoff from construction activities can contain large amounts of sediments and suspended solids which are harmful to fish and other aquatic life.
- Untreated stormwater from roads and urban areas can adversely impact water quality due to sediments, toxic metals, pesticides, herbicides, oils and greases, and possible human pathogens including fecal coliform bacteria.
- Untreated stormwater runoff from roads and urban areas can be toxic to aquatic life including fish.

SCIENCE

science and result from existing Federal and State laws that require stormwater treatment systems to be properly designed, constructed, maintained and operated to:

1. Prevent pollution of state waters and protect water quality, including compliance with state water quality standards;
2. Satisfy state requirements for all known available and reasonable methods of prevention, control and treatment (AKART) of wastes prior to discharge to waters of the State; and
3. Satisfy the federal technology based treatment requirements under 40 CFR part 125.3.

Under the demonstration approach, the timeline and expectations for providing technical justification of stormwater management practices will depend on the complexity of the individual project and the nature of the receiving environment. In each case, the project proponent may be asked to document to the satisfaction of the permitting agency or other approval authority that the practices they have selected will result in compliance with the water quality protection requirements of the permit or other local, State, or Federal water-quality-based project approval condition. This approach may be more cost effective for large, complex or unusual types of projects.

Project proponents that choose to follow the stormwater management practices contained in approved stormwater technical manuals are presumed to have satisfied this demonstration requirement and do not need provide technical justification to support the selection of BMPs for the project. Following the stormwater management practices in this Manual means adhering to the guidance provided for proper selection, design, construction, implementation, operation and maintenance of BMPs. Approved stormwater technical manuals include this Manual and other equivalent stormwater management guidance documents approved by Ecology. This approach will generally be more cost effective for typical development and redevelopment projects.

1.1.4 Comparison of the Stormwater Management Manuals for Eastern and Western Washington

Both the *Stormwater Management Manual for Eastern Washington* (SWMMEW) and the *Stormwater Management Manual for Western Washington* (SWMMWW) are based on the same standard: protecting water quality. The Manuals are organized differently, with the SWMMEW comprised of eight chapters and the SWMMWW comprised of five volumes. The eight Core Elements of the SWMMEW include the same goals as the ten Minimum Requirements of the SWMMWW, but again the organization is different. Differences in climate, hydrology, and the current understanding of rainfall-runoff relationships on the two sides of the State led to different approaches in the two Manuals for designing and sizing treatment facilities. Special considerations for the arid climate and for freezing weather are included in the SWMMEW but not in the SWMMWW. As we gain better understanding of the natural systems on both sides of the State and as approaches to managing stormwater continue to improve, both Manuals will be updated.

1.2 Effects of Urbanization

Managing stormwater may not seem necessary in arid and semi-arid regions where rainfall is generally a welcome event. However, the quality and habitat function of receiving waters in arid and semi-arid climates are affected by pollutants carried by stormwater runoff and by the changes in the patterns of runoff from the land following development. Hydrologic and water quality changes caused by urbanization can result in irreversible changes to the biological systems that were supported by the natural hydrologic system.

1.2.1 Water Quality Changes

Although few data are available specifically from eastern Washington, studies across the Nation have found that urbanization causes increases in the types and quantities of pollutants in receiving waters. Regardless of the climatic setting, runoff from urban areas has been shown to contain many different types of pollutants, depending on the nature of the activities in those areas.

- The runoff from roads and highways is contaminated with pollutants from vehicles, and typical pollutants in road runoff include: oil and grease, polynuclear aromatic hydrocarbons (PAHs), lead, zinc, copper, cadmium, sediments (soil particles) and road salts and other anti-icers.
- Runoff from industrial areas typically contains even more types of heavy metals, sediments, and a broad range of man-made organic pollutants, including phthalates, PAHs and other petroleum hydrocarbons.
- Runoff from commercial areas contains concentrated road-based pollutant runoff and may also contain other pollutants typical of industrial and/or residential areas.
- Residential areas contribute the same road-based pollutants to runoff, as well as herbicides; pesticides; nutrients (from fertilizers and animal wastes); bacteria, viruses and other pathogens (from animal wastes).

The pollutants in urban runoff can be dissolved in the water column or can be attached to solid particles that settle in streambeds, lakes, or wetlands. All of these contaminants can impair the beneficial uses of the receiving waters (both ground and surface waters). Metals are of particular concern for discharges to surface waters due to the sensitivity of aquatic life to fairly low concentrations, especially copper and zinc. Pesticides and PAHs are of particular importance to discharges to groundwater.

Table 1.1 shows typical concentrations of a limited number of pollutants found in urban stormwater runoff. The pollutant concentrations in stormwater runoff from arid watersheds tend to be higher than that of humid watersheds, since rain events are infrequent and pollutants have more time to accumulate on impervious surfaces. Pervious areas in arid and semi-arid regions also tend to produce higher sediment and organic carbon concentrations because the sparse vegetative cover does little to prevent soil erosion in uplands and along channels when it does rain.

Table 1.1 – Mean concentrations of selected pollutants in urban stormwater runoff across the United States and in arid and semi-arid regions.

Source: several studies summarized in Watershed Protection Techniques, Vol. 3 No. 3, March 2000.

Location	Total Suspended Solids (mg/L)	Total Copper (ug/L)	Total Zinc (ug/L)	Total Lead (ug/L)	Total Phosphorus (ug/L)
National Average	78	14	162	68	320
Phoenix, AZ	227	47	204	72	410
Boise, ID	116	34	342	46	750
Denver, CO	384	60	350	250	800
San Jose, CA	258	58	500	105	830
Dallas, TX	663	40	540	330	780

Table 1.2 shows typical concentrations of a limited number of pollutants from stormwater runoff generated by different land uses.

Table 1.2 – Mean concentrations of selected pollutants in stormwater runoff from different land uses in the State of Oregon.

Note: In-pipe industry means the samples were taken in stormwater pipes. Instream industry means the samples were taken in streams flowing through industrial areas. Samples for all other categories were taken from within stormwater pipes.

Source: Strecker et al*, 1997.*

Land Use	Total Suspended Solids (mg/L)	Total Copper (ug/L)	Dissolved Copper (ug/L)	Total Zinc (ug/L)	Total Phospho-rus (ug/L)
In-pipe industry	194	53	9	629	633
Instream industry	102	24	7	274	509
Transportation	169	35	8	236	376
Commercial	92	32	9	168	391
Residential	64	14	6	108	365
Open	58	4	4	25	166

Table 1.3 shows typical concentrations of a limited number of pollutants in highway runoff. These pollutants were detected in 46% to 100% of the samples collected for 102 sites with AADT =<30,000 and 93.5% to 100% of the samples collected for 231 sites with AADT >30,000. In this study,

concentrations of cadmium copper, lead, and zinc frequently exceed State surface water quality standards for the protection of aquatic life regardless of whether the annual average daily traffic count on the road was more or less than 30,000; and concentrations of arsenic, chromium, lead, and coliform bacteria frequently exceed State groundwater quality standards.

Table 1.3 – Mean concentrations of selected pollutants in highway stormwater runoff in the State of California.

Source: California Department of Transportation, 2002.

Annual Average Daily Traffic (AADT)	Total Suspended Solids (mg/L)	Dissolved & Total Cadmium (ug/L)	Dissolved & Total Copper (ug/L)	Dissolved & Total Lead (ug/L)	Dissolved & Total Zinc (ug/L)
Less than or equal to 30,000	160	0.13	6.9	1.3	33
		0.32	16	12	90
Greater than 30,000	160	0.30	16	7.6	93
		0.89	39	64	260

The Washington State Department of Transportation submitted data in to Ecology in its fourth year NPDES Program Summary (Molash, 1999) for two State highways: SR 18 in Thurston County, with an average daily traffic (ADT) count of 18,000; and SR5 in Clark County, with an ADT of 101,000. For copper, the acute water quality standard was exceeded in 40% of the samples collected on each highway, with the concentrations in those samples ranging from 1.1 times the standard to 8.5 times the standard. For zinc, the acute water quality standard was exceeded in 60% of the samples collected on SR5 and in 70% of the samples collected on SR8, with the concentrations in those samples ranging from 1.3 times the standard to 14 times the standard.

While instream dilution of the higher concentrations from any single project might prevent impairment of the beneficial uses of a water, capacity does not exist in most urban streams to dilute the discharges from all of the sources in the watershed, and the cumulative effect of all of the discharges in the watershed is much more likely to impair the beneficial uses of the receiving water.

Urbanization may also cause changes in water temperature. Stormwater heated from impervious surfaces and exposed treatment and detention ponds may be discharged to streams with less riparian vegetation for shade. Urbanization also reduces recharge of groundwater, a source of cool water contributions to stream flows.

Regardless of the eventual land use conversion, the sediment load produced by a construction site can increase turbidity in the receiving water. Fine sediments can be deposited over the natural sediments of the receiving water and degrade fish spawning areas and instream habitat for other aquatic life.

This Manual provides guidance on runoff treatment practices for reducing the impacts of pollutant-laden stormwater from individual sites through Source Control, Construction Stormwater Pollution Prevention, and Water Quality Treatment Best Management Practices (BMPs). Section 1.4.2 provides the background of developing Source Control BMPs; Core Element #3 in Chapter 2.2.3 defines the requirements for applying these BMPs. Section 1.4.3 provides the background of developing runoff treatment BMPs; Core Element #5 in Chapter 2.2.5 defines the requirements for applying these BMPs. Core Element #2 in Chapter 2.2.2 and all of Chapter 7 are devoted to Construction Stormwater Pollution Prevention.

1.2.2 Hydrologic Changes

Just as the landscape of eastern Washington includes prairies, pine forests, the shrub-steppe, channeled scablands, and vast areas of irrigated and dry land agriculture, the hydrology of streams in eastern Washington varies tremendously. Average annual precipitation varies from 6 to more than 60 inches. Streambed material varies from basalt rock to highly erodible loess soils. Many streams flow only during the relatively wet winter and spring seasons or only during a runoff-producing rainstorm or snowmelt event. The hydrology of other streams has been altered by seasonal irrigation practices.

Regardless of the hydrologic and geologic setting, streams can be impacted by urbanization of their watersheds. As development occurs, land is cleared and impervious surfaces such as roads, parking lots, rooftops, and sidewalks are added. Roads are cut through slopes and low spots are filled. The natural soil structure is lost due to grading and compaction during construction. Drainage patterns are irrevocably altered. Maintained landscapes that have much higher runoff characteristics often replace the natural vegetation. The accumulation of these changes may affect the natural hydrology by:

- Increasing the peak volumetric flow rates of runoff;
- Increasing the total volume of runoff;
- Decreasing the time it takes for runoff to reach a natural receiving water;
- Increasing stream velocities;
- Reducing groundwater recharge;
- Increasing the frequency and duration of high stream flows;
- Increasing inundation of wetlands during and after wet weather; and
- Reducing stream flows and wetland water levels during the dry season.

Figure 1.2 illustrates some of these hydrologic changes. As a consequence of these changes in hydrology, stream channels may experience both increased flooding and reduced base flows; natural riffles, pools, gravel bars, and other areas may be altered or destroyed. Increased channel erosion, loss of hydraulic complexity, degradation of habitat, and changes in the composition of species present in receiving waters may follow.

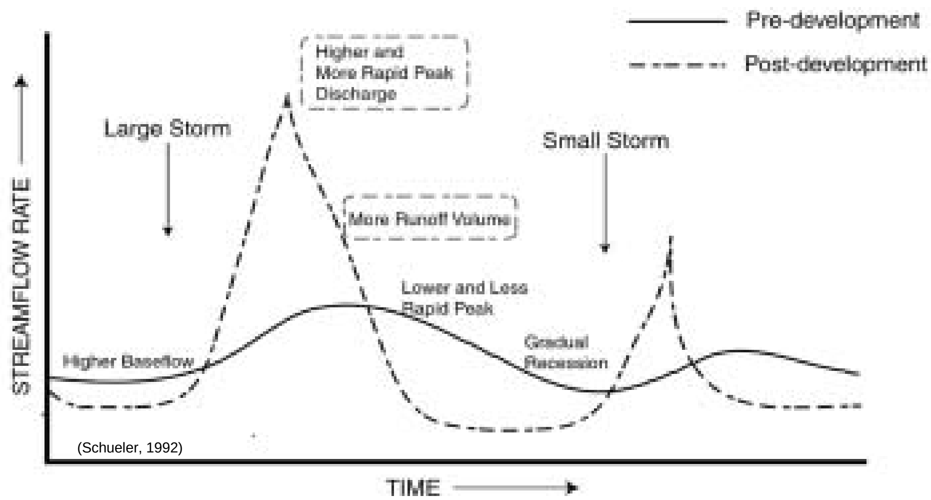

Figure 1.2 – Changes in hydrology following development

These changes do not result from any one project; they are the cumulative effect of all of the development in a watershed.

From a stream morphology standpoint, smaller flood events that approximate bankfull conditions and occur naturally once or twice a year (1.5 to 2-year frequency) are the most influential discharges and most easily changed with added urban runoff. It is these smaller flood events that shape the channel and are referred to as “effective flows” because over time they move the most sediment and transform the dimensions of a stream channel. When effective flows increase in size, duration and frequency the most common impact is changes in channel morphology to accommodate the rise in erosive energy delivered to receiving streams on an annual basis.

Although specific data and studies for eastern Washington are not currently available, research in streams in arid, semi-arid and humid climatic settings has shown that this accommodation commonly takes place by widening and down cutting of the streambed, damaging habitats and potentially reducing biologic diversity. Research has shown that as developed impervious areas reach 5% of land cover within a watershed the connection between runoff from impervious areas and channel response through erosion begins to occur.

Erosion problems from an aquatic ecosystem perspective are much more subtle than from an engineering perspective: streambank undercutting and failures occur long after changes to the habitat function of the streambed. Stream channel erosion control can be accomplished by constructing

BMPs that detain runoff flows and also by physical stabilization of eroding stream banks. Both types of measures may be necessary in urban streams, but only the former is covered in this Manual.

When comparing the pre-developed (or existing) hydrograph with the developed condition hydrograph, the concern is not limited to the peak flow events; mitigating the duration of the flood flows is also important for stream channel stability and habitat. Detention basins that match peak runoff directly contribute more water to a stream over a longer period of time and extend the length of time the peak discharge rate is moving sediments in the streambed. The cumulative impacts of many detention basins operating in a watershed and merging downstream further compound flooding and erosion problems.

Because these changes are the cumulative result of development in a watershed, most new development in most watersheds must control flows. The intent of flow control is to prevent increases in the stream channel erosion rates that are characteristic of natural conditions by releasing post-developed runoff in a manner that delivers approximately the same amount of erosive energy to the stream as it received under pre-developed conditions.

Flow control in this Manual is targeted to smaller water bodies, especially first to third order streams or water bodies with contributing watershed areas of less than 100 square miles. These streams are most susceptible to changes in runoff patterns caused by development. In larger water bodies, the location of the development activity plays a greater role: in general, development that occurs nearer to a large stream channel and that does not encroach on the natural flood plain has less of an effect than development activities in the upper watershed – which are instead likely to impact smaller tributary stream channels.

This Manual provides guidance on stormwater management practices for controlling excess runoff volume from individual sites through Flow Control Best Management Practices (BMPs). Section 1.4.4 provides the background of developing these BMPs; Core Element #6 in Chapter 2.2.6 defines the requirements for applying these BMPs.

1.3 Relationship of this Manual to Federal, State and Local Regulatory Requirements

This Manual is one tool in the efforts to manage and reduce the impacts of urban stormwater discharges. At the date of publication of this Manual, the following regulatory programs and permits exist that may directly or indirectly require a project proponent to properly manage stormwater.

1.3.1 NPDES and State Waste Discharge Stormwater Permits for Municipalities

In Washington State, the Cities of Seattle and Tacoma; King, Pierce, Snohomish, and Clark Counties; and the Washington State Department of Transportation facilities within those jurisdictions have been subject to U.S. Environmental Protection Agency (EPA) National Pollutant Discharge Elimination System (NPDES) Phase I Stormwater Regulations (40 CFR Part 122). EPA adopted NPDES Phase II stormwater regulations in December 1999. Those rules identify additional municipalities that are subject to NPDES municipal stormwater permitting requirements. In eastern Washington there are no Phase I communities; Ecology has determined that fifteen cities and eight counties in the five census-defined urbanized areas of eastern Washington are subject to the requirements. The census-defined urbanized areas in eastern Washington are: Clarkston, Spokane, Tri-Cities, Wenatchee and Yakima. Another five (Ellensburg, Moses Lake, Pullman, Sunnyside and Walla Walla) or more additional municipalities may be subject to the requirements, depending upon an analysis that Ecology must perform. Federal regulations require that Phase II permits be issued by December 2002 and that designated Phase II communities submit an application for permit coverage by March 2003.

The federal regulations specify minimum measures for municipal stormwater programs for compliance with the Phase II rules. One of those measures is the adoption of a program for "post-construction stormwater management in new development and redevelopment." Another is a program for "construction site stormwater runoff control." This Manual provides technical guidance for projects to comply with municipal stormwater requirements in these two areas. For additional information on the Phase II Municipal permit and the minimum control measures, see Ecology's website and the publication: *Model Municipal Stormwater Program for Eastern Washington*.

Note to reviewers: *The Subcommittee's work on the Model Program is completed. Printed copies of the Model Program will be available in late July or early August 2003. The document should be available for downloading from Ecology's website by mid July.*

Local jurisdictions covered under the Phase II Municipal Stormwater NPDES Permit must apply the Manual or an approved equivalent to their own capital improvement and other public works projects. And all local jurisdictions should work to identify and prioritize stormwater management actions that will effectively protect local water quality.

In Washington State under RCW 90.48, all permits for discharges of pollutants apply to discharges to groundwater as well as discharges to surface water. Jurisdictions applying for coverage under the Phase II Municipal Stormwater NPDES Permit will receive a combined NPDES State Waste Discharge Permit.

1.3.2 Industrial Stormwater General Permit
(NPDES and State Waste Discharge Baseline General Permit for Stormwater Discharges Associated With Industrial Activities)

Businesses subject to the Industrial Stormwater General Permit have to prepare and implement a Stormwater Pollution Prevention Plan in accordance with the terms of that permit. The general permit, which was reissued August 2002, requires a description and implementation of operational source control BMPs and structural source control BMPs as applicable to their industrial activity. Additionally, application of erosion and sediment control BMPs, flow control BMPs and treatment BMPs is required if necessary to address an erosion, flow, or pollution problem.

This Manual can be used to select and design stormwater BMPs for industrial sites eastern Washington.

1.3.3 Construction Stormwater General Permit
(NPDES and State Waste Discharge General Permit for Stormwater Discharges Associated With Construction Activity)

Operators of construction activities are required to seek coverage under the Construction Stormwater General Permit if the activity results in the disturbance of five acres or greater (including clearing, grading and excavation activities) and also has a discharge of stormwater to a surface water and/or to a storm drain used to convey water to a stream, lake, or wetland.

Beginning March 10, 2003, the U.S. Environmental Protection Agency’s Phase II Rule (Federal Register, Vol.64, No. 235, pages 68722-68852) requires operators of “Small Construction” activities disturbing greater than one acre of land to obtain an NPDES permit before discharging stormwater to a surface water or storm drain.

The Construction Stormwater General Permit requires the development and implementation of a Stormwater Pollution Prevention Plan (SWPPP). The SWPPP must detail the various Best Management Practices (BMPs) that will be used during construction to prevent erosion and sedimentation that could impact downstream water quality. This Manual may be used by project proponents and others in the development of the SWPPP and in the selection, design and application of erosion and sediment runoff control BMPs.

1.3.4 Underground Injection Control Authorizations

One of the provisions of the Federal Safe Drinking Water Act is to protect Underground Sources of Drinking Water (USDW). The Underground Injection Control (UIC) Program was established to protect USDW by regulating the discharges of fluids into the subsurface by underground injection wells. In 1984 Ecology adopted Chapter 173-218 WAC to implement the program.

Subsurface infiltration systems, such as drywells, are classified as Class V injection wells in the EPA's Federal UIC program. The two requirements of the UIC program are:

- A non-endangerment performance standard must be met, prohibiting discharges that allow movement of fluids containing contaminants into potential underground sources of drinking water, and
- All UIC facility owners/operators must provide inventory information by registering the facilities.

Under the Federal UIC regulations, the definition of an underground injection well is a bored, drilled, or driven shaft whose depth is greater than the largest surface dimension; or a dug hole whose depth is greater than the largest surface dimension; or an improved sinkhole; or a subsurface fluid distribution system which includes an assemblage of perforated pipes, drain tiles, or other similar mechanisms intended to distribute fluids below the surface of the ground. Examples of a UIC well or a subsurface infiltration system are drywells, drain fields, pipe or french drains and other similar devices that discharge to ground.

Note to reviewers: *Ecology is proposing to revise the existing UIC rule (Chapter 173-218 WAC). The proposed changes to the rule include rule authorization for properly managed stormwater from defined sources to be discharged to subsurface infiltration systems. Proper management would be based on following applicable best management practices as described in Ecology's current regional stormwater manuals or an approved equivalent manual. This Manual will be the applicable manual for eastern Washington. For more information about the rule revision contact Mary Shaleen-Hansen at maha461@ecy.wa.gov or (360) 407-6143. Information on the UIC Rule can also be accessed through Ecology's website at* http://www.ecy.wa.gov/programs/wq/grndwtr/uic

1.3.5 Endangered Species Act

Project proponents planning to discharge stormwater into bodies of water that provide habitat for threatened or endangered species are expected to properly manage their stormwater. This Manual may be used by project proponents to satisfy federal Endangered Species Act requirements as identified by the federal service agencies.

1.3.6 Section 401 Water Quality Certifications

For projects that require a fill or dredge permit under Section 404 of the Clean Water Act, Ecology must certify to the U.S. Army Corps of Engineers that the proposed project will not violate water quality standards, including state sediment standards. In order to make such a determination, Ecology may do a more specific review of the potential impacts of a stormwater discharge from the construction phase of the project and from the completed project. As a result of that review, Ecology may condition its certification to require:

- Application of the Core Elements and BMPs in this Manual; or
- Application of alternative requirements determined to be necessary to comply with State water quality standards.

1.3.7 Hydraulic Project Approvals (HPAs)

Under Chapter 77.55 RCW, the Hydraulics Act, the Washington State Department of Fish and Wildlife has the authority to require actions when stormwater discharges related to a project would change the natural flow or bed of State waters. The implementing mechanism is the issuance of a Hydraulics Project Approval (HPA) permit. In exercising this authority, Fish and Wildlife may require:

- Compliance with the provisions of this Manual; or
- Application of alternative requirements that are determined to be necessary to meet their statutory obligations to protect fish and wildlife.

1.3.8 Aquatic Lands Use Authorizations

As the steward of public aquatic lands, the Department of Natural Resources (DNR) may require a stormwater outfall to have a valid use authorization and to avoid or mitigate impacts to natural resources. Through its use authorizations, which are issued under authority of Chapter 79.90 through 96, and in accordance with Chapter 332-30 WAC, DNR may require:

- Compliance with the provisions of this Manual; or
- Application of alternative requirements that are determined to be necessary to meet their statutory obligations to protect the quality of the State's aquatic lands.

1.3.9 Requirements Identified through Watershed/Basin Planning or Total Maximum Daily Loads

A number of the requirements of this Manual can be superseded by the adoption of ordinances and rules to implement the recommendations of watershed plans or basin plans. Local governments may initiate their own watershed or basin planning processes to identify more stringent or alternative requirements. They may choose to develop a watershed plan in accordance with the Watershed Management Act (Chapter 90.82 RCW) that includes water quality and habitat elements. They may also choose to develop a basin plan in accordance with Chapter 400-12 WAC. As long as the actions or requirements identified in those plans and implemented through local or State ordinances or rules comply with applicable state and Federal regulations (e.g., the Clean Water Act), they can supersede the requirements in this Manual. The determination of whether such local requirements comply with Federal and State statutes must be made by the regulatory agency or agencies responsible for implementing those regulations.

Any requirement of this Manual may also be superseded or added to through the adoption of actions and requirements identified in a Total Maximum Daily Load (TMDL) that is approved by the EPA. However, it is likely that many TMDLs will require use of the BMPs in this Manual.

According to the federal Phase II rules, Ecology may include requirements in Municipal Stormwater NPDES permits including programmatic activities and other actions identified in completed TMDLs if those actions are deemed necessary to achieve the waste load allocation and restore water quality. In accordance with EPA's November 2002 policy *Establishing Total Maximum Daily Load (TMDL) Wasteload Allocations (WLAs) for Storm Water Sources and NPDES Permit Requirements Based on Those WLAs* the waste load allocation itself will not become a permit requirement. The full text of EPA's policy can be viewed at http://www.epa.gov/npdes/pubs/final-wwtmdl.pdf

1.3.10 Other Local Government Requirements

Local governments have the option of applying more stringent requirements than those in this Manual. They are not required to base those more stringent requirements on a watershed/basin plan or their obligations under a TMDL. Project proponents should always check with the local governmental agency with jurisdiction to determine the stormwater requirements that apply to their project.

1.3.11 Local Government Role in Implementing State/Federal Permit Requirements and Programs

Due to their knowledge and understanding of local water bodies, relationships with local businesses, and proximity to project sites, local governments can play an important role in implementing and enforcing permits and programs such as Construction and Industrial Stormwater Permits and the Underground Injection Control program. Ecology is ultimately responsible for implementation of these and other permits and programs in Washington State, but recognizes that these programs can have only limited success without the support and assistance of local jurisdictions.

Specific suggested “Responsibilities of Local Jurisdictions” are highlighted in Chapter 2.1.2 “Redevelopment” and in each Core Element in Chapter 2.2 of this Manual. These sections are provided as guidance for jurisdictions that are planning programmatic activities to manage stormwater to protect local water quality. A few of these potential roles may be further defined through the UIC rule revision and the Phase II municipal stormwater permitting process for those jurisdictions. But in most cases Ecology simply hopes to develop and maintain a cooperative working relationship with the local jurisdiction and focus limited resources on sites with the greatest potential to impact water quality.

1.4 Best Management Practices for Stormwater Management

1.4.1 Best Management Practices (BMPs)

The method by which the Manual mitigates the adverse impacts of development and redevelopment is through the application of Best Management Practices (BMPs). The BMPs included in this Manual have been approved by Ecology; as new technologies are evaluated and approved, additional BMPs will be published as updates to this Manual.

BMPs are defined as schedules of activities, prohibitions of practices, structural facilities, maintenance procedures, and/or managerial practices that when used singly or in combination prevent or reduce the release of pollutants and other adverse impacts to waters of Washington State. The basic types of BMPs are source control, water quality treatment, and flow control. BMPs that involve construction of engineered structures are often referred to as facilities in this Manual.

The primary purpose of using BMPs is to protect the beneficial uses of water resources (1) through prevention of contamination, (2) through the reduction of pollutant concentrations and loads, and/or (3) through management of discharge flow rates to prevent increased stream channel erosion. If it is found that beneficial uses are still threatened or impaired following the implementation of BMPs advocated in this Manual, then additional controls may be required.

1.4.2 Source Control BMPs

Source Control BMPs prevent pollution or other adverse effects of stormwater from occurring. Most of these BMPs are common-sense “good housekeeping” measures and are targeted for various pollutant-generating activities and sources. Source Control BMPs may be either operational or structural; examples include methods as varied as sweeping, using mulches and covers on disturbed soil, putting roofs over outside storage areas, and constructing berms around potential pollutant source areas to prevent both stormwater run-on and pollutant runoff. Core Element #3 “Source Control” in Chapter 2 defines the requirements for applying these BMPs; and Chapter 8 describes the procedures for implementing these BMPs.

It is generally more cost effective to use source controls to prevent pollutants from entering runoff than to treat runoff to remove pollutants. However, since source controls cannot prevent all impacts some combination of measures will usually be needed. Project proponent should try to design and place structures at the site so that stormwater does not come into contact with pollutants, reducing the requirement for treatment.

1.4.3 Water Quality Treatment BMPs

Water Quality Treatment BMPs include facilities that remove pollutants from stormwater by filtration, biological uptake, adsorption, and/or gravity settling of particulate pollutants. The need for a project to provide runoff treatment facilities depends on (1) the type and amount of pollutants expected to be generated by the completed project and (2) the vulnerability of the receiving waters to the pollutants of concern. A combination of BMPs may be required to protect the receiving waters.

Water Quality Treatment BMPs can accomplish significant levels of pollutant load reductions if properly selected, designed, operated and maintained. Some Water Quality Treatment BMPs are targeted for removal of a specific type of pollutant; others are effective at removing several classes of pollutants. Some BMPs may be appropriate only for certain climates or under other conditions.

It is not generally practical to treat 100% of the annual stormwater runoff volume generated by a project site. Some of the design specifications for Water Quality Treatment BMPs in this Manual are established such that the BMPs are presumed to treat at least 90% of the total average annual runoff volume; this amount is considered to be a reasonable goal for capturing as many contaminants as practicable. Other BMP design specifications are based on treating the “first flush” of each storm event: stormwater produced by first rainstorm following a dry period during which pollutants have accumulated on impervious surfaces is commonly believed to carry a majority of the pollutants in urban runoff.

For groundwater, the potential of filtration through the vadose zone to remove the solid phase portion of the total concentration may result in concentrations meeting State groundwater quality standards (WAC 173-200). However, relying on the vadose zone to remove pollutants may result in contaminated soil, especially for sites with more than moderate to high pollutant loadings. See Chapter 5.6 for the background and rationale for allowing use of the vadose zone to provide treatment in certain cases.

Core Element #5 “Runoff Treatment” in Chapter 2 defines the requirements for applying these BMPs; and Chapters 4 and 5 describe the design criteria and procedures for implementing these BMPs.

1.4.4 Flow Control BMPs

Flow Control BMPs may control the rate, frequency, and/or flow duration of stormwater surface runoff. Excess stormwater runoff volumes are generally managed by use of infiltration, evaporation, or detention facilities. On-site infiltration is the preferred means of disposing of stormwater runoff but is feasible only where more porous soils are available and the water table is not too near to the land surface. With the lower amounts of runoff in the arid and semi-arid climate of eastern Washington, infiltration is feasible in many areas of new development.

For projects with discharges to surface waters, detention ponds are designed and operated to meet established flow control requirements. The concept of detention is to collect runoff from a developed area and release it at a slower rate than it enters the collection system. The reduced release rate requires temporary storage of the excess amounts in a pond with release occurring over a few hours or days. The volume of storage needed is dependent on (1) the size of the drainage area; (2) the extent of disturbance of the natural vegetation, topography, and soils and creation of effective impervious surfaces – surfaces that drain to a stormwater collection system; and (3) how rapidly the water is allowed to leave the detention pond, i.e., the target release rates.

Historic flow control measures have focused on controlling runoff by matching the pre- and post-development peak flow rates for the certain recurrence intervals. This level of control does not adequately address the increased duration at which those high flows occur because the volume of water from the post-developed condition is increased as compared to the pre-developed condition. The approach of only matching the peak flow rates fails to protect stream habitats from increased erosional energy.

To protect stream channels from increased erosion, it is necessary to control the durations over which a stream channel experiences geomorphically significant flows such that the energy imparted to the stream channel does not increase significantly. Discharges to lakes are controlled primarily to protect the outlet stream. Geomorphically significant flows are those that are capable of moving sediments; for most streams, these flows are within the 1.5- to 2-year range of recurrence intervals. If the pre-development 2-year peak runoff rate is met for the entire 2-year post-development runoff volume, the stream experiences that flow rate for the longer period necessary to release the increased volume of runoff in the post-developed condition. In the absence of a continuous runoff model a full duration standard cannot be achieved. A partial duration standard can be implemented by releasing the post-developed 2-year runoff volume at half of the pre-developed 2-year peak flow rate, thus reducing the total erosional energy to somewhat nearer to that of the pre-developed condition. This target will translate into lower release rates and larger detention ponds. The size of the facility can be reduced by reducing the extent to which a site is disturbed.

For discharges to wetlands, the objective of flow control is to not alter the natural hydroperiod. This means that flows from a development should be controlled such that the wetland is within certain elevations at different times of the year and that short-term elevation changes are within prescribed limits. If the amount of surface water runoff draining to a wetland is increased because of land conversion from forested to impervious areas, it may be necessary to bypass some water around the wetland in the wet season. (Bypassed stormwater must still meet flow control and treatment requirements applicable to the receiving water.) If however, the wetland was fed by local ground water elevations during the dry season, the impervious surface additions and the bypassing practice may cause variations from the dry season elevations. Accurate estimates of what should be done to maintain the natural hydroperiod require data collection prior to the development activity and the use of a continuous runoff model.

Core Element #6 "Flow Control" in Chapter 2 defines the requirements for applying these BMPs; and Chapters 4 and 6 describe the design criteria and procedures for implementing these BMPs.

1.4.5 New and Emerging BMPs

Ecology encourages the development and implementation of new approaches to managing and treating stormwater. This Manual is intended to be a living document, and project proponents should check Ecology's website for additional BMPs that have been approved since the publication of this Manual. More information is provided in Chapter 5.12 about the new Statewide protocol for testing new and emerging stormwater management technologies.

1.5 How to Apply this Manual

The users of this Manual will be engineers, planners, private industry, environmental scientists, plan reviewers and inspectors at the local, State, and Federal government levels. Ecology may approve other stormwater management manuals developed by local jurisdictions, the Washington State Department of Transportation or other entities as being equivalent to this Manual. Local government officials may adopt and apply the requirements of this Manual directly or adopt and apply the requirements of an equivalent manual (see Section 1.5.2, Alternative Technical Manuals below). Local government staff may use this Manual or an equivalent manual as a reference for reviewing stormwater site plans; checking source control, runoff treatment and flow control facility designs; and for providing technical advice in general. Private industry may use the Manual for information on how to develop and implement stormwater site plans and as a reference for technical specifications of Best Management Practices (BMPs).

The Manual itself has no independent regulatory authority. The Core Elements and technical guidance in the Manual only become required through:

- Ordinances and rules established by local governments; and
- Permits and other authorizations issued by local, State, and federal authorities.

Local jurisdictions may adopt and apply the Core Elements, thresholds, definitions, BMP selection processes, and BMP design criteria of this Manual or an equivalent manual. Staff at local governments and agencies with permitting jurisdiction may use this Manual in reviewing Stormwater Site Plans, checking BMP designs, and providing technical advice to project proponents.

Federal, State, and local permits may refer to this Manual or the BMPs contained in this Manual. In those cases, affected permit-holders or applicants should use this Manual for specific guidance on how to comply with permit conditions.

<u>Project proponents should start by reading Chapter 2 of this Manual</u>. Chapter 2 explains the requirements of the Core Elements and defines how the Core Elements should be applied to individual projects and to particular levels of development.

For several of the Core Elements, thresholds are identified. These are the levels or conditions (*e.g.* project size or proposed land use) at or for which an action becomes required for that project. The thresholds presented in Chapter 2 are *technical thresholds*. However, *regulatory thresholds* may be established in ordinances, rules, permits or other authorizations; these thresholds are not included in this Manual but may modify certain thresholds that need to be met for a given project to comply with one or more Core Elements.

1.5.1 Stormwater Technical Manual

This Manual serves as a single technical stormwater manual for eastern Washington. It provides uniform stormwater management standards and is a central repository for BMPs. Ecology will maintain the region's technical stormwater manual for new development and redevelopment and will update, revise and republish this Manual as appropriate.

1.5.2 Alternative Technical Manuals

Cities, counties, and other agencies may choose to develop alternative technical manuals. Those agencies and jurisdictions subject to State and federal regulatory programs that refer to this Manual may be directed to submit their manuals to Ecology. The submittal must include an outline of significant differences between the manuals and demonstrate how the alternative manual is substantively equivalent to this Manual. Ecology will work with jurisdictions to ensure that alternative manuals meet the regulatory objectives for which this Manual is being required (*e.g.* protection of water quality). Where Ecology is uncertain that a local jurisdiction or agency requirement provides sufficient protection, it may provisionally approve the requirement. The provisions would require the local jurisdiction or agency to implement an approved monitoring effort to assess the performance of the local requirement. Jurisdictions and agencies choosing to develop alternative manuals may be directed to adopt this Manual in the interim.

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Chapter 2 - Core Elements for New Development and Redevelopment

2.1 Introduction

This chapter identifies and defines the eight Core Elements of stormwater management. These Core Elements are applicable to new development and redevelopment projects in eastern Washington that discharge to surface waters or to UIC rule-authorized subsurface infiltration systems. Not all Core Elements apply to every project, and depending on the type and size of a project, different combinations of the eight Core Elements will apply. See Chapter 1.3 of this Manual for the regulatory framework and conditions under which the Manual may be required for various projects; also see Chapter 1.1.3 for a description of using a demonstrative approach to protecting water quality in lieu of following the Manual. Best Management Practices (BMPs) for implementing the Core Elements are described in Chapters 5 through 8 of this Manual. Specific project exemptions are listed in Section 2.1.3 and 2.1.4 below. See the Glossary for definitions of some of the words and phrases used in this section.

The Core Elements are:

1. **Preparation of a Stormwater Site Plan**
2. **Construction Stormwater Pollution Prevention**
3. **Source Control of Pollution**
4. **Preservation of Natural Drainage Systems**
5. **Runoff Treatment**
6. **Flow Control**
7. **Operation and Maintenance**
8. **Local Requirements**

Each of these Core Elements is described in detail in Section 2.2. Project proponents need to be familiar with the contents of this Chapter in order to determine which Core Elements apply to a given project.

Both **Guidelines** and **Supplemental Guidelines** are provided under the Redevelopment definition and under the Core Elements. The guidelines must be followed in order for a project to comply with the stormwater management provisions set forth in this Manual. Supplemental guidelines are optional and are included for consideration under special circumstances; these guidelines may be required in certain jurisdictions.

