City of Bellingham

Stormwater Comprehensive Plan

2007

Clear Creek Solutions, Inc.
Parametrix

EXECUTIVE SUMMARY

The purpose of this plan is to provide a comprehensive stormwater plan for the City of Bellingham, Washington, and more specifically, for the portions of the Whatcom Creek, Silver Beach, Padden Creek, Chuckanut Creek, Squalicum Creek, and Silver Creek watersheds inside the City of Bellingham.

The purpose of this plan is also to address requirements and regulatory issues that create the need to plan and tackle difficult stormwater issues. These requirements and issues are included in the NPDES Phase II municipal stormwater permit, Endangered Species Act regulations, Puget Sound Plan recommendations, and City of Bellingham regulations.

This stormwater plan provides input to all of the above-described programs, plans, and regulations as they relate to stormwater requirements and regulatory issues. However, this plan does not have the scope or mandate to specifically identify item-by-item compliance measures for individual programs, plans, and regulations. Rather, this plan and accompanying stormwater modeling software provide a tool for the City of Bellingham to show how the city is addressing its stormwater and pollutant control obligations, as required by local, state, and federal law.

The goals and objectives of the Comprehensive Stormwater Plan include:

- Analysis of existing stormwater facilities and aquatic resources,
- Identification of existing stormwater problems,
- Analysis of alternative stormwater solutions,
- Documentation of the stormwater plan for implementation by city staff, and
- Providing the city staff a tool to address stormwater and pollutant control obligations, as required by local, state, and federal law.

The watershed study areas exhibit a variety of storm and surface water characteristics. Drainage features include wetlands, streams, ponds, open channels, culverts, and pipe systems. The City's land use varies from forest and agriculture to residential, commercial, and industrial.

Stormwater solutions include both structural and non-structural solutions. The solutions focus on providing practical and environmentally sensitive solutions to allow responsible land use development and yet maintain valuable aquatic resources.

This comprehensive stormwater plan is an update of the 1995 Watershed Master Plan developed for the City of Bellingham by HDR Engineering, Inc. Where possible, information from the 1995 plan has been incorporated in this comprehensive stormwater plan.

The hydrologic and hydraulic computer modeling work done as part of this stormwater plan meets Ecology's definition of basin planning and satisfies the requirements of the NPDES Phase II permit alternative approach to Ecology's Minimum Requirement #7.

The stormwater computer model provided to the City of Bellingham by Clear Creek Solutions also allows city staff to refine and update the city's land use and infrastructure information, as needed, to investigate and correct stormwater problems throughout the city.

The hydrologic and hydraulic modeling for the City of Bellingham Comprehensive Stormwater Plan was based on continuous simulation methodology. Continuous simulation modeling keeps track of the entire hydrologic cycle on an hourly or smaller time step for multiple years.

The continuous simulation modeling software used for the comprehensive stormwater plan is the Western Washington Hydrology Model version 3 (WWHM3). WWHM3 was originally developed for the Washington State Department of Ecology by Clear Creek Solutions, Inc. WWHM3 uses EPA HSPF as its computational engine to compute stormwater runoff. Stormwater runoff routing is computed using HSPF for open channel conveyance systems and PCSWMM for stormwater pipe conveyance systems. City of Bellingham GIS stormwater conveyance system data were used to model the stormwater pipe systems.

The 1995 HDR stormwater calculations were made using Waterworks software. Conveyance system data from the Waterworks models were used in WWHM3 where City GIS conveyance system data did not exist.

The stormwater drainage analysis was conducted using the Stormwater Management Model (SWMM) module of the WWHM3 software. The hydrology for each basin was established as described earlier in the computer model methodology section. After the basin hydrology was analyzed, a conveyance system was developed for the SWMM module. Conveyance system data were drawn from various sources and are described in more detail in the following basin-specific sections.