The sections on **Responsibilities of Local Jurisdictions** are provided as guidance for jurisdictions that are planning programmatic activities to manage stormwater to protect surface and ground water quality.

2.1.1 New Development

New development is the conversion of previously undeveloped or pervious surfaces to impervious surfaces and managed landscape areas not specifically exempt below in Section 2.1.3 or 2.1.4. See Chapter 1 for the regulatory framework under which a project may be directed to use this Manual or an approved equivalent.

All new development projects must comply with:
Core Element #1 Preparation of a Stormwater Site Plan,
Core Element #2 Construction Stormwater Pollution Prevention,
Core Element #3 Source Control of Pollution,
Core Element #4 Preservation of Natural Drainage Systems, and
Core Element #8 Local Requirements.

When the thresholds for Core Element #5 Runoff Treatment are met (see Section 2.2.5), the following Core Elements also apply:
Core Element #5 Runoff Treatment, and
Core Element #7 Operation and Maintenance.

When the thresholds for Core Element #6 Flow Control are met (see Section 2.2.6), the following Core Elements also apply:
Core Element #6 Flow Control, and
Core Element #7 Operation and Maintenance.

Projects that add new lanes on an existing roadway or otherwise expand the pavement edge are included in the definition of new development because they create new impervious surfaces.

2.1.2 Redevelopment

Redevelopment is defined as the replacement of impervious surfaces on a developed site. Impervious surface replacements defined as exempt maintenance activities in Section 2.1.3 and other projects identified in Section 2.1.4 have reduced requirements. The project proponent must identify what Core Elements apply to all of the new and replaced impervious surfaces created by the project. All new impervious surfaces added during a redevelopment project are subject to the Core Elements identified in 2.1.1 above. The following sections apply to the impervious surfaces replaced by a redevelopment project.

Objective

The long-term goal of the redevelopment standard is to reduce stormwater pollution from existing developed sites, especially when a water quality problem has been identified or the site is being upgraded to a use with a greater potential to contribute pollution to the receiving waters. More stringent redevelopment thresholds and requirements may be identified through a water cleanup plan such as a Total Maximum Daily Load (TMDL) study and allocation or another basin planning process.

To encourage redevelopment projects, replaced surfaces are not required to meet new stormwater standards unless the noted use or area thresholds are met or exceeded for the redevelopment project scope. As long as the replaced surfaces have similar pollution-generating potential, the amount of pollutants discharged should not be significantly different. However, following a rationale consistent with other utility standards, some redevelopment projects are required to meet current stormwater standards. (When a structure or a property undergoes significant remodeling, local jurisdictions may require the site to meet new building code requirements such as onsite sewage disposal systems, wheelchair access provisions and(or) fire systems.) Upgrading stormwater infrastructure is generally more economical when included as part of a redevelopment project than when undertaken as a separate effort.

See Chapter 1 for the regulatory framework under which a redevelopment project may be directed to use this Manual or an approved equivalent.

Impervious surfaces created by development are classified as either non-pollutant-generating (NPGIS) or pollutant-generating (PGIS) as described in detail in Section 2.2.5 Core Element #5 Definitions. NPGIS and PGIS with low pollutant loadings probably comprise the majority of the impervious surfaces in a watershed, and the PGIS with low pollutant loadings may contribute a substantial portion of the cumulative stormwater pollutant load received by a water body. But in the absence of a documented water quality problem, the standard for applying runoff treatment to redevelopment projects in Eastern Washington applies primarily to sites where pollutant concentrations in runoff are expected to exceed water quality standards. Therefore, replaced impervious surfaces with low pollutant loadings are not generally subject to runoff treatment requirements in Eastern Washington; but treatment is required for redeveloped surfaces (PGIS) with medium or high pollutant loadings (see guidelines below).

Guidelines

When the following conditions are met, the identified Core Elements (detailed in Sections 2.2.1 through 2.2.8) apply to replaced impervious surfaces. For projects that are implemented in incremental stages, the redevelopment threshold applies to the total amount of impervious surfaces added or replaced. To maintain their integrity and function, stormwater treatment facilities must be sized for the entire flow that is directed to them.

Where replacement of 5,000 square feet or more of existing PGIS occurs:

- **Core Elements 1, 2, 3, 4, 7, and 8** shall apply to the portion of the site where any impervious surfaces are replaced (includes both PGIS and NPGIS areas).

- **Core Elements 2 and 3** shall be applied to the entire site that is affected by the project activities.
- In addition to the above requirements, **Core Element 5** shall be applied to the replaced PGIS area at the site if any of the following conditions exist. Unless otherwise noted, the project is only required to provide basic runoff treatment to remove solids.
  - The project takes place at an industrial site with outdoor handling, processing, storage or transfer of solid raw materials or finished products.
  - The project takes place at a commercial site with outdoor storage or transfer of solid raw materials or treated wood products.
  - The project is upgrading from a soft shoulder to a curb and gutter roadway with an average daily traffic volume of 7,500 or more vehicles.
  - The project replaces or upgrades the surface of a parking area where the projected number of trip ends exceeds 40 per 1,000 square feet of building area or 100 total trip ends per day. Additional treatment to remove both oil and metals is required if the projected number of trip ends exceeds 100 per 1,000 square feet of building area or 300 total trip ends per day.
  - The project upgrades the surface of an urban road where the projected average daily traffic volume is 7,500 or more vehicles per day. (An *upgrade* is defined as the replacement of paved areas with a better surface or in a way that enhances the traffic capacity of the road.) Additional treatment to remove both oil and metals is required if the average daily traffic volume is greater than 30,000 vehicles per day.
  - The project upgrades the surface of a rural road or freeway where the projected average daily traffic volume is 15,000 or more vehicles per day. Additional treatment to remove both oil and metals is required if the average daily traffic volume is greater than 30,000 vehicles per day. (A *freeway* is defined as a multilane, arterial highway with full access control.) For highways with limited access control without significant impediments to the flow of traffic, this definition may also be applied.
  - The project affects the area within 500 feet of a controlled intersection on a limited access control highway with projected average daily traffic volume of 7,500 or more vehicles per day. Only this area must be treated.
  - A replacement or upgrade as part of a project that enhances the traffic-carrying capacity of an urban road where the projected average daily traffic volume is 7,500 or more vehicles per day or

enhances the traffic-carrying capacity of a rural road, freeway or highway with limited access control where the projected average daily traffic volume is 15,000 or more vehicles per day.

- The project is at a “high-use site” as defined in Section 2.2.5 Core Element #5 Definitions. Additional treatment must be provided to remove oil at high-use sites.
- The site discharges to a receiving water that has a documented water quality problem by an official State listing under any applicable section of the Clean Water Act, under any provision of the Safe Drinking Water Act, or as otherwise determined by the local jurisdiction. This provision is limited to documented water quality problems for metals, oil and grease, coliform bacteria, sediment, suspended solids, phosphorus or any other water quality problem to which stormwater is considered a contributor.
- A need for additional stormwater control measures has been identified through a TMDL or other water cleanup plan or other planning process.

- In addition to the above requirements, **Core Element 6** shall be applied to <u>all of the replaced impervious surfaces at the site</u> (includes both PGIS and NPGIS areas) if required by the State, federal, or local jurisdiction based on flooding studies or habitat assessments.

If the local jurisdiction has an equivalent or more stringent retrofit program in place, then those requirements may replace these conditions. The program must meet the intent of the requirements above and may need to be approved by Ecology. The requirements must be at least as stringent as the thresholds above, meaning that the number and types of projects regulated by the new requirements is the same or greater. Local jurisdictions can select from various bases for identifying projects that must retrofit the replaced impervious surfaces on the project site. Those can include:

- Exceeding 50% of the assessed value of the existing improvements;
- Exceeding 50% of the replacement value of the existing site;
- Exceeding a certain dollar value of improvements;
- Exceeding a certain ratio of the new impervious surfaces to the total of replaced plus new impervious surfaces; or exceeding an established threshold of added or replaced surfaces (e.g. the project adds 10,000 square feet or more of new impervious surfaces or replaces 20,000 square feet of impervious surfaces);
- There is a change in the use of the site to a use with greater potential to contaminate stormwater.

The local jurisdiction may allow the Core Elements to be met for an area with equivalent flow and pollution characteristics within the same site. For public road projects, the equivalent area does not have to be within the project limits, but must drain to the same water body segment and be located upstream from a confluence with another water body downstream from the project site.

A local jurisdiction may provide exemptions or institute a maximum retrofitting cost provision for redevelopment projects from compliance with Core Elements for treatment, flow control, and wetlands protection as applied to the replaced impervious surfaces if the local jurisdiction has adopted a plan and a schedule that fulfills those requirements in regional facilities.

Supplemental Guidelines

Local jurisdictions may institute a stop-loss provision on the application of stormwater requirements to replaced impervious surfaces. A stop-loss provision is an upper limit on the extent to which a requirement is applied. For instance, there could be a maximum percentage of the estimated total project costs that are dedicated to meeting stormwater requirements. A project would not have to incur additional stormwater costs above that maximum though the standard redevelopment requirements will not be fully achieved. Allowances may also be made for sites that would, by imposing the treatment requirement, become non-conforming to other requirements that apply to the site. Every effort should still be made to find creative ways to meet the intent of the Core Elements. The allowance for a stop-loss provision pertains to the extent that treatment, flow control and wetlands protection requirements are imposed on replaced impervious surfaces. It does not apply to meeting stormwater requirements for new impervious surfaces.

Local jurisdictions may also establish criteria for allowing redevelopment projects to pay a fee in lieu of constructing water quality or flow control facilities on a redeveloped site. At a minimum, the fee should be the equivalent of an engineering estimate of the cost of meeting all applicable stormwater requirements for the project. The local jurisdiction should use such funds for the implementation of stormwater control projects that would have similar benefits to the same receiving water as if the project had constructed its required improvements. Expenditure of such funds is subject to other State statutory requirements.

Ecology cautions local jurisdictions about the potential long-term consequences of allowing a fee-in-lieu of stormwater facilities. Sites that are allowed to pay a fee continue without stormwater controls. If it is determined, through future basin planning for instance, that controls on such sites are necessary to achieve water quality goals or legal requirements, the public may bear the costs for providing those controls.

Sites with 100% existing building coverage that are currently connected to a municipally-owned storm sewer or combined sewer must be evaluated on a case-by-case basis to continue to be connected without treatment; additional local requirements such as flow restrictors may also be required.

Responsibilities of Local Jurisdictions

As part of the routine project approval and permitting process, local jurisdictions should review redevelopment project plans for intent and completeness in meeting the redevelopment guidelines. Where space is limited, staff may assist project proponents in modifying BMPs and(or) finding creative ways to meet the intent of the Core Elements. Local jurisdictions should begin planning regional treatment facilities in areas where meeting the on-site treatment objectives for individual redevelopment projects will be challenging.

2.1.3 Exemptions

The following practices are exempted from the Core Elements:

Forest Practices
Forest practices regulated under Title 222 WAC are exempt from the provisions of the Core Elements. Conversions of forest lands to other uses are not exempt.

Commercial Agriculture
Commercial agriculture practices involving working the land for production are generally exempt. However, the construction of impervious surfaces is not exempt.

Road and Parking Area Maintenance
The following road and parking area maintenance practices are exempt (see also Section 2.1.4 Partial Exemptions below):

- Pothole and square cut patching;
- Crack sealing;
- Resurfacing with in-kind material without expanding the road prism;
- Overlaying existing asphalt or concrete pavement with bituminous surface treatment (BST or “chip seal”), asphalt or concrete without expanding the area of coverage;
- Shoulder grading;
- Reshaping/regrading drainage systems; and
- Vegetation maintenance.

2.1.4 Partial Exemptions

Underground Utility Projects
Underground utility projects that replace the ground surface with in-kind material or materials with similar runoff characteristics are subject only to Core Element #2 Construction Stormwater Pollution Prevention.

Road Maintenance and Upgrades
The following practices are subject to Core Element #2 Construction Stormwater Pollution Prevention:

- Removing and replacing a concrete or asphalt roadway to base course or lower without expanding impervious surfaces.
- Repairing the roadway base.
- Overlaying existing gravel with bituminous surface treatment (BST or “chip seal”) or asphalt or concrete without expanding the area of coverage, or overlaying BST with asphalt, without expanding the area of coverage. <u>This exemption from additional Core Elements applies under the following conditions</u>:
  - For roads, these practices are exempt from additional Core Elements **only** if the traffic surface is or will be subject to an average daily traffic volume of less than 7,500 on an urban road or an average daily traffic volume of less than 15,000 vehicles on a rural road, freeway or limited access control highway.
  - For parking areas, these practices are exempt from additional Core Elements **only** if the traffic surface is or will be subject to less than 40 trip ends per 1,000 square feet of building area or 100 total trip ends.

Safety Improvement Projects
These projects are subject to Core Element #2 Construction Stormwater Pollution Prevention. Certain safety improvement projects such as sidewalks, bike lanes, bus pullouts and other transit improvements must be evaluated on a case-by-case basis to determine whether additional Core Elements apply. A safety project that enhances the traffic capacity of a roadway is not exempt from the other Core Elements.

2.1.5 Local Exceptions/Variances

<u>Guidelines</u>

Exceptions to the Core Elements may be granted prior to permit approval and construction. The local jurisdiction may grant an exception following an application for an exception with legal public notice per the local jurisdiction’s guidance and requirements for exceptions and variances. The administrator’s decision should include a written finding of fact that documents the following:

- There are special physical circumstances or conditions affecting the property such that the strict application of these provisions would deprive the applicant of reasonable use of the parcel of land in question, and every effort to find creative ways to meet the intent of the Core Elements has been made; and

- That the granting of the exception will not be detrimental to the public health and welfare, nor injurious to other properties in the vicinity and/or downstream, and to the quality of waters of the State; and
- The exception is the least possible exception that could be granted to comply with the intent of the Core Elements.

If the local jurisdiction chooses to allow jurisdiction-wide exceptions or variances to the requirements of the Manual, those exceptions must be approved by the permitting authority. Project-specific design deviations based on site-specific conditions generally do not require approval of the permitting authority and are left to the discretion of the local jurisdiction.

Supplemental Guidelines

The adjustment and exception provisions are an important element of the plan review and enforcement programs. They are intended to maintain a necessary flexible working relationship between local officials and applicants. Local jurisdictions should consider these requests judiciously, keeping in mind both the need of the applicant to maximize cost-effectiveness and the need to protect off-site properties and resources from damage.

2.2 Core Elements

This section describes the eight Core Elements for stormwater management at development and redevelopment sites in eastern Washington. Chapters 5 through 8 of this Manual contain Best Management Practices (BMPs) to choose from in implementing these Core Elements for each project.

The requirements of these Core Elements do not excuse any discharge from the obligation to apply whatever technology is necessary to comply with State water quality standards, Chapter 173-201A WAC, or State ground water standards, Chapter 173-200 WAC. Additional treatment requirements to meet those standards may be required by federal, State, or local jurisdictions.

This Manual is intended to assist projects discharging to surface water and projects with discharges to groundwater via Underground Injection Control (UIC) Facilities in complying with regulatory requirements to protect water quality. Nearly all of this section applies to projects with discharges to surface water, and most of it also applies to projects with discharges to groundwater. Each Core Element includes a section identifying the applicability of that Core Element to projects disposing of stormwater runoff using UIC facilities in order to clarify how the Core Element might be applied differently for projects discharging to surface and ground waters. Some Core Elements also include a section on applicability to wetlands where special considerations are needed for those discharges.

2.2.1 Core Element #1
Preparation of a Stormwater Site Plan

Objective

Stormwater management is most successful when integrated into project planning and design. Projects are expected to demonstrate compliance with the applicable Core Elements through preparation of a Stormwater Site Plan.

Guidelines

All projects that are subject to Core Elements #2, #3, #4, #5, #6 or #8 are expected to complete a Stormwater Site Plan (SSP). When required, Stormwater Site Plans shall be prepared in accordance with Chapter 3 of this Manual.

Projects proposed by departments and agencies within the local jurisdiction must comply with this requirement. The local jurisdiction shall determine the process for ensuring proper project review, inspection, and compliance by its own departments and agencies.

Applicability to UIC Facilities

This Core Element applies to projects with drywells and other UIC rule-authorized subsurface infiltration systems when Core Elements #2, #3, #4, #5, #6 or #8 are required.

Supplemental Guidelines

A simplified SSP may be developed by the local jurisdiction and made available for use by proponents of small projects.

Responsibilities of Local Jurisdictions

As part of the routine project approval and permitting process, local jurisdictions should review SSPs for completeness and adequacy in fulfilling the objectives of the Core Elements. Plan review staff should be trained in the application of this Manual or the approved local equivalent.

2.2.2 Core Element #2
Construction Stormwater Pollution Prevention

Objective

Runoff from project sites during the construction phase can contribute quantities of sediment and other contaminants sufficient to result in water quality violations. Sediment-laden runoff can enter newly constructed drywells, reducing their infiltration capacity and lifetime of operation or increasing maintenance costs.

Controlling erosion and preventing sediment and other pollutants from leaving the project site during the construction phase is achievable through implementation of selected Best Management Practices (BMPs) that are appropriate both to the site and to the season during which construction activities take place. The Construction Stormwater Pollution Prevention Plan (SWPPP) identifies project-specific guidance for preventing pollution resulting from erosion and sediment runoff during the construction phase. A well-written SWPPP provides guidance that is neither over- nor under-protective for the project site. The Construction SWPP should include seasonally-appropriate guidance and anticipate adjustments that may be necessary in the event of delays in the construction schedule. If deemed appropriate, Construction SWPPPs may be revised during the construction phase of the project. The Construction SWPPP must be maintained on the construction site for reference and use by project personnel.

Guidelines

All projects are responsible for preventing erosion and discharge of sediment into surface waters and must consider each of the twelve elements of pollution prevention in order to determine which controls are appropriate for the project site. Chapter 7 of this Manual identifies and describes appropriate Best Management Practices (BMPs) for each of these elements.

Construction SWPPP Elements

The twelve Construction SWPPP elements are listed below. See Chapter 7 for a description of each of these elements and suggested BMPs for each element.

1. Mark Clearing Limits
2. Establish Construction Access
3. Control Flow Rates
4. Install Sediment Controls
5. Stabilize Soils
6. Protect Slopes
7. Protect Drain Inlets
8. Stabilize Channels and Outlets
9. Control Pollutants
10. Control De-Watering
11. Maintain BMPs
12. Manage the Project

If a Construction SWPPP is found to be inadequate with respect to applicable erosion and sediment control requirements (*i.e.* sediment-laden water is leaving the site), then the local jurisdiction shall require that other BMPs be implemented as appropriate.

Applicability to UIC Facilities

This Core Element is required for all projects with drywells and other UIC rule-authorized subsurface infiltration systems to protect and ensure the proper long-term function of the UIC facility. Preventing sediment from entering the facility may be all that is necessary to achieve this objective. Source control during construction (SWPPP element #9) is also required to prevent contamination of groundwater by fuel or other potential pollutants.

Supplemental Guidelines

The local jurisdiction may allow development of generic Construction SWPPPs that apply to commonly conducted projects such as public road activities.

Responsibilities of Local Jurisdictions

Local jurisdictions should review SWPPPs for completeness and adequacy in meeting the objectives of this Core Element. Staff inspecting projects during construction should be trained in assessing the application of erosion and sediment control BMPs; if problems are identified, staff should review the SWPPPs on-site and discuss appropriate modifications with operators.

2.2.3 Core Element #3 Source Control of Pollution

Objective

The intent of Source Control Best Management Practices (BMPs) is to prevent pollutants from coming into contact with stormwater. Source control BMPs are a cost-effective means of reducing pollutant loading and concentrations in stormwater and should be a first consideration in all projects.

Guidelines

Following construction, projects shall apply all known, available and reasonable source control BMPs. Source control BMPs shall be selected, designed, and maintained according to this Manual.

Considering opportunities for structural separation of surfaces exposed to pollutants and other source control alternatives during the project design stage may result in eliminating or reducing the size of facilities required under Core Element #5 Runoff Treatment.

Applicability to Wetlands

This Core Element is required for all projects with discharges to wetlands. Operational and source control BMPs may not be sufficient to protect wetlands from salts and other chemical anti-icers and deicers that can accumulate and impact the biological functions of a wetland. Separation and routing of runoff to an alternate discharge location may be necessary to protect the wetland from runoff from road and other surfaces subject to such chemical use.

Applicability to UIC Facilities

This Core Element is required for all projects with discharges to drywells and other UIC rule-authorized subsurface infiltration systems.

Supplemental Guidelines

A basin plan adopted and implemented by a local jurisdiction or a Total Maximum Daily Load (TMDL, also known as a Water Clean-up Plan) may be used to develop more stringent source control requirements that are tailored to a specific basin.

Source Control BMPs include Operational BMPs and Structural Source Control BMPs. See Chapter 8 for design details of these BMPs. For construction sites, see Chapter 7.

Responsibilities of Local Jurisdictions

During plan review, local jurisdictions should evaluate whether selected source BMPs will meet the objectives of this Core Element. Staff conducting inspections of commercial and industrial facilities should be trained in assessing the proper selection and implementation of source control BMPs; staff should review pollution prevention and spill control plans and discuss appropriate modifications with operators if a problem is identified.

2.2.4 Core Element #4 Preservation of Natural Drainage Systems

Objective

Natural drainage patterns should be maintained and discharges from the project site should occur at the natural location to the maximum extent practicable. Preservation of natural drainage systems provides multiple benefits for stormwater management. Creating new drainage patterns results in more site disturbance and more potential for erosion and sedimentation during and after construction. Creating new discharge points can create significant stream channel erosion problems as the receiving water body typically must adjust to the new flows. Diversions can cause greater impacts than would otherwise occur by discharging runoff at the natural location. Wetlands can be severely degraded by discharges from urban development due to pollutants in the runoff and also due to disruption of the natural hydrology (especially changes in water levels and the duration of inundations) of the wetland system.

Guidelines

To the maximum extent practicable, stormwater should be discharged in the same manner, at the same location, and at the same flow rate and volume as under the conditions that existed prior to development. Because some change in natural flow patterns is unavoidable following development, the preferred options for discharge of excess stormwater are, in order of preference to maintain natural drainage systems:

1. Infiltrate on-site.
2. Infiltrate off-site.

3. Maintain dispersed sheet flow to match natural conditions.
4. Discharge to existing ditch networks, canals, or other dispersal methods that allow for potential groundwater recharge.
5. Discharge to wetlands, if allowed.
6. Discharge to existing private or municipally-owned stormwater systems, if allowed.
7. Evaporate on-site or off-site.
8. Create a new outfall for discharge to surface waters.

This Core Element includes stormwater infiltration if that is the natural discharge method for the site. The designer shall investigate whether shallow groundwater, a sensitive aquifer, or other concerns will affect design choices for the project.

The manner by which runoff is discharged from the project site must not cause a significant adverse impact to downstream receiving waters and down-gradient properties. This should be addressed as part of the offsite analysis described in Appendix 3A.

All outfalls must address energy dissipation as necessary. A project proponent who believes that energy dissipation should not be required for a new outfall must provide justification in the project's stormwater site plan or drainage study report.

Runoff treatment or flow control may be required prior to any discharge according to the requirements of Core Elements #5 or #6.

Applicability to Wetlands

Discharge of stormwater to existing jurisdictional wetlands, either directly or via a conveyance system, should be avoided unless the wetland receives surface runoff from the existing site. If possible, only stormwater from landscape and roof areas should be discharged to wetlands. The discharge must comply with all applicable Core Elements to ensure that wetlands receive the same level of protection as any other waters of the State. See Core Elements #5 Runoff Treatment and #6 Flow Control for guidelines for evaluating whether an existing wetland may be used as a runoff treatment or flow control facility.

Applicability to UIC Facilities

This Core Element applies to all projects with discharges to drywells and other UIC rule-authorized subsurface infiltration systems.

Supplemental Guidelines

For projects with no identified discharge point, local jurisdictions may wish to adopt guidance for disposal of water collected for runoff treatment per the requirements of Core Element #5 Runoff Treatment. The guidance is intended to protect downstream properties from flooding as a result of post-construction concentrated runoff.

Where no conveyance system exists at the adjacent down-gradient property line, and the discharge was previously unconcentrated flow or significantly lower concentrated flow, then measures must be taken to prevent down-gradient impacts. Drainage easements from downstream property owners may be needed and should be obtained prior to approval of engineering plans.

Designs for outfall systems to protect against adverse impacts from concentrated runoff are included in Chapter 5.

Responsibilities of Local Jurisdictions

During plan review, local jurisdictions should consider whether the construction and stormwater management approaches meet the objectives of this Core Element. Local jurisdictions may also wish to provide project proponents with resources about appropriate low impact development (LID) techniques that can assist in meeting the objectives of this Core Element. For additional information about LID approaches and links to demonstration projects and research activities, see websites and links provided by the U.S. Environmental Protection Agency, Puget Sound Water Quality Action Team, or Ecology.

2.2.5 Core Element #5 Runoff Treatment

Objective

The purpose of runoff treatment is to reduce pollutant loads and concentrations in stormwater runoff using physical, biological, and chemical removal mechanisms to protect water quality so that beneficial uses of receiving waters are maintained and where applicable, restored. The most effective basic treatment BMPs remove about 80% of the total suspended solids contained in the runoff treated and a much smaller percentage of the dissolved pollutants. An analysis of the proposed land use at the project site is used to determine the pollutants of concern. In some cases, additional treatment to remove oil, metals, and(or) phosphorus from stormwater runoff may be required to protect water quality.

The goal of this Core Element is to treat approximately 90% of the annual runoff generated by the pollutant-generating surfaces at a project site. The total quantity of pollutants removed from the stormwater will vary greatly from site to site based on precipitation patterns, land use, effectiveness of source control, and operation and maintenance of the treatment facilities. Proper operation and maintenance of runoff treatment BMPs may be more significant than the actual volume of runoff treated in protecting receiving waters over the long term.

When site conditions are appropriate, infiltration can potentially be the most effective Best Management Practice for runoff treatment. Given sufficient treatment capacity in the vadose zone below an Underground Injection and Control (UIC) facility, such as a drywell, and the water table, no pre-treatment may be required for many of the pollutants of concern in stormwater. The criteria for determining whether pre-treatment is required for a given proposed land use and site location are explained in Chapter 5.6.

Definitions

Non-Pollutant Generating Impervious Surfaces (NPGIS)

NPGIS are considered to be insignificant or low sources of pollutants in stormwater runoff. Roofs that are subject only to atmospheric deposition or normal heating, ventilation and air conditioning vents are considered NPGIS. The following may also be considered NPGIS: paved bicycle pathways and pedestrian sidewalks that are separated from and not subject to drainage from roads for motor vehicles, fenced fire lanes, infrequently used maintenance access roads, and "in-slope" areas of roads. Sidewalks that are regularly treated with salt or other deicing chemicals are not considered NPGIS.

Pollutant Generating Impervious Surfaces (PGIS)

PGIS are considered to be significant sources of pollutants in stormwater runoff. Such surfaces include those that are subject to vehicular use, industrial activities, or storage of erodible or leachable materials that receive direct rainfall or run-on or blow-in of rainfall. Metal roofs are considered to be PGIS unless coated with an inert, non-leachable material. Roofs that are subject to venting of manufacturing, commercial or other indoor pollutants are also considered PGIS. A surface, whether paved or not, shall be considered PGIS if it is regularly used by motor vehicles. The following are considered regularly-used surfaces: roads, unvegetated road shoulders, bike lanes within the traveled lane of a roadway, driveways, parking lots, unfenced fire lanes, vehicular equipment storage yards, and airport runways.

Average Daily Traffic (ADT) and Trip Ends

The expected number of vehicles using a roadway or parking area is represented by the projected averge daily traffic volume considered in designing the roadway or by the projected trip end counts for the parking area associated with a proposed land use. ADT and trip end counts must be estimated using "Trip Generation" published by the Institute of Transportation Engineers or from a traffic study prepared by a professional engineer or transportation specialist with expertise in traffic volume estimation. ADT and trip end counts shall be made for the design life of the project. For project sites with seasonal or varied use, evaluate the highest period of expected traffic impacts.

High-Use Sites

High-use sites generate high concentrations of oil due to high traffic turnover or the frequent transfer of oil and(or) other petroleum products. High-use sites are land uses where sufficient quantities of free oil are likely to be present such that they can be effectively removed with special treatment. A high-use site is any one of the following:

- A road intersection with expected ADT of 25,000 vehicles or more on the main roadway and 15,000 vehicles or more on any intersecting roadway, excluding projects proposing primarily pedestrian or bicycle use improvements; or

∉ A commercial or industrial site with an expected trip end count equal to or greater than 100 vehicles per 1,000 square feet of gross building area (best professional judgment should be used in comparing this criterion with the following criterion); or

∉ A customer or visitor parking lot with an expected trip end count equal to or greater than 300 vehicles (best professional judgment should be used in comparing this criterion with the preceding criterion); or

∉ Commercial on-street parking areas on streets with an expected total ADT count equal to or greater than 7,500; or

∉ Fueling stations and facilities; or

∉ A commercial or industrial site subject to petroleum storage and transfer in excess of 1,500 gallons per year, not including locations where heating fuel is routinely delivered to end users (heating fuel handling and storage facilities <u>are</u> subject to this definition); or

∉ A commercial or industrial site subject to use, storage, or maintenance of a fleet of 25 or more diesel vehicles that are over 10 tons gross weight (trucks, buses, trains, heavy equipment, etc.); or

∉ Maintenance and repair facilities for vehicles, aircraft, construction equipment, railroad equipment or industrial machinery and equipment; or

∉ Outdoor areas where hydraulic equipment is stored; or

∉ Log storage and sorting yards and other sites subject to frequent use of forklifts and(or) other hydraulic equipment; or

∉ Railroad yards.

Exemptions

Any of the exemptions below may be negated by requirements set forth in a Total Maximum Daily Load (TMDL) or other water clean-up plan.

Basic Treatment Exemptions

Non-pollutant generating impervious surface (NPGIS) areas are exempt from basic treatment requirements *unless* the runoff from these areas is not separated from the runoff generated from pollutant generating impervious (PGIS) surface areas. All runoff treatment facilities must be sized for the entire flow that is directed to them. Projects that meet the requirements for dispersal and infiltration (see Chapter 6, particularly BMP T5.30) and do not meet the requirements for oil treatment are exempt from basic treatment requirements. Discharges to surface water from projects with a total PGIS area <5,000 square feet are exempt from basic treatment requirements *unless* those areas are subject to the storage or handling of hazardous substances, materials or wastes as defined in 49 CFR 171.8, RCW 70.105.010, and(or) RCW 70.136.020. Discharges to UIC facilities may be exempt from basic treatment requirements if the vadose zone matrix between the bottom of the facility and the water table provides adequate treatment capacity (see Chapter 5.6).

Metals Treatment Exemptions

Discharges to nonfish-bearing streams are exempt from additional metals treatment requirements. Direct discharges to the main channels of the following rivers and direct discharges to the following lakes are exempt from metals treatment requirements: Banks Lake, Lake Chelan, Columbia River, Grande Ronde River, Kettle River, Klickitat River, Methow River, Moses Lake, Potholes Reservoir, Naches River, Okanogan River, Pend Oreille River, Similkameen River, Snake River, Spokane River, Wenatchee River, and Yakima River. Discharges to groundwater via rule-authorized Underground Injection and Control (UIC) facilities (see Chapter 5.6), are also exempt from metals treatment requirements. Restricted residential and employee-only parking areas are exempt from metals treatment requirements unless subject to through traffic. Certain exemptions may exist for Category 4 wetlands (see "Use of Existing Wetlands to Provide Runoff Treatment" under Guidelines below.)

Oil Treatment Exemptions

No high-use sites are exempt from oil treatment requirements.

<u>Guidelines</u>

Treatment facilities shall be selected, designed, sized, constructed, operated and maintained in accordance with the guidance in Chapters 4 and 5 of this Manual. The flow chart at the beginning of Chapter 5 is intended to assist project proponents in selecting treatment BMPs.

All runoff treatment facilities must be sized for the applicable design storm(s) described in this section or according to alternative guidance as required by the local jurisdiction. In order to maintain the integrity and function of the treatment systems, stormwater runoff treatment facilities must be sized for the entire flow that is directed to them.

If it is possible for the project to meet treatment requirements by dispersal and infiltration (see Chapter 6, BMP T5.30), the runoff should not be collected and concentrated; otherwise flow control (Core Element #6) may be required.

When this Core Element is required, Core Element #7 Operation and Maintenance is also required.

Applicability to UIC Facilities

Discharge of untreated stormwater from PGIS to drywells and other UIC rule-authorized subsurface infiltration systems can be acceptable if the geologic matrix and depth to groundwater provide sufficient treatment capacity as determined per the criteria in Chapter 5.6 of this Manual. The narrative and tables in Chapter 5.6 describe the pollutant loading source area and vadose zone treatment capacity classifications that are used in making this determination. UIC facilities that discharge into geologic matrices without sufficient treatment capacity must be preceded by runoff treatment in accordance with this Core Element. Note that discharges to drywells that contain process water or other any other discharges besides stormwater will not be UIC rule-authorized and require individual permits. Discharges of stormwater from certain industrial and commercial sites to UIC facilities are be prohibited (see the complete list in Chapter 5.6); discharges of process water to UIC facilities are also prohibited. Additional local requirements may apply for any discharge to a drywell or other infiltration facility.

Basic Treatment Requirements

Runoff treatment is required for all projects creating 5,000 square feet or more of pollutant-generating impervious surfaces (PGIS) unless the discharge is to a qualified UIC facility (see section above) or satisfies the requirements for full dispersion (see Chapter 6, BMP T5.30). Treatment is required for discharges to all surface waters of the State, including perennial and seasonal streams, lakes and wetlands where the PGIS threshold is met. Certain exemptions may exist for Category 4 wetlands (see later section on "Use of Existing Wetlands to Provide Runoff Treatment"). Runoff treatment is also required for discharges of stormwater to groundwater via UIC facilities where the vadose zone does not provide adequate treatment capacity (see Chapter 5.6). Project designers should also consider the possible impact of additional TSS loading from pervious areas at the project site on the long-term function of the treatment facility.

Metals Treatment Requirements

Metals treatment is required for moderate use sites that meet any of the following definitions and discharge to a non-exempt surface water:

- Industrial sites subject to handling, storage, production, or disposal of metallic products or other materials, particularly those containing arsenic, cadmium, chromium, copper, lead, mercury, nickel or zinc; or
- An urban road with expected ADT count greater than 7,500; or
- A rural road or freeway with expected ADT count greater than 15,000; or
- A commercial or industrial site with an expected trip end count equal to or greater than 40 vehicles per 1,000 square feet of gross building area; or
- A customer or visitor parking lot with an expected total ADT count equal to or greater than 100 vehicles; or
- Runoff from metal roofs not coated with an inert, non-leachable material.

Oil Control Requirements

Oil control is required for all high-use sites (see definition above). Some sites will require a spill control type of oil control facility (see Chapter 8) for source control separate from or in addition to this treatment requirement. Projects proposing a high-use site must provide oil controls in addition to any other water quality treatment required per this Core Element.

High-use roadway intersections shall treat lanes where vehicles accumulate during the signal cycle, including left and right turn lanes and through lanes, from the beginning of the left turn pocket. If no left turn pocket exists, the treatable area shall begin at a distance equal to three car lengths from the stop line. If runoff from the intersection drains to more than two collection areas that do not combine within the intersection, treatment may be limited to any two of the collection areas where the cars stop.

High-use sites must treat runoff from the high-use portion of the site using oil control treatment options in Chapter 5 of this Manual prior to discharge or infiltration. For high-use sites located within a larger project area, only the impervious area associated with the high-use site is subject to oil control treatment, but the flow from that area must be separated; otherwise the treatment controls must be sized for the entire area.

Phosphorus Treatment Requirements

Phosphorus treatment is only required where federal, State, or local government has determined that a water body is sensitive to phosphorus and that a reduction in phosphorus from new development and redevelopment is necessary to achieve the water quality standard to protect its beneficial uses. Where it is deemed necessary, a strategy will be adopted to achieve the reduction in phosphorus. The strategy will be based on knowledge of the sources of phosphorus and the effectiveness of the proposed methods of removing phosphorus. Contact the local jurisdiction to determine if phosphorus treatment is required for your project.

Treatment Facility Sizing

Each treatment BMP is sized based on a water quality design volume, or a water quality design flow rate. Local jurisdictions should adopt criteria to provide for consistent sizing of treatment facilities. The methods for predicting post-development runoff volumes and flow rates are included in Chapter 4 of this Manual. Specific design criteria for treatment facilities also may be identified in Chapter 5 in order to achieve the performance goal of a particular BMP.

Water quality design volume: Volume-based treatment BMPs are sized the same whether located upstream or downstream from detention facilities. Each local government should specify which of the following methods will be used in their jurisdiction. If the local jurisdiction has not identified a preferred method, the default method shall be Method 1.

Method 1: The volume of post-developed runoff predicted from the regional storm with a six-month return frequency.

Method 2: The volume of post-developed runoff predicted from the SCS Type IA 24-hour storm with a six-month return frequency.

Method 3: In Regions 2 and 3, volume-based facilities may be sized for 0.5 inch predicted post-development runoff produced from all impervious surface areas that contribute flow to the treatment facility. (This method is modified for design of BMP T6.30 Bioinfiltration swale in Chapter 5.) See Figure 2.1 for a map of the approximate delineation of the four climatic regions in eastern Washington; a more detailed map is provided in Chapter 4 (see figure 4.3.1).

Method 4: The volume of post-developed runoff predicted from the SCS Type II storm with a six-month return frequency.

Method 5: Another sizing approach and criteria based on peer-reviewed methods and supported by local data that meet the objective of treating at least 90% of the annual volume of runoff from the site.

Snowmelt factor: Snowmelt should be considered in determining the water quality design volume. This is especially important in Regions 1 and 4 and also applies to other areas of eastern Washington. Check for local requirements. A snowmelt factor based on the water content of the average daily depth of snow (or based on some other appropriate measurement) should be added to the depth of precipitation for calculating runoff treatment volume. See Chapter 4.2.8 for details.

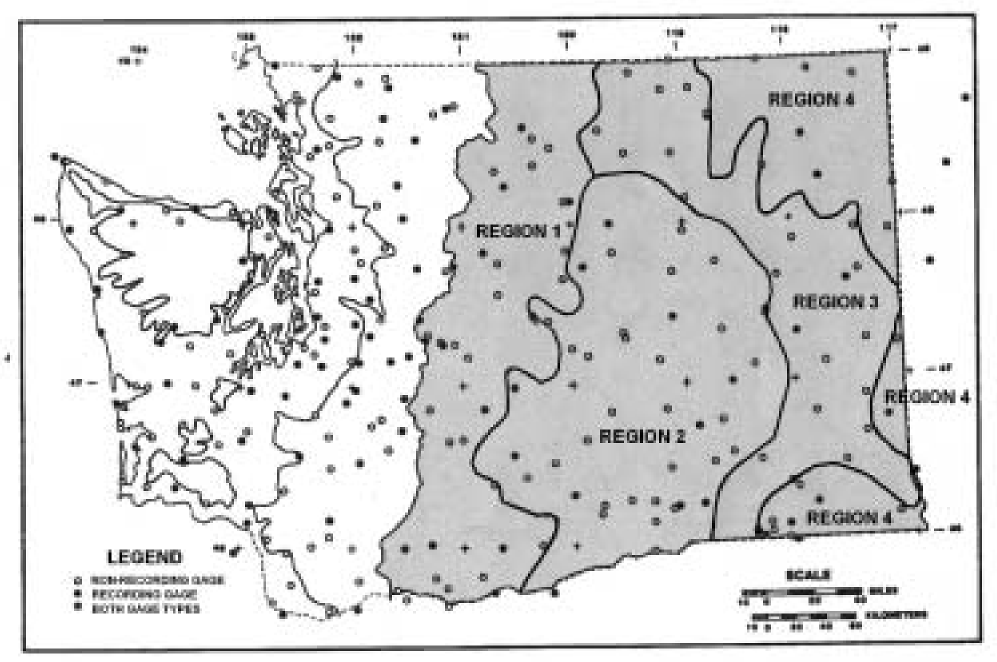


Figure 2.1 – Approximate delineation of climatic regions in eastern Washington

Water quality design flow rate: Flow-rate-based treatment BMPs are sized the differently depending on whether they are located upstream or downstream from detention facilities, if detention is required. Each local government should specify which of the following methods will be used in their jurisdiction to size facilities preceding detention ponds. If the local jurisdiction has not identified a preferred method, the default method shall be Method 1.*For runoff treatment facilities preceding detention facilities or when detention facilities are not required:*

Method 1: The post-developed runoff flow rate predicted from the short-duration storm with a six-month return frequency. (Time intervals are specified in the BMP designs.)

Method 2: The post-developed runoff flow rate predicted from the SCS Type II 24-hour storm with a six-month return frequency. (Time intervals are specified in the BMP designs.)

Method 3: The post-developed runoff flow rate calculated by the Rational Method using the two-year Mean Recurrence Interval (see Chapter 4). This method may only be used to design facilities based on instantaneous peak flow rates.

For runoff treatment facilities sited downstream of detention facilities: The full 2-year release rate of the detention facility.

Bypass Requirements

A bypass must be provided for all treatment BMPs unless the facility is able to convey the 25-year short-duration storm without damaging the BMP or dislodging pollutants from within it. Extreme runoff events may produce high flow velocities through BMPs that can damage and or dislodge pollutants from within the facility. The designer must check the maximum allowable velocity (typically less than 2 ft/s) or shear stress specified for the BMP and implement a flow bypass as necessary to prevent exceeding these velocities. Bypass is not recommended for wet ponds, constructed wetlands and similar volume-based treatment facilities. Inlet structures for these facilities should be designed to dampen velocities; the pond dimensions will further dissipate the energy. In these facilities, larger storms will be retained for a shorter detention time than the shorter storms for which the ponds are designed. See Chapter 5.3.1 for bypass design information.

Use of Existing Wetlands to Provide Runoff Treatment

Stormwater treatment facilities are not allowed within a wetland or its natural vegetated buffer except for:

∉ Necessary conveyance systems approved by the local government; or
∉ As allowed in a wetland mitigation plan; or
∉ When the requirements below are met:

A wetland can be considered for use in stormwater treatment if:

The wetland meets the criteria for "Hydrologic Modification of a Wetland" in Core Element #6 Flow Control;

and either:

It is a Category 4 wetland according to the *Eastern Washington Wetland Rating System* (see the final rating form provided on Ecology's website);

or:

It is a Category 3 wetland according to the *Eastern Washington Wetland Rating System* and the wetland has been previously disturbed by human activity, as evidenced by agriculture, fill areas, ditches *or* the wetland is dominated by introduced or invasive weedy plant species as identified in the rating analysis.

Basic treatment is required prior to discharge to Category 3 wetlands; a Category 3 wetland that meets the above requirements may be used to meet metals treatment requirements. Oil treatment required for all discharges to wetlands from high use sites (see definition).

Caution: Wetlands may accumulate the salts in anti-icing and deicing chemicals, so use of such chemicals should be limited in the areas discharging to the wetland (see Core Element #3 Source Control).

Mitigation is usually required for the impact of using a wetland as a stormwater treatment facility. Appropriate measures include expansion, enhancement and/or preservation of a buffer around the wetland.

Additional Requirements

Additional treatment or siting requirements may be imposed by federal, State or local governments to achieve specific water quality protection or restoration goals. Check with the local jurisdiction for additional requirements.

Supplemental Guidelines

See Chapters 4 and 5 of this Manual for detailed guidance on selection, design, construction, operation and maintenance of treatment facilities. The water quality design volumes and flow rates are intended to size facilities to capture and effectively treat at least 90% of the annual runoff volume in eastern Washington.

Additional exemptions from metals treatment requirements for rural roads or small isolated commercial projects located outside Urban Growth Area boundaries may be considered on a case-by-case basis after consideration of the ability of basic treatment to protect water quality in the receiving water. Some receiving waters will have sufficient capacity to dilute the metals concentration from the cumulative stormwater discharges so water quality standards are not violated; other water bodies will not have sufficient mixing and dilution capacity. In making a determination, the local jurisdiction or other agency reviewing the project needs to consider: the average lowest monthly flow in the water body; and the existing and expected metals contributions from the surrounding area based on the zoning and probable future land use. The analysis must determine whether a water quality violation is likely to occur when a thunderstorm following an extended period of dry weather contributes polluted runoff from future build out areas to the water body during low flow conditions.

If the runoff generated from a project site by the water quality design storm discharges to a conveyance system that does not reach a surface water body or UIC facility, then basic treatment is not required. The analysis must consider all of the water flowing to the conveyance system, not just the water from the project site.

Project designers are encouraged to consider site grading, conveyance and other design specifications that separate NPGIS from PGIS runoff to avoid treating all of the runoff from the site. Designers are also encouraged to keep PGIS runoff from portions of the site that require oil or metals treatment separate from PGIS areas that only need basic treatment where it might be possible to avoid treating all of the runoff from the site to the higher standard.

Responsibilities of Local Jurisdictions

During plan review, local jurisdictions should evaluate whether the objectives of this Core Element have been met. Staff should be aware of any current water clean-up plans (including TMDLs), sole-source aquifer protection measures, well-head protection areas or other requirements to protect or restore water quality.

Each local government should identify a preferred method for calculating (1) runoff volumes and (2) flow rates to ensure consistent sizing of treatment BMPs in their jurisdiction and to facilitate plan review. Local jurisdictions may choose to accept projects designed per the requirements of the Washington State Department of Transportation's *Highway Runoff Manual* or another approved equivalent manual. Proponents of unique or complex projects may wish to use other methodologies, and staff should work with those designers to ensure that the objectives of this Core Element are met.

Local jurisdictions are encouraged to assist in development and testing of new treatment methodologies. See Chapter 5.12 for more information.

2.2.6 Core Element #6 Flow Control

Objective

The purpose of flow control is to mitigate to the maximum extent practicable the impacts of increased storm runoff volumes and flow rates on streams in eastern Washington. The intent of this Core Element is to prevent cumulative future impacts from urban runoff; the impacts of prior development and (or) flow modifications in eastern Washington are not addressed through this Manual.

Wherever possible, infiltration is the preferred method of flow control for urban runoff. Some stream habitat problems in eastern Washington result from reduced instream flows during the hot summer months. Flow control using detention basins will not address this issue and may exacerbate it; but the cumulative effect of infiltrating urban runoff should have a neutral or possibly beneficial effect.

This Core Element is targeted to smaller water bodies, especially first to third order streams or water bodies with contributing watershed areas of less than 100 square miles. These streams are more susceptible to changes in runoff patterns caused by development.

This Core Element is also targeted to wetlands. Discharges to wetlands should maintain the hydrology (depth and duration of inundation) of the existing condition in order to protect the unique vegetation and other characteristics necessary to support existing and designated uses.

Design specifications for conveyance and flood prevention are determined by local jurisdictions. This Core Element does not address those issues.

Exemptions

Flow control is not required for all discharges to surface waters in eastern Washington because flow control is not always needed to protect stream morphology. The exemptions listed below are provided to assist local jurisdictions in determining which projects should be subjected to this Core Element. Any project may be subject to local requirements for flow control to prevent flooding. All projects are encouraged to infiltrate storm runoff on site to the greatest extent possible.

In consideration of other environmental issues, a local jurisdiction may wish to require flow control for one or more of the types of projects or water bodies listed below. Conversely, following analysis of a particular water body and/or its watershed, a local jurisdiction may determine that flow control is not necessary for certain discharges or to protect certain water bodies, or decide to provide a regional stormwater facility instead of requiring site-by-site flow control facilities. See additional information in the supplemental guidelines.

The following projects and discharges are exempt from flow control requirements to protect stream morphology. Runoff treatment may still be required per Core Element #5. Local jurisdictions may override any exemptions.

1. Any project that does not discharge runoff to a non-exempt surface water either directly or via a conveyance system.

2. Any project able to disperse, without discharge to surface waters, the total post-developed 25-year runoff volume on property that is under the functional control of the project proponent. See guidelines for dispersion in Chapter 6, particularly BMP T5.30.

3. A road project able to disperse, without discharge to surface waters, the total post-developed 25-year runoff volume on land for which this use has been specifically authorized by the controlling entity. See guidelines for dispersion in Chapter 6, particularly BMP T5.30.

4. A project constructing less than 10,000 square feet of total impervious surfaces. Local jurisdictions may establish a different impervious surface area threshold (see Core Element #8 Local Requirements).

5. A project discharging to stream reaches consisting primarily of irrigation return flows and not providing habitat for fish spawning and rearing. Projects should match the pre-developed 2-year and 25-year peak runoff rates for these discharges. The local irrigation district may impose other requirements.

6. A project discharging <u>directly</u> to:

   - Any of the rivers or lakes on the list of exempt surface waters below; or
   - Reservoirs on the Columbia, Snake, Pend Oreille, or Spokane Rivers; or
   - Other reservoirs with outlet controls that are operated for varying discharges to the downstream reaches as for hydropower, flood control, irrigation, or drinking water supplies. Uncontrolled, flow-through impoundments are not exempt.

   Projects may also discharge to these waters through a publicly owned conveyance system with sufficient capacity; permission must be granted by the owner/operator of the conveyance system.

   In order to be exempted, the discharge must meet all of the following requirements:

   a. The project area must be drained by a conveyance system that is comprised entirely of manmade conveyance elements (e.g., pipes, ditches, outfall protection, etc.); and
   b. The conveyance system must extend to the ordinary high water line of the receiving water, <u>or</u> (in order to avoid construction activities in sensitive areas) flows are properly dispersed before reaching the buffer zone of the sensitive area; <u>and</u>
   c. Any erodible elements of the conveyance system for the project area must be adequately stabilized to prevent erosion; <u>and</u>
   d. Surface water from the project area must not be diverted from or increased to an existing wetland, stream, or near-shore habitat sufficient to cause a significant adverse impact. Adverse impacts are expected from uncontrolled flows causing a significant increase or decrease in the 1.5- to 2-year peak flow rate.

Exempt surface waters:
Asotin Creek downstream of confluence with George Creek
Banks Lake
Bumping River downstream of confluence with American River
Lake Chelan
Cle Elum River downstream of Cle Elum Lake
Columbia River
Colville River downstream of confluence with Chewelah Creek
Grande Ronde River
Kettle River downstream of confluence with Boulder Creek
Klickitat River downstream of confluence with West Fork
Latah Creek (formerly called Hangman Creek) downstream of confluence with Rock Creek (in Spokane County)
Little Spokane River downstream of confluence with Deadman Creek
Lower Crab Creek
Methow River downstream of confluence with Icicle Creek
Moses Lake
Naches River downstream of confluence with Bumping River
Okanogan River
Palouse River downstream of confluence with South Fork Palouse River
Pend Oreille River
Potholes Reservoir
Rock Creek (in Whitman County) downstream of confluence with Cottonwood Creek
Similkameen River
Snake River
Spokane River
Teanaway River downstream of confluence of north and west forks
Tieton River downstream of Rimrock Lake
Toppenish Creek downstream of confluence with Wanity Slough
Touchet River downstream of confluence with Patit Creek
Tucannon River downstream of confluence with Pataha Creek
Walla Walla River downstream of confluence with Mill Creek
Wenatchee River downstream of confluence with Eagle Creek
Yakima River downstream of Lake Easton

This list of exempt water bodies is generally comprised of fifth or greater order stream channels and lakes with watershed areas greater than 100 square miles. The list is subject to change as more information is gathered.

7. A project discharging to a wetland that has no surface water outlet does not need to meet the flow control requirements to protect stream morphology. Flow control may still be required to protect the wetland (see Core Element 4 Protection of Natural Drainage Systems and Outfalls and also the guidelines for wetlands below).

8. A project located at a site with less than 10” average annual rainfall that discharges to a seasonal stream which is not connected via surface flow to a non-exempt surface water by runoff generated by the 2-year regional storm.
9. A project that discharges to a stream which flows only during runoff-producing events; the runoff carried by the stream following the 2-year regional storm must not discharge via surface flow to a non-exempt surface water. The stream may carry runoff during an average annual snowmelt event but must not have a period of baseflow during a year of normal precipitation.

Any additional exemptions to and overriding of this Core Element are left to the local jurisdiction based on basin planning and studies (see Supplemental Guidelines). These plans and studies should consider: the total impervious area in the watershed under likely future development scenarios; other possible development impacts or contributions toward increasing future streamflow volumes and changing the stream channel morphology and/or increasing the potential for streambank erosion; other potential cumulative downstream effects; and unique habitat characteristics.

Guidelines

Non-exempt projects shall construct stormwater flow control facilities for any discharge of stormwater directly, or through a conveyance system, into surface water. Discharges to groundwater are exempt from the flow control requirements of this Manual, but may be subject to design specifications or other restrictions established by local jurisdictions. Flow control facilities shall be selected, designed, constructed, operated and maintained according to the criteria in Chapters 4 and 6. The requirements below apply to projects whose stormwater discharges into a non-exempt surface water, either directly or indirectly through a natural or man-made conveyance system. For a list of exempt surface waters, see the Exemptions section above.

In order to prevent localized erosion, energy dissipation at the point of discharge is required for all projects unless site-specific conditions or extremely low discharge rates warrant an exception (see Core Element #4 Preservation of Natural Drainage Systems).

When this Core Element is required, Core Element #7 Operation and Maintenance is also required.

Hydrologic Analysis

Pre- and post-development runoff volumes and flow rates shall be estimated using the methods described in Chapter 4 of this manual or by an alternate method approved by the local jurisdiction. Pre-developed conditions are those that currently exist at the site unless the local jurisdiction has imposed other requirements.

Application to Non-Exempt Streams

To protect stream morphology, projects shall limit the peak rate of runoff to 50% of the pre-developed 2-year peak flow and maintain the pre-developed 25-year peak runoff rate for the regional storm (see Chapter 4 Hydrologic Analysis).

Application to Wetlands and Lakes

To protect wetland hydrology, if the wetland does not have an outlet to a stream or has a direct outlet to an exempt river or lake, the project shall maintain the pre-developed 2-year and 25-year peak runoff rates for the regional storm. If the wetland has an outlet to a non-exempt stream, the project shall meet the flow control design requirement above to protect the stream. Category 3 or 4 wetlands may be excluded from this requirement and used as detention and/or treatment facilities if the criteria below for "Hydrologic Modification of a Wetland" (and in Core Element #5, for treatment) are met. Discharges to lakes shall maintain the pre-developed 2-year and 25-year peak runoff rates for the regional storm.

Considerations for Very Low Flow Rates

In many cases the two-year pre-developed flow rate is zero cubic feet per second, or the flow rate is so small that it is impracticable to design a pond to release at the prescribed flow rate from an engineered outlet structure. In these cases the total post-developed 2-year storm runoff volume must be infiltrated (preferred) or stored in a retention pond for evaporation, and the detention pond designed to release the pre-developed 10-year and 25-year flow rates. See Chapter 6 for pond and release structure design information.

Hydrologic Modification of a Wetland

Hydrologic modification of a wetland for the purpose of stormwater management means that the wetland will receive a greater total volume of surface runoff following the proposed development than it receives in the current condition (see Chapter 4 Hydrologic Analysis). Hydrologic modification is not allowed if the wetland is classified as Category 1 or 2 according to the *Eastern Washington Wetland Rating System* (see the final rating form provided on Ecology's website) unless the project proponent demonstrates that preferred methods of excess stormwater disposal (*e.g.* infiltration) are not possible at the site and that other options (*e.g.* evaporation) would result in more damage to the wetland by limiting baseflow.

A wetland can be considered for hydrologic modification if it is a Category 3 or 4 wetland according to the *Eastern Washington Wetland Rating System* and:

- There is good evidence that the natural hydrologic regime of the wetland can be restored by augmenting its water supply with excess stormwater runoff; or the wetland is under imminent threat exclusive of stormwater management and could receive greater protection if acquired for a stormwater management project rather than left in existing ownership;

and

- ∉ The runoff from the same natural drainage basin; the wetland lies in the natural routing of the runoff; and the site plan allows runoff discharge at the natural location. Exceptions may be made for regional facilities planned by the local jurisdiction, but the wetland should receive water from sites in the same watershed.

Mitigation is usually required for the impact of hydrologic modification to a wetland. Appropriate measures include expansion, enhancement and/or preservation of a buffer around the wetland.

Applicability to UIC facilities

This Core Element does not apply to projects using drywells and other UIC rule-authorized subsurface infiltration systems. See Chapter 6 for supplemental guidance on sizing drywells.

Supplemental Guidelines

Local jurisdictions may adopt a conservative, restricted set of curve numbers for estimating pre-development runoff. Ecology recommends that local jurisdictions consider applying natural vegetative cover pre-development conditions. Natural vegetative cover has a moderating influence on runoff generation during rain-on-snow events, and changes in cover should be a primary consideration in evaluating the change in pre- and post-development runoff volumes in many areas of eastern Washington.

Local jurisdictions may require detention basins to be designed to match a different return-interval (e.g. 10-year, 50-year, or 100-year) peak flow rate instead of or in addition to the 25-year peak flow rate. In all cases where the discharge is to non-exempt streams, detention basins must be designed to release or retain 50% of the 2-year peak flow rate.

The local jurisdiction or project proponent may also evaluate the substrate of a stream to determine whether the requirement to release the post-development 2-year peak volume at 50% of the 2-year pre-development peak flow rate should be adjusted. The release rate of 50% of the 2-year peak flow rate is a middle ground that should be protective for most streams and was chosen for its ease of application. However, for a highly erodible substrate such as sand or loess the target should be closer to 20% of the 2-year peak flow rate; and for an erosion-resistant substrate such as clay, the target could be closer to 90% of the 2-year peak flow rate. The substrate should be evaluated for at least a half-mile downstream of the proposed discharge and the probable build-out conditions, together with studies and findings by Leopold *et. al.* (1964), Williams (1978), Harvey and Watson (1986), Hammer (1972), Bledsoe and Watson (2001), Booth (1997) and Cappuccitti and Page (2000) should be considered in making the determination.

In order to reduce potential effects of increased water temperatures during the hot summer months, projects should consider withholding the total post-development runoff volume produced by the 2-year short-duration storm in the detention facility for infiltration (preferred) and/or evaporation.

A number of proven and emerging “Low Impact Development” (LID) techniques may be applied at sites in eastern Washington to reduce impervious surface areas and minimize the increase in post-development runoff rates from a project site. Such techniques include use of porous pavement, grassed pavers, and curb cuts to small surface depressions instead of raised planting beds in parking areas. See Ecology’s, the U.S. Environmental Protection Agency’s or the Puget Sound Water Quality Action Team’s websites for additional information about LID approaches and links to demonstration projects and research activities. The Washington State Department of Transportation also proposes to include a section on LID techniques for roads in the next revision of the *Highway Runoff Manual*.

Local jurisdictions may require detention basins to be designed to match the 10-year peak flow in addition to 50% of the two-year peak flow and the full 25-year peak flow. The purpose of this design specification is to improve the function of the detention basin in matching predeveloped peaks between 50% of the two-year peak flow and the full 25-year peak flow and possibly reduce the size of the detention facility.

Local jurisdictions may engage in basin planning, studies, zoning restrictions etc. that result in watershed- or reach- specific changes to the requirements of this Core Element.

Additional exemptions to this Core Element may be granted to projects discharging to surface water where the long-term, projected total man-made impervious surface area in the contributing watershed is less than 5% of the total area, and at least 65% of the natural vegetative cover is retained. This determination must be based on current and probable future zoning requirements and build out conditions as determined through a basin analysis conducted by the local jurisdiction (see below). This analysis could also be done for a road project in a rural area; although dispersion (see Chapter 6, particularly BMP T5.30) would be preferable to conveyance of runoff to a non-exempt stream.

Local jurisdictions may also exempt a project discharging to a seasonal stream where downstream analysis has concluded that the stream channel morphology was established by past glacial or catastrophic flooding events and the stream channel is capable of carrying a larger frequent streamflow without incision or widening. The stream must not discharge via surface flow to a non-exempt stream.

Suggested Approach for Additional Exemptions

In order for a jurisdiction to exempt other water bodies or reaches from flow control requirements, the local jurisdiction must provide scientific justification for the exemption. (The exemption may apply only to restricted areas within a watershed.) This means the jurisdiction must determine that under probable build-out conditions in the watershed, disregarding this Core Element will not adversely affect the receiving waters. Adverse impacts are expected from uncontrolled flows causing a significant increase in the 1.5- to 2-year recurrence interval peak instream flow rate. Documentation must be provided showing that significant increases in instream flow rates will not take place under the maximum projected development condition for the contributing watershed. The documentation should at least include the following elements:

- Analysis of available historical streamflow data for the water body (for a lake, the outlet stream may be the primary water body of interest for flow control) and hydrologic modeling of the watershed under both undeveloped and projected future build-out conditions.
- Observation of downstream channel conditions including assessment of the geomorphic conditions, instream habitat and resident benthic community.
- Maps or geographic analyses showing:
  - current and probable future zoning (with definitions for density of development in each category);
  - the portion of watershed under the jurisdiction of the petitioner;
  - projected total man-made impervious surface areas; and
  - area of native vegetation preserved under probable future build-out conditions.
- Description of the watershed planning efforts undertaken by the petitioning jurisdiction and cooperative planning efforts undertaken with other agencies and jurisdictions with authority in the watershed.

A local jurisdiction also should consider and utilize the above information in planning and designing a regional flow facility, and in particular for determining the appropriate capacity and operation requirements of the facility.

Responsibilities of Local Jurisdictions

During plan review, local jurisdictions should evaluate whether the objectives of this Core Element have been met. Local jurisdictions should establish design criteria for conveyance systems, flood protection, and drywells and other UIC facilities.

In particular, local governments should determine whether the default design criterion of the 25-year runoff volume for detention/retention flow control facilities is appropriate to meet local flood protection goals and, if it is not, establish a different upper boundary design criterion.

Local governments should consider establishing an impervious area threshold below which projects are not required to provide flow control facilities. The exemption should be based on an evaluation for the local area of the amount of impervious surface area necessary to generate an appreciable change in runoff from the 6-month and 2-year regional storm events. Alternatively, a project generating less than 0.1 cfs increase in runoff for the 25-year regional storm could be exempt.

Local governments should also determine whether the default design criteria for drywells in Chapter 6 are appropriate to meet local goals. In particular, knowledge of local geology and groundwater levels may lead to specific siting and infiltration capacity requirements, or to development of presumptive infiltration rates for certain areas in the local jurisdiction. These criteria and local information should be made readily available to designers.

2.2.7 Core Element #7 Operation and Maintenance

Objective

Inadequate maintenance or improper operation is a common cause of failure for stormwater facilities, including drywells. To ensure that stormwater control facilities are adequately maintained and properly operated, projects are required to plan for and perform appropriate preventive maintenance and performance checks at regular intervals.

Guidelines

Where structural BMPs are required, projects shall operate and maintain the facilities in accordance with an Operation and Maintenance (O&M) plan that is prepared in accordance with the provisions in Chapters 5 and 6 of this Manual. The O&M plan shall address all proposed stormwater facilities and BMPs, and identify the party (or parties) responsible for maintenance and operation; the O&M plan must also address the long-term funding mechanism that will support proper O&M. At private facilities, a copy of the plan shall be retained onsite or within reasonable access to the site, and shall be transferred with the property to the new owner. For public facilities, a copy of the plan shall be retained in the appropriate department. A log of maintenance activity that indicates what actions were taken shall be kept and be available for inspection by the local jurisdiction.

The local jurisdiction may develop a generic O&M plan for BMPs that are commonly used in public projects; commercial and residential property developers may also develop generic O&M plans for BMPs that are commonly used in their projects. Checklists of O&M actions and procedures may be helpful to the operators.

Applicability to UIC facilities

This Core Element is required for all projects with discharges to drywells and other UIC rule-authorized subsurface infiltration systems that require a two-stage drywell or runoff pre-treatment (see Chapter 5.6).

Supplemental Guidelines

The description of each BMP in Chapters 5, 6, and 7 of this Manual includes a section on maintenance. Chapter 6 includes a schedule of maintenance standards for drainage facilities. Local jurisdictions should consider more detailed requirements for maintenance logs, such as a record of where wastes are disposed.

Responsibilities of Local Jurisdictions

As part plan review and approval, local jurisdictions should consider requiring a performance bond for operation and maintenance of BMPs at the site (see Section 2.3.1 Financial Liability). Staff can enforce proper operation and maintenance requirements during site inspections or in response to complaints about a site or facility.

2.2.8 Core Element #8
Local Requirements

Objective

This manual describes the minimum Core Elements for stormwater management at project sites in eastern Washington. Due to the variety in hydrology, climate, topography, soils, and priorities for protection of water resources in some areas of eastern Washington, discretion is provided to local jurisdictions in expanding and implementing stormwater requirements.

Guidelines

All projects, regardless of size, shall meet additional local requirements for flood control, discharges to wetlands, protection of sensitive areas, basin plans, aquifer protections, special water quality requirements based on Total Maximum Daily Load (TMDL) or Water Clean-up Plan, or for any other purpose. Check with the local jurisdiction for the local requirements that are applicable to your project.

Applicability to UIC facilities

This Core Element is required for all projects with discharges to drywells and other UIC rule-authorized subsurface infiltration systems.

Responsibilities of Local Jurisdictions

The following specific local requirements, if identified, should be made readily available to project proponents and designers:

- Simplified Stormwater Site Plans (SSPs) or Construction Stormwater Pollution Prevention Plans (SWPPPs) that may have been developed for specific types of projects;
- Actions required under current water clean-up plans (such as TMDLs) or other measures necessary to protect or restore water quality
- Sole-source aquifer protection requirements and(or) well-head protection area requirements;

- Preferred methods for calculating runoff volumes and flow rates to ensure consistent sizing of treatment BMPs within the jurisdiction;
- Development and testing of new treatment methodologies that may be underway;
- Information on Low Impact Development (LID) techniques that could reduce the amount of impervious surface area at projects;
- Design criteria for conveyance systems and flood prevention;
- Design criteria for drywells, particularly infiltration capacity requirements; and related local geologic information;
- Any alternative impervious area or other threshold below which projects are not required to provide flow control facilities;
- Additional exemptions (or exceptions) to the list of exempt surface waters;
- Detailed operation and maintenance requirements; and
- Any other adjustments to the Core Elements or to the Redevelopment requirements in Section 2.1.2.

2.3 Optional Guidance

The following guidance is offered as recommendations to local jurisdictions.

2.3.1 Financial Liability

Performance bonding or other appropriate financial guarantees should be required for all projects to ensure construction of drainage facilities in compliance with these standards. The type of financial instrument required is less important than ensuring there are adequate funds available in the event that performance is unsatisfactory or non-compliance occurs.

2.3.2 Adjustments

Adjustments to the Core Elements may be granted prior to permit approval and construction. The drainage manual administrator of the local jurisdiction may grant an adjustment provided that a written finding of fact is prepared, that addresses the following:

- The adjustment provides substantially equivalent environmental protection, and
- The objectives of safety, function, environmental protection and facility maintenance, based upon sound engineering, are met.

2.3.3 Thresholds

Local jurisdictions may decrease the size of regulated projects and increase the number of requirements.

Table of Contents

Chapter 3 - Preparation of Stormwater Site Plans

3.1 Introduction

The Stormwater Site Plan is the comprehensive report containing all of the technical information and analysis necessary for regulatory agencies to evaluate a proposed new development or redevelopment project for compliance with stormwater requirements. Contents of the Stormwater Site Plan will vary with the type and size of the project, individual site characteristics, and special requirements of the local jurisdiction.

The scope of the Stormwater Site Plan also varies depending on the applicability of Core Elements (see Chapter 2).

This chapter describes the contents of a Stormwater Site Plan and provides a general procedure for how to prepare the plan. The specific BMPs and design methods and standards to be used are contained in Chapters 4 to 8.

The goal of this chapter is to provide a framework for uniformity in plan preparation. Such uniformity will promote predictability throughout the region and help secure prompt governmental review and approval. Properly drafted engineering plans and supporting documents will also facilitate the operation and maintenance of the proposed system long after its review and approval.

State law requires that engineering work be performed by or under the direction of a professional engineer licensed to practice in Washington State. Plans involving construction of treatment facilities or flow control facilities (detention ponds or infiltration basins), structural source control BMPs, or drainage conveyance systems generally involve engineering principles and shall be prepared by or under the direction of a licensed engineer. Construction Stormwater Pollution Prevention Plans (SWPPPs) that involve engineering calculations must also be prepared by or under the direction of a licensed engineer.

3.2 Stormwater Site Plans: Step-By-Step

3.2.1 The Steps to Developing a Stormwater Site Plan

Four basic steps should be followed during the preparation of a stormwater site plan.

Step 1 – Collect and Analyze Information on Existing Conditions

Step 2 – Determine Applicable Core Elements

Step 3 – Prepare a Permanent Stormwater Control Plan

Step 4 – Prepare a Construction Stormwater Pollution Prevention Plan.

Steps 1 and 2 are qualtitative in nature, while Steps 3 and 4 synthesize the information gathered in Steps 1 and 2 into practical designs. Additional information on data collection and investigation can be found in Design and Construction of Urban Stormwater Management Systems, ASCE, 1992. The level of detail needed for each step depends upon the project size, as explained in the individual steps. A narrative description of each of these steps follows.

Step 1 – Collect and Analyze Information on Existing Conditions

Collect and review information on the existing site conditions, including topography, drainage patterns, soils, ground cover, presence of critical areas, adjacent areas, existing development, existing stormwater facilities, and adjacent on- and off-site utilities. Analyze data to determine site limitations including:

- Areas with high potential for erosion and sediment deposition (based on soil properties, slope, etc.);
- Locations of sensitive and critical areas (e.g. vegetative buffers, wetlands, steep slopes, floodplains, geologic hazard areas, streams, etc.); and
- Observation of potential runoff contribution from off-site basins.

Delineate these areas on the site map required as part of Step 3, Prepare a Permanent Stormwater Control Plan. Prepare an Existing Conditions Summary that will be submitted as part of the Site Plan. Part of the information collected in this step should be used to help prepare the Construction Stormwater Pollution Prevention Plan.

Downstream Analysis and Mitigation Procedure (for projects with surface discharge only)

Development projects that propose to discharge stormwater offsite are required to submit a downstream analysis report that assesses the potential off-site water quality, erosion, slope stability, and drainage impacts associated with the project and that proposes appropriate mitigation of those impacts. Projects that do not discharge stormwater offsite do not need to perform a downstream analysis. An initial qualitative analysis should extend downstream for the entire flow path from the project site to the receiving water or up to one mile or to a point where the impact to receiving waters are minimal or nonexistent as determined by the local jurisdiction. If a receiving water is within one-quarter mile, the analysis should extend within the receiving water to one-quarter mile from the project site. The analysis should extend one-quarter mile beyond any improvements proposed as mitigation. The analysis should extend upstream to a point where backwater effects created by the project cease. Upon review of the qualitative analysis, the local jurisdiction may require that a quantitative analysis be performed. A full description of a typical downstream analysis procedure, along with a sample checklist to aid in the preparation and review of a downstream analysis, are included in Appendix 3A.

Step 2 – Determine and Read the Applicable Core Elements

The NPDES Phase II permit or local jurisdiction establishes project size thresholds for the application of Core Elements (in Chapter 2), to new development and redevelopment projects. The designer of the Stormwater Site Plan should meet with local officials to agree on the applicable Core Elements, prior to proceeding to Step 3.

Step 3 – Prepare a Permanent Stormwater Control Plan

Select stormwater control BMPs and facilities that will serve the project site in its developed condition. The designer may want to consider the use of landscaping and/or low impact development techniques for stormwater quantity and quality control. The local jurisdiction may have landscaping or low impact development policies and they should be incorporated where required. Several references are available on the topic of low impact development:

http://www.lowimpactdevelopment.org/

http://www.epa.gov/owow/nps/lidlit.html

http://www2.ncsu.edu/ncsu/CIL/WRRI/news/so00lowimpactmanuals.html

A preliminary design of the BMPs and facilities is necessary to determine how they will fit within and serve the entire preliminary development layout. After a preliminary design is developed, the designer may want to reconsider the site layout to reduce the need for construction of facilities, or the size of the facilities by reducing the amount of impervious surfaces created and increasing the areas to be left undisturbed. After the designer is satisfied with the BMP and facilities selections, the information must be presented within a Permanent Stormwater Control Plan. The Permanent Stormwater Control Plan typically consists of a Drainage Report and a set of Construction Plans.

Drainage Report

The Drainage Report is to be inclusive, clear, legible, and reproducible, with a complete set of drainage computations. The computations are to be presented in a rational format with information included so as to allow a reviewer to be able to reproduce the same results. The computations should provide sufficient information for an unbiased third party to be able to review the report and determine that all applicable standards have been met. All assumptions and computer input and output data, and variables listed in the computer printouts, should be clearly identified. Computer printouts should clearly show which subbasin(s) they are applicable to, and the design storm event identified thereon if multiple-storm events are addressed in the design. Copies of design charts, nomographs or other design aids used in the analysis should be included in the calculations.

All relevant geotechnical information related to the project, and all site specific soil logs and subsurface testing information should be included in the Drainage Report or provided in a separate report prepared and stamped by the geotechnical engineer.

The Drainage Report should also include a basin map. Under most conditions both a pre-developed basin map and post-developed basin map should be provided, unless deemed unnecessary by the local jurisdiction. See Appendix 3B for a checklist of items to be included on the basin map.

The Drainage Report is to identify existing drainage facilities which are clearly inadequate or need repair, such as collapsed culverts or culverts with a substantial amount of debris. The condition and capacity of existing drainage facilities located onsite, which are proposed to be utilized by the development, should be evaluated and disclosed in the drainage report.

Calculations for detention and infiltration ponds may include the following: inflow and outflow hydrographs, level-pool routing calculations, a listing of the maximum water surface elevation, a pond volume rating table (e.g., stage vs. storage), and discharge rating table (e.g., stage vs. discharge). Each hydrograph and level-pool routing calculation sheet is to have clearly marked: the design storm event, the applicable subbasin(s), and the pond identification name, which corresponds with the basin map and plans.

The drainage submittal should incorporate all calculations for the determination of the required size of the systems. Typical calculations include:

- Hydrology computations
- Inlet capacities
- Detention/Retention storage capacities
- Culvert and pipe system capacities and outlet velocities
- Ditch capacities and velocities
- Map with the project plotted thereon

A copy of applicable floodplain maps, or studies within the project area should be included in the Drainage Report.

Construction Plans

Construction plans should be prepared for all open and closed stormwater collection systems. The plans should call out sufficient hydraulic and physical data for construction of the system, and future evaluation of the design. A checklist describing many of the items typically shown on construction plans is included in Appendix 3C.

Step 4 – Prepare a Construction Stormwater Pollution Prevention Plan

The Construction SWPPP must contain sufficient information to satisfy the local jurisdiction that the potential pollution problems have been adequately addressed for the proposed project. An adequate Construction

SWPPP includes a narrative and drawings. The narrative is a written statement that explains the pollution prevention decisions made for a particular project. The narrative contains concise information concerning existing site conditions, construction schedules, and other pertinent items that are not contained on the drawings. The drawings and notes describe

where and when the various BMPs should be installed, the performance the BMPs are expected to achieve, and actions to be taken if the performance goals are not achieved.