Generally, after the conveyance network was developed and model calibration parameter values were established, an initial model analysis was performed to identify surcharging pipes and culverts throughout the network. SWMM's automatic pipe resizing routine was then used to increase the pipe diameter in the vicinity of the surcharging pipes identified during the initial model analysis. This routine provides required conveyance capacity through the system by increasing the capacity of all pipes that would be affected by an increase in downstream flow resulting from improved upstream conveyance capacity. The resizing routine uses an iterative process, incrementally increasing conveyance sizes, until flow is conveyed without surcharging. This routine solves the problem of resizing a single pipe only to shift a flooding problem downstream. The model-identified problems (i.e., surcharging pipes) and potential solutions (increased pipe diameters) are summarized for each basin.

The automatic pipe resizing routine also includes conveyance capacities of open channels. To use this routine for an open channel, the SWMM module first converts the open channel to an equivalent capacity pipe diameter. Locations of open channels are shown on the basin maps.

Cost opinions for capital improvement projects have been prepared for the Whatcom Creek Basin. As discussed in the computer model methodology section, GIS data were most readily available for the Whatcom Creek Basin, but not available for much of the drainage area outside of that basin. Therefore, model results identifying system deficiencies are more reliable for the Whatcom Creek Basin than for the other basins. However, even within the Whatcom Creek Basin, GIS data were not available for portions of the existing conveyance system and had to be interpolated as discussed earlier in this report. With the available conveyance system data, model results in other basins are considered conceptual and intended for planning-level decision-making only. These results for the other basins are not considered detailed enough to generate reliable cost opinions at this time. Cost opinions for capital improvement projects in these other basins can be prepared in the future as additional system data are acquired and the model is updated.

The City of Bellingham will be using the conveyance system sizing information presented in this plan to identify specific projects for in-depth study prior to design and construction.

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INTRODUCTION

Purpose and Authority

The purpose of this plan is to provide a comprehensive stormwater plan for the City of Bellingham, Washington, and more specifically, for the portions of the Whatcom Creek, Silver Beach, Padden Creek, Chuckanut Creek, Squalicum Creek, and Silver Creek watersheds inside the City of Bellingham.

The purpose of this plan is also to address requirements and regulatory issues that create the need to plan and tackle difficult stormwater issues. These requirements and issues are included in the NPDES Phase II municipal stormwater permit, Endangered Species Act regulations, Puget Sound Plan recommendations, and City of Bellingham regulations.

NPDES Phase II

The Department of Ecology has issued NPDES Phase II municipal stormwater permits that affect 98 cities and 12 counties, including the City of Bellingham. The National Pollutant Discharge Elimination System (NPDES) permitting program was developed to achieve the goals of the federal Clean Water Act. The requirements of the NPDES Phase II municipal stormwater permit include public involvement and education, adoption of ordinances to control runoff from new development, illicit discharge detection and elimination, and the development of an operation and maintenance program to reduce pollutant runoff from municipal operations.

The Phase II permit includes rules for mitigation of the impacts of additional runoff from new development (Minimum Requirement #7: Flow Control). For the purposes of flow control new development is defined as:

- Creates or adds 10,000 square feet, or more, of new impervious surface area, or
- Converts ¾ acres, or more, of native vegetation to lawn or landscaped areas, or
- Converts 2.5 acres, or more, of native vegetation to pasture, or
- Increases 100-year flood frequency by 0.1 cubic feet per second, or more.

The standard flow control requirement requires that stormwater discharges from new development match the pre-developed discharge durations for the range of pre-developed discharge rates from 50% of the 2-year peak flow up to the full 50-year peak flow. Flow control mitigation facilities (for example, a stormwater pond) shall be selected, designed, and maintained in accordance with Volume III of the *Stormwater Management Manual for Western Washington* (2005) or an approved equivalent.

Basin or watershed planning may be used by a municipality to tailor Minimum Requirement #7 (and other minimum requirements) to local hydrologic conditions to improve stormwater management efficiency. Basin planning can also be used to support alternative treatment, flow control, and/or wetland protection requirements through the construction and use of regional stormwater facilities.

Basin planning also provides a mechanism by which the minimum requirements and implementing best management practices (BMPs) can be evaluated and refined based on an analysis of a basin or watershed. Basin plans may be used to develop control strategies to address impacts from future development and to correct specific problems whose sources are known or suspected. Basin planning requires the use of computer models and field work to verify and support the models.