The 12 Elements listed below must be considered in the development of the Construction SWPPP unless site conditions render the element unnecessary and the exemption from that element is clearly justified in the narrative of the Construction SWPPP. These elements are described in detail in Chapter 7. They cover the general water quality protection strategies of limiting site impacts, preventing erosion and sedimentation, and managing activities and sources.

The 12 Elements are:

- Mark Clearing Limits
- Establish Construction Access
- Control Flow Rates
- Install Sediment Controls
- Stabilize Soils
- Protect Slopes
- Protect Drain Inlets
- Stabilize Channels And Outlets
- Control Pollutants
- Control De-Watering
- Maintain BMPs
- Manage the Project

A complete description of each Element and the BMPs applicable to particular Elements are given in Chapter 7.

On construction sites that discharge to surface water, the primary consideration in the preparation of the Construction SWPPP is compliance with the State Water Quality Standards. The step-by-step procedure outlined in Chapter 7 is recommended for the development of these Construction SWPPPs. A checklist is contained in Chapter 7 that may be helpful in preparing and reviewing the Construction SWPPP.

On construction sites that infiltrate all stormwater runoff, the primary consideration in the preparation of the Construction SWPPP is the protection of the infiltration facilities from fine sediments during the construction phase and protection of ground water from other pollutants. Several of the other elements are very important at these sites as well, such as marking the clearing limits, establishing the construction access, and managing the project.

Under current federal regulations, if a project disturbs greater than one acre and discharges to surface water, the local jurisdiction may require review and approval of the SWPPP prior to construction.

3.2.2 Plans Required After Stormwater Site Plan Approval

This section includes the specifications and contents required of those plans submitted after the local government agency with jurisdiction has approved the original Stormwater Site Plan.

Stormwater Site Plan Changes

If the designer wishes to make changes or revisions to the originally approved stormwater site plan, the proposed revisions should be submitted to the local jurisdiction with review authority prior to construction. The submittals should include the following:

1. Brief narrative description of the change and the purpose/reason for the change.
2. Substitute pages of the originally approved Stormwater Site Plan that include the proposed changes.
3. Revised drawings showing structural changes.
4. Other supporting information that explains and supports the reason for the change.

Final Corrected Plan Submittal

If the project included construction of conveyance systems, treatment facilities, flow control facilities, or structural source control BMPs, the applicant should submit a final corrected plan (Record Drawings) to the local government agency with jurisdiction when the project is completed. These should be engineering drawings that accurately represent the project as constructed. These corrected drawings must be legibly drafted revisions that are stamped, signed, and dated by a licensed engineer registered in the state of Washington.

Appendix 3A – Downstream Analysis

Objective: To identify and evaluate potential offsite water quality, erosion, slope stability, and drainage impacts that could result from the proposed project, and to determine measures to mitigate potential impacts or mitigate aggravating existing problems. Aggravated means increasing the frequency of occurrence and/or severity of an already existing problem.

Guidelines: Some of the common negative impacts of land development can be erosion of downgradient properties, localized flooding, and slope failures. These are caused by increased surface water volumes and changed runoff patterns. Taking the precautions of offsite analysis can reduce future property damage and public safety risks.

The existing or potential impacts to be evaluated and mitigated should include:

- Conveyance system capacity problems;
- Localized flooding;
- Upland erosion impacts, including landslide hazards;
- Stream channel erosion at the outfall location;
- Violations of surface water quality standards as identified in a Basin Plan or a TMDL (Water Clean-up Plan); or violations of ground water standards in a wellhead protection area, or any other known violation that exists.

Projects are required to initially submit, with the permit application, a qualitative analysis of each downstream system leaving the site. The analysis should accomplish four tasks:

Task 1 – Define and map the study area.

A submission of a site map showing site property lines; a topographic map (at a minimum a USGS 1:24000 Quadrangle Topographic map) showing site boundaries, study area boundaries, downstream flowpath, and potential/existing problems.

Task 2 – Review all available information on the study area.

This should include all available basin plans, ground water management area plans, drainage studies, floodplain/floodway FEMA maps, wetlands inventory maps, Critical Areas maps, stream habitat reports, etc.

Task 3 – Field inspect the study area.

The design engineer should physically inspect the existing on- and offsite drainage systems of the study area for existing or potential problems and drainage features. An initial inspection and investigation should include:

- Investigate problems reported or observed during the resource review
- Locate existing/potential constrictions or capacity deficiencies in the drainage system
- Identify existing/potential flooding problems
- Identify existing/potential overtopping, scouring, bank sloughing, or sedimentation
- Identify significant destruction of aquatic habitat (e.g., siltation, stream incision)
- Collect qualitative data on features such as land use, impervious surface, topography, soils, presence of streams, wetlands
- Collect information on pipe sizes, channel characteristics, drainage structures
- Verify tributary drainage areas identified in Task 1
- In some cases it may be required or appropriate to contact the local jurisdiction with drainage review authority, neighboring property owners, and residents about drainage problems
- Note date and weather at time of inspection

Task 4 – Describe the drainage system, and its existing and predicted problems.

For each drainage system component (e.g., pipe, culvert, bridges, outfalls, ponds, vaults) the following should be covered in the analysis: location, physical description, problems, and field observations. All existing or potential problems (e.g., ponding water, erosion) identified in Tasks 2 and 3 above should be described. The descriptions should be used to determine whether adequate mitigation can be identified, or whether more detailed quantitative analysis is necessary. The following information should be provided for each existing or potential problem:

- Magnitude of or damage caused by the problem
- General frequency and duration
- Return frequency of storm or flow when the problem occurs (may require quantitative analysis)
- Water elevation when the problem occurs
- Names and concerns of parties involved
- Current mitigation of the problem
- Possible cause of the problem
- Whether the project is likely to aggravate the problem or create a new one.

Upon review of this analysis, the local government may require mitigation measures to address the problems, or a quantitative analysis, depending upon the presence of existing or predicted flooding, erosion, or water quality problems, and on the proposed design of the onsite drainage facilities. The analysis should repeat Tasks 3 and 4 above, using quantitative field data including profiles and cross-sections.

The quantitative analysis should provide information on the severity and frequency of an existing problem or the likelihood of creating a new problem. It should evaluate proposed mitigation intended to avoid aggravation of the existing problem and to avoid creation of a new problem.

Appendix 3B – Basin Maps

PROJECT: ____

LOCATION: ____

DESIGNER: ____________________________ **COMPANY:** _______________________

DATE: __________________________________

The following items should be included on pre-developed and post-developed basin maps:

- Site boundary
- Basin limits, both on-site and off-site areas which contribute or receive stormwater runoff onto or from the project, field verified by the engineer.
- Drainage sub-basins. All sub-basins should be clearly labeled and correlated with the calculations.
- Topographic contours, which should extend beyond the project or drainage basin boundaries to the extent necessary to confirm basin limits used in the calculations; or, in the absence of topographic mapping being available, the Engineer may field verify the basin limits, including contributing off-site areas, and should describe how the basin limits were determined.
- Significant drainage features, natural or man-made, such as creeks, seasonal drainage channels, culverts, closed depressions, manholes, etc.
- Time of concentration routes, clearly labeled and correlated with the calculations.
- Footprint of proposed drainage features, such as ponds, vegetated or other infiltration facilities, pipe routes, ditches, etc.
- Indications of floodplain limits, as defined by FEMA or other studies.
- North arrow and scale bar.
- Wetlands
- Existing easements

Appendix 3C – Stormwater Construction Plans

PROJECT: ____

LOCATION: ____

DESIGNER: ____________________________ COMPANY: _______________________

DATE: _________________________________

The following items should be included on stormwater construction plans, as applicable:

Ã A plan-profile of all key drainage systems, including streets, roads, and drainage facilities.

Ã Elevation Datum

Ã North Arrow

Ã Right-of-Way details

Ã Outfall details

Ã Ditch details

Ã Invert elevations, slopes and lengths of ditches

Ã Cross sections of all open ditches

Ã Elevations of all inlet grates

Ã Size, types, invert elevations and lengths of all culverts and pipe systems

Ã Invert elevations of the existing or other proposed drainage system to which the drainage plan proposes to connect.

Ã Stationing of all inlets, culverts and pipe systems angle points

Ã Invert elevations of pipes at all structures such as catch basins or manholes

Ã Construction details for inlets, drywells, detention facilities, etc. (notes referring to Standard plans may suffice where applicable)

Ã Drainage easements shown, with key dimensions for depicting location, width, and length.

Ã The location of existing underground and above ground utilities

Ã Lot grading elevations where appropriate

Ã Grading plan for drainage ponds. The grading plan should include existing contours, proposed contours and catch points. A typical cross-section of the pond should be provided in the plans, showing bottom of pond elevation, maximum water surface elevation for the design storm(s), inlet and outlet elevations, berm elevation and slopes, and keyway location and dimensions.

- Ã Drainage ponds, pipe inlets and outlets, ditches, and drainage structures, which are serving public roads or are in single-family residential neighborhoods, should be horizontally defined with respect to property corners, street stationing, or a coordinate system.
- Ã Drainage ditches should have their longitudinal grades defined with either a profile or elevation grades at intervals of 50 feet. Ditch centerlines and flow directions should be also be illustrated.
- Ã Summary of short and long-term operation and maintenance requirements

Table of Contents

Chapter 4 - Hydrologic Analysis and Design

4.1 Introduction

4.1.1 Purpose

The purpose of this chapter is to provide guidance for sizing (1) runoff treatment facilities for subsurface infiltration systems and surface water discharges; and (2) flow control facilities for protection of stream morphology. The chapter does not provide guidance for sizing flood control facilities, conveyance systems, or subsurface infiltration facilities (drywells), though these methods may be used. Contact the local jurisdiction regarding design requirements for these elements.

4.1.2 Hydrologic Analysis Methods and Applicability

The local jurisdiction may approve one or more of the following methods to analyze stormwater runoff from projects for design of runoff treatment and flow control BMPs subject to these Guidelines:

- Single Event Hydrograph Methods including SCS Hydrograph and Santa Barbara Urban Hydrograph (SBUH)
- SCS Curve Number Equations
- Level Pool Routing
- Rational Method
- Other Hydrograph Models Approved by Local Jurisdictions

Table 4.1.1 summarizes the situations in which each of these methods may be used.

Sections 4.4 through 4.7 describe the use of the Rational, SCS Curve Number Equations, Single Event Hydrograph, and Level Pool Routing methods in greater detail.

Other hydrograph models that are approved by local jurisdictions should be peer-reviewed and supported by local data; some may require special expertise and experience in their application. Local jurisdictions may also approve custom local design storms that are based on local historical data and applied in a manner that meets the objectives of Core Elements #5 Runoff Treatment and #6 Flow Control in Chapter 2.

Table 4.1.1
Applicability of Hydrologic Analysis Methods
For Runoff Treatment and Flow Control Design

Method	**Application**
Single Event Hydrograph Method – Soil Conservation Service (SCS) Hydrograph or Santa Barbara Urban Hydrograph (SBUH)	Allowable method for computing peak runoff rates and runoff volumes for design of runoff treatment BMPs. Required method for design of flow control BMPs. Computer is recommended due to intensive nature of calculations. Some SCS hydrograph models such as TR-55 are restricted to 24-hour hyetographs and will not allow the custom long and short-duration storm hyetographs developed for Eastern Washington.
Soil Conservation Service (SCS) Curve Number Equations	Allowable method for computing volumes for water quality facilities based on SCS Hydrograph method. Can be determined using a calculator.
Level-Pool Reservoir Routing	Required method for routing hydrograph and determining size of flow control BMPs. Input may be SCS or SBUH hydrographs. Computer is recommended due to intensive nature of calculations.
Rational	Allowable method for computing peak runoff rates for flow based water quality BMPs such as biofiltration swales and oil/water separators. Common method for calculating peak flows for the design of drywells and conveyance systems. Can be determined using a calculator or spreadsheet program.
Other Rainfall-Runoff Models that generate a Hydrograph	Other models can be used if approved by the local jurisdiction and the models provide equivalent treatment levels. Computer is recommended for most models due to intensive nature of calculations.

4.1.3 Hydrologic Analysis for Core Element #5 – Runoff Treatment

Runoff treatment BMPs are utilized to treat the stormwater runoff from pollutant generating surfaces. Core Element #5 in Chapter 2 identifies the design storm that needs to be treated. Each treatment BMP is sized based on a water quality design volume, or a water quality design flow rate. Local jurisdictions should adopt criteria to provide for consistent sizing of treatment facilities. The methods for predicting post-development runoff volumes and flow rates are included in this chapter of the Manual. Specific design criteria for treatment facilities also may be identified in Chapter 5 in order to achieve the performance goal of a particular BMP.

4.1.4 Hydrologic Analysis for Core Element #6 – Flow Control

Core Element #6 in Chapter 2 identifies the design storms that need to be matched when designing flow control BMPs. It also lists projects that are exempt from flow control. In order to design a flow control BMP, a hydrograph model needs to be run for the existing and developed conditions. The suggested hydrograph method is the Single Event Hydrograph such as SCS or SBUH method, however local jurisdictions are authorized to use other methods or more stringent design storm criteria.

4.2 Design Storm Distributions

The design storms to be used in Eastern Washington are based on two parameters:

- Total rainfall volume (depth in inches).
- Rainfall distribution (dimensionless).

The design storm event is specified by return period (months and/or years) and duration. The following sections explain total rainfall depth and rainfall distribution associated with a design storm.

All storm event hydrograph methods require the input of a rainfall distribution or design storm hyetograph. The design storm hyetograph is essentially a plot of rainfall depth versus time for a given design period and duration. It is usually presented as a dimensionless plot of unit rainfall depth (incremental rainfall depth for each time interval divided by the total rainfall depth) versus time.

Design storm distribution for all Regions (1, 2, 3, 4):

- Option 1: the short-duration storm distribution.
- Option 2: the regional long-duration storm distribution.
- Option 3: the SCS Type IA storm distribution.
- Option 4: the SCS Type II storm distribution.
- Option 5: allow the design criteria currently in use by the local jurisdictions to be used.

Additional design storm distribution for Region 2:

- Option 6: identify a storm distribution for areas with less than 10 inches per year of average annual precipitation and apply the Region 3 storm distribution to sites with more than 10 inches of average annual precipitation.

4.2.1 SCS Type II and Type IA Hyetographs

The Type II hyetograph is a standard SCS (NRCS) rainfall distribution that has a high intensity peak and has been utilized in Eastern Washington since the 1970's, and is also used throughout much of the United States. The Type IA hyetograph is also a standard NRCS rainfall distribution. It is applicable to Western Washington and the eastern slopes of the Cascade Mountains. These are two of four 24-hour storm distribution types commonly used in SCS hydrograph methods.

See Figure 4.2.1 and 4.2.2 for graphical representation of these two SCS hyetographs. Tabular values of these hyetographs are in Table 4.2.2 and 4.2.3.

FIGURE 4.2.1
SCS Type IA Hyetograph

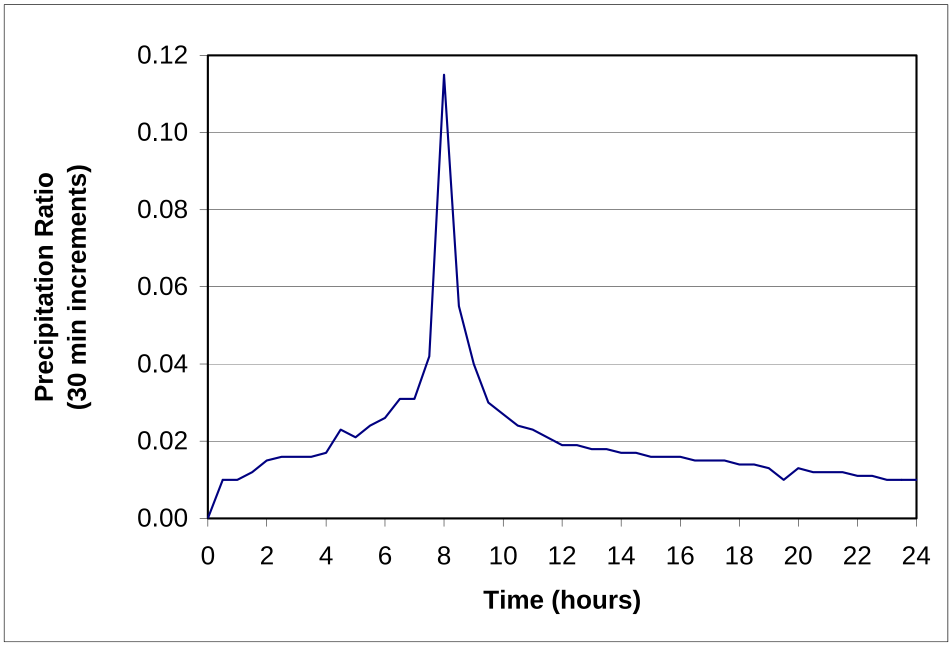
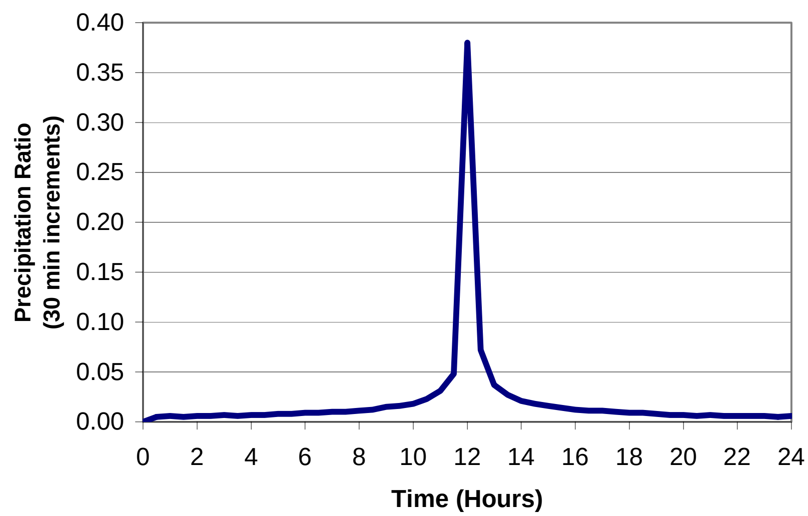


FIGURE 4.2.2
SCS Type II Hyetograph



4.2.2 Custom Design Storm Hyetographs

Rainfall patterns during storms were analyzed in Eastern Washington. See Appendix 4A. It was concluded that the SCS Type II rainfall distribution does not match the historical records for two custom storm types of interest for stormwater analyses in eastern Washington: the short-duration thunderstorm and the long-duration winter storm.

Short-duration thunderstorms can occur in the late spring through early-fall seasons and are characterized by high intensities for short periods of time over localized areas. These types of storms can produce high rates of runoff and flash flooding in urban areas and are important where flood peak discharge and/or erosion are design considerations.

Long-duration general storms can occur at anytime of the year, but are more common in the late-fall through winter period, and in the late-spring and early-summer periods. General storms in eastern Washington are characterized by sequences of storms and intervening dry periods, often occurring over several days. Low to moderate intensity precipitation is typical during the periods of storm activity. These types of events can produce floods with moderate peak discharge and large runoff volumes. The runoff volume can be augmented by snowmelt when precipitation falls on snow during winter and early-spring storms. These types of storm events are important where both runoff volume and peak discharge are design considerations.

When utilizing the custom design storms, it is necessary to note that Eastern Washington has been divided into four climatic regions to reflect the differences in storm characteristics and the seasonality of storms. The four climatic regions (Figure 4.3.1) include:

Region 1 – East Slopes of Cascade Mountains

This region is comprised of mountain areas on the east slopes of the Cascade Mountains. It is bounded to the west by the Cascade crest and generally bounded to the east by the contour line of 16-inches mean annual precipitation.

Region 2 – Central Basin

The Central Basin region is comprised of the Columbia Basin and adjacent low elevation areas in central Washington. It is generally bounded to the west by the contour line of 16-inches mean annual precipitation at the base of the east slopes of the Cascade Mountains. The region is bounded to the north and east by the contour line of 12-inches mean annual precipitation. The majority of the area in this region receives about eight inches of mean annual precipitation. Many of the larger cities in eastern Washington are in this region including: Ellensburg, Kennewick, Moses Lake, Pasco, Richland, Wenatchee, and Yakima.

Region 3 – Okanogan, Spokane, Palouse

This region is comprised of inter-mountain areas and includes areas near Okanogan, Spokane, and the Palouse. It is bounded to the northwest by the contour line of 16-inches mean annual precipitation at the base of the east slopes of the Cascade Mountains. It is bounded to the south and west by the contour line of 12-inches mean annual precipitation at the eastern edge of the Central Basin. It is bounded to the northeast by the Kettle River Range and Selkirk Mountains at approximately the contour line of 22-inches mean annual precipitation. It is bounded to the southeast by the Blue Mountains also at the contour line of 22-inches mean annual precipitation.

Region 4 – Northeastern Mountains and Blue Mountains

This region is comprised of mountain areas in the easternmost part of Washington State. It includes portions of the Kettle River Range and Selkirk Mountains in the northeast, and includes the Blue Mountains in the southeast corner of eastern Washington. Mean annual precipitation ranges from a minimum of 22-inches to over 60-inches. The western boundary of this region is the contour line of 22-inches mean annual precipitation.

4.2.3 Storm Analysis

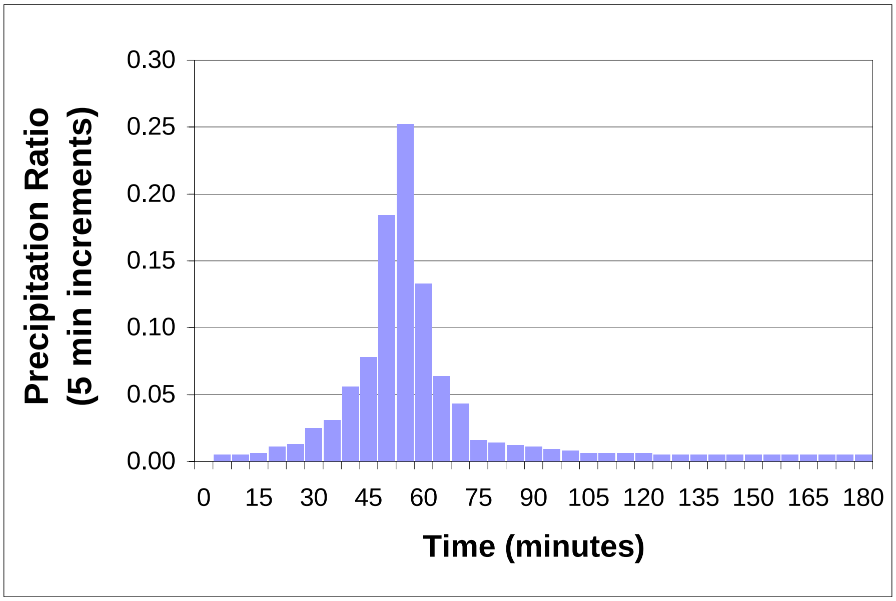
It was concluded, based upon analyses of historical storms in Eastern Washington, that the short-duration summer thunderstorm typically generates the greatest peak discharges for small urban watersheds. Use of short-duration thunderstorms are therefore appropriate for design of conveyance structures and biofiltration swales. Those analyses also indicate that the long-duration winter storm typically generates the greatest runoff volume. Long-duration design storms are therefore appropriate for design of stormwater detention and water quality treatment facilities where runoff volume is the primary concern.

Based on these analyses, synthetic design storms were developed for the short-duration thunderstorm and long-duration winter storm. The design storms were developed in a manner that replicated temporal characteristics observed in storms from areas climatologically similar to Eastern Washington.

Short-Duration Storm

Short durations, high intensity, and smaller volumes relative to winter storms characterize summer thunderstorms. The short-duration storm was selected to be 3 hours in duration. The storm temporal pattern is shown in Figure 4.2.3 as a unit hyetograph. Tabular values are listed in Table 4.2.4. Total precipitation is 1.06 times the 2-hour precipitation amount. There is one short-duration storm for all climate regions in Eastern Washington.

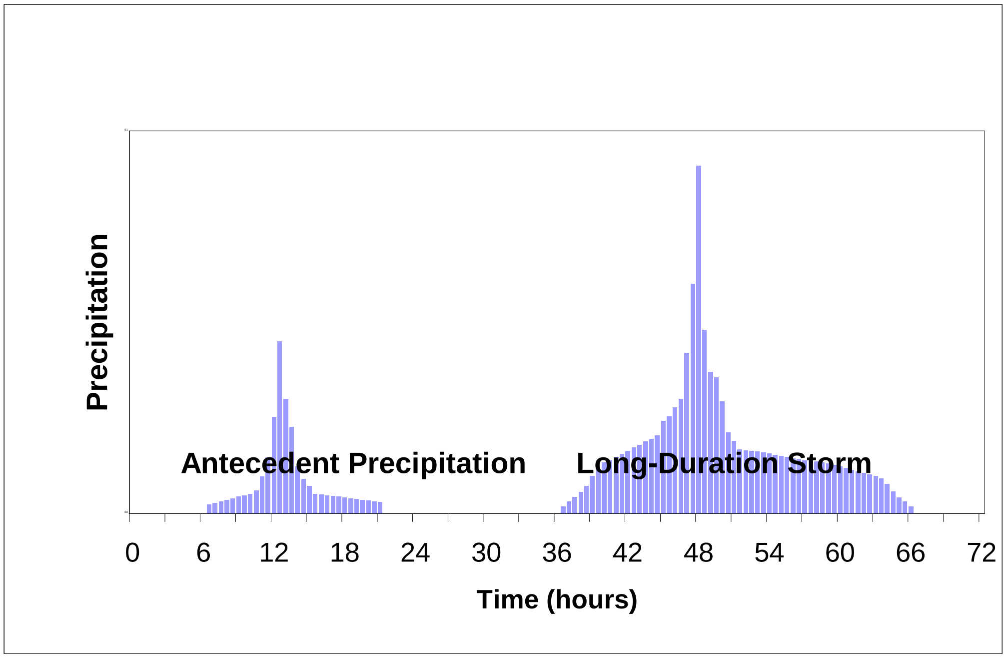
FIGURE 4.2.3
Short-Duration Storm Unit Hyetograph



Long-Duration Storm (Varies by Region)

The long-duration storm varies by region and is comprised of a series of storm events separated by a dry intervening period, occurring during a 72-period of time. A sample 72-hour long-duration storm hyetograph is shown in Figure 4.2.4.

FIGURE 4.2.4
Sample Long-Duration Storm Hyetograph



The smaller event (from 6 to 21 hours above) is insufficient to generate runoff that is present when the larger precipitation commences. For that reason, it is not necessary to directly model the smaller precipitation event. Only the larger portion (commencing at 36 hours as shown above) is necessary to directly model.

The larger portion is similar to the 24-hour SCS Type IA storm. For all regions, the SCS Type IA storm is sufficiently similar to the four regional long-duration storm hyetographs to use directly.

Local jurisdictions may choose to use the regional long-duration hyetographs or the 24-hour SCS Type IA hyetograph. For Regions 3 and 4, the differences are very minor. Precipitation total is no more than seven percent more than the 24-hour SCS Type IA storm and durations are slightly longer. For Region 2 there are no measurable differences in precipitation total and duration. For Region 1, the differences are greater, with precipitation being 16 percent greater than the 24-hour SCS Type IA storm and duration being more than 40% longer. With the regional long-duration hyetographs having more total precipitation but spread over more time than the 24-hour SCS Type IA, computed peak flows and hydrographs tend to be reasonably similar.

Tabular values of the regional long-duration storm hyetographs are listed in Table 4.2.5 to 4.2.8.

For the long-duration storm, if the 24-hour SCS Type IA storm is used, the precipitation totals are the 24-hour amounts without adjustment. If the regional long-duration hyetographs are used, then the precipitation totals need to be adjusted as indicated for Regions 1, 3, and 4.

Regardless if the 24-hour SCS Type IA or regional hyetographs are used for long-duration storm modeling, the prior soil wetting produced by the smaller storm event (from 6 hours to 21 hours above) that is not modeled needs to be accounted for. The amount of antecedent precipitation can be expressed as a percentage of the total precipitation modeled, as shown in Table 4.2.1.

Table 4.2.1
Antecedent Precipitation Prior to Long-Duration Storm

Region #	Region Name	Antecedent Precipitation as Percentage of 24-Hour SCS Type IA Storm Precipitation
1	East Slope Cascades	33%
2	Central Basin	19%
3	Okanogan, Spokane, Palouse	27%
4	NE & Blue Mountains	36%

Region #	Region Name	Antecedent Precipitation as Percentage of Regional Long-Duration Storm Hyetograph Precipitation
1	East Slope Cascades	28%
2	Central Basin	19%
3	Okanogan, Spokane, Palouse	25%
4	NE & Blue Mountains	34%

Curve number adjustments, based on engineering analysis and judgment of the antecedent precipitation, soils characteristics, and surface conditions are to be considered. The Antecedent Moisture Condition discussion in this chapter is one basis for adjustment. Another is the use of the Soil Conservation Service county surveys that include estimates of permeability and/or infiltration rates.

Table 4.2.2: SCS Type IA Storm Hyetograph Values

Time (0.1 hours)	Incremental Rainfall	Cumulative Rainfall
0.0	0.000	0.000
0.1	0.002	0.002
0.2	0.002	0.004
0.3	0.002	0.006
0.4	0.002	0.008
0.5	0.002	0.010
0.6	0.002	0.012
0.7	0.002	0.014
0.8	0.002	0.016
0.9	0.002	0.018
1.0	0.002	0.020
1.1	0.003	0.023
1.2	0.003	0.026
1.3	0.003	0.029
1.4	0.003	0.032
1.5	0.003	0.035
1.6	0.003	0.038
1.7	0.003	0.041
1.8	0.003	0.044
1.9	0.003	0.047
2.0	0.003	0.050
2.1	0.003	0.053
2.2	0.003	0.056
2.3	0.004	0.060
2.4	0.003	0.063
2.5	0.003	0.066
2.6	0.003	0.069
2.7	0.003	0.072
2.8	0.004	0.076
2.9	0.003	0.079
3.0	0.003	0.082
3.1	0.003	0.085
3.2	0.003	0.088
3.3	0.003	0.091
3.4	0.004	0.095
3.5	0.003	0.098
3.6	0.003	0.101
3.7	0.004	0.105
3.8	0.004	0.109
3.9	0.003	0.112
4.0	0.004	0.116
4.1	0.004	0.120
4.2	0.003	0.123
4.3	0.004	0.127
4.4	0.004	0.131
4.5	0.004	0.135
4.6	0.004	0.139
4.7	0.004	0.143
4.8	0.004	0.147
4.9	0.005	0.152
5.0	0.004	0.156
5.1	0.005	0.161
5.2	0.004	0.165
5.3	0.005	0.170
5.4	0.005	0.175
5.5	0.005	0.180
5.6	0.005	0.185
5.7	0.005	0.190
5.8	0.005	0.195
5.9	0.005	0.200
6.0	0.006	0.206
6.1	0.006	0.212
6.2	0.006	0.218
6.3	0.006	0.224
6.4	0.007	0.231
6.5	0.006	0.237
6.6	0.006	0.243
6.7	0.006	0.249
6.8	0.006	0.255
6.9	0.006	0.261
7.0	0.007	0.268
7.1	0.007	0.275
7.2	0.008	0.283
7.3	0.008	0.291
7.4	0.009	0.300
7.5	0.010	0.310
7.6	0.021	0.331
7.7	0.024	0.355
7.8	0.024	0.379
7.9	0.024	0.403
8.0	0.022	0.425
8.1	0.014	0.439
8.2	0.013	0.452
8.3	0.010	0.462
8.4	0.010	0.472
8.5	0.008	0.480
8.6	0.009	0.489
8.7	0.009	0.498
8.8	0.007	0.505
8.9	0.008	0.513
9.0	0.007	0.520
9.1	0.007	0.527
9.2	0.006	0.533
9.3	0.006	0.539
9.4	0.006	0.545
9.5	0.005	0.550
9.6	0.006	0.556
9.7	0.005	0.561
9.8	0.006	0.567
9.9	0.005	0.572
10.0	0.005	0.577
10.1	0.005	0.582
10.2	0.005	0.587
10.3	0.005	0.592
10.4	0.004	0.596
10.5	0.005	0.601
10.6	0.005	0.606
10.7	0.004	0.610
10.8	0.005	0.615
10.9	0.005	0.620
11.0	0.004	0.624
11.1	0.004	0.628
11.2	0.005	0.633
11.3	0.004	0.637
11.4	0.004	0.641
11.5	0.004	0.645
11.6	0.004	0.649
11.7	0.004	0.653
11.8	0.004	0.657
11.9	0.003	0.660
12.0	0.004	0.664
12.1	0.004	0.668
12.2	0.003	0.671
12.3	0.004	0.675
12.4	0.004	0.679
12.5	0.004	0.683
12.6	0.004	0.687
12.7	0.003	0.690
12.8	0.004	0.694
12.9	0.003	0.697
13.0	0.004	0.701
13.1	0.004	0.705
13.2	0.003	0.708
13.3	0.004	0.712
13.4	0.004	0.716

Table 4.2.2 (continued): SCS Type IA Storm Hyetograph Values

Time (0.1 hours)	Incremental Rainfall	Cumulative Rainfall
13.5	0.003	0.719
13.6	0.003	0.722
13.7	0.004	0.726
13.8	0.003	0.729
13.9	0.004	0.733
14.0	0.003	0.736
14.1	0.003	0.739
14.2	0.004	0.743
14.3	0.003	0.746
14.4	0.003	0.749
14.5	0.004	0.753
14.6	0.003	0.756
14.7	0.003	0.759
14.8	0.004	0.763
14.9	0.003	0.766
15.0	0.003	0.769
15.1	0.003	0.772
15.2	0.004	0.776
15.3	0.003	0.779
15.4	0.003	0.782
15.5	0.003	0.785
15.6	0.003	0.788
15.7	0.004	0.792
15.8	0.003	0.795
15.9	0.003	0.798
16.0	0.003	0.801
16.1	0.003	0.804
16.2	0.003	0.807
16.3	0.003	0.810
16.4	0.003	0.813
16.5	0.003	0.816
16.6	0.003	0.819
16.7	0.003	0.822
16.8	0.003	0.825
16.9	0.003	0.828
17.0	0.003	0.831
17.1	0.003	0.834
17.2	0.003	0.837
17.3	0.003	0.840
17.4	0.003	0.843
17.5	0.003	0.846
17.6	0.003	0.849
17.7	0.002	0.851
17.8	0.003	0.854
17.9	0.003	0.857

Time (0.1 hours)	Incremental Rainfall	Cumulative Rainfall
18.0	0.003	0.860
18.1	0.003	0.863
18.2	0.002	0.865
18.3	0.003	0.868
18.4	0.003	0.871
18.5	0.003	0.874
18.6	0.002	0.876
18.7	0.003	0.879
18.8	0.003	0.882
18.9	0.002	0.884
19.0	0.003	0.887
19.1	0.003	0.890
19.2	0.002	0.892
19.3	0.003	0.895
19.4	0.002	0.897
19.5	0.003	0.900
19.6	0.003	0.903
19.7	0.002	0.905
19.8	0.003	0.908
19.9	0.002	0.910
20.0	0.003	0.913
20.1	0.002	0.915
20.2	0.003	0.918
20.3	0.002	0.920
20.4	0.002	0.922
20.5	0.003	0.925
20.6	0.002	0.927
20.7	0.003	0.930
20.8	0.002	0.932
20.9	0.002	0.934
21.0	0.003	0.937
21.1	0.002	0.939
21.2	0.002	0.941
21.3	0.003	0.944
21.4	0.002	0.946
21.5	0.002	0.948
21.6	0.003	0.951
21.7	0.002	0.953
21.8	0.002	0.955
21.9	0.002	0.957
22.0	0.002	0.959
22.1	0.003	0.962
22.2	0.002	0.964
22.3	0.002	0.966
22.4	0.002	0.968

Time (0.1 hours)	Incremental Rainfall	Cumulative Rainfall
22.5	0.002	0.970
22.6	0.002	0.972
22.7	0.002	0.974
22.8	0.002	0.976
22.9	0.002	0.978
23.0	0.002	0.980
23.1	0.002	0.982
23.2	0.002	0.984
23.3	0.002	0.986
23.4	0.002	0.988
23.5	0.002	0.990
23.6	0.002	0.992
23.7	0.002	0.994
23.8	0.002	0.996
23.9	0.002	0.998
24.0	0.002	1.000

Table 4.2.3: SCS Type II Storm Hyetograph Values

Time (0.1 hours)	Incremental Rainfall	Cumulative Rainfall
0.0	0.000	0.000
0.1	0.001	0.001
0.2	0.001	0.002
0.3	0.001	0.003
0.4	0.001	0.004
0.5	0.001	0.005
0.6	0.001	0.006
0.7	0.001	0.007
0.8	0.001	0.008
0.9	0.001	0.009
1.0	0.002	0.011
1.1	0.001	0.012
1.2	0.001	0.013
1.3	0.001	0.014
1.4	0.001	0.015
1.5	0.001	0.016
1.6	0.001	0.017
1.7	0.001	0.018
1.8	0.002	0.020
1.9	0.001	0.021
2.0	0.001	0.022
2.1	0.001	0.023
2.2	0.001	0.024
2.3	0.002	0.026
2.4	0.001	0.027
2.5	0.001	0.028
2.6	0.001	0.029
2.7	0.002	0.031
2.8	0.001	0.032
2.9	0.001	0.033
3.0	0.002	0.035
3.1	0.001	0.036
3.2	0.001	0.037
3.3	0.001	0.038
3.4	0.002	0.040
3.5	0.001	0.041
3.6	0.001	0.042
3.7	0.002	0.044
3.8	0.001	0.045
3.9	0.002	0.047
4.0	0.001	0.048
4.1	0.001	0.049
4.2	0.002	0.051
4.3	0.001	0.052
4.4	0.002	0.054

Time (0.1 hours)	Incremental Rainfall	Cumulative Rainfall
4.5	0.001	0.055
4.6	0.002	0.057
4.7	0.001	0.058
4.8	0.002	0.060
4.9	0.001	0.061
5.0	0.002	0.063
5.1	0.002	0.065
5.2	0.001	0.066
5.3	0.002	0.068
5.4	0.002	0.070
5.5	0.001	0.071
5.6	0.002	0.073
5.7	0.002	0.075
5.8	0.001	0.076
5.9	0.002	0.078
6.0	0.002	0.080
6.1	0.002	0.082
6.2	0.002	0.084
6.3	0.001	0.085
6.4	0.002	0.087
6.5	0.002	0.089
6.6	0.002	0.091
6.7	0.002	0.093
6.8	0.002	0.095
6.9	0.002	0.097
7.0	0.002	0.099
7.1	0.002	0.101
7.2	0.002	0.103
7.3	0.002	0.105
7.4	0.002	0.107
7.5	0.002	0.109
7.6	0.002	0.111
7.7	0.002	0.113
7.8	0.003	0.116
7.9	0.002	0.118
8.0	0.002	0.120
8.1	0.002	0.122
8.2	0.003	0.125
8.3	0.002	0.127
8.4	0.003	0.130
8.5	0.002	0.132
8.6	0.003	0.135
8.7	0.003	0.138
8.8	0.003	0.141
8.9	0.003	0.144

Time (0.1 hours)	Incremental Rainfall	Cumulative Rainfall
9.0	0.003	0.147
9.1	0.003	0.150
9.2	0.003	0.153
9.3	0.004	0.157
9.4	0.003	0.160
9.5	0.003	0.163
9.6	0.003	0.166
9.7	0.004	0.170
9.8	0.003	0.173
9.9	0.004	0.177
10.0	0.004	0.181
10.1	0.004	0.185
10.2	0.004	0.189
10.3	0.005	0.194
10.4	0.005	0.199
10.5	0.005	0.204
10.6	0.005	0.209
10.7	0.006	0.215
10.8	0.006	0.221
10.9	0.007	0.228
11.0	0.007	0.235
11.1	0.008	0.243
11.2	0.008	0.251
11.3	0.010	0.261
11.4	0.010	0.271
11.5	0.012	0.283
11.6	0.024	0.307
11.7	0.047	0.354
11.8	0.077	0.431
11.9	0.137	0.568
12.0	0.095	0.663
12.1	0.019	0.682
12.2	0.017	0.699
12.3	0.014	0.713
12.4	0.012	0.725
12.5	0.010	0.735
12.6	0.008	0.743
12.7	0.008	0.751
12.8	0.008	0.759
12.9	0.007	0.766
13.0	0.006	0.772
13.1	0.006	0.778
13.2	0.006	0.784
13.3	0.005	0.789
13.4	0.005	0.794

Table 4.2.3 (continued): SCS Type II Storm Hyetograph Values

Time (0.1 hours)	Incremental Rainfall	Cumulative Rainfall
13.5	0.005	0.799
13.6	0.005	0.804
13.7	0.004	0.808
13.8	0.004	0.812
13.9	0.004	0.816
14.0	0.004	0.820
14.1	0.004	0.824
14.2	0.003	0.827
14.3	0.004	0.831
14.4	0.003	0.834
14.5	0.004	0.838
14.6	0.003	0.841
14.7	0.003	0.844
14.8	0.003	0.847
14.9	0.003	0.850
15.0	0.004	0.854
15.1	0.002	0.856
15.2	0.003	0.859
15.3	0.003	0.862
15.4	0.003	0.865
15.5	0.003	0.868
15.6	0.002	0.870
15.7	0.003	0.873
15.8	0.002	0.875
15.9	0.003	0.878
16.0	0.002	0.880
16.1	0.002	0.882
16.2	0.003	0.885
16.3	0.002	0.887
16.4	0.002	0.889
16.5	0.002	0.891
16.6	0.002	0.893
16.7	0.002	0.895
16.8	0.003	0.898
16.9	0.002	0.900
17.0	0.002	0.902
17.1	0.002	0.904
17.2	0.002	0.906
17.3	0.002	0.908
17.4	0.002	0.910
17.5	0.002	0.912
17.6	0.002	0.914
17.7	0.001	0.915
17.8	0.002	0.917
17.9	0.002	0.919

Time (0.1 hours)	Incremental Rainfall	Cumulative Rainfall
18.0	0.002	0.921
18.1	0.002	0.923
18.2	0.002	0.925
18.3	0.001	0.926
18.4	0.002	0.928
18.5	0.002	0.930
18.6	0.001	0.931
18.7	0.002	0.933
18.8	0.002	0.935
18.9	0.001	0.936
19.0	0.002	0.938
19.1	0.001	0.939
19.2	0.002	0.941
19.3	0.001	0.942
19.4	0.002	0.944
19.5	0.001	0.945
19.6	0.002	0.947
19.7	0.001	0.948
19.8	0.001	0.949
19.9	0.002	0.951
20.0	0.001	0.952
20.1	0.001	0.953
20.2	0.002	0.955
20.3	0.001	0.956
20.4	0.001	0.957
20.5	0.001	0.958
20.6	0.002	0.960
20.7	0.001	0.961
20.8	0.001	0.962
20.9	0.002	0.964
21.0	0.001	0.965
21.1	0.001	0.966
21.2	0.001	0.967
21.3	0.001	0.968
21.4	0.002	0.970
21.5	0.001	0.971
21.6	0.001	0.972
21.7	0.001	0.973
21.8	0.002	0.975
21.9	0.001	0.976
22.0	0.001	0.977
22.1	0.001	0.978
22.2	0.001	0.979
22.3	0.002	0.981
22.4	0.001	0.982

Time (0.1 hours)	Incremental Rainfall	Cumulative Rainfall
22.5	0.001	0.983
22.6	0.001	0.984
22.7	0.001	0.985
22.8	0.001	0.986
22.9	0.002	0.988
23.0	0.001	0.989
23.1	0.001	0.990
23.2	0.001	0.991
23.3	0.001	0.992
23.4	0.001	0.993
23.5	0.001	0.994
23.6	0.002	0.996
23.7	0.001	0.997
23.8	0.001	0.998
23.9	0.001	0.999
24.0	0.001	1.000

Table 4.2.4: Short-Duration Storm Hyetograph Values – All Regions

Use 2-hour precipitation value times 1.06 to determine 3-hour total precipitation amount.

Time (minutes)	Time (hours)	Incremental Rainfall	Cumulative Rainfall
0	0	0.0000	0.0000
5	0.08	0.0047	0.0047
10	0.17	0.0047	0.0094
15	0.25	0.0057	0.0151
20	0.33	0.0104	0.0255
25	0.42	0.0123	0.0378
30	0.50	0.0236	0.0614
35	0.58	0.0292	0.0906
40	0.67	0.0528	0.1434
45	0.75	0.0736	0.2170
50	0.83	0.1736	0.3906
55	0.92	0.2377	0.6283
60	1.00	0.1255	0.7538
65	1.08	0.0604	0.8142
70	1.17	0.0406	0.8548
75	1.25	0.0151	0.8699
80	1.33	0.0132	0.8831
85	1.42	0.0113	0.8944
90	1.50	0.0104	0.9048
95	1.58	0.0085	0.9133
100	1.67	0.0075	0.9208
105	1.75	0.0057	0.9265
110	1.83	0.0057	0.9322
115	1.92	0.0057	0.9379
120	2.00	0.0057	0.9436
125	2.08	0.0047	0.9483
130	2.17	0.0047	0.9530
135	2.25	0.0047	0.9577
140	2.33	0.0047	0.9624
145	2.42	0.0047	0.9671
150	2.50	0.0047	0.9718
155	2.58	0.0047	0.9765
160	2.67	0.0047	0.9812
165	2.75	0.0047	0.9859
170	2.83	0.0047	0.9906
175	2.92	0.0047	0.9953
180	3.00	0.0047	1.0000

Table 4.2.5: Long-Duration Storm Hyetograph Values; Region 1: Cascade Mountains

Use 24-hour precipitation value times 1.16 to determine long-duration storm precipitation total.

Time (hours)	Incremental Rainfall	Cumulative Rainfall
0.0	0.0000	0.0000
0.5	0.0024	0.0024
1.0	0.0036	0.0060
1.5	0.0040	0.0101
2.0	0.0047	0.0148
2.5	0.0051	0.0199
3.0	0.0054	0.0253
3.5	0.0058	0.0311
4.0	0.0062	0.0374
4.5	0.0066	0.0439
5.0	0.0078	0.0517
5.5	0.0096	0.0614
6.0	0.0120	0.0733
6.5	0.0138	0.0871
7.0	0.0150	0.1022
7.5	0.0157	0.1179
8.0	0.0164	0.1343
8.5	0.0171	0.1513
9.0	0.0178	0.1691
9.5	0.0185	0.1876
10.0	0.0192	0.2067
10.5	0.0198	0.2266
11.0	0.0205	0.2471
11.5	0.0212	0.2683
12.0	0.0220	0.2904
12.5	0.0226	0.3130
13.0	0.0235	0.3364
13.5	0.0243	0.3608
14.0	0.0297	0.3905
14.5	0.0338	0.4243
15.0	0.0507	0.4750
15.5	0.0315	0.5066
16.0	0.0283	0.5349
16.5	0.0257	0.5606
17.0	0.0231	0.5837
17.5	0.0214	0.6051
18.0	0.0183	0.6234
18.5	0.0168	0.6402
19.0	0.0165	0.6566
19.5	0.0161	0.6728
20.0	0.0158	0.6886
20.5	0.0154	0.7040
21.0	0.0151	0.7191
21.5	0.0148	0.7339
22.0	0.0144	0.7483
22.5	0.0141	0.7623
23.0	0.0137	0.7761
23.5	0.0134	0.7894
24.0	0.0130	0.8025
24.5	0.0127	0.8151
25.0	0.0123	0.8275
25.5	0.0120	0.8395
26.0	0.0117	0.8512
26.5	0.0115	0.8627
27.0	0.0112	0.8739
27.5	0.0110	0.8849
28.0	0.0107	0.8956
28.5	0.0104	0.9060
29.0	0.0102	0.9162
29.5	0.0099	0.9261
30.0	0.0097	0.9358
30.5	0.0088	0.9446
31.0	0.0079	0.9525
31.5	0.0071	0.9596
32.0	0.0063	0.9659
32.5	0.0058	0.9717
33.0	0.0054	0.9772
33.5	0.0050	0.9822
34.0	0.0047	0.9869
34.5	0.0043	0.9912
35.0	0.0039	0.9950
35.5	0.0030	0.9981
36.0	0.0019	1.0000

Table 4.2.6: Long-Duration Storm Hyetograph Values; Region 2: Central Basin

Use 24-hour precipitation value (times 1.00) to determine long-duration storm precipitation total.

Time (hours)	Incremental Rainfall	Cumulative Rainfall
0.0	0.0000	0.0000
0.5	0.0054	0.0054
1.0	0.0086	0.0140
1.5	0.0100	0.0240
2.0	0.0120	0.0360
2.5	0.0130	0.0490
3.0	0.0140	0.0630
3.5	0.0150	0.0780
4.0	0.0160	0.0940
4.5	0.0170	0.1110
5.0	0.0187	0.1297
5.5	0.0228	0.1525
6.0	0.0283	0.1808
6.5	0.0305	0.2113
7.0	0.0335	0.2448
7.5	0.0365	0.2813
8.0	0.0484	0.3297
8.5	0.0622	0.3919
9.0	0.0933	0.4852
9.5	0.0527	0.5380
10.0	0.0402	0.5782
10.5	0.0372	0.6154
11.0	0.0348	0.6502
11.5	0.0331	0.6833
12.0	0.0289	0.7122
12.5	0.0252	0.7374
13.0	0.0219	0.7593
13.5	0.0191	0.7783
14.0	0.0167	0.7950
14.5	0.0148	0.8098
15.0	0.0134	0.8232
15.5	0.0123	0.8355
16.0	0.0116	0.8471
16.5	0.0110	0.8581
17.0	0.0105	0.8686
17.5	0.0103	0.8789
18.0	0.0103	0.8892
18.5	0.0104	0.8996
19.0	0.0105	0.9100
19.5	0.0105	0.9205
20.0	0.0104	0.9309
20.5	0.0102	0.9412
21.0	0.0100	0.9512
21.5	0.0097	0.9609
22.0	0.0093	0.9702
22.5	0.0087	0.9789
23.0	0.0083	0.9872
23.5	0.0078	0.9950
24.0	0.0050	1.0000

Table 4.2.7: Long-Duration Storm Hyetograph Values; Region 3: Okanogan – Spokane – Palouse

Use 24-hour precipitation value times 1.06 to determine long-duration storm precipitation total.

Time (hours)	Incremental Rainfall	Cumulative Rainfall	Time (hours)	Incremental Rainfall	Cumulative Rainfall	Time (hours)	Incremental Rainfall	Cumulative Rainfall
0.0	0.0000	0.0000	10.5	0.0282	0.2999	21.0	0.0131	0.8346
0.5	0.0017	0.0017	11.0	0.0395	0.3394	21.5	0.0130	0.8475
1.0	0.0030	0.0047	11.5	0.0564	0.3958	22.0	0.0128	0.8603
1.5	0.0041	0.0088	12.0	0.0855	0.4813	22.5	0.0126	0.8729
2.0	0.0053	0.0141	12.5	0.0451	0.5265	23.0	0.0123	0.8852
2.5	0.0068	0.0209	13.0	0.0348	0.5612	23.5	0.0120	0.8972
3.0	0.0092	0.0301	13.5	0.0335	0.5948	24.0	0.0116	0.9088
3.5	0.0108	0.0409	14.0	0.0276	0.6223	24.5	0.0112	0.9200
4.0	0.0126	0.0535	14.5	0.0199	0.6422	25.0	0.0108	0.9308
4.5	0.0132	0.0667	15.0	0.0179	0.6601	25.5	0.0104	0.9412
5.0	0.0139	0.0806	15.5	0.0158	0.6759	26.0	0.0100	0.9512
5.5	0.0147	0.0952	16.0	0.0156	0.6915	26.5	0.0096	0.9607
6.0	0.0154	0.1106	16.5	0.0154	0.7069	27.0	0.0092	0.9699
6.5	0.0162	0.1268	17.0	0.0152	0.7221	27.5	0.0086	0.9785
7.0	0.0169	0.1437	17.5	0.0150	0.7372	28.0	0.0074	0.9859
7.5	0.0177	0.1614	18.0	0.0148	0.7519	28.5	0.0054	0.9913
8.0	0.0184	0.1798	18.5	0.0145	0.7664	29.0	0.0040	0.9953
8.5	0.0192	0.1990	19.0	0.0142	0.7806	29.5	0.0030	0.9983
9.0	0.0228	0.2219	19.5	0.0139	0.7945	30.0	0.0017	1.0000
9.5	0.0238	0.2457	20.0	0.0136	0.8081			
10.0	0.0260	0.2717	20.5	0.0133	0.8215			

Table 4.2.8: Long-Duration Storm Hyetograph Values; Region 4: Eastern Mountains

Use 24-hour precipitation value times 1.07 to determine long-duration storm precipitation total.

Time (hours)	Incremental Rainfall	Cumulative Rainfall	Time (hours)	Incremental Rainfall	Cumulative Rainfall	Time (hours)	Incremental Rainfall	Cumulative Rainfall
0.0	0.0000	0.0000	10.5	0.0278	0.2996	21.0	0.0132	0.8181
0.5	0.0015	0.0015	11.0	0.0399	0.3394	21.5	0.0131	0.8312
1.0	0.0031	0.0046	11.5	0.0531	0.3925	22.0	0.0129	0.8441
1.5	0.0047	0.0094	12.0	0.0796	0.4722	22.5	0.0129	0.8570
2.0	0.0064	0.0158	12.5	0.0441	0.5162	23.0	0.0128	0.8697
2.5	0.0082	0.0239	13.0	0.0329	0.5492	23.5	0.0127	0.8825
3.0	0.0104	0.0343	13.5	0.0303	0.5795	24.0	0.0127	0.8951
3.5	0.0115	0.0458	14.0	0.0291	0.6086	24.5	0.0126	0.9077
4.0	0.0123	0.0581	14.5	0.0199	0.6284	25.0	0.0124	0.9201
4.5	0.0130	0.0711	15.0	0.0166	0.6451	25.5	0.0121	0.9322
5.0	0.0137	0.0848	15.5	0.0155	0.6606	26.0	0.0116	0.9438
5.5	0.0145	0.0993	16.0	0.0153	0.6759	26.5	0.0109	0.9547
6.0	0.0152	0.1145	16.5	0.0151	0.6910	27.0	0.0101	0.9647
6.5	0.0160	0.1305	17.0	0.0149	0.7059	27.5	0.0090	0.9738
7.0	0.0167	0.1472	17.5	0.0148	0.7207	28.0	0.0077	0.9814
7.5	0.0174	0.1646	18.0	0.0146	0.7353	28.5	0.0061	0.9875
8.0	0.0182	0.1828	18.5	0.0144	0.7496	29.0	0.0051	0.9926
8.5	0.0190	0.2019	19.0	0.0142	0.7639	29.5	0.0045	0.9971
9.0	0.0207	0.2226	19.5	0.0140	0.7779	30.0	0.0029	1.0000
9.5	0.0232	0.2458	20.0	0.0137	0.7915			
10.0	0.0260	0.2717	20.5	0.0134	0.8049			

4.2.4 Precipitation Magnitude/Frequency Analysis

The current source for precipitation magnitude-frequency estimates is NOAA Atlas II, which is based on data collected from about 1940 through 1966, and NOAA Technical Report Number 36, which used data through the late 1970's. In both of these studies, precipitation statistics were computed for each gage and used to produce point precipitation estimates at each site. The accuracy of the estimates was strongly related to the length of record at each site. Better estimates were obtained for more common events with lesser accuracy for more rare events.

The total depth of rainfall (in tenths of an inch) for storms of 24-hour duration and 2, 5, 10, 25, 50 and 100-year recurrence intervals are published by the NOAA. The information is presented in the form of "isopluvial" maps for each state. Isopluvial maps are contour maps where the contours represent total inches of rainfall for a specific duration.

The isopluvial map for Eastern Washington for the 2-year recurrence interval for the 2-hour duration storm event is shown in Figure 4.3.2. This map is from the Dam Safety Guidelines, Technical Note 3, Design Storm Construction, Washington State Department of Ecology, Water Resources Program, report 92-55G, April 1993. This map is used for designs based on the short-duration storm.

The isopluvial maps for Eastern Washington for the 2, 10, 25, 50 and 100-year recurrence interval for 24-hour duration storm events are shown in Figures 4.3.3 to 4.3.7. These are excerpted from NOAA Atlas 2. The NOAA Atlas 2 maps are available on the Internet. The 24-hour isopluvial maps are used for designs based on the long-duration storm and 24-hour storms.

4.2.5 Precipitation Magnitude for 24-Hour and Long-Duration Water Quality Storm

The frequency of the long-duration water quality storm is a 6-month recurrence interval or twice per year return period. Unfortunately the NOAA Atlas 2 maps require the conversion of 2-year 24-hour precipitation to 6-month 24-hour precipitation.

The following equation is used to determine the 6-month precipitation.

$$P_{wqs} = C_{wqs} (P_{2yr24hr})$$

where: P_{wqs} is the 24-hour precipitation (inches) for the storm recurrence interval of 6 months. This precipitation is used with the long-duration storm hyetograph or 24-hour SCS (NRCS) Type IA or Type II hyetographs, depending on the design storm option selected by the jurisdiction.

C_{wqs} is a coefficient from Table 4.2.9 for computing the 6-month 24-hour precipitation based on the climate region; and

$P_{2yr24hr}$ is the 2-year, 24-hour precipitation from Figure 4.3.3.

Values of the coefficient C_{wqs} are based on the Generalized Extreme Value (GEV) distribution whose distribution parameters can be expressed as a function of mean annual precipitation for eastern Washington. Table 4.2.9 lists values of the coefficient C_{wqs} for all four regions. Figure 4.3.1 can be used to determine the climate region for the site.

Table 4.2.9
Coefficients C_{wqs} For Computing Twice/Year 24-Hour Precipitation

Region #	Region Name	C_{wqs}
1	East Slope Cascades	0.70
2	Central Basin	0.66
3	Okanogan, Spokane, Palouse	0.69
4	NE & Blue Mountains	0.70

4.2.6 Precipitation Magnitude for Long-Duration Storms

Table 4.2.10 provides the multipliers, by region, for the conversion of the 24-hour precipitation to the regional long-duration storm precipitation.

Table 4.2.10
Conversion Factor for 24-Hour to Regional Long-Duration Storm Precipitation

Region #	Region Name	Conversion Factor 24-Hour to Regional Long-Duration Storm Precipitation
1	East Slope Cascades	1.16
2	Central Basin	1.00
3	Okanogan, Spokane, Palouse	1.06
4	NE & Blue Mountains	1.07

4.2.7 Precipitation Magnitude for Short-Duration Storms

The only mapped frequency of the short-duration storm is a 2-year recurrence interval. The design of Flow Based Treatment BMPs using the Single Event Hydrograph Model requires the conversion of the 2-year 2-hour precipitation to the 6-month 2-hour precipitation. The design of other BMPs or conveyance elements based on the short-duration storm could also require the conversion of the 2-year 2-hour precipitation to a different recurrence interval.

The following equation is used to determine 2-hour precipitation for a selected return period.

$P_{sds} = C_{sds} (P_{2yr2hr})$

where: P_{sds} is the 2-hour precipitation (inches) for a selected return period for the short-duration storm

C_{sds} is a coefficient from Table 4.2.11 for computing the 2-hour precipitation for a selected return period based on the 2-year 2-hour precipitation; and

P_{2yr2hr} is the 2-year, 2-hour precipitation from Figure 4.3.2.

Values of the coefficient C_{sds} are based on the Generalized Extreme Value (GEV) distribution whose distribution parameters can be expressed as a function of mean annual precipitation for eastern Washington. Table 4.2.11 lists values of the coefficient C_{sds} for selected return periods for various magnitudes of mean annual precipitation. An isopluvial map of mean annual precipitation is shown in Figure 4.3.1 and can be used to determine the mean annual precipitation for the site.

Table 4.2.11
Coefficients C_{sds} for Computing 2-Hour Precipitation for Selected Return Periods

Region #	Mean Annual Precipitation (In)	6-Month	1-Year	10-Year	25-Year	50-Year	100-Year
2	6-8	0.61	0.79	1.63	2.17	2.68	3.29
	8-10	0.62	0.80	1.60	2.09	2.55	3.09
	10-12	0.64	0.81	1.56	2.02	2.44	2.92
2, 3	12-16	0.66	0.82	1.51	1.90	2.26	2.66
3	16-22	0.67	0.83	1.47	1.82	2.13	2.48
1, 4	22-28	0.69	0.84	1.43	1.74	2.01	2.31
	28-40	0.70	0.85	1.40	1.68	1.92	2.19
	40-60	0.72	0.86	1.36	1.61	1.82	2.05
	60-120	0.74	0.87	1.33	1.55	1.74	1.93

The multiplier for the conversion of the 2-hour precipitation to the short-duration (3-hour) storm precipitation is 1.06 in all regions.

4.2.8 Snow: Rain-on-Snow and Snowmelt Design [Optional]

The following information on snow considerations, including rain-on-snow and snowmelt design, is optional guidance for detention and water quality design when required by the local jurisdiction. Other Cold Weather Considerations for BMP design is included in Section 5.2.3.

Snow Considerations

In many regions, an inevitable consequence of cold weather is precipitation in the form of snow. Table 4.2.12 illustrates some typical snowfall amounts for eastern Washington as compiled by Desert Research Institute in Nevada. While snowfall amounts are often converted to water equivalents and treated as individual events for the purpose of predicting annual precipitation events, in fact snowfall from multiple events may accumulate over time thus creating storage of potential runoff volumes. This storage may be released gradually over time in the form of snowmelt or it may be converted to runoff rapidly by rain-on-snow events. Gradual melting can cause problems because the runoff may fill or saturate stormwater BMPs prior to an actual design event and consequently produce wet soil conditions and more runoff. Refreezing during cold evenings may exasperate some of the problems.

Table 4.2.12

Average Annual Snowfall at Select Eastern Washington Cities

Location	Period of Record	Average Annual Snowfall (inches)
Asotin 14 SW	1976-2000	14.5
Cle Elum	1931-2000	80.5
Dayton 1 WSW	1931-2000	17.8
Ellensburg	1901-2000	27.7
Ephrata Airport FCWOS	1949-2000	18.3
Goldendale	1931-2000	25.0
Kennewick	1948-2000	6.9
Leavenworth 3 S	1948-2000	95.2
Methow 2 S	1970-2000	38.3
Newport	1927-2000	59.4
Othello 6 ESE	1941-2000	4.2
Prosser 4 NE	1931-2000	7.9
Pullman 2 NW	1940-2000	28.1
Quincy 1 S	1941-2000	13.2
Richland	1948-2000	8.5
Spokane WSO Airport	1889-2000	41.4
Walla Walla FAA Airport	1949-1995	17.4
Wenatchee	1877-2000	27.6
Yakima WSO AP	1946-2000	24.1

Because of the many physical factors involved, snowmelt is a complicated process, with large annual variations in the melting rate frequently occurring. While the criteria presented here address the affects of rain-on-snow, and snowmelt, several simplifying assumptions are made. Where local data or experiences are available, more sophisticated methods should be substituted.

Rain-on-Snow Considerations

For water quality volume, rain-on-snow events can be important in many eastern Washington regions. Although the size of rainfall events typically used in BMP design may or may not produce a significant amount of snowmelt, runoff produced by these events is high because of frozen and saturated ground conditions beneath the snow cover. The actual melting and runoff processes are quite complicated and require information not readily available in most areas. The Stormwater Practices for Cold Climates document prepared by the Center for Watershed Protection suggested the following five-step simplified procedure. As with other referenced methodology, this approach has not been well tested for eastern Washington, however it does provides a basis for estimating rain-on-snow volumes which could be used and refined with experience.

Calculating Rain-on-Snow Volume (Center for Watershed Protection):

Step 1. Many rules for sizing water quality volumes are based on treating a rainfall event with a specified occurrence frequency, such as treating the 1-year, 24-hour rainfall event. The same process has been proposed for rain-on-snow events. However, rather than including all precipitation events, it is necessary to develop a dataset of rainfall events that occurred only for those months where snow is on the ground. Snow events, as well as non-runoff producing events ($P < 0.1$ inch), should be excluded from this data set. The result is a recurrence frequency for rain-on-snow events. Because the ground is frozen and/or saturated, this precipitation distribution is also the same as the runoff distribution.

Step 2. Calculate a similar rainfall distribution for months without snow cover.

Step 3. Determine the runoff distribution for months without snow cover. Because we have excluded non-runoff producing events from the distribution, the runoff is equal to:

$$R = 1.0 * P * (0.05 + 0.9 I)$$

If the impervious percentage (I) is known (assume 40 %) then, for months without snow:

$$R = 0.41 * P$$

Where P is the precipitation for a return frequency computed in Step 2. A runoff distribution for "summer" is developed by multiplying all of the precipitation values used in Step 2 by the 0.41 multiplier determined previously in this step.

Step 4. Take the "winter" runoff distribution data from Step 1 and combine it with the "summer" runoff distribution computed in Step 3. Sort the data and rank it accordingly to determine an overall annual runoff distribution. Determine the 90th percentile value and use it for design purposes as long as this value is greater than the summer precipitation event.

It should again be pointed out that this methodology does not include any contribution from snowmelt. As previously stated, it is predicated on the assumption that design storm precipitation quantities are not large enough to produce significant melt quantities.

The US Army Corps of Engineers developed an expression to estimate the melt as a function of precipitation and temperature. The equation is:

$$M_s = 0.00695 * (T_{rain} - 32)\ P_r$$

This equation predicts that 2.5 inches of rainfall precipitation (P_r) at a rainfall temperature of 50 ^oF, would melt 0.31 inches of snow. Whether this represents a significant increase in required volume would depend on the site.

A note concerning the impacts of snowmelt is warranted. Because the ground is generally frozen during snowmelt or rain-on-snow events, the difference between pre- and post- project discharges are often quite small. For this reason, snowmelt and rain-on-snow events rarely need to be considered when designing for channel or overbank protection.

<u>Additional Rain-on-Snow Considerations:</u>

Rain-on-snow could affect the flow in the evaluation of the long-duration storms, especially in regions with high snowfall. Except for higher elevations with deeper snowpacks, it should be assumed that a long-duration design storm results in the complete melting and runoff of the typical snowpack. To determine the typical snowpack calculate the average daily snow depth from December to February which is available on the Internet for many Eastern Washington locations. If the average daily snow depth is less than 1 inch, then the rain-on-snow effect can be considered negligible and should not be considered in the analysis. Assuming 20 percent moisture content, determine the water equivalent. A sample of the average daily snow depths and precipitation adjustment amount for selected cities is in Table 4.2.13.

Snowmelt can also be considered in water quality design. Melting snow from the roadways and from the snow piles alongside the roadways have significant amounts of pollutants generated from the vehicles, deicers, and roadway salts. The water quality facilities should be located downstream of the snowmelt areas and can be sized for snowmelt, especially in regions with high snowfall.

Table 4.2.13
Snowmelt Adjustment Factors

City	Average Daily Snow Depth (In.)	Water Equivalent (In.) (24-hour Storm Precipitation Adjustment)	24-Hour/72-Hour Precipitation Ratio – based on Climate Region	Long-Duration Storm Precipitation Adjustment (In.)
Colville	5.00	1.0	.70	.70
Clarkston	.33	N/A	N/A	N/A
Goldendale	1.67	.33	.67	.22
Moses Lake	.67	.13	.84	.11
Omak	4.67	.93	.75	.70
Pullman	1.33	.27	.70	.19
Richland	.33	N/A	N/A	N/A
Spokane Airport	2.33	.47	.75	.35
Walla Walla	1.00	.20	.75	.15
Wenatchee	2.67	.53	.84	.45
Yakima	2.00	.40	.84	.34

For projects that are located above 2500 feet elevation, a separate study or local data should be used as the average snow depth is significant and varies widely.

The assumption is that the entire average daily snow melt on the ground will melt during the long-duration storm. Since the long-duration storm is a three day duration, the water equivalent for the peak 24 hours will be less than if the long-duration storm were only 24 hours. The adjustment factor is the ratio of the 24-hour precipitation to the 72-hour precipitation and varies based on climate region. In order to utilize the snowmelt factor with the long-duration storm hyetograph, the Long-Duration Storm Precipitation Adjustment should be added to the 24-hour design storm precipitation.

The CN used shall be for normal Antecedent Moisture Condition II.

If the Mean Annual Precipitation (MAP) at the project site varies from the MAP at the nearest known snowdepth record location, the average daily snowdepth will also vary. To determine the estimated average daily snowdepth, multiply the known average daily snowdepth and all other factors by the ratio of Mean Annual Precipitation (MAP) at the project site to the Mean Annual Precipitation at the record location.

For example: A project is located in Cashmere where the MAP is 14 inches. The nearest snowdepth record location is Wenatchee. The snowdepth at Wenatchee is 2.67 inches from Table 4.2.13 and the MAP from Figure 4.3.1 is 10 inches. The estimated snowdepth for Cashmere is 2.67 * 14/10 = 3.74 inches.

Snowmelt

In relatively dry regions that receive much of their precipitation as snowfall, the sizing is heavily influenced by the snowmelt event. A typical recommendation is to oversize the facility when average annual snowfall depth is greater than or equal to annual precipitation depth. This assumes snow is approximately 10% water. The sizing criteria for the treatment of water quality are based on the following four assumptions:

1. BMPs should be sized to treat the spring snowmelt event,
2. Snowmelt runoff is influenced by the moisture content of the spring snowpack and soil moisture,
3. No more than five percent of the annual runoff volume should bypass treatment during the spring snowmelt event, and
4. Because snowmelt occurs over several days, BMPs can treat a snowmelt volume greater than their size would indicate.

Although snowmelt occurs continuously throughout the winter and spring months, the characteristics and rates of runoff may vary. As rules of thumb, 1/2 of the snowfall is assumed to melt in the winter if the average daily maximum January temperature is < 25 ^{o}F and 2/3 of the snowfall melts if the temperature is between 25 and 35 ^{o}F. Winter melting events have high concentrations of soluble pollutants such as chlorides and metals, because of “preferential elution” from the snowpack (Jeffries, 1988). Conversely, spring snowmelt is higher in suspended solids and hydrophobic elements, such as hydrocarbons, which can remain in the snowpack until the last five to ten percent of water leaves the snowpack (Marsalek, 1991).

Three methods for estimating snowmelt are available, as described below.

Snowmelt Method 1 (Stahre and Urbonas):

Although snowmelt rates can be as high as 0.15 inches/hour (0.151 cfs/acre) under extreme conditions, Stahre and Urbonas (1989) recommended the following minimum design values:

Snowmelt = Impervious surface area x 0.04 cfs/acre + Pervious surface area x 0.02 cfs/acre

Snowmelt Method 2 (US Army Corps of Engineers):

The above rates from the Stahre and Urbonas method are not universally accepted. The US Army Corps of Engineers proposed the following temperature index solution for daily snowmelt (M_s) in inches per day:

$$M_s = C_m (T_{air} - T_{base})$$

Where T_{air} is the average daily air temperature (^oF), T_{base} is the base temperature (typically around 32 ^oF when using average daily air temperature), and C_m is the melt-rate coefficient in inches/ ^oF. This coefficient can be variable depending on site conditions. The relative magnitude of this factor is shown in Table 4.2.14.

Table 4.2.14

Melt-rate Coefficients for Various Conditions (assuming T_{base} = 32 ^oF)

Case	T_{air} (^oF)	Melt (inches)	C_m (inches/ ^oF)	Comment
1	70	2.57	0.068	Clear, low albedo
2	70	2.40	0.073	Case 1 2/40% forest
3	65	1.51	0.040	Case 1 w/cloud cover
4	70	1.73	0.046	Case 1 w/fresh snow
5	50	3.24	0.180	Heavy rain, windy
6	50	2.92	0.163	Light rain, windy
7	50	1.11	0.062	Light rain, light wind

Snowmelt Method 3 (Center for Watershed Protection):

The Stormwater Practices for Cold Climates document prepared by the Center for Watershed Protection presents a straightforward methodology for calculating snowmelt runoff in seven steps. The method is general and a specific application for eastern Washington has not yet been developed. However, it does provide a basis for estimation which could be used and refined as more knowledge becomes available with experience. The procedure is as follows:

Step 1. The procedure is based on the assumption that oversizing is necessary if the average annual precipitation is less than half the average annual snowfall depth. For example, if the average annual precipitation is 15 inches and the average annual snowfall is 16 inches (or more), oversizing will be required.

Step 2. Determine the annual losses from sublimation and snow removal.

Step 3. Determine the annual water equivalent loss from winter snowmelt events. This requires an assumption regarding the amount of water in an inch of snow. Assuming that the water equivalence of the snow is 1:10, an average annual snowfall of 40 inches, and 15 percent lost to the combination of sublimation and snow removal, the total water amount is:

$$M_s = \frac{1}{10}(40 - (0.15 * 40)) \approx 3.4\ inches$$

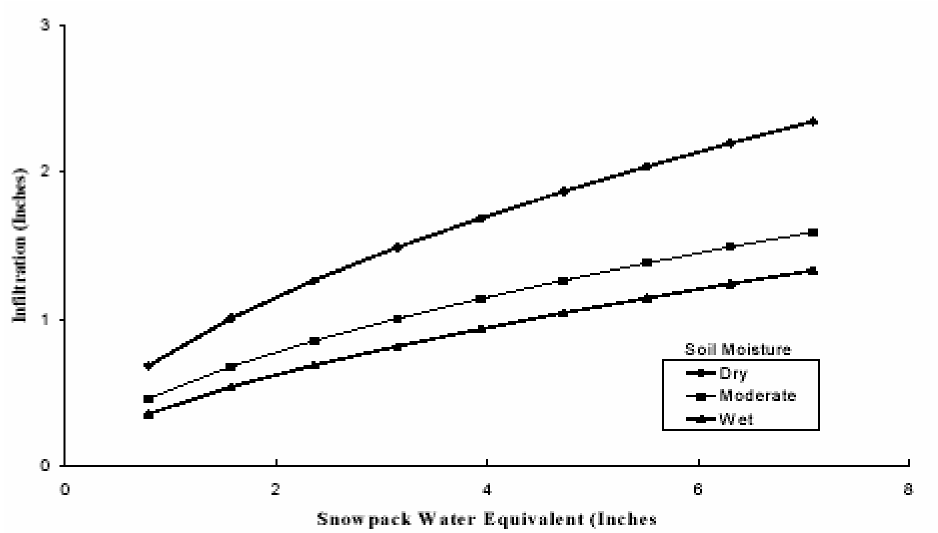
This factor is multiplied by the temperature factor (1/2 if the average daily maximum January temperature is < 25 ^{o}F and 2/3 if the temperature is between 25 and 35 ^{o}F). Assuming the average daily maximum January temperature is 24 ^{o}F, the final snowpack water equivalent (M_s) is 1.7 inches.

Step 4. Calculate the snowmelt runoff volume, R_s, using:

$$R_s = (1 - I)*(M_s - F) + (I)(M_s)$$

Where I is the impervious fraction of the watershed, F is the infiltration (inches), and Ms is the snowpack water equivalent (inches).