The hydrologic and hydraulic computer modeling work done as part of this stormwater plan meets Ecology's definition of basin planning and satisfies the requirements of the NPDES Phase II permit alternative approach to Ecology's Minimum Requirement #7. The stormwater computer model provided to the City of Bellingham by Clear Creek Solutions also allows city staff to refine and update the city's land use and infrastructure information, as needed, to investigate and correct stormwater problems throughout the city.

Endangered Species Act

The purpose of the federal Endangered Species Act (ESA) is to provide a means whereby the ecosystems upon which endangered species and threatened species depend may be conserved, to provide a program for the conservation of such endangered species and threatened species.

One of the policies of the ESA is the adoption of Habitat Conservation Plans (HCPs). A HCP identifies an endangered species and how the species' habitat will be managed to minimize incidental takings. The U.S. Fish and Wildlife Service and NOAA Fisheries Service maintain the ESA listing. In Washington state Chinook salmon are considered threatened in the Puget Sound drainages.

Stormwater impacts salmon habitat by increasing flood flows and stream channel erosion and by adding pollutants to both local streams and Puget Sound. Development of this stormwater plan will assist the City of Bellingham in the evaluation of stormwater impacts on critical fish habitat and the development of Habitat Conservation Plans to minimize the impacts.

Puget Sound Plan

The Puget Sound Plan is a conservation and recovery plan developed by the Governor's Puget Sound Action Team. The Puget Sound Plan focuses on maintaining and enhancing the ecology of Puget Sound. Polluted stormwater runoff is one of the significant problems that has been identified as adversely affecting the ecology of the Sound. One of the seven major priorities listed in the 2005-2007 plan is reducing the harm of stormwater runoff.

Improving stormwater management is one of the three major tasks to reducing stormwater runoff pollution. The Department of Ecology is coordinating this effort through the issuance of NPDES Phase II permits and specifying actions to reduce stormwater pollution, including erosion control.

Applying low impact development (LID) practices is also being encouraged by the Puget Sound Plan. LID practices are techniques to control or reduce stormwater runoff at the source. Examples of different LID practices include rain gardens, bioretention, green roofs, and porous pavement. All of these practices/facilities can be modeled in WWHM3 (Western Washington Hydrology Model version 3) to evaluate their effectiveness in reducing stormwater runoff.

Informing and educating the public is the third major task identified by the Puget Sound Action Team to reduce stormwater runoff harm. This involves showing the public and the business community how individual practices and activities can have an adverse impact on stormwater water quality and the ecology of Puget Sound.

City of Bellingham Regulations

The City of Bellingham has enacted a number of regulations and code requirements to protect the city's aquatic resources. Development and design standards provide rules and guidance in the form of the Critical Areas Ordinance, Land Use Development Code (BMC Title 20), Public Works Development Guidelines and Improvement Standards, Shoreline Management Master Program, and the City Comprehensive Plan and the Growth Management Act (RCW 36.70A).

The purpose of the Critical Areas Ordinance (CAO) is to designate and classify environmentally sensitive and hazardous areas as Critical Areas and to protect, maintain and restore these areas and their functions and values, while also allowing for reasonable use of public and private property. One of the goals of the CAO is to prevent cumulative adverse environmental impacts to water quality, wetlands, and fish and wildlife habitat, and the overall net loss of wetlands, frequently flooded areas, and habitat conservation areas. This is done by identifying Critical Areas and establishing appropriate buffers to protect these areas.

The Land Use Development Code (BMC Title 20) identifies zoning regulations for 23 specific neighborhoods in the City of Bellingham. Each area within a neighborhood is assigned a specific zoning together with special conditions, prerequisite considerations, and special regulations. These special conditions, prerequisite considerations, and special regulations include identified stormwater issues and problems and mandate the use of specific mitigation measures to correct or prevent stormwater and water quality problems.