Figure 4.2.5 Snowmelt Infiltration as a Function of Soil Moisture



To continue the example, for moderate soil moisture conditions and 1.7 inches of snowpack water, the infiltration amount is 0.65 inches. Furthermore, if the impervious percent is 40%, then:

$$R_s = (1 - I)*(M_s - F) + (I)(M_s) = (1 - 0.4)*(1.7 - 0.65) + 0.4(1.7)$$

$$R_s = 1.31 \text{ inches}$$

Step 5. Determine the annual runoff volume. While there are several acceptable ways of computing this value, Shuler (1987) proposed a "Simple Method" whereby annual runoff (R) in inches is given by:

$$R = 0.9 * P * (0.05 + 0.9 I)$$

Assuming the annual precipitation is 15 inches/year and the impervious coefficient is still 0.4, then:

$$R = 0.9 * 15 * (0.05 + 0.9 * 0.4) = 5.54 \text{ inches}$$

Step 6. Determine the amount of runoff to be treated (T) for a 20-acre site.

$$T = (R_s - 0.05 *R) * Area /12$$

$T = (1.31 – 0.05*5.54)*(50)/12 = 4.3$ acre-feet

Step 7. Because snowmelt occurs over several days or even weeks, the BMP does not have to treat the entire water quality volume over a 24-hr period. A 50 percent reduction in the volume is used to determine how much storage is required. Thus, the water quality treatment volume (WQ_v) is given by:

$WQ_v = ½ * T = 2.15$ acre-feet

Finally, this volume should be compared with the volume from precipitation considerations to determine which is more conservative.

4.3 Precipitation Maps

Precipitation maps for eastern Washington are included in Appendix 4C, as listed in the figures below:

4.4 Rational Method

Applicability

The rational method is an allowable method for computing peak runoff rates for flow based runoff treatment BMPs such as biofiltration swales and oil/water separators. It is also a common method for computing the peak runoff rate for design of drywells and conveyance systems.

4.4.1 Introduction

The primary source for this section is the WSDOT Hydraulics Manual, 1998.

Design peak runoff rates may be determined by the Rational formula:

$$Q = C I A$$

where

Q = Runoff, cubic feet per second
C = Runoff coefficient
I = Rainfall intensity, inches per hour
A = Contributing area, acres

The runoff coefficients (C) should be based on Table 4.4.1.

The coefficients in Table 4.4.1 are applicable for peak storms of 10-year or less frequency. Less frequent, higher intensity storms will require the use of higher coefficients because infiltration and other losses have a proportionally smaller effect on runoff. Generally, when designing for a 25-year frequency, the coefficient should be increased by 10 percent. The runoff coefficient should never be increased above 0.90.

The equation for calculating rainfall intensity is:

$I = m / (T_c)^n$

Where: I = Rainfall intensity in inches per hour

T_c = Time of concentration in minutes

The rainfall intensity (I) coefficients (m and n) have been determined for all major cities for the 2-, 10-, 25-, 50-, and 100-year mean recurrence intervals (MRI). These coefficients were developed from NOAA Atlas 2. The coefficients for selected cities in Eastern Washington are in Table 4.4.2.

4.4.2 Time of Concentration for Rational Method

If rainfall is applied at a constant rate over a drainage basin, it would eventually produce a constant peak rate of runoff. The amount of time that passes from the moment that the constant rainfall begins to the moment that the constant rate of runoff begins is called the time of concentration. This is the time required for the surface runoff to flow from the most hydraulically remote part of the drainage basin to the location of concern.

Actual precipitation does not fall at a constant rate. A precipitation event will begin with a small rainfall intensity then, sometimes very quickly, build to a peak intensity and eventually taper down to no rainfall. Because rainfall intensity is variable, the time of concentration is included in the rational method so that the designer can determine the proper rainfall intensity to apply across the basin. The intensity that should be used for design purposes is the highest intensity that will occur with the entire basin contributing flow to the location where the designer is interested in knowing the flow rate. It is important to note that this may be a much lower intensity than the absolute maximum intensity. The reason is that it often takes several minutes before the entire basin is contributing flow but the absolute maximum intensity lasts for a much shorter time so the rainfall intensity that creates the greatest runoff is less than the maximum by the time the entire basin is contributing flow.

Most drainage basins will consist of different types of ground covers and conveyance systems that flow must pass over or through. These are referred to as flow segments. It is common for a basin to have flow segments that are overland flow and flow segments that are open channel flow. Urban drainage basins often have flow segments that are flow through a storm drain pipe in addition to the other two types. A travel time (the amount of time required for flow to move through a flow segment) must be computed for each flow segment. The time of concentration is equal to the sum of all the flow segment travel times.

For a few drainage areas, a unique situation occurs where the time of concentration that produces the largest amount of runoff is less than the time of concentration for the entire basin. This can occur when two or more subbasins have dramatically different types of cover (i.e., different runoff coefficients). The most common case would be a large paved area together with a long narrow strip of natural area. In this case, the designer should check the runoff produced by the paved area alone to determine if this scenario would cause a greater peak runoff rate than the peak runoff rate produced when both land segments are contributing flow. The scenario that produces the greatest runoff should be used, even if the entire basin is not contributing flow to this runoff.

The procedure described below for determining the time of concentration for overland flow was developed by the United States Natural Resources Conservation Service (formerly known as the Soil Conservation Service). It is sensitive to slope, type of ground cover, and the size of channel. The designer should never use a time of concentration less than 5 minutes. The time of concentration can be calculated as follows:

$$T_t = \frac{L}{K\sqrt{S}}$$

$$T_c = T_{t1} + T_{t2} + \ldots + T_{tnz}$$

where: T_t = Travel time of flow segment in minutes
T_c = Time of concentration in minutes
L = Length of segment in feet
K = Ground cover coefficient in feet per minute
S = Slope of segment in feet per feet

Table 4.4.1
Runoff Coefficients, C, For Rational Method -- 10-Year or Less Frequency

	FLAT	ROLLING 2% - 10%	HILLY OVER 10%
Pavement and Roofs	0.90	0.90	0.90
Earth Shoulders	0.50	0.50	0.50
Drives and Walks	0.75	0.80	0.85
Gravel Pavement	0.50	0.55	0.60
City Business Areas	0.80	0.85	0.85
Suburban Residential*	0.25	0.35	0.40
Single Family Residential*	0.30	.040	0.50
Lawns, Sandy Soil	0.10	0.15	0.20
Lawn, Heavy Soil	0.17	0.22	0.35
Grass Shoulders	0.25	0.25	0.25
Side Slopes, Earth	0.60	0.60	0.60
Side Slopes, Turf	0.30	0.30	0.30
Median Areas, Turf	0.25	0.30	0.30
Cultivated Land, Clay and Loam	0.50	0.55	0.60
Cultivated Land, Sand and Gravel	0.25	0.30	0.35
Industrial Areas, Light	0.50	0.70	0.80
Industrial Areas, Heavy	0.60	0.80	0.90
Parks and Cemeteries	0.10	0.15	0.25
Playgrounds	0.20	0.25	0.30
Woodland and Forests	0.10	0.15	0.20
Meadows and Pasture Land	0.25	0.30	0.35
Pasture with Frozen Ground	0.40	0.45	0.50

Source: WSDOT Hydraulics Manual, January 1997

Note: Generally, when designing for a 25-year frequency, the coefficient should be increased by 10 percent. The runoff coefficient should never be increased above 0.90.

Table 4.4.2
Index to Rainfall Coefficients

Location	2-Year MRI		10-Year MRI		25-Year MRI		50-Year MRI		100-Year MRI	
	m	n	m	n	m	n	m	n	m	n
Clarkston and Colfax	5.02	0.628	8.24	0.635	10.07	0.638	11.45	0.639	12.81	0.639
Colville	3.48	0.558	6.98	0.610	9.07	0.626	10.65	0.635	12.26	0.642
Ellensburg	2.89	0.590	7.00	0.649	9.43	0.664	11.30	0.672	13.18	0.678
Leavenworth	3.04	0.530	5.62	0.575	7.94	0.594	9.75	0.606	11.08	0.611
Moses Lake	2.61	0.583	6.99	0.655	9.58	0.671	11.61	0.681	13.63	0.688
Omak	3.04	0.583	6.63	0.633	8.74	0.647	10.35	0.654	11.97	0.660
Pasco and Kennewick	2.89	0.590	7.00	0.649	9.43	0.664	11.30	0.672	13.18	0.678
Snoqualmie Pass	3.61	0.417	6.56	0.459	7.72	0.459	8.78	0.461	10.21	0.476
Spokane	3.47	0.556	6.98	0.609	9.09	0.626	10.68	0.635	12.33	0.643
Stevens Pass	4.73	0.462	8.19	0.500	8.53	0.484	10.61	0.499	12.45	0.513
Walla Walla	3.33	0.569	7.30	0.627	9.67	0.645	11.45	0.653	13.28	0.660
Wenatchee	3.15	0.535	6.19	0.579	7.94	0.592	9.32	0.600	10.68	0.605
Yakima	3.86	0.608	7.37	0.644	9.40	0.654	10.93	0.659	12.47	0.663

Source: WSDOT Hydraulics Manual, January 1997

Note: *MRI equals Mean Recurrence Interval*

Table 4.4.3
Ground Cover Coefficients

Type of Cover		K
Forest with heavy ground cover		150
Minimum tillage cultivation		280
Short pasture grass or lawn		420
Nearly bare ground		600
Small roadside ditch w/grass		900
Paved area		1,200
Gutter flow	4 in. deep	1,500
	6 in. deep	2,400
	8 in. deep	3,100
Storm Sewers	12 in. diam.	3,000
	18 in. diam.	3,900
	24 in. diam.	4,700
Open Channel Flow (n = .040)	12 in. deep	1,100
Narrow Channel (w/d =1)	2 ft. deep	1,800
	4 ft. deep	2,800
Open Channel Flow (n = .040)	1 ft. deep	2,000
Wide Channel (w/d =9)	2 ft. deep	3,100
	4 ft. deep	5,000

Source: WSDOT Hydraulics Manual, January 1997

4.5 SCS Curve Number Equations

Applicability

The SCS Curve number equations is an allowable method for computing storage volumes for volume based treatment BMPs based on the SCS hydrograph method. The SCS curve numbers are also used in the Single Event Hydrograph Methods such as SCS Hydrograph and Santa Barbara Urban Hydrograph.

4.5.1 Introduction

The primary source for this section is the Surface Water Management Manual for Western Washington, by Dept. of Ecology, 2001 and Urban Hydrology for Small Watersheds TR-55, by Natural Resources Conservation Service, 1986.

This method can be used to size the volume of treatment BMPs when the design criteria is based on the volume of runoff. Computer models are not required for this method. Required input consists of precipitation, pervious and impervious area and curve numbers.

4.5.2 Area

Drainage sub-basin areas should be delineated in a manner that runoff characteristics are as homogeneous as practicable and in reasonable configurations. Sub-basin configurations should be contiguous and consistent with surface runoff patterns. Refer to 4.5.3 Curve Number for discussion regarding when weighted averaging is appropriate and not appropriate.

4.5.3 Curve Number

The Natural Resources Conservation Service (NRCS, formerly the Soil Conservation Service) has for many years conducted studies into the runoff characteristics of various land types. After gathering and analyzing extensive data, the NRCS has developed relationships between land use, soil type, vegetation cover, interception, infiltration, surface storage, and runoff. These relationships have been characterized by a single runoff coefficient called a "curve number (CN)." The National Engineering Handbook - Section 4: Hydrology (NEH-4, SCS, 1985) contains a detailed description of the development and use of the curve number method. The CN indicates the runoff potential of a watershed. Higher CNs have a higher potential for runoff. The CN is a combination of a hydrologic soil group, a land use and a treatment class (cover).

NRCS is considering revisions to the curve numbers but, at the time of this writing, has not completed that effort. When revised curve numbers are adopted by NRCS they should be considered for use in lieu of the values published herein.

The combination of soil type and land use is called the "soil-cover complex." The soil-cover complexes have been assigned to one of four hydrologic soil groups, according to their runoff characteristics. SCS has classified over 4,000 soil types into these four soil groups. Table 4.5.1 shows the hydrologic soil group of some of the common soils in Eastern Washington and provides a brief description of the four hydrologic soil group classifications. For details on the hydrologic soil group for other soil types refer to the SCS maps published for each county.

Table 4.5.1
Hydrologic Soil Group of Selected Soils in Eastern Washington
See SCS Soils Maps for Additional Soil and Hydrologic Groups

Soil Group	Hydrologic Group*	Soil Group	Hydrologic Group*
Athena	B	Laketon	C
Bernhill	B	Lance	B
Bong	A	Larkin	B
Bonner	B	Latah	D
Brickel	C	Marble	A
Bridgeson	D	Mondovi	B
Caldwell	C	Moscow	C
Cedonia	B	Naff	B
Cheney	B	Narcisse	C
Clayton	B	Nez Perce	C
Cocolalla	D	Palouse	B
Dearyton	C	Peone	D
Dragoon	C	Phoebe	B
Eloika	B	Reardan	C
Emdent	D	Schumacher	B
Freeman	C	Semiahmoo	D
Garfield	C	Snow	B
Garrison	B	Speigle	B
Glenrose	B	Spokane	C
Green Bluff	B	Springdale	A
Hagen	B	Tekoa	C
Hardesty	B	Uhlig	B
Hesseltine	B	Vassar	B
Konner	D	Wethey	C
Lakesol	B	Wolfeson	C

* From SCS, TR-55, Second Edition, June 1986, Appendix A.

Hydrologic Soil Group Classifications

A. Low runoff potential: Soils having high infiltration rates, even when thoroughly wetted, and consisting chiefly of deep, well-to-excessively drained sands or gravels. These soils have a high rate of water transmission.

B. Moderately low runoff potential: Soils having moderate infiltration rates when thoroughly wetted, and consisting chiefly of moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.

C. Moderately high runoff potential: Soils have slow infiltration rates when thoroughly wetted, and consisting chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine textures. These soils have a slow rate of water transmission.

D. High runoff potential: Soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a hardpan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission.

The following are important criteria/considerations for selection of CN values:

Many factors may affect the CN value for a given land use. For example, the movement of heavy equipment over bare ground may compact the soil so that it has a lesser infiltration rate and greater runoff potential than would be indicated by strict application of the CN value based on predevelopment conditions at the site.

Separate CN values must be selected for the pervious and impervious areas of an urban basin or sub-basin. For all developed areas, the percent impervious must be estimated from best available plans, topography, or aerial photography and verified by field reconnaissance. Generally, the pervious area CN value shall be a weighted average of all the pervious area CN values within the sub-basin. However, if two areas within the same sub-basin have CN values which are different by more than 20 points, separate hydrographs need to be generated for the two areas and the hydrographs then added together to determine the sub-basin's runoff characteristics.

Directly connected impervious areas are areas such as roofs and driveways from which runoff directly enters the drainage system without first traversing an area of pervious ground. Unconnected impervious areas are areas whose runoff is spread over a pervious area as sheet flow and include such items as a tennis court in the middle of a lawn. Unconnected impervious areas can be weighted with pervious areas.

Table 4.5.2 gives CNs for agricultural, suburban, and urban land use classifications. These Curve Number values listed in Table 4.5.2 are applicable under normal antecedent moisture conditions (AMC II) and are the basis of design in Eastern Washington.

Conditions where there is high groundwater, or shallow bedrock can cause a significant increase in runoff. If these conditions exist, it needs to be addressed by the design engineer. For a more complete discussion of computing weighted CN values, see NRCS publication 210-VI-TR-55, Second Ed, June 1986.

Antecedent Moisture Condition

The moisture condition in a soil at the onset of a storm event, referred to as the antecedent moisture condition (AMC), has a significant effect on both the volume and rate of runoff. Recognizing that fact, the SCS developed three antecedent soil moisture conditions, labeled conditions I, II, and III. The description of each condition is:

AMC I: soils are dry but not to wilting point

AMC II: average conditions

AMC III: heavy rainfall, or light rainfall and low temperatures have occurred within the last 5 days; near saturated or saturated soil

The table shown below gives seasonal rainfall limits for the three antecedent soil moisture conditions:

Total 5-day Antecedent Rainfall (inches)

AMC	Dormant Season	Growing Season
I	Less than 0.5	Less than 1.4
II	0.5 to 1.1	1.4 to 2.1
III	Over 1.1	Over 2.1

Varying antecedent moisture conditions are used in the design of evaporation ponds in Section 6.4. See Table 4.5.3 for the curve number conversions for different antecedent moisture conditions for the case of Ia = 0.2S. For other conversion, see the SCS National Engineering Handbook No. 4, 1985.

Supplemental Guidelines

Local jurisdictions may wish to restrict the curve numbers used to describe the existing condition and generate the runoff in the predeveloped condition. The lower curve numbers result in lower runoff and mitigate for past changes to the natural drainage patterns. Restricting the allowable curve numbers can also reduce the subjectiveness that is inherent in the selection of curve numbers.

Table 4.5.2
Runoff Curve Numbers for Selected Agricultural, Suburban, and Urban Areas

	CNs for hydrologic soil group			
Cover type and hydrologic condition	A	B	C	D
Open Space (lawns, parks, golf courses, cemeteries, landscaping, etc.): [1]				
Poor condition (grass cover <50% of the area)	68	79	86	89
Fair condition (grass cover on 50% to 75% of the area)	49	69	79	84
Good condition (grass cover on >75% of the area)	39	61	74	80
Impervious Areas:				
Open water bodies: lakes, wetlands, ponds etc.	100	100	100	100
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)	98	98	98	98
Porous Pavers and Permeable Interlocking Concrete (assumed as 85% impervious and 15% lawn):				
Fair lawn condition (weighted average CNs)	95	96	97	97
Gravel (including right-of-way)	76	85	89	91
Dirt (including right-of-way)	72	82	87	89
Pasture, Grassland, or Range-Continuous Forage for Grazing:				
Poor condition (ground cover <50% or heavily grazed with no mulch).	68	79	86	89
Fair condition (ground cover 50% to 75% and not heavily grazed)	49	69	79	84
Good condition (ground cover >75% and lightly or only occasionally grazed)	39	61	74	80
Cultivated Agricultural Lands:				
Row Crops (good) e.g. corn, sugar beets, soy beans	64	75	82	85
Small Grain (good) e.g. wheat, barley, flax	60	72	80	84
Meadow (continuous grass, protected from grazing and generally mowed for hay):	30	58	71	78
Brush (brush-weed-grass mixture with brush the major element):				
Poor (<50% ground cover)	48	67	77	83
Fair (50% to 75% ground cover)	35	56	70	77
Good (>75% ground cover)	30[2]	48	65	73
Woods - grass combination (orchard or tree farm):[3]				
Poor	57	73	82	86
Fair	43	65	76	82
Good	32	58	72	79
Woods:				
Poor (Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning)	45	66	77	83
Fair (Woods are grazed but not burned, and some forest litter covers the soil)	36	60	73	79
Good (Woods are protected from grazing, and litter and brush adequately cover the soil)	30	55	70	77
Herbaceous (mixture of grass, weeds, and low-growing brush, with brush the minor element):[4]				
Poor (<30% ground cover)		80	87	93
Fair (30% to 70% ground cover)		71	81	89
Good (>70% ground cover)		62	74	85
Sagebrush with Grass Understory:[4]				
Poor (<30% ground cover)		67	80	85
Fair (30% to 70% ground cover)		51	63	70
Good (>70% ground cover)		35	47	55
For a more detailed and complete description of land use curve numbers refer to chapter two (2) of the Soil Conservation Service's Technical Release No. 55 , (210-VI-TR-55, Second Ed., June 1986).				

[1] Composite CNs may be computed for other combinations of open space cover type.

[2] Actual curve number is less than 30; use CN = 30 for runoff computations.

[3] CNs shown were computed for areas with 50% woods and 50% grass (pasture) cover. Other combinations of conditions may be computed from the CNs for woods and pasture.

[4] Curve numbers have not been developed for group A soils.

Table 4.5.3
Curve Numbers Conversions for Different Antecedent Moisture Conditions (Case Ia = 0.2 S)

CN for AMC II	CN for AMC I	CN for AMC III	CN for AMC II	CN for AMC I	CN for AMC III
100	100	100	76	58	89
99	97	100	75	57	88
98	94	99	74	55	88
97	91	99	73	54	87
96	89	99	72	53	86
95	87	98	71	52	86
94	85	98	70	51	85
93	83	98	69	50	84
92	81	97	68	48	84
91	80	97	67	47	83
90	78	96	66	46	82
89	76	96	65	45	82
88	75	95	64	44	81
87	73	95	63	43	80
86	72	94	62	42	79
85	70	94	61	41	78
84	68	93	60	40	78
83	67	93	59	39	78
82	66	92	58	38	76
81	64	92	57	37	75
80	63	91	56	36	75
79	62	91	55	35	74
78	60	90	54	34	73
77	59	89	50	31	70

Source: SCS-NEH4. Table 10.1.

Example: The following is an example of how CN values are selected for a sample project.

Select CNs for the following development:

Existing Land Use-- woods (thin stand, poor cover)

Future Land Use -- 80% impervious

Basin Size -- 10 acres

Soil Type -- 80% Garfield, 20% Bonner split between the pervious and impervious areas.

Table 4.5.1 shows that Garfield soil belongs to the "C" hydrologic soil group and Bonner soil belongs to the "B" group. Therefore, for the existing condition, CNs of 77 and 66 are read from Table 4.5.2 and area weighted to obtain a CN value of 75.

For the developed condition with 80 percent impervious the impervious and pervious areas of 8.0 acres and 2.0 acres respectively. The impervious area CN-value is 98. The 2.0 acres of pervious area consists of 70 percent grass landscaping covering the same proportions of Garfield and Bonner soil (80 percent and 20 percent respectively). Therefore, CNs of 79 and 69 are read from Table 4.5.2 fair condition open space and area weighted to obtain a pervious area CN value of 77. The result of this example are summarized below:

On-Site Condition	Existing	Developed
Land use	Woods	Multi-Family
Pervious area	10.0 ac.	2.0 ac.
CN of pervious area	75	77
Impervious area	0 ac	8.0 ac
CN of impervious area	---	98

SCS Curve Number Equations

The rainfall-runoff equations of the SCS curve number method relates a land area's runoff depth (precipitation excess) to the precipitation it receives and to its natural storage capacity. The amount of runoff from a given watershed is solved with the following equations:

$$Q = \frac{(P\ 4\ 0.2S)^2}{P\ 2\ 0.8S} \qquad \text{(4-1)}$$

$$S = \frac{1000}{CN} - 10 \qquad \text{(4-2)}$$

$Q = 0$ for $P < 0.2S$

Where,

Q is the actual direct runoff depth (inches)

P is the total storm rainfall depth over the area (inches)

S is the potential abstraction or potential maximum natural detention over the area due to infiltration, storage, etc. (inches)

CN is the runoff curve number

The combination of the above equations allows for estimation of the total runoff volume by computing the total runoff depth, Q, given the total precipitation depth, P.

The following is an example for determining design treatment volume.

The project location is Ellensburg.
The contributing area requiring treatment is 4.5 acres.
The curve number of the area is 98 (which corresponds to paved surfaces).
The value of S is 1000/98 – 10 = 0.20.

The 2-year 24-hour precipitation from Figure 4-3.3 is 0.8 inches.
C_{wqs} for Region 2 from Table 4.2.8 is 0.66.
24 to 72 Hour Conversion Factor for Region 2 from Table 4.2.11 is 1.19.

For Method 2, the total amount of rainfall during the long-duration storm would be:

P = (0.80 inches) (0.66) (1.19) = 0.63 inches

For Method 4, the total amount of rainfall during the 24-hour storm would be:

P = (0.80 inches) (0.66) = 0.53 inches

Continuing on with Method 2, the amount of rainfall that would become runoff would be:

Q = [0.63 - 0.2 (0.20)]2 /[0.63 + 0.8 (0.20)] = 0.44 inches

This computed runoff represents inches over the tributary area. Therefore, the total volume of runoff is found by multiplying Q by the area (with necessary conversions):

Total runoff Volume (cu-ft)	=	(3,630) (cu-ft/ac-in)	(Q) (in)	(A) (ac)

The total runoff volume is:

3,630 cu. ft./acre-in. x 0.44 in. x 4.5 acres = 7,187 cu. ft.

This is the design volume for treatment BMPs for which the design criterion is based on volume of runoff.

When developing the runoff hydrograph, the above equation for Q is used to compute the incremental runoff depth for each time interval from the incremental precipitation depth given by the design storm hyetograph. This time distribution of runoff depth is often referred to as the precipitation excess and provides the basis for synthesizing the runoff hydrograph.

4.6 Single Event Hydrograph Methods

Applicability

Single Event Hydrograph Methods are the required method for designing flow control BMPs. They are an allowable method for computing peak runoff rates and runoff volumes for design of runoff treatment BMPs. Single Event Hydrograph Methods include Soil Conservation Service (SCS) and Santa Barbara Urban Hydrograph (SBUH). Commercially available computer programs for these methods may be used, if the sponsor’s engineer acquires acceptance from the local jurisdiction. Said acceptance shall be obtained prior to submittal of plans and calculations.

4.6.1 Hydrograph Design Process

This section presents the general process involved in conducting a hydrologic analysis using hydrograph methods to a) design retention/detention flow control facilities and b) determine water quality treatment volumes. The exact step-by-step method for entering data into a computer model varies with the different models and is not described here. See the documentation or Help module of the computer program. Pre-developed and post-developed site runoff conditions need to be determined and documented in the Stormwater Site Plan.

The process for designing retention/detention flow control facilities is described as follows:

Review the Core Element #6 in Chapter 2 to determine all requirements that will apply to the proposed project.

1. Determine the climate region and Mean Annual Precipitation (MAP). (See Figure 4.3.1)
2. Determine 2 rainfalls for site. (See Figures 4.3.3 and 4.3.5)
   - 2-year – 24-hour
   - 25-year – 24-hour
3. Determine pre-developed soils type and hydrologic group (A, B, C, or D) from SCS maps.
4. Determine pre-developed and post-developed drainage basin areas, and determine the subsequent pervious and impervious area for each condition (in acres).
5. Determine curve numbers for pervious and impervious area using hydrologic soil group for both the pre-developed and post-developed condition. (See Table 4.5.2)
6. Determine pre-developed and post-developed time of concentration. (Some computer models will do this calculation if the designer enters length, slope, roughness and flow type.)
7. Select storm hyetograph and analysis time interval. Check analysis time interval is appropriate for use with storm hyetograph time increment.
8. Input data obtained from Steps 2, 4, 5, 6, and 7 into the computer model for each pre-developed and post-developed storm event.
9. Have the computer model compute the hydrographs.
10. Review the peak flow rate for the pre-developed conditions in the 2-year and 25-year design storms. The allowable release rate for the 2-year storm is 50 percent of the pre-developed 2-year peak flow. The allowable release rate for the 25-year storm is equal to the pre-developed 25-year peak flow. Note that in some cases the pre-developed 2-year peak flow rate may be 0 cfs, which means there is no discharge from the site. The 2-year post-developed

flows in this situation must be retained as dead storage that will ultimately infiltrate or evaporate.

11. Review the peak flow rate for post-developed conditions in the 2-year and 25-year storms. Compare the increases in peak flow rates for 2-year and 25-year design storms to determine if the project qualifies for an exemption.
12. Assume the size of the detention facility and input the data into the computer model. Most computer models will allow a vault or a pond detention facility, with or without infiltration. Refer to the volume of the design storm hydrograph computed in Step 10 for a good assumption of the detention volume required.
13. Assume the size of the orifice structure and input the data into the computer model. A single orifice at the bottom of the riser may suffice in some cases. In other projects multiple orifices may result in decreased pond sizes. A good approximation would be to assume a 1 inch diameter orifice per 0.05 cfs outflow for a typical pond. Note that the design engineer should check with the local jurisdiction to determine the minimum allowable orifice diameter.
14. Use the computer model to route the post-developed hydrographs through the detention facility and orifice structure. Compare the post-developed peak outflow rates to allowable release rates from Step 11.
15. If the post-developed peak outflow rates exceed the allowable release rates, adjust detention volume, orifice size, orifice height, or number of orifices. Keep running the computer model and adjusting the parameters until the post-developed outflow rates are less than or equal to the allowable release rates.
18. Calculations are complete.

The process for designing water quality treatment volumes or flow rates is described as follows. Note that the data for many of the initial steps matches the data utilized in designing retention/detention flow control facilities described above.

1. Review the Core Element #5 in Chapter 2 to determine all requirements that will apply to the proposed project.
2. Determine the climate region and Mean Annual Precipitation (MAP). (See Figure 4.3.1)
3. Determine one of the following rainfalls for site depending on the treatment BMP. (See Figures 4.3.2 and 4.3.3)
   - 2-year – 2-hour for flow based treatment BMPs
   - 2-year – 24-hour for volume based treatment BMPs

4. Multiply the rainfall by the appropriate coefficient to determine the 6-month precipitation.
   - C_{sds} from Table 4.2.11 for 2-year – 2-hour precipitation
   - C_{wqs} from Table 4.2.9 for 2-year – 24-hour precipitation
5. Determine the existing soils type and hydrologic group (A, B, C, or D) from SCS maps.
6. Determine post-developed drainage basin areas, and determine the subsequent pervious and impervious area requiring treatment that contributes flow to the treatment BMP (in acres).
7. Determine curve numbers for pervious and impervious area using hydrologic soil group for the post-developed condition. (See Table 4.5.2)
8. Determine post-developed time of concentration. (Some computer models will do this calculation if the designer enters length, slope, roughness and flow type.)
9. If modeling the short- or long-duration storm hyetograph, select the 3-hour short-duration storm hyetographs (See Table 4.2.4) or regional long-duration storm hyetographs for the climate region (See either Table 4.2.2 or Tables 4.2.5 to 4.2.8) and analysis time interval. Check analysis time interval is appropriate for use with storm hyetograph time increment.
10. Input data obtained from Steps 4, 6, 7, 8 and 9 into the computer model for the post-developed storm event.
11. Have the computer model compute the hydrograph.
12. For the design of flow based treatment BMPs, the computed peak flow form the 6-month – 2-hour hydrograph is the design flow.
13. For the design of volume based treatment BMPs, the computed volume from the 6-month – 24-hour (or long-duration design) storm is the design volume.

4.6.2 Hydrograph Parameters

All storm event hydrograph methods require the input of parameters that describe the physical drainage basin characteristics. These parameters provide the basis from which the runoff hydrograph is developed. This section describes one of the three key parameters used to develop the runoff hydrograph using the SCS or SBUH method. The other two parameters are area and curve number, which are described in Section 4.5.

4.6.3 Travel Time and Time of Concentration

The time of concentration for rainfall shall be computed for all overland flow, ditches, channels, gutters, culverts, and pipe systems. When using the SBUH or SCS methods, the time of concentration for the various surfaces and conveyances should be computed using the following methods, which are based on the methods described in Chapter 3, NRCS publication 210-VI-TR-55, Second Ed., June 1986.

Travel time (T_t) is the time it takes water to travel from one location to another in a watershed. T_t is a component of time of concentration (T_c), which is the time for runoff to travel from the hydraulically most distant point of the watershed. T_c is computed by summing all the travel times for consecutive components of the drainage conveyance system. T_c influences the shape and peak of the runoff hydrograph. Urbanization usually decreases T_c, thereby increasing the peak discharge. But T_c can be increased as a result of (a) ponding behind small or inadequate drainage systems, including storm drain inlets and road culverts, or (b) reduction of land slope through grading.

Water moves through a watershed as sheet flow, shallow concentrated flow, open channel flow, or some combination of these. The type that occurs is best determined by field inspection.

Travel time (T_t) is the ratio of flow length to flow velocity:

$$T_t = L / 60\,V \quad \text{(4-3)}$$

where

T_t = travel time (min)

L = flow length (ft)

V = average velocity (ft/s), and

60 = conversion factor from seconds to minutes.

Time of concentration (T_c) is the sum of T_t values for the various consecutive flow segments.

$$T_c = T_{t_1} + T_{t_2} + \ldots T_{t_m} \quad \text{(4-4)}$$

where

T_c = time of concentration (min), and

m = number of flow segments

Sheet Flow: Sheet flow is flow over plane surfaces. It usually occurs in the headwater of streams. With sheet flow, the friction value (n_s) (a modified Manning's effective roughness coefficient that includes the effect of raindrop impact; drag over the plane surface; obstacles such as litter, crop ridges, and rocks; and erosion and transportation of sediment) is used. These n_s values are for very shallow flow depths of about 0.1 foot and are only used for travel lengths up to 300 feet. Table 4.6.1 gives Manning's n. values for sheet flow for various surface conditions.

For sheet flow up to 300 feet, use Manning's kinematic solution to directly compute T_t:

$$T_t = \frac{0.42\ (n_s L)^{0.8}}{(P_2)^{0.5}\ (s_o)^{0.4}} \quad \text{................ (4-5)}$$

where

T_t = travel time (min),
n_s = sheet flow Manning's effective roughness coefficient (from Table 4.6.1),
L = flow length (ft),
P_2 = 2-year, 24-hour rainfall (in), (from Figure 4.3.3) and
s_o = slope of hydraulic grade line (land slope, ft/ft)

Shallow Concentrated Flow: After a maximum of 300 feet, sheet flow is assumed to become shallow concentrated flow. The average velocity for this flow can be calculated using the k_s values from Table 4.6.1 in which average velocity is a function of watercourse slope and type of channel. After computing the average velocity using the Velocity Equation below, the travel time (T_t) for the shallow concentrated flow segment can be computed using the Travel Time Equation described above.

Velocity Equation

A commonly used method of computing average velocity of flow, once it has measurable depth, is the following equation:

$$V = k \cdot \sqrt{s_o} \quad \text{.. (4-6)}$$

where:

V = velocity (ft/s)
k = time of concentration velocity factor (ft/s)
s_o = slope of flow path (ft/ft)

"k" values in Table 4.6.1 have been computed for various land covers and channel characteristics with assumptions made for hydraulic radius using the following rearrangement of Manning's equation:

$k = (1.49\ (R)^{0.667})/n$; .... (4-7)

where
R = an assumed hydraulic radius
n = Manning's roughness coefficient for open channel flow (from Tables 4.6.1 or 4.6.2)

Table 4.6.1
"n" And "k" Values for Use in Computing Time Of Concentration

FOR SHEET FLOW	**n_s**
Smooth surfaces (concrete, asphalt, gravel, or bare hard soil)	0.011
Fallow fields of loose soil surface (no vegetal residue)	0.05
Cultivated soil with crop residue (slope < 0.20 ft/ft)	0.06
Cultivated soil with crop residue (slope > 0.20 ft/ft)	0.17
Short prairie grass and lawns	0.15
Dense grass	0.24
Bermuda grass	0.41
Range, natural	0.13
Woods or forest, poor cover	0.40
Woods or forest, good cover	0.80
FOR SHALLOW, CONCENTRATED FLOW	**k_s**
Forest with heavy ground litter and meadows (n = 0.10)	3
Brushy ground with some trees (n =0.06)	5
Fallow or minimum tillage cultivation (n = 0.04)	8
High grass (n = 0.035)	9
Short grass, pasture and lawns (n = 0.030)	11
Newly-bare ground (n = 0.025)	13
Paved and gravel areas (n = 0.012)	27
CHANNEL FLOW (INTERMITTENT, R = 0.2)	**k_c**
Forested swale with heavy ground litter (n=0.10)	5
Forested drainage course/ravine with defined channel bed (n=0.050)	10
Rock-lined waterway (n=0.035)	15
Grassed waterway (n=0.030)	17
Earth-lined waterway (n=0.025)	20
CMP pipe (n=0.024)	21
Concrete pipe (n=0.012)	42
Other waterways and pipes	0.508/n
CHANNEL FLOW (CONTINUOUS STREAM, R =0.4)	**k_c**
Meandering stream with some pools (n=0.040)	20
Rock-lined stream (n=0.035)	23
Grassed stream (n=0.030)	27
Other streams, man-made channels and pipe	0.807/n

Table 4.6.2
Other Values of the Roughness Coefficient "n" for Channel Flow

Type of Channel and Description	Manning's "n"*	Type of Channel and Description	Manning's "n"*
A. Constructed Channels		6. Sluggish reaches, weedy	
a. Earth, straight and uniform		deep pools	0.070
1. Clean, recently completed	0.018	7. Very weedy reaches, deep	
2. Gravel, uniform selection,	0.025	pools, or floodways with	
clean		heavy stand of timber and	
3. With short grass, few	0.027	underbrush	0.100
weeds		b. Mountain streams, no vegetation	
b. Earth, winding and sluggish		in channel, banks usually steep,	
1. No vegetation	0.025	trees and brush along banks	
2. Grass, some weeds	0.030	submerged at high stages	
3. Dense weeds or aquatic		1. Bottom: gravel, cobbles and	
plants in deep channels	0.035	few boulders	0.040
4. Earth bottom and rubble		2. Bottom: cobbles with large	
sides	0.030	boulders	0.050
5. Stony bottom and weedy		B-2 Flood plains	
banks	0.035	a. Pasture, no brush	
6. Cobble bottom and clean		1. Short grass	0.030
sides	0.040	2. High grass	0.035
c. Rock lined		b. Cultivated areas	
1. Smooth and uniform	0.035	1. No crop	0.030
2. Jagged and irregular	0.040	2. Mature row crops	0.035
d. Channels not maintained,		3. Mature field crops	0.040
weeds and brush uncut		c. Brush	
1. Dense weeds, high as flow		1. Scattered brush, heavy	
depth	0.080	weeds	0.050
2. Clean bottom, brush on		2. Light brush and trees	0.060
sides	0.050	3. Medium to dense brush	0.070
3. Same, highest stage of		4. Heavy, dense brush	0.100
flow	0.070	d. Trees	
4. Dense brush, high stage	0.100	1. Dense willows, straight	0.150
B. Natural Streams		2. Cleared land with tree	
B-1 Minor streams (top width		stumps, no sprouts	0.040
at flood stage < 100ft.)		3. Same as above, but with	
a. Streams on plain		heavy growth of sprouts	0.060
1. Clean, straight, full stage		4. Heavy stand of timber, a few	
no rifts or deep pools	0.030	down trees, little	
2. Same as above, but more		undergrowth, flood stage	
stones and weeds	0.035	below branches	0.100
3. Clean, winding, some		5. Same as above, but with	
pools and shoals	0.040	flood stage reaching	
4. Same as above, but some		branches	0.120
Weeds	0.040		
5. Same as 4, but more			
Stones	0.050		

*Note, these "n" values are "normal" values for use in analysis of channels. For conservative design for channel capacity the "maximum" values listed in other references should be considered. For channel bank stability the minimum values should be considered.

Open Channel Flow: Open channels are assumed to begin where surveyed cross section information has been obtained, where channels are visible on aerial photographs, or where lines indicating streams appear (in blue) on United States Geological Survey (USGS) quadrangle sheets. The k_c values from Table 4.6.1 used in the Velocity Equation above or water surface profile information can be used to estimate average flow velocity. Average flow velocity is usually determined for bank-full conditions. After average velocity is computed the travel time (T_t) for the channel segment can be computed using the Travel Time Equation above.

Lakes or Wetlands: Sometimes it is necessary to estimate the velocity of flow through a lake or wetland at the outlet of a watershed. This travel time is normally very small and can be assumed as zero. Where significant attenuation may occur due to storage effects, the flows should be routed using the "level pool routing" technique described in Section 4.7.

Limitations: The following limitations apply in estimating travel time (T_t).

Manning's kinematic solution should not be used for sheet flow longer than 300 feet.

In watersheds with storm sewers, carefully identify the appropriate hydraulic flow path to estimate T_c. Storm sewers generally handle only a small portion of a large event. The rest of the peak flow travels by streets, lawns, and so on, to the outlet. Consult a standard hydraulics textbook to determine average velocity in pipes for either pressure or nonpressure flow.

A culvert or bridge can act as a reservoir outlet if there is significant storage behind it. A hydrograph should be developed to this point and the "level pool routing" technique should be used to determine the outflow rating curve through the culvert or bridge.

Time of Concentration Example: The following is an example of travel time and time of concentration calculations.

Given: An existing drainage basin having a selected flow route composed of the following 4 segments: (Note: Drainage basin has a P_2 = 0.8 inches.)

Segment 1: L = 200 ft, Forest with good cover (sheet flow)
s_o = 0.03 ft/ft, n_s = 0.80
Segment 2: L = 300 ft, Pasture (shallow concentrated flow)
s_o = 0.04 ft/ft, k_s = 11
Segment 3: L = 300 ft, Grassed waterway (intermittent channel)
s_o = 0.05, k_c = 17
Segment 4: L = 500 ft, Grass-lined stream (continuous)
s_o = 0.02, k_c = 27

Calculate travel times (T_t's) for each reach and then sum them to calculate the drainage basin time of concentration (T_c).

Segment 1: Sheet flow, (L < 300 feet)

$$T_t = \frac{0.42(n_s L)^{0.8}}{(P_2)^{0.5}(s_o)^{0.4}}$$

$$T_1 = \frac{(0.42)[(0.80)(200)]^{0.8}}{(0.8)^{0.3}(0.03)^{0.4}} = \underline{106 \text{ minutes}}$$

Segment 2: Shallow concentrated flow

$$V = k_s \sqrt{s_o}$$

$$V_2 = (11)\sqrt{(0.04)} = 2.2 \text{ ft/s}$$

$$T_2 = \frac{L}{60V} = \frac{(300)}{60(2.2)} = \underline{2 \text{ minutes}}$$

Segment 3: Intermittent channel flow

$$V_4 = (17)\sqrt{(0.05)} = 3.8 \text{ ft/s}$$

$$T_4 = \frac{(300)}{60(3.8)} = \underline{1 \text{ minute}}$$

Segment 4: Continuous stream

$$V_5 = (27)\sqrt{(0.02)} = 3.8 \text{ ft/s}$$

$$T_5 = \frac{(500)}{60(3.8)} = \underline{2 \text{ minutes}}$$

$$T_c = T_1 + T_2 + T_3 + T_4$$

$$T_c = 106 + 2 + 1 + 2 = \underline{111 \text{ minutes}}$$

It is important to note how the initial sheet flow segment's travel time dominates the time of concentration computation. This will nearly always be the case for relatively small drainage basins and in particular for the existing site conditions. This also illustrates the significant impact urbanization has on the surface runoff portion of the hydrologic process.

The time of concentration should be calculated for each significantly different slope. Travel time for flow in pipes, ditches and gutters should be computed as a function of the velocity as defined by the Manning formula.

4.6.4 Hydrograph Synthesis

This section presents a description of the Santa Barbara Urban Hydrograph (SBUH) method. This method is used to synthesize the runoff hydrograph from precipitation excess (time distribution of runoff) and time of concentration.

The SBUH method was developed by the Santa Barbara County Flood Control and Water Conservation District, California. The SBUH method directly computes a runoff hydrograph without going through an intermediate process (unit hydrograph) as the SCSUH method does. By comparison, the calculation steps of the SBUH method are much simpler and can be programmed on a calculator or a spreadsheet program. Commercial software is also available that can perform these calculations.

The SBUH method uses two steps to synthesize the runoff hydrograph:

Step 1 - Compute the instantaneous hydrograph, and

Step 2- Compute the runoff hydrograph.

The instantaneous hydrograph, l(t), in cfs, at each time step, dt, is computed as follows:

$l(t) = 60.5\ R(t)\ A/dt$

where

R(t) = total runoff depth (both impervious and pervious runoffs) at time increment dt, in inches (also known as precipitation excess)

A = area in acres

dt = time interval in minutes*

Note: *A maximum time interval of 5 minutes will be used for all short-duration design storms. A maximum time interval of 30 minutes will be used for all long-duration design storms.*

The runoff hydrograph, Q(t), is then obtained by routing the instantaneous hydrograph l(t), through an imaginary reservoir with a time delay equal to the time of concentration, T_c, of the drainage basin. The following equation estimates the routed flow, Q(t):

$$Q(t+1) = Q(t) + w[l(t) + l(t+1) - 2Q(t)]$$

where,

$$w = dt/(2T_c + dt)$$

dt = time interval in minutes

Example: To illustrate the SBUH method, Figure 4.6.1 shows a runoff hydrograph computed by this method. These examples were prepared using spreadsheet program. These examples illustrate how the method can be performed with a personal computer. In order to save space, time increments with all values equal to zero have been omitted.

Figure 4.6.1
Example SBUH Runoff Hydrograph

Existing Site Condition

REGION 2, 25-YEAR LONG-DURATION STORM

Given				
	Area (ac.) = **5.0**	P_t (inches) = **1.6**	d_t (min.)= **30**	T_c (min)= **40**
w =routing constant $=d_t/(2T_c + d_t)$ = **0.2727**				
Pervious Area (ac.):	Area = **5.0**	CN = **65**	S = (1000/CN) -10 = **5.38**	0.2S = **1.08**
Impervious Area (ac.):	Area = **0.0**	CN = **98**	S = (1000/CN) -10 = **0.20**	0.2S = **0.04**

Column (3) = rainfall distribution
Column (4) = Column (3) x P_t
Column (5) = P = Accumulated sum of Column (4)
Column (6) = (If P Ω0.2S)= 0; (If P } 0.2S)= [(Column (5) – 0.2)^2/(Column (5) + 0.8S)]
where PERVIOUS AREA S value is used
Column (7) = Column (6) of present step – Column (6) of previous step
Column (8) = (If P Ω0.2S)= 0; (If P } 0.2S)= [(Column (5) – 0.2)^2/(Column (5) + 0.8S)]
where IMPERVIOUS AREA S value is used
Column (9) = Column (8) of present step – Column (8) of previous step
Column (10) = [(PERVIOUS AREA/TOTAL AREA) * Column (7)] + [(IMPERVIOUS AREA/TOTAL AREA) x Column (9)]
Column (11) = (60.5 x Column (10) x TOTAL AREA)/d_t
Column (12) = Column (12) of previous time + w[(Column (11) of previous time step + Column (11) of present time step) – (2 x Column (12) of previous time step)]
where $w = d_t /(2T_c + d_t)$

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
					Pervious Area		Impervious Area				
Time Incr.	Time (min)	Rainfall Distrib. (fraction)	Incre. Rainfall (inches)	Accumul. Rainfall (inches)	Accum. Runoff (inches)	Incre. Runoff (inches)	Accum. Runoff (inches)	Incre. Runoff (inches)	Total Runoff (inches)	Instant Flowrate (cfs)	Design Flowrate (cfs)
1	0	0.00000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	0.00
2	30	0.00000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	0.00
3	60	0.00000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	0.00
…											
90	2670	0.06220	0.100	0.934	0.000	0.000	0.495	0.089	0.000	0.0	0.00
91	2700	0.09330	0.149	1.083	0.000	0.000	0.632	0.137	0.000	0.0	0.00
92	2730	0.05275	0.084	1.167	0.001	0.001	0.711	0.079	0.001	0.0	0.00
93	2760	0.04025	0.064	1.232	0.004	0.003	0.772	0.061	0.003	0.0	0.01
94	2790	0.03717	0.059	1.291	0.008	0.004	0.828	0.056	0.004	0.0	0.02
95	2820	0.03483	0.056	1.347	0.013	0.005	0.881	0.053	0.005	0.0	0.03
96	2850	0.03307	0.053	1.400	0.018	0.005	0.931	0.051	0.005	0.1	0.04

(1)	(2)	(3)	(4)	(5)	(6) Pervious Area	(7)	(8) Impervious Area	(9)	(10)	(11)	(12)
Time Incr.	Time (min)	Rainfall Distrib. (fraction)	Incre. Rainfall (inches)	Accumul. Rainfall (inches)	Accum. Runoff (inches)	Incre. Runoff (inches)	Accum. Runoff (inches)	Incre. Runoff (inches)	Total Runoff (inches)	Instant Flowrate (cfs)	Design Flowrate (cfs)
97	2880	0.02893	0.046	1.446	0.024	0.005	0.976	0.044	0.005	0.1	0.05
98	2910	0.02519	0.040	1.486	0.029	0.005	1.015	0.039	0.005	0.1	0.05
99	2940	0.02189	0.035	1.521	0.034	0.005	1.048	0.034	0.005	0.0	0.05
100	2970	0.01906	0.030	1.552	0.039	0.005	1.078	0.029	0.005	0.0	0.05
101	3000	0.01670	0.027	1.579	0.043	0.004	1.103	0.026	0.004	0.0	0.05
102	3030	0.01480	0.024	1.602	0.047	0.004	1.126	0.023	0.004	0.0	0.04
103	3060	0.01336	0.021	1.624	0.050	0.004	1.147	0.021	0.004	0.0	0.04
104	3090	0.01234	0.020	1.643	0.054	0.004	1.166	0.019	0.004	0.0	0.04
105	3120	0.01156	0.018	1.662	0.057	0.003	1.184	0.018	0.003	0.0	0.04
106	3150	0.01096	0.018	1.679	0.061	0.003	1.201	0.017	0.003	0.0	0.04
107	3180	0.01054	0.017	1.696	0.064	0.003	1.217	0.016	0.003	0.0	0.03
108	3210	0.01032	0.017	1.713	0.067	0.003	1.233	0.016	0.003	0.0	0.03
109	3240	0.01028	0.016	1.729	0.070	0.003	1.249	0.016	0.003	0.0	0.03
110	3270	0.01038	0.017	1.746	0.074	0.003	1.265	0.016	0.003	0.0	0.03
111	3300	0.01046	0.017	1.763	0.077	0.004	1.282	0.016	0.004	0.0	0.03
112	3330	0.01046	0.017	1.779	0.081	0.004	1.298	0.016	0.004	0.0	0.04
113	3360	0.01040	0.017	1.796	0.085	0.004	1.314	0.016	0.004	0.0	0.04
114	3390	0.01025	0.016	1.812	0.088	0.004	1.330	0.016	0.004	0.0	0.04
115	3420	0.01004	0.016	1.828	0.092	0.004	1.346	0.016	0.004	0.0	0.04
116	3450	0.00974	0.016	1.844	0.096	0.004	1.361	0.015	0.004	0.0	0.04
117	3480	0.00926	0.015	1.859	0.099	0.003	1.375	0.014	0.003	0.0	0.04
118	3510	0.00868	0.014	1.873	0.102	0.003	1.389	0.014	0.003	0.0	0.04
119	3540	0.00832	0.013	1.886	0.106	0.003	1.402	0.013	0.003	0.0	0.03
120	3570	0.00781	0.012	1.899	0.109	0.003	1.414	0.012	0.003	0.0	0.03
121	3600	0.00500	0.008	1.907	0.111	0.002	1.422	0.008	0.002	0.0	0.03
122	3630	0.00000	0.000	1.907	0.111	0.000	1.422	0.000	0.000	0.0	0.02
123	3660	0.00000	0.000	1.907	0.111	0.000	1.422	0.000	0.000	0.0	0.01
124	3690	0.00000	0.000	1.907	0.111	0.000	1.422	0.000	0.000	0.0	0.00
125	3720	0.00000	0.000	1.907	0.111	0.000	1.422	0.000	0.000	0.0	0.00
…											
145	4320	0.00000	0.000	1.907	0.111	0.000	1.422	0.000	0.000	0.0	0.00

Developed Site Condition

REGION 2, 25-YEAR LONG-DURATION STORM

Given				
Area (ac.) = **5.0**		P_t (inches) = **1.6**	d_t (min.)= **30**	T_c (min)= **5**
w =routing constant $=d_t/(2T_c + d_t)$ = **0.750**				
Pervious Area (ac.):	Area = **0.5**	CN = **65**	S = (1000/CN) -10 = **5.38**	0.2S = **1.08**
Impervious Area (ac.):	Area = **4.5**	CN = **98**	S = (1000/CN) -10 = **0.20**	0.2S = **0.04**

Column (3) = rainfall distribution
Column (4) = Column (3) x P_t
Column (5) = P = Accumulated sum of Column (4)
Column (6) = (If P Ω0.2S)= 0; (If P } 0.2S)= [(Column (5) – 0.2)^2/(Column (5) + 0.8S)]
where PERVIOUS AREA S value is used
Column (7) = Column (6) of present step – Column (6) of previous step
Column (8) = (If P Ω0.2S)= 0; (If P } 0.2S)= [(Column (5) – 0.2)^2/(Column (5) + 0.8S)]
where IMPERVIOUS AREA S value is used
Column (9) = Column (8) of present step – Column (8) of previous step
Column (10) = [(PERVIOUS AREA/TOTAL AREA) * Column (7)] + [(IMPERVIOUS AREA/TOTAL AREA) x Column (9)]
Column (11) = (60.5 x Column (10) x TOTAL AREA)/d_t
Column (12) = Column (12) of previous time + w[(Column (11) of previous time step + Column (11) of present time step) – (2 x Column (12) of previous time step)]
where $w = d_t /(2T_c+ d_t)$

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
					Pervious Area		Impervious Area				
Time Incr.	Time (min)	Rainfall Distrib. (fraction)	Incre. Rainfall (inches)	Accum. Rainfall (inches)	Accum. Runoff (inches)	Incre. Runoff (inches)	Accum. Runoff (inches)	Incre. Runoff (inches)	Total Runoff (inches)	Instant Flowrate (cfs)	Design Flowrate (cfs)
1	0	0.00000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	0.00
2	30	0.00000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	0.00
3	60	0.00000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	0.00
…											
22	630	0.01669	0.027	0.046	0.000	0.000	0.000	0.000	0.000	0.0	0.00
23	660	0.02831	0.045	0.092	0.000	0.000	0.010	0.010	0.009	0.1	0.07
24	690	0.04680	0.075	0.167	0.000	0.000	0.048	0.038	0.034	0.3	0.29
25	720	0.03120	0.050	0.217	0.000	0.000	0.081	0.033	0.030	0.3	0.34
26	750	0.02549	0.041	0.257	0.000	0.000	0.111	0.030	0.027	0.3	0.26
27	780	0.01451	0.023	0.281	0.000	0.000	0.129	0.018	0.016	0.2	0.20
28	810	0.00445	0.007	0.288	0.000	0.000	0.135	0.006	0.005	0.1	0.06
29	840	0.00202	0.003	0.291	0.000	0.000	0.138	0.003	0.002	0.0	0.02
30	870	0.00192	0.003	0.294	0.000	0.000	0.140	0.002	0.002	0.0	0.02
31	900	0.00172	0.003	0.297	0.000	0.000	0.142	0.002	0.002	0.0	0.02

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
					Pervious Area		Impervious Area				
Time Incr.	Time (min)	Rainfall Distrib. (fraction)	Incre. Rainfall (inches)	Accum. Rainfall (inches)	Accum. Runoff (inches)	Incre. Runoff (inches)	Accum. Runoff (inches)	Incre. Runoff (inches)	Total Runoff (inches)	Instant Flowrate (cfs)	Design Flowrate (cfs)
32	930	0.00152	0.002	0.299	0.000	0.000	0.144	0.002	0.002	0.0	0.02
33	960	0.00132	0.002	0.301	0.000	0.000	0.146	0.002	0.002	0.0	0.02
34	990	0.00112	0.002	0.303	0.000	0.000	0.147	0.001	0.001	0.0	0.01
35	1020	0.00092	0.001	0.305	0.000	0.000	0.149	0.001	0.001	0.0	0.01
36	1050	0.00072	0.001	0.306	0.000	0.000	0.150	0.001	0.001	0.0	0.01
37	1080	0.00052	0.001	0.307	0.000	0.000	0.150	0.001	0.001	0.0	0.01
38	1110	0.00000	0.000	0.307	0.000	0.000	0.150	0.000	0.000	0.0	0.00
39	1140	0.00000	0.000	0.307	0.000	0.000	0.150	0.000	0.000	0.0	0.00
…											
72	2130	0.00000	0.000	0.307	0.000	0.000	0.150	0.000	0.000	0.0	0.00
73	2160	0.00000	0.000	0.307	0.000	0.000	0.150	0.000	0.000	0.0	0.00
74	2190	0.00544	0.009	0.315	0.000	0.000	0.157	0.007	0.006	0.1	0.05
75	2220	0.00856	0.014	0.329	0.000	0.000	0.169	0.011	0.010	0.1	0.10
76	2250	0.01000	0.016	0.345	0.000	0.000	0.182	0.013	0.012	0.1	0.12
77	2280	0.01200	0.019	0.364	0.000	0.000	0.198	0.016	0.015	0.1	0.14
78	2310	0.01300	0.021	0.385	0.000	0.000	0.216	0.018	0.016	0.2	0.16
79	2340	0.01400	0.022	0.407	0.000	0.000	0.235	0.019	0.017	0.2	0.17
80	2370	0.01500	0.024	0.431	0.000	0.000	0.256	0.021	0.019	0.2	0.19
81	2400	0.01600	0.026	0.457	0.000	0.000	0.279	0.023	0.020	0.2	0.20
82	2430	0.01700	0.027	0.484	0.000	0.000	0.304	0.024	0.022	0.2	0.22
83	2460	0.01869	0.030	0.514	0.000	0.000	0.331	0.027	0.024	0.2	0.24
84	2490	0.02281	0.036	0.551	0.000	0.000	0.364	0.033	0.030	0.3	0.29
85	2520	0.02832	0.045	0.596	0.000	0.000	0.406	0.042	0.038	0.4	0.37
86	2550	0.03050	0.049	0.645	0.000	0.000	0.451	0.045	0.041	0.4	0.41
87	2580	0.03350	0.054	0.698	0.000	0.000	0.502	0.050	0.045	0.5	0.45
88	2610	0.03650	0.058	0.757	0.000	0.000	0.557	0.055	0.050	0.5	0.50
89	2640	0.04842	0.077	0.834	0.000	0.000	0.631	0.074	0.067	0.7	0.63
90	2670	0.06220	0.100	0.934	0.000	0.000	0.727	0.096	0.086	0.9	0.84
91	2700	0.09330	0.149	1.083	0.000	0.000	0.871	0.145	0.130	1.3	1.22
92	2730	0.05275	0.084	1.167	0.001	0.001	0.954	0.082	0.074	0.7	0.94
93	2760	0.04025	0.064	1.232	0.004	0.003	1.017	0.063	0.057	0.6	0.52
94	2790	0.03717	0.059	1.291	0.008	0.004	1.075	0.058	0.053	0.5	0.57
95	2820	0.03483	0.056	1.347	0.013	0.005	1.130	0.055	0.050	0.5	0.49
96	2850	0.03307	0.053	1.400	0.018	0.005	1.182	0.052	0.047	0.5	0.49
97	2880	0.02893	0.046	1.446	0.024	0.005	1.227	0.046	0.042	0.4	0.43
98	2910	0.02519	0.040	1.486	0.029	0.005	1.267	0.040	0.036	0.4	0.37
99	2940	0.02189	0.035	1.521	0.034	0.005	1.301	0.034	0.032	0.3	0.33
100	2970	0.01906	0.030	1.552	0.039	0.005	1.331	0.030	0.028	0.3	0.28
101	3000	0.01670	0.027	1.579	0.043	0.004	1.358	0.026	0.024	0.2	0.25
102	3030	0.01480	0.024	1.602	0.047	0.004	1.381	0.023	0.021	0.2	0.22

(1)	(2)	(3)	(4)	(5)	(6) Pervious Area	(7)	(8) Impervious Area	(9)	(10)	(11)	(12)
Time Incr.	Time (min)	Rainfall Distrib. (fraction)	Incre. Rainfall (inches)	Accum. Rainfall (inches)	Accum. Runoff (inches)	Incre. Runoff (inches)	Accum. Runoff (inches)	Incre. Runoff (inches)	Total Runoff (inches)	Instant Flowrate (cfs)	Design Flowrate (cfs)
103	3060	0.01336	0.021	1.624	0.050	0.004	1.402	0.021	0.019	0.2	0.20
104	3090	0.01234	0.020	1.643	0.054	0.004	1.422	0.019	0.018	0.2	0.18
105	3120	0.01156	0.018	1.662	0.057	0.003	1.440	0.018	0.017	0.2	0.17
106	3150	0.01096	0.018	1.679	0.061	0.003	1.457	0.017	0.016	0.2	0.16
107	3180	0.01054	0.017	1.696	0.064	0.003	1.474	0.017	0.015	0.2	0.16
108	3210	0.01032	0.017	1.713	0.067	0.003	1.490	0.016	0.015	0.2	0.15
109	3240	0.01028	0.016	1.729	0.070	0.003	1.506	0.016	0.015	0.2	0.15
110	3270	0.01038	0.017	1.746	0.074	0.003	1.523	0.016	0.015	0.2	0.15
111	3300	0.01046	0.017	1.763	0.077	0.004	1.539	0.017	0.015	0.2	0.15
112	3330	0.01046	0.017	1.779	0.081	0.004	1.556	0.017	0.015	0.2	0.15
113	3360	0.01040	0.017	1.796	0.085	0.004	1.572	0.016	0.015	0.2	0.15
114	3390	0.01025	0.016	1.812	0.088	0.004	1.589	0.016	0.015	0.2	0.15
115	3420	0.01004	0.016	1.828	0.092	0.004	1.604	0.016	0.015	0.1	0.15
116	3450	0.00974	0.016	1.844	0.096	0.004	1.620	0.015	0.014	0.1	0.14
117	3480	0.00926	0.015	1.859	0.099	0.003	1.635	0.015	0.014	0.1	0.14
118	3510	0.00868	0.014	1.873	0.102	0.003	1.648	0.014	0.013	0.1	0.13
119	3540	0.00832	0.013	1.886	0.106	0.003	1.662	0.013	0.012	0.1	0.12
120	3570	0.00781	0.012	1.899	0.109	0.003	1.674	0.012	0.011	0.1	0.12
121	3600	0.00500	0.008	1.907	0.111	0.002	1.682	0.008	0.007	0.1	0.08
122	3630	0.00000	0.000	1.907	0.111	0.000	1.682	0.000	0.000	0.0	0.01
123	3660	0.00000	0.000	1.907	0.111	0.000	1.682	0.000	0.000	0.0	0.00
124	3690	0.00000	0.000	1.907	0.111	0.000	1.682	0.000	0.000	0.0	0.00
…											
144	4290	0.00000	0.000	1.907	0.111	0.000	1.682	0.000	0.000	0.0	0.00
145	4320	0.00000	0.000	1.907	0.111	0.000	1.682	0.000	0.000	0.0	0.00

4.7 Level-Pool Routing Method

4.7.1 Introduction

This section presents a general description of the methodology for routing a hydrograph through an existing retention/detention facility or closed depression, and for sizing a new retention/detention facility using hydrograph analysis.

The "level pool routing" technique presented here is one of the simplest and most commonly used hydrograph routing methods. This method is described in "Handbook of Applied Hydrology," Chow, Ven Te, 1964, and elsewhere, and is based on the continuity equation:

Inflow - Outflow = Change in storage

$$\left(\frac{I_1 + I_2}{2} - \frac{O_1 + O_2}{2} \right) = \frac{\div S}{\div t} = S_2 - S_1$$

where

I	=	Inflow at time 1 and time 2
O	=	Outflow at time 1 and time 2
S	=	Storage at time 1 and time 2
$\div t$	=	Time interval, time 2 – time 1

The time interval, $\div t$, must be consistent with the time interval used in developing the inflow hydrograph. The time interval used for the 6-hour storm is 5 minutes while the time interval for the 72-hour storm is 30 minutes. The $\div t$ variable can be eliminated by dividing it into the storage variables to obtain the following rearranged equation:

$$I_1 + I_2 + 2S_1 - O_1 = O_2 + 2S_2$$

If the time interval, $\div t$, is in minutes, the units of storage (S) are now [cubic feet/min] which can be converted to cfs by multiplying by 1 min/60 sec.

The terms on the left-hand side of the equation are known from the inflow hydrograph and from the storage and outflow values of the previous time step. The unknowns O_2 and S_2 can be solved interactively from the given stage-storage and stage-discharge curves.

The following steps are required in performing level-pool hydrograph routing:

Develop stage-storage relationship, which is a function of inflow and pond geometry.

Develop the routing curve for the hydrograph and pond, which is a graph of outflow from the pond at a given stage versus the quantity O + 2S for the same stage. The outflow is a function of stage (head above the orifice) and the control structure configuration.

Route the inflow hydrograph through the proposed facility by applying the continuity equation above at each time step, where the inflow hydrograph supplies values of I, the stage-storage relationship supplies values of S, and the routing curve supplies values of O.

The commercially available SBUH hydrograph computer models use the level pool routing methodology to shift hydrographs and size infiltration and detention facilities.

Appendix 4A – Background Information on Design Storms

by MGS Engineering Consultants

Overview of Storm Types

There are two storm types of interest for stormwater analyses in eastern Washington. Short-duration thunderstorms can occur in the late-spring through early-fall seasons and are characterized by high intensities for short periods of time over localized areas. These types of storms can produce high rates of runoff and flash-flooding and are important where flood peak discharge and/or erosion are design considerations.

Long-duration general storms can occur at anytime of the year, but are more common in the late-fall through winter period, and in the late-spring and early-summer periods. General storms in eastern Washington are characterized by sequences of storm activity and intervening dry periods, often occurring over several days. Low to moderate intensity precipitation is typical during the periods of storm activity. These types of events can produce floods with large runoff volumes and moderate peak discharge. The runoff volume can be augmented by snowmelt when precipitation falls on snow during winter and early-spring storms. These types of storm events are important where both runoff volume and peak discharge are design considerations.

Design storms are constructed utilizing two components: a precipitation magnitude for a specified duration; and a dimensionless storm pattern. The precipitation magnitude for the specified duration is determined based on the desired level of service (return period of the storm, years) and is used to scale the dimensionless storm pattern to produce the design storm. Specifically, the 2-hour precipitation amount for a selected return period is used for scaling the short-duration thunderstorm. The 24-hour precipitation amount for a selected return period is used for scaling the long-duration general storm.

This appendix provides information on the methods and data that were used for analysis and development of design storms for both short-duration thunderstorms and long-duration general storms. The dimensionless storm patterns for the short-duration thunderstorm and long-duration general storm were developed from analyses of historical storms and contain storm characteristics that are representative of the conditions frequently observed in significant storms.

Climatic Regions

Eastern Washington has been divided into four climatic regions to reflect differences in storm characteristics and the seasonality of storms. The four climatic regions (see Figure 4.3.1) include:

Region 1 – East Slopes of Cascade Mountains

This region is comprised of mountain areas on the east slopes of the Cascade Mountains. It is bounded to the west by the Cascade crest and bounded to the east by a generalized contour line of 16-inches mean annual precipitation.

Region 2 – Central Basin

The Central Basin region is comprised of the Columbia Basin and adjacent low elevation areas in central Washington. It is bounded to the west by the generalized contour line of 16-inches mean annual precipitation that forms the east slopes of the Cascade Mountains, and bounded to the north and east by the contour line of 14-inches mean annual precipitation. Many of the larger cities in eastern Washington are in this region including: Ellensburg, Kennewick, Moses Lake, Pasco, Richland, Wenatchee, and Yakima.

Region 3 – Okanogan , Spokane, Palouse

This region is comprised of inter-mountain areas and includes areas near Okanogan, Spokane, and the Palouse. It is bounded to the west by the east slopes of the Cascade Mountains and the Central Basin, bounded to the northeast by the Kettle River Range and Selkirk Mountains, and bounded to the southeast by the Blue Mountains. It generally occupies an area with mean annual precipitation ranging from 14-inches to 22-inches.

Region 4 – Northeastern Mountains and Blue Mountains

This region is comprised of mountain areas in the easternmost part of Washington State. It includes portions of the Kettle River Range and Selkirk Mountains in the northeast, and includes the Blue Mountains in the southeast corner of eastern Washington. Mean annual precipitation ranges from a minimum of 22-inches to over 60-inches. The western boundary of this region is a generalized contour line of 22-inches mean annual precipitation.

Seasonality of Storms

Information on the seasonality of storms is useful in providing information for selection of antecedent conditions to be used with the design storms for rainfall-runoff modeling at undeveloped sites.

Short-duration thunderstorms are warm season events that occur from late-spring through early-fall throughout eastern Washington (Figure 4A-1). Antecedent conditions for rainfall-runoff modeling of thunderstorms should be selected consistent with the conditions expected at the time of year when thunderstorms have historically occurred.

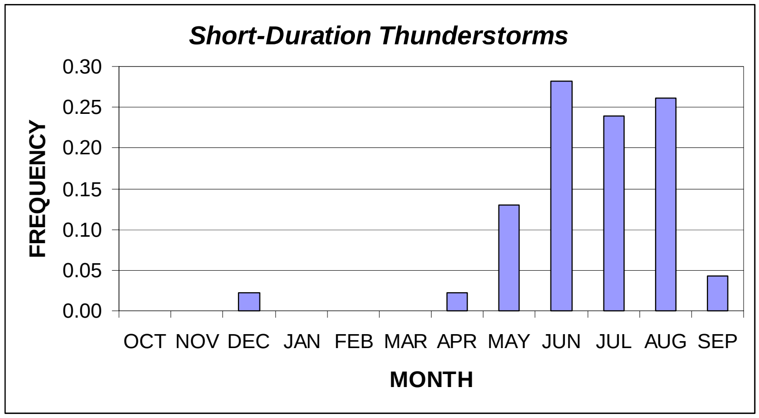


Figure 4A-1 – Seasonality of Short-Duration Thunderstorms in Eastern Washington

The seasonality of long-duration general storms varies across eastern Washington. General storms occur in late-fall and winter on the east slopes of the Cascade Mountains (Figure 4A-2a) and are generally associated with concurrent storm activity in western Washington. In contrast, general storms in the more eastern climatic regions, may or may not be associated with concurrent storms in western Washington. Long-duration general storms occur in both the cool and warm seasons in the Central Basin, Okanogan, Spokane, and Palouse regions. The storm seasons are reasonably well-defined with more frequent storm activity from fall through early-spring, and from late-spring through early-summer (Figure 4A-2b). The seasonality of long-duration general storms in the eastern mountain areas is similar to that for Climatic Regions 2 and 3, except that the winter season is dominant (Figure 4A-2c) with a greater frequency of storm events in the winter season. These seasonalities of storm occurrences should be considered when selecting antecedent conditions for rainfall-runoff modeling.

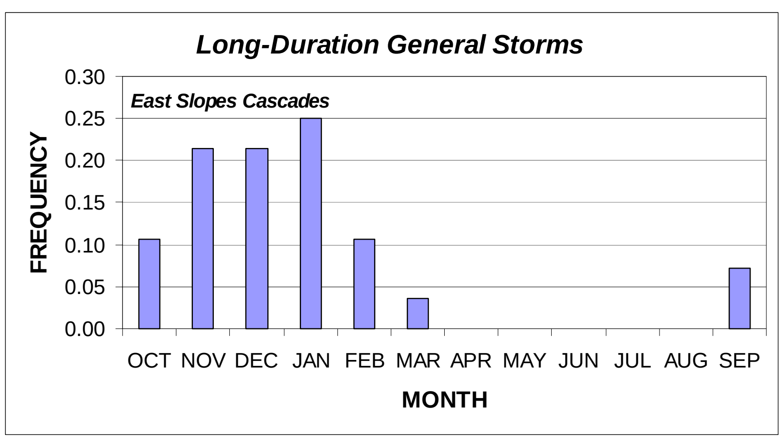


Figure 4A-2a – Seasonality of Long-Duration General Storms for the East Slopes of the Cascade Mountains

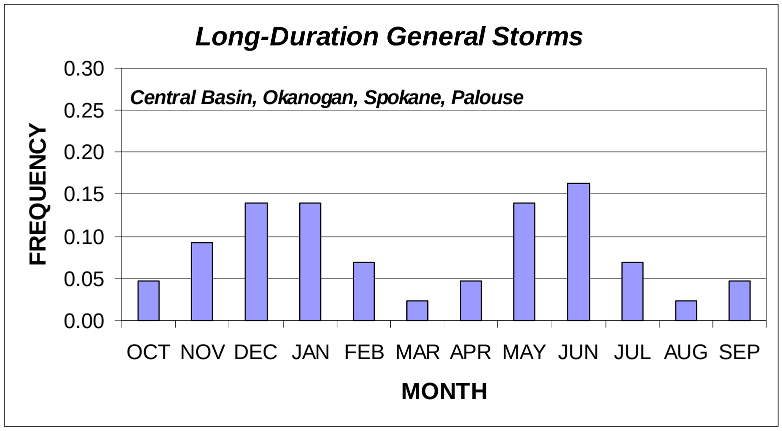


Figure 4A-2b – Seasonality of Long-Duration General Storms for the Central Basin, Okanogan, Spokane, and Palouse

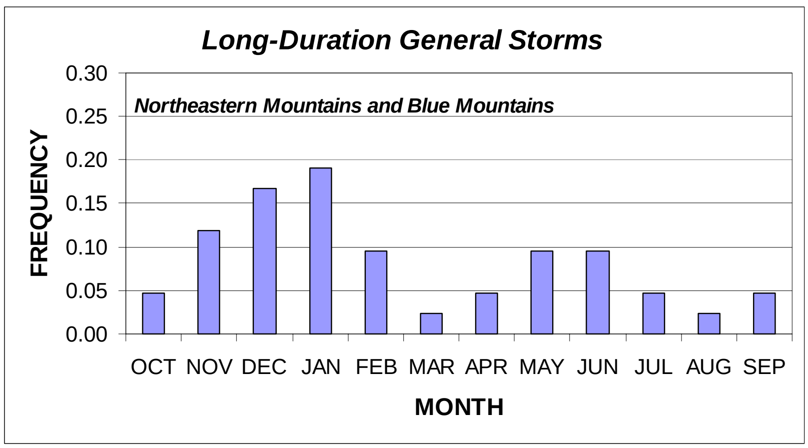


Figure 4A-2c – Seasonality of Long-Duration General Storms for the Northeastern Mountains and Blue Mountains

Dimensionless Design Storm Patterns

The temporal pattern of a design storm is important because it influences the magnitude of the flood peak discharge and runoff volume produced by the storm. Elements of the design storm that are important in rainfall-runoff modeling include: total storm volume; storm duration; maximum intensity during the storm; duration of the high intensity portion(s) of the storm; elapsed time to the high-intensity portion of the storm; and the magnitude, sequencing and temporal pattern of incremental precipitation amounts within the storm. Each of these storm characteristics was examined in the analysis of historical storms in eastern Washington. The storm characteristics were analyzed using a variety of procedures developed by the National Weather Service[3,6], Schaefer[10], and the US Geological Survey[8]. A total of 37 short-duration thunderstorms and 59 long-duration general storms were analyzed that occurred in the period from 1940 to 2000. Attachment A contains a listing of storm dates, locations, and precipitation amounts for storms that were analyzed.

Dimensionless design storms for the short-duration thunderstorm and long-duration general storm were developed in a manner to contain storm characteristics that are representative of the conditions observed in historical storms. Specifically, mean values of storm characteristics and commonly occurring temporal patterns were used in assembling the design storm temporal patterns.

Long-Duration General Storms

Long-duration general storms in eastern Washington are associated with organized weather systems that produce low to moderate intensity precipitation over broad areas. General storms are typically comprised of sequences of storm activity and intervening dry periods, often occurring over several days. Each of these important characteristics is preserved in the long-duration dimensionless storm patterns.