The Shoreline Management Master Program includes the goal of shoreline protection. Specific shoreline protection policies focus on flood protection through the use of floodplain management. This is done through the use of flood protection and streamway modifications. These are activities occurring within the streamway and upland areas which are designed to reduce overbank flow of high waters and stabilize eroding stream banks. It is recognized that improper flood control upstream results in increased flood damage downstream. Floodplain management as a means of flood control has advantages of maintaining the natural characteristics of the shoreline while protecting adjacent property without amplifying potential flood damage downstream. Regulations used to protect the floodplain include the prohibition of construction of incompatible structures and fills and the use of bank stabilization for the purposes of protecting property from erosion.

The 1995 Bellingham Comprehensive Plan, including subsequent amendments, was adopted by the City of Bellingham as a guide to the growth and improvement of the city. As such it locally implements the state's Growth Management Act (RCW 36.70A). The Growth Management Act mandates the inclusion of a land use element designating the proposed general distribution and general location and extent of the uses of land, where appropriate, for agriculture, timber production, housing, commerce, industry, recreation, open spaces, general aviation airports, public utilities, public facilities, and other land uses. The land use element shall include population densities, building intensities, and estimates of future population growth. The land use element shall provide for protection of the quality and quantity of groundwater used for public water supplies. Where applicable, the land use element shall review drainage, flooding, and stormwater runoff in the area and nearby jurisdictions and provide guidance for corrective actions to mitigate or cleanse those discharges that pollute waters of the state, including Puget Sound or waters entering Puget Sound.

The City of Bellingham's requirements for stormwater management are currently contained in Bellingham Municipal Code Sections 15.16, 15.40 and 15.42. These regulations largely emulated the 2005 *Stormwater Management Manual for Western Washington* from Ecology. There are some differences between the City code and the Ecology manual. The major differences are:

- The City requires replaced impervious surfaces to always be considered in the determination of BMP thresholds and for those surfaces to be mitigated.
- The City allows replaced impervious surfaces that meet redevelopment criteria to be considered as 50% forested and 50% in the existing condition as of September 1995.
- The City has allowed the use of the Santa Barbara Urban Hydrograph until such time as the WHMM3 model for Bellingham has been calibrated for use. This applies only to those sites or projects that are disturb less than one acre. Phased or related projects are considered together for this threshold.

The Public Works Development Guidelines and Improvement Standards include standard plans for controlling drainage and stormwater runoff. These plans are provided for the design of catch basin, storm drainage, and pipe conveyance systems.

This stormwater plan provides input to all of the above-described programs, plans, and regulations as they relate to stormwater requirements and regulatory issues. However, this plan does not have the scope nor budget to specifically identify item-by-item compliance measures for individual programs, plans, and regulations. Rather, this plan and accompanying stormwater modeling software provide a tool for the City of Bellingham to show how the City is addressing its stormwater and pollutant control obligations, as required by local, state, and federal law.

Acting under Chapter 90 RCW, the City of Bellingham authorized Clear Creek Solutions, Inc., to prepare this plan in an agreement dated July 6, 2005.

Goals and Objectives

The goals and objectives of this Comprehensive Stormwater Plan include:

- Analysis of existing stormwater facilities and aquatic resources,
- Identification of existing stormwater problems,
- Analysis of alternative stormwater solutions,
- Documentation of the stormwater plan for implementation by city staff, and
- Providing the city staff a tool to address stormwater and pollutant control obligations, as required by local, state, and federal law.

Report Overview

The watershed study areas exhibit a variety of storm and surface water characteristics. Drainage features include wetlands, streams, ponds, open channels, culverts, and pipe systems. The City's land use varies from forest and agriculture to residential, commercial, and industrial.

Stormwater solutions include both structural and non-structural solutions. The solutions focus on providing practical and environmentally sensitive solutions to allow responsible land use development and yet maintain valuable aquatic resources.

This comprehensive stormwater plan is an update of the 1995 Watershed Master Plan developed for the City of Bellingham by HDR Engineering, Inc. The 1995 plan included information on stream assessments, wetlands, pollutant loadings, and stormwater flows and problem areas. The stream assessments, wetlands, and pollutant loading elements of the 1995 plan are still valid and should be consulted for information. For continuity, summaries of these elements from the 1995 plan have been incorporated in this stormwater plan, where possible. In addition, the original 1995 plan is included as a reference document in Appendix C of this 2007 plan.

The stormwater flows and problem areas information has been updated based on new hydrology modeling methodology required by the Department of Ecology. The 1995 plan used single-event hydrologic modeling methodology. This methodology has found to be inappropriate for stormwater modeling. This 2007 plan uses continuous simulation hydrologic modeling. Continuous simulation hydrologic modeling is described in more detail in the following section.

Methodology

The hydrologic and hydraulic modeling for the City of Bellingham Comprehensive Stormwater Plan is based on continuous simulation methodology. Continuous simulation modeling keeps track of the entire hydrologic cycle on an hourly or smaller time step for multiple years.

The 1995 HDR stormwater calculations were made using single-event Waterworks hydrology software. The single-event hydrology modeling results are no longer considered useful due to inappropriate assumptions required for single-event modeling and the inability of single-event modeling to do flow duration analyses.

The advantages of continuous simulation modeling over single-event modeling are:

1. Continuous simulation modeling does not need to make inappropriate assumptions about the rainfall-runoff relationship. Single-event modeling assumes that the 25-year storm causes the 25-year flood. This is often not true. Depending on antecedent soil moisture conditions, a 25-year storm may cause a larger or smaller flood. Continuous simulation modeling does not need to make this assumption. Actual historical rainfall data are used in the modeling, soil moisture conditions are computed for each time step, and the flood frequency is statistically calculated based on annual peak flow values in accordance with federal standards, as prescribed in U.S. Water Council Bulletin 17B (1981).

2. Continuous simulation modeling provides a complete range of flows from summer low flows to winter floods for multiple years of record. This range of flows can be used to perform flow duration analyses. Flow duration (percent of time that a flow is exceeded) is used to determine whether or not the number of hours of erosive flows is increased as land use changes. The Department of Ecology has determined that the erosive flow range is from 50% of the 2-year peak flow to the full 50-year and requires the use of this flow duration range in the NPDES Phase II permits. Continuous simulation modeling provides the full range of simulated flows required for flow duration analysis; single-event modeling, by its very nature, cannot be used to do flow duration analyses and will not meet NPDES Phase II permit requirements.

The continuous simulation modeling software used for the comprehensive stormwater plan is the Western Washington Hydrology Model version 3 (WWHM3). WWHM3 was originally developed for the Washington State Department of Ecology by Clear Creek Solutions, Inc. WWHM3 uses EPA HSPF as its computational engine to compute stormwater runoff.

HSPF, developed for the U.S. Environmental Protection Agency in the late 1970s, simulates the entire water cycle for extended periods of time. Model algorithms and options include hydrologic, and associated water quality, processes on pervious and impervious land surfaces and in streams and well-mixed impoundments.

HSPF uses continuous rainfall and other meteorological records to compute streamflow hydrographs and water quality constituents. HSPF simulates interception, soil moisture, surface runoff, interflow, base flow, evapotranspiration, groundwater recharge, channel routing, and water quality (water quality was not modeled in Bellingham). HSPF can simulate one or many pervious or impervious unit areas discharging to one or many river reaches or reservoirs. Frequency and duration analysis can be done for any time series. Any time period from a few days to hundreds of years may be simulated. HSPF is generally used to assess the effects of landuse change, reservoir operations, point or nonpoint source treatment alternatives, flow diversions, etc. All time series data are saved to the Watershed Data Management (WDM) file for later statistical analysis.

As discussed later in the plan, WWHM3's HSPF hydrology parameter values are based on regional watershed calibrations performed by the U.S. Geological Survey. These are the default values used in WWHM3. Two of the City of Bellingham's watersheds, Silver Beach Creek and Whatcom Creek, were calibrated to determine appropriate HSPF parameter values that best represented the hydrology of the city's watersheds. The calibration and results are discussed in the Model Development section of this plan.

Stormwater runoff routing is computed using HSPF for open channel conveyance systems and PCSWMM for stormwater pipe conveyance systems. City of Bellingham GIS stormwater conveyance system data were used to model the stormwater pipe systems. Conveyance system data from the 1995 Waterworks models were used