While many of the characteristics of general storms are similar throughout eastern Washington, some storm characteristics vary by climatic region. For example, in mountain areas, the duration of precipitation is longer and the length of intervening dry periods is shorter, relative to that in the Central Basin. Thus, separate long-duration design storm patterns were needed for each climatic region.

An example of a scaled long-duration design storm is shown in Figure 4A-3, which was obtained by scaling (multiplying) the incremental ordinates of the dimensionless design storm (see Table 4.2.6) by a 24-hour precipitation value of 0.82-inches. Differences in temporal patterns between the four climatic regions can be seen in Figures 4B-1 through 4B-4, which compare long-duration water quality design storms for the four climatic regions.

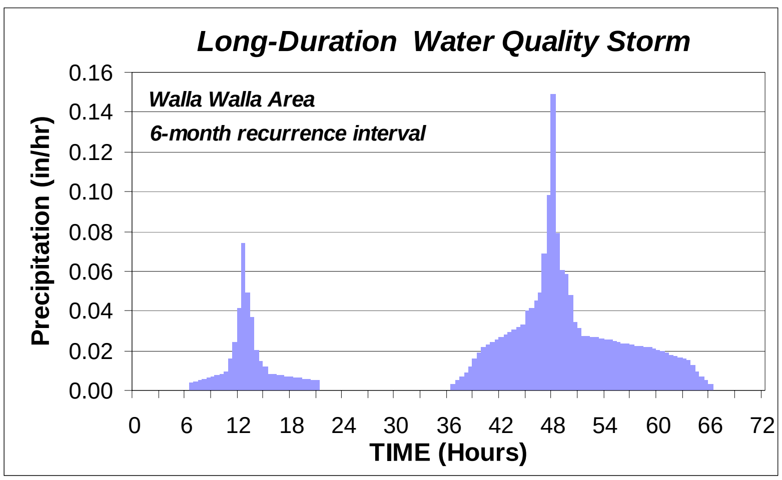


Figure 4A-3 – Example Long-Duration Design Storm

Short-Duration Thunderstorms

Short-duration thunderstorms are characterized by very high-intensity rainfall occurring over isolated areas. The duration of the high-intensity portion of the storm may last from 5-minutes to 30-minutes with a total duration typically ranging from less than an hour to several hours. These storms are convective events, commonly occurring in the late-afternoon and early-evening hours in the summer where atmospheric instabilities are often driven by solar heating. They are frequently accompanied by lightning and thunder.

Analysis of historical storms indicates that short-duration thunderstorms have similar characteristics throughout eastern Washington. Therefore, one dimensionless design storm pattern is applicable to all four climatic regions. An example of a scaled short-duration design storm is shown in Figure 4A-4, which was obtained by scaling (multiplying) the incremental ordinates of the dimensionless design storm (see Table 4.2.1) by a 2-hour precipitation value of 0.50-inches.

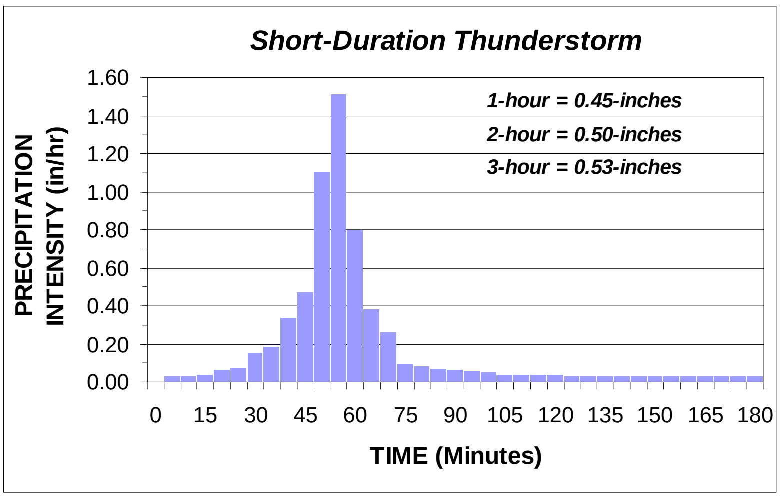


Figure 4A-4 – Example Short-Duration Design Storm

References

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Appendix 4A-1 – Historical Storms Used for Development of Design Storms in Eastern Washington

Long-Duration General Storms

Region 1 – Cascade Mountains

PRECIPITATION STATION	STORM DATE	PRECIPITATION 24-HOUR (in)	PRECIPITATION 72-HOUR (in)
Diablo Dam	24-Oct-1945	6.42	9.23
Underwood	11-Dec-1946	4.04	7.27
Hood River Exp Station	6-Jan-1948	3.33	4.53
Diablo Dam	16-Feb-1949	8.12	9.64
Diablo Dam	9-Feb-1951	6.47	12.99
Satus Pass	24-Nov-1960	3.12	4.46
Lucerne 2NNW	19-Nov-1962	3.05	3.45
Mazama	27-Feb-1972	3.80	5.97
Mount Adams RS	13-Jan-1973	6.00	11.39
Satus Pass	15-Jan-1974	3.60	6.05
Lucerne 2NNW	1-Dec-1975	3.17	5.99
Satus Pass	13-Dec-1977	3.30	5.02
Mazama	12-Jan-1980	3.20	3.62
Stehekin 4NW	23-Jan-1982	5.00	6.80
Stevens Pass	3-Dec-1982	6.50	7.40
Carson Fish Hatch	9-Dec-1987	6.20	7.90
Lake Wenatchee	9-Jan-1990	5.30	7.60
Easton	22-Nov-1990	6.40	10.20
Glenwood	27-Oct-1994	3.80	4.10
Easton	8-Feb-1996	4.10	8.90
Glenwood	28-Dec-1998	3.70	4.70

Region 2 – Central Basin

PRECIPITATION STATION	STORM DATE	PRECIPITATION 24-HOUR (in)	PRECIPITATION 72-HOUR (in)
Lind 3NE	25-Jun-1942	1.53	1.77
Harrington 4ENE	21-Sep-1945	1.52	2.10
Coulee Dam 1SW	28-May-1948	1.66	1.74
Harrington 4ENE	25-Sep-1948	1.51	1.65
Centerville	19-Jan-1953	2.36	2.76
Naches 10NW	14-Jan-1956	1.43	1.60
McNary Dam	2-Oct-1957	3.15	3.17
Yakima	24-Dec-1964	1.40	2.83
Harrington 1NW	23-Dec-1966	1.12	1.28
Ellensburg	4-Dec-1974	1.30	2.00
Chief Joe Dam	18-Sep-1986	1.50	1.70
Wenatchee	10-Dec-1987	1.77	1.82
Yakima	19-Nov-1996	1.40	1.57

Region 3 – Okanogan/Spokane/Palouse

PRECIPITATION STATION	STORM DATE	PRECIPITATION 24-HOUR (in)	PRECIPITATION 72-HOUR (in)
Pullman 2NW	15-Sep-1947	2.10	2.60
Oroville	16-Nov-1950	1.96	2.04
Spokane WSO AP	18-Dec-1951	1.58	1.67
Spokane WSO AP	25-Nov-1960	1.41	1.86
Pullman 2NW	22-Nov-1961	1.96	2.52
Dixie 4SE	23-Nov-1964	2.70	2.92
Dayton 9SE	22-Dec-1964	3.01	4.70
Dayton 9SE	2-Jan-1966	2.53	3.69
Moscow 5NE ID	23-Dec-1972	1.80	2.70
Moscow 5NE ID	11-Nov-1973	1.70	2.90
Colville Airport	16-Nov-1973	1.55	1.98
Walla Walla WSO	14-Oct-1980	3.08	3.63
Moscow 5NE ID	9-Feb-1996	1.50	3.20
Whitman Mission	19-Nov-1996	2.00	2.40
Ola ID	27-Dec-1996	3.10	5.00
Republic	27-May-1998	2.50	2.80
Spokane WSO AP	13-Apr-2000	1.53	1.73

Region 4 – Northeastern Mountains and Blue Mountains

PRECIPITATION STATION	STORM DATE	PRECIPITATION 24-HOUR (in)	PRECIPITATION 72-HOUR (in)
Bonners Ferry 1SW	18-Nov-1946	2.78	4.09
Pullman 2NW	15-Sep-1947	2.10	2.60
Pullman 2NW	22-Nov-1961	1.96	2.52
Dayton 9SE	22-Dec-1964	3.01	4.70
Dayton 9SE	2-Jan-1966	2.53	3.69
Moscow 5NE ID	23-Dec-1972	1.80	2.70
Moscow 5NE ID	11-Nov-1973	1.70	2.90
Colville Airport	16-Nov-1973	1.55	1.98
Coeur D Alene RS	15-Jan-1974	1.90	3.70
Dworshak Fish Hatch ID	2-Dec-1977	2.30	2.40
Plummer 3WSW ID	25-Dec-1980	2.10	2.80
Boundary Switchyard	15-Feb-1986	3.10	3.19
Boundary Switchyard	4-Jan-1989	2.30	2.50
Moscow 5NE ID	9-Feb-1996	1.50	3.20
Ola ID	27-Dec-1996	3.10	5.00
Northport	27-May-1998	2.40	2.80

Short-Duration Thunderstorms

All Regions

PRECIPITATION STATION	CLIMATIC REGION	STORM DATE	PRECIPITATION 1-HOUR (in)	PRECIPITATION 2-HOUR (in)
Ellensburg	2	12-May-1943	0.31	0.62
Dayton 1WSW	3	8-Jul-1946	0.78	0.79
Sunnyside	2	7-Jun-1947	1.62	1.62
Oroville	3	16-Jun-1947	1.19	1.25
Methow	2	17-Jun-1950	0.89	0.89
Wilson Creek	2	18-Jun-1950	1.50	1.50
Colville	4	19-Jul-1950	0.92	1.00
Wilson Creek	2	24-Jul-1950	0.80	0.80
Wenatchee Exp Station	2	10-Aug-1952	1.29	1.29
Colville	4	6-Jul-1956	0.81	0.82
Naches 10NW	2	5-May-1957	0.70	0.90
Republic RS	3	5-Jul-1958	1.10	1.10
Methow	2	8-Jul-1958	1.33	1.33
Republic RS	3	9-Aug-1962	1.17	1.26
Pomeroy	3	13-Sep-1966	1.12	1.12
Withrow 4WNW	2	14-Aug-1968	0.64	0.94
Walla Walla WSO	3	26-May-1971	1.64	1.75
Yakima	2	18-Aug-1975	0.70	0.98
Whitman Mission	3	5-Aug-1977	0.94	0.94
Dayton 1WSW	3	7-Jul-1978	1.20	1.20
Boundary Switchyard	4	21-May-1981	0.90	1.10
Naches 10NW	2	7-Jul-1982	1.20	1.20
Chewelah	3	20-Jul-1983	0.90	1.00
Republic RS	3	10-Aug-1983	0.90	1.50
Easton	1	26-Aug-1983	1.80	1.80
Naches 10NW	2	1-Aug-1984	0.80	0.80
Lake Wenatchee	1	11-Feb-1985	0.90	1.10
Mazama	1	16-Jul-1985	1.00	1.10
Diablo Dam	1	20-Jul-1992	0.80	1.10
Chief Joe Dam	2	23-Jul-1992	0.70	1.00
Dixie 4SE	4	7-Aug-1992	0.70	0.90
Boundary Switchyard	4	23-May-1989	1.00	1.00
Chief Joe Dam	2	9-Jul-1993	1.10	1.10
Lind 3NE	2	22-Jul-1993	1.30	1.40
Stevens Pass	1	2-Jun-1998	1.00	1.00
Northport	4	11-Jul-1998	1.10	1.10
Colville	4	3-Jun-1999	1.00	1.90

Appendix 4B – Regional 72-Hour Long-Duration Storm Hyetographs in Eastern Washington

The 72-hour long-duration hyetographs are published in this appendix, but not recommended for direct use as there is concern that the SCS Method does not produce realistic results when using multi peak hyetographs. The initial abstraction (loss) is computed from the first contribution of rainfall with no accounting for the dry period between the two hyetographs to allow for initial abstraction again. This produces greater peak flows and runoff volumes than would otherwise be computed using just the second hyetograph, even while the first hyetograph is not sufficient to generate direct runoff or substantially increase soil moisture present at the start of the second hyetograph.

Note the 72-hour hyetographs are not unit hyetographs, but have maximum values equal to the ratio of the total 72-hour precipitation to the 24-hour precipitation.

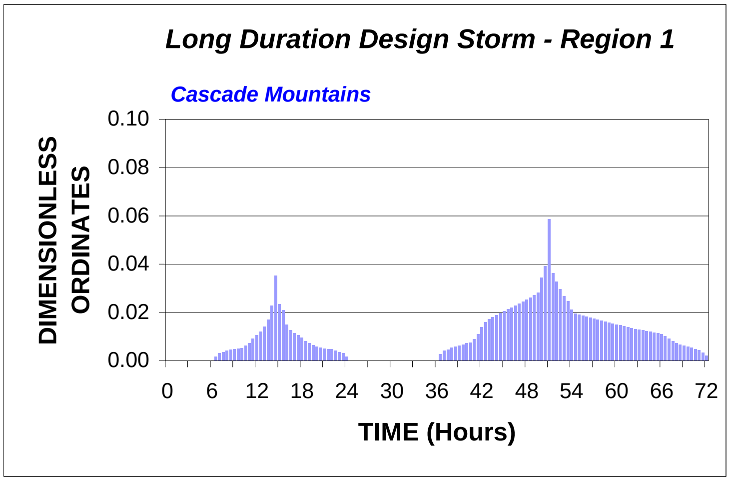

Figure 4B-1

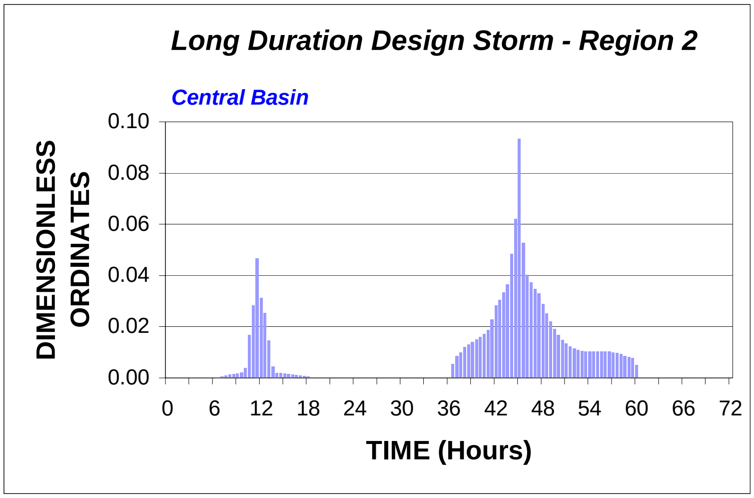

Figure 4B-2

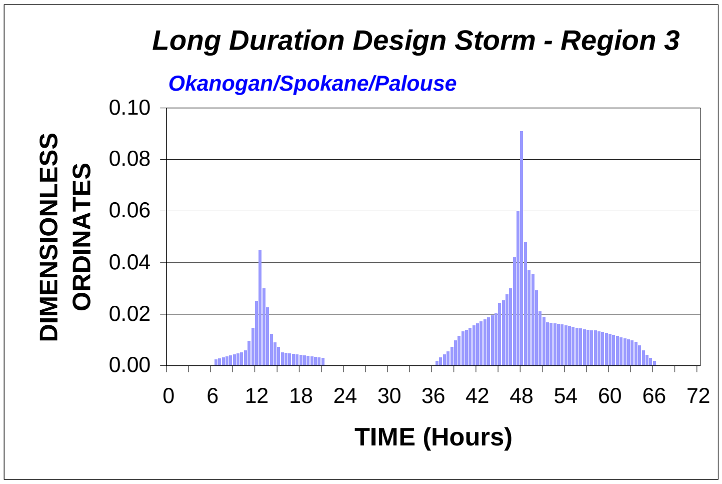

Figure 4B-3

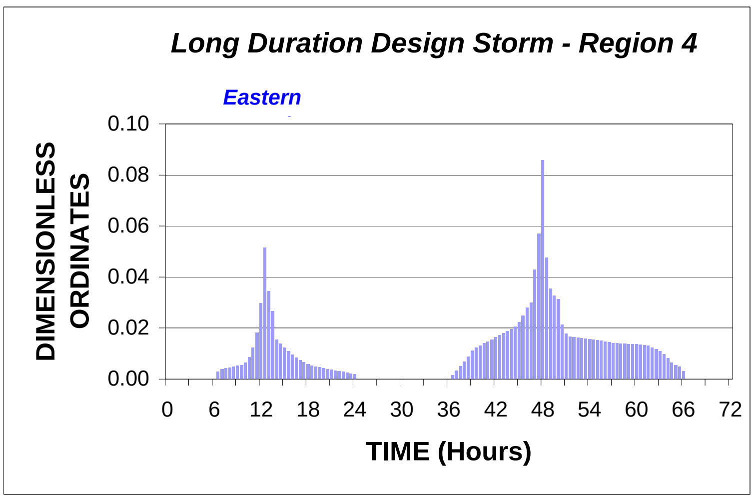

Figure 4B-4

72-Hour Long-Duration Storm Hyetograph Values; Region 1: Cascade Mountains

Note: Use 24-hour precipitation value to scale this storm hyetograph.

Time (hours)	Incremental Rainfall	Cumulative Rainfall
0.0	0.00000	0.00000
0.5	0.00000	0.00000
1.0	0.00000	0.00000
1.5	0.00000	0.00000
2.0	0.00000	0.00000
2.5	0.00000	0.00000
3.0	0.00000	0.00000
3.5	0.00000	0.00000
4.0	0.00000	0.00000
4.5	0.00000	0.00000
5.0	0.00000	0.00000
5.5	0.00000	0.00000
6.0	0.00000	0.00000
6.5	0.00179	0.00179
7.0	0.00321	0.00500
7.5	0.00370	0.00870
8.0	0.00420	0.01290
8.5	0.00470	0.01760
9.0	0.00490	0.02250
9.5	0.00510	0.02760
10.0	0.00530	0.03290
10.5	0.00634	0.03924
11.0	0.00740	0.04664
11.5	0.00920	0.05584
12.0	0.01080	0.06664
12.5	0.01214	0.07878
13.0	0.01424	0.09302
13.5	0.01712	0.11014
14.0	0.02288	0.13302
14.5	0.03540	0.16842
15.0	0.02360	0.19202
15.5	0.02101	0.21303
16.0	0.01499	0.22802
16.5	0.01279	0.24081
17.0	0.01144	0.25225
17.5	0.01070	0.26295
18.0	0.00960	0.27255
18.5	0.00814	0.28069
19.0	0.00730	0.28799
19.5	0.00657	0.29456
20.0	0.00598	0.30054
20.5	0.00551	0.30605
21.0	0.00516	0.31121
21.5	0.00494	0.31615
22.0	0.00485	0.32100
22.5	0.00420	0.32520
23.0	0.00370	0.32890
23.5	0.00320	0.33210
24.0	0.00180	0.33390
24.5	0.00000	0.33390
25.0	0.00000	0.33390
25.5	0.00000	0.33390
26.0	0.00000	0.33390
26.5	0.00000	0.33390
27.0	0.00000	0.33390
27.5	0.00000	0.33390
28.0	0.00000	0.33390
28.5	0.00000	0.33390
29.0	0.00000	0.33390
29.5	0.00000	0.33390
30.0	0.00000	0.33390
30.5	0.00000	0.33390
31.0	0.00000	0.33390
31.5	0.00000	0.33390
32.0	0.00000	0.33390
32.5	0.00000	0.33390
33.0	0.00000	0.33390
33.5	0.00000	0.33390
34.0	0.00000	0.33390
34.5	0.00000	0.33390
35.0	0.00000	0.33390
35.5	0.00000	0.33390
36.0	0.00000	0.33390
36.5	0.00277	0.33667
37.0	0.00423	0.34090
37.5	0.00467	0.34557
38.0	0.00550	0.35107
38.5	0.00590	0.35697
39.0	0.00630	0.36327
39.5	0.00670	0.36997
40.0	0.00723	0.37720
40.5	0.00760	0.38480
41.0	0.00907	0.39387
41.5	0.01116	0.40503
42.0	0.01387	0.41890
42.5	0.01600	0.43490
43.0	0.01740	0.45230
43.5	0.01820	0.47050
44.0	0.01900	0.48950
44.5	0.01980	0.50930
45.0	0.02060	0.52990
45.5	0.02140	0.55130
46.0	0.02220	0.57350
46.5	0.02300	0.59650
47.0	0.02380	0.62030
47.5	0.02460	0.64490
48.0	0.02550	0.67040
48.5	0.02620	0.69660
49.0	0.02720	0.72380
49.5	0.02820	0.75200
50.0	0.03445	0.78645
50.5	0.03920	0.82565
51.0	0.05880	0.88445
51.5	0.03652	0.92097
52.0	0.03280	0.95377
52.5	0.02980	0.98357
53.0	0.02680	1.01037
53.5	0.02484	1.03521
54.0	0.02116	1.05637
54.5	0.01943	1.07580
55.0	0.01910	1.09490
55.5	0.01870	1.11360
56.0	0.01830	1.13190
56.5	0.01790	1.14980
57.0	0.01750	1.16730
57.5	0.01710	1.18440
58.0	0.01670	1.20110
58.5	0.01630	1.21740
59.0	0.01590	1.23330
59.5	0.01550	1.24880
60.0	0.01510	1.26390
60.5	0.01470	1.27860
61.0	0.01430	1.29290
61.5	0.01390	1.30680
62.0	0.01360	1.32040
62.5	0.01330	1.33370
63.0	0.01300	1.34670
63.5	0.01270	1.35940
64.0	0.01240	1.37180
64.5	0.01210	1.38390
65.0	0.01180	1.39570
65.5	0.01150	1.40720
66.0	0.01120	1.41840
66.5	0.01020	1.42860
67.0	0.00920	1.43780
67.5	0.00820	1.44600
68.0	0.00734	1.45334
68.5	0.00675	1.46009
69.0	0.00630	1.46639
69.5	0.00585	1.47224
70.0	0.00540	1.47764
70.5	0.00495	1.48259
71.0	0.00450	1.48709
71.5	0.00350	1.49059
72.0	0.00225	1.49284

72-Hour Long-Duration Storm Hyetograph Values; Region 2: Central Basin

Note: Use 24-hour precipitation value to scale this storm hyetograph.

Time (hours)	Incremental Rainfall	Cumulative Rainfall
0.0	0.00000	0.00000
0.5	0.00000	0.00000
1.0	0.00000	0.00000
1.5	0.00000	0.00000
2.0	0.00000	0.00000
2.5	0.00000	0.00000
3.0	0.00000	0.00000
3.5	0.00000	0.00000
4.0	0.00000	0.00000
4.5	0.00000	0.00000
5.0	0.00000	0.00000
5.5	0.00000	0.00000
6.0	0.00000	0.00000
6.5	0.00030	0.00030
7.0	0.00060	0.00090
7.5	0.00090	0.00180
8.0	0.00120	0.00300
8.5	0.00150	0.00450
9.0	0.00180	0.00630
9.5	0.00210	0.00840
10.0	0.00394	0.01234
10.5	0.01669	0.02903
11.0	0.02831	0.05734
11.5	0.04680	0.10414
12.0	0.03120	0.13534
12.5	0.02549	0.16083
13.0	0.01451	0.17534
13.5	0.00445	0.17979
14.0	0.00202	0.18181
14.5	0.00192	0.18373
15.0	0.00172	0.18545
15.5	0.00152	0.18697
16.0	0.00132	0.18829
16.5	0.00112	0.18941
17.0	0.00092	0.19033
17.5	0.00072	0.19105
18.0	0.00052	0.19157
18.5	0.00000	0.19157
19.0	0.00000	0.19157
19.5	0.00000	0.19157
20.0	0.00000	0.19157
20.5	0.00000	0.19157
21.0	0.00000	0.19157
21.5	0.00000	0.19157
22.0	0.00000	0.19157
22.5	0.00000	0.19157
23.0	0.00000	0.19157
23.5	0.00000	0.19157
24.0	0.00000	0.19157
24.5	0.00000	0.19157
25.0	0.00000	0.19157
25.5	0.00000	0.19157
26.0	0.00000	0.19157
26.5	0.00000	0.19157
27.0	0.00000	0.19157
27.5	0.00000	0.19157
28.0	0.00000	0.19157
28.5	0.00000	0.19157
29.0	0.00000	0.19157
29.5	0.00000	0.19157
30.0	0.00000	0.19157
30.5	0.00000	0.19157
31.0	0.00000	0.19157
31.5	0.00000	0.19157
32.0	0.00000	0.19157
32.5	0.00000	0.19157
33.0	0.00000	0.19157
33.5	0.00000	0.19157
34.0	0.00000	0.19157
34.5	0.00000	0.19157
35.0	0.00000	0.19157
35.5	0.00000	0.19157
36.0	0.00000	0.19157
36.5	0.00544	0.19701
37.0	0.00856	0.20557
37.5	0.01000	0.21557
38.0	0.01200	0.22757
38.5	0.01300	0.24057
39.0	0.01400	0.25457
39.5	0.01500	0.26957
40.0	0.01600	0.28557
40.5	0.01700	0.30257
41.0	0.01869	0.32126
41.5	0.02281	0.34407
42.0	0.02832	0.37239
42.5	0.03050	0.40289
43.0	0.03350	0.43639
43.5	0.03650	0.47289
44.0	0.04842	0.52131
44.5	0.06220	0.58351
45.0	0.09330	0.67681
45.5	0.05275	0.72956
46.0	0.04025	0.76981
46.5	0.03717	0.80698
47.0	0.03483	0.84181
47.5	0.03307	0.87488
48.0	0.02893	0.90381
48.5	0.02519	0.92900
49.0	0.02189	0.95089
49.5	0.01906	0.96995
50.0	0.01670	0.98665
50.5	0.01480	1.00145
51.0	0.01336	1.01481
51.5	0.01234	1.02715
52.0	0.01156	1.03871
52.5	0.01096	1.04967
53.0	0.01054	1.06021
53.5	0.01032	1.07053
54.0	0.01028	1.08081
54.5	0.01038	1.09119
55.0	0.01046	1.10165
55.5	0.01046	1.11211
56.0	0.01040	1.12251
56.5	0.01025	1.13276
57.0	0.01004	1.14280
57.5	0.00974	1.15254
58.0	0.00926	1.16180
58.5	0.00868	1.17048
59.0	0.00832	1.17880
59.5	0.00781	1.18661
60.0	0.00500	1.19161
60.5	0.00000	1.19161
61.0	0.00000	1.19161
61.5	0.00000	1.19161
62.0	0.00000	1.19161
62.5	0.00000	1.19161
63.0	0.00000	1.19161
63.5	0.00000	1.19161
64.0	0.00000	1.19161
64.5	0.00000	1.19161
65.0	0.00000	1.19161
65.5	0.00000	1.19161
66.0	0.00000	1.19161
66.5	0.00000	1.19161
67.0	0.00000	1.19161
67.5	0.00000	1.19161
68.0	0.00000	1.19161
68.5	0.00000	1.19161
69.0	0.00000	1.19161
69.5	0.00000	1.19161
70.0	0.00000	1.19161
70.5	0.00000	1.19161
71.0	0.00000	1.19161
71.5	0.00000	1.19161
72.0	0.00000	1.19161

72-Hour Long-Duration Storm Hyetograph Values; Region 3: Okanogan – Spokane – Palouse

Note: Use 24-hour precipitation value to scale this storm hyetograph.

Time (hours)	Incremental Rainfall	Cumulative Rainfall
0.0	0.00000	0.00000
0.5	0.00000	0.00000
1.0	0.00000	0.00000
1.5	0.00000	0.00000
2.0	0.00000	0.00000
2.5	0.00000	0.00000
3.0	0.00000	0.00000
3.5	0.00000	0.00000
4.0	0.00000	0.00000
4.5	0.00000	0.00000
5.0	0.00000	0.00000
5.5	0.00000	0.00000
6.0	0.00000	0.00000
6.5	0.00240	0.00240
7.0	0.00280	0.00520
7.5	0.00320	0.00840
8.0	0.00360	0.01200
8.5	0.00403	0.01603
9.0	0.00440	0.02043
9.5	0.00480	0.02523
10.0	0.00520	0.03043
10.5	0.00600	0.03643
11.0	0.00968	0.04611
11.5	0.01476	0.06087
12.0	0.02524	0.08611
12.5	0.04500	0.13111
13.0	0.03000	0.16111
13.5	0.02267	0.18378
14.0	0.01233	0.19611
14.5	0.00901	0.20512
15.0	0.00731	0.21243
15.5	0.00520	0.21763
16.0	0.00500	0.22263
16.5	0.00480	0.22743
17.0	0.00460	0.23203
17.5	0.00440	0.23643
18.0	0.00420	0.24063
18.5	0.00400	0.24463
19.0	0.00380	0.24843
19.5	0.00360	0.25203
20.0	0.00340	0.25543
20.5	0.00320	0.25863
21.0	0.00300	0.26163
21.5	0.00000	0.26163
22.0	0.00000	0.26163
22.5	0.00000	0.26163
23.0	0.00000	0.26163
23.5	0.00000	0.26163
24.0	0.00000	0.26163
24.5	0.00000	0.26163
25.0	0.00000	0.26163
25.5	0.00000	0.26163
26.0	0.00000	0.26163
26.5	0.00000	0.26163
27.0	0.00000	0.26163
27.5	0.00000	0.26163
28.0	0.00000	0.26163
28.5	0.00000	0.26163
29.0	0.00000	0.26163
29.5	0.00000	0.26163
30.0	0.00000	0.26163
30.5	0.00000	0.26163
31.0	0.00000	0.26163
31.5	0.00000	0.26163
32.0	0.00000	0.26163
32.5	0.00000	0.26163
33.0	0.00000	0.26163
33.5	0.00000	0.26163
34.0	0.00000	0.26163
34.5	0.00000	0.26163
35.0	0.00000	0.26163
35.5	0.00000	0.26163
36.0	0.00000	0.26163
36.5	0.00180	0.26343
37.0	0.00320	0.26663
37.5	0.00437	0.27100
38.0	0.00563	0.27663
38.5	0.00722	0.28385
39.0	0.00978	0.29363
39.5	0.01150	0.30513
40.0	0.01340	0.31853
40.5	0.01400	0.33253
41.0	0.01480	0.34733
41.5	0.01560	0.36293
42.0	0.01640	0.37933
42.5	0.01720	0.39653
43.0	0.01800	0.41453
43.5	0.01880	0.43333
44.0	0.01960	0.45293
44.5	0.02040	0.47333
45.0	0.02430	0.49763
45.5	0.02534	0.52297
46.0	0.02766	0.55063
46.5	0.03000	0.58063
47.0	0.04200	0.62263
47.5	0.06000	0.68263
48.0	0.09100	0.77363
48.5	0.04801	0.82164
49.0	0.03700	0.85864
49.5	0.03568	0.89432
50.0	0.02932	0.92364
50.5	0.02114	0.94478
51.0	0.01900	0.96378
51.5	0.01680	0.98058
52.0	0.01660	0.99718
52.5	0.01640	1.01358
53.0	0.01620	1.02978
53.5	0.01600	1.04578
54.0	0.01570	1.06148
54.5	0.01540	1.07688
55.0	0.01510	1.09198
55.5	0.01480	1.10678
56.0	0.01450	1.12128
56.5	0.01420	1.13548
57.0	0.01390	1.14938
57.5	0.01379	1.16317
58.0	0.01361	1.17678
58.5	0.01338	1.19016
59.0	0.01310	1.20326
59.5	0.01276	1.21602
60.0	0.01236	1.22838
60.5	0.01192	1.24030
61.0	0.01148	1.25178
61.5	0.01104	1.26282
62.0	0.01061	1.27343
62.5	0.01018	1.28361
63.0	0.00976	1.29337
63.5	0.00918	1.30255
64.0	0.00782	1.31037
64.5	0.00579	1.31616
65.0	0.00421	1.32037
65.5	0.00315	1.32352
66.0	0.00185	1.32537
66.5	0.00000	1.32537
67.0	0.00000	1.32537
67.5	0.00000	1.32537
68.0	0.00000	1.32537
68.5	0.00000	1.32537
69.0	0.00000	1.32537
69.5	0.00000	1.32537
70.0	0.00000	1.32537
70.5	0.00000	1.32537
71.0	0.00000	1.32537
71.5	0.00000	1.32537
72.0	0.00000	1.32537

FINAL DRAFT

72-Hour Long-Duration Storm Hyetograph Values; Region 4: Eastern Mountains

Note: Scale by 24-hour precipitation

Time (hours)	Incremental Rainfall	Cumulative Rainfall
0.0	0.00000	0.00000
0.5	0.00000	0.00000
1.0	0.00000	0.00000
1.5	0.00000	0.00000
2.0	0.00000	0.00000
2.5	0.00000	0.00000
3.0	0.00000	0.00000
3.5	0.00000	0.00000
4.0	0.00000	0.00000
4.5	0.00000	0.00000
5.0	0.00000	0.00000
5.5	0.00000	0.00000
6.0	0.00000	0.00000
6.5	0.00300	0.00300
7.0	0.00390	0.00690
7.5	0.00423	0.01113
8.0	0.00456	0.01569
8.5	0.00490	0.02059
9.0	0.00523	0.02582
9.5	0.00556	0.03138
10.0	0.00650	0.03788
10.5	0.00868	0.04656
11.0	0.01246	0.05902
11.5	0.01824	0.07726
12.0	0.02976	0.10702
12.5	0.05160	0.15862
13.0	0.03440	0.19302
13.5	0.02655	0.21957
14.0	0.01545	0.23502
14.5	0.01388	0.24890
15.0	0.01232	0.26122
15.5	0.01089	0.27211
16.0	0.00961	0.28173
16.5	0.00848	0.29020
17.0	0.00748	0.29768
17.5	0.00661	0.30430
18.0	0.00590	0.31019
18.5	0.00532	0.31552
19.0	0.00489	0.32040
19.5	0.00459	0.32499
20.0	0.00430	0.32930
20.5	0.00401	0.33330
21.0	0.00372	0.33702
21.5	0.00343	0.34045
22.0	0.00313	0.34358
22.5	0.00284	0.34642
23.0	0.00255	0.34897
23.5	0.00226	0.35123
24.0	0.00197	0.35319
24.5	0.00000	0.35319

Time (hours)	Incremental Rainfall	Cumulative Rainfall
25.0	0.00000	0.35319
25.5	0.00000	0.35319
26.0	0.00000	0.35319
26.5	0.00000	0.35319
27.0	0.00000	0.35319
27.5	0.00000	0.35319
28.0	0.00000	0.35319
28.5	0.00000	0.35319
29.0	0.00000	0.35319
29.5	0.00000	0.35319
30.0	0.00000	0.35319
30.5	0.00000	0.35319
31.0	0.00000	0.35319
31.5	0.00000	0.35319
32.0	0.00000	0.35319
32.5	0.00000	0.35319
33.0	0.00000	0.35319
33.5	0.00000	0.35319
34.0	0.00000	0.35319
34.5	0.00000	0.35319
35.0	0.00000	0.35319
35.5	0.00000	0.35319
36.0	0.00000	0.35319
36.5	0.00167	0.35486
37.0	0.00333	0.35819
37.5	0.00510	0.36329
38.0	0.00690	0.37019
38.5	0.00879	0.37898
39.0	0.01121	0.39019
39.5	0.01240	0.40259
40.0	0.01320	0.41579
40.5	0.01400	0.42979
41.0	0.01480	0.44459
41.5	0.01560	0.46019
42.0	0.01640	0.47659
42.5	0.01720	0.49379
43.0	0.01800	0.51179
43.5	0.01880	0.53059
44.0	0.01960	0.55019
44.5	0.02050	0.57069
45.0	0.02230	0.59299
45.5	0.02500	0.61799
46.0	0.02800	0.64599
46.5	0.03000	0.67599
47.0	0.04295	0.71894
47.5	0.05720	0.77614
48.0	0.08580	0.86194
48.5	0.04751	0.90945
49.0	0.03549	0.94494
49.5	0.03265	0.97759

Time (hours)	Incremental Rainfall	Cumulative Rainfall
50.0	0.03135	1.00894
50.5	0.02140	1.03034
51.0	0.01790	1.04824
51.5	0.01670	1.06494
52.0	0.01650	1.08144
52.5	0.01630	1.09774
53.0	0.01610	1.11384
53.5	0.01590	1.12974
54.0	0.01570	1.14544
54.5	0.01550	1.16094
55.0	0.01535	1.17629
55.5	0.01508	1.19137
56.0	0.01471	1.20608
56.5	0.01442	1.22050
57.0	0.01421	1.23471
57.5	0.01407	1.24878
58.0	0.01395	1.26273
58.5	0.01385	1.27658
59.0	0.01377	1.29035
59.5	0.01370	1.30405
60.0	0.01365	1.31770
60.5	0.01358	1.33128
61.0	0.01338	1.34466
61.5	0.01300	1.35766
62.0	0.01245	1.37011
62.5	0.01174	1.38185
63.0	0.01085	1.39270
63.5	0.00975	1.40245
64.0	0.00825	1.41070
64.5	0.00654	1.41724
65.0	0.00546	1.42270
65.5	0.00484	1.42754
66.0	0.00316	1.43070
66.5	0.00000	1.43070
67.0	0.00000	1.43070
67.5	0.00000	1.43070
68.0	0.00000	1.43070
68.5	0.00000	1.43070
69.0	0.00000	1.43070
69.5	0.00000	1.43070
70.0	0.00000	1.43070
70.5	0.00000	1.43070
71.0	0.00000	1.43070
71.5	0.00000	1.43070
72.0	0.00000	1.43070

Appendix 4C – Precipitation Maps

Precipitation maps for eastern Washington are included on the following pages, as listed below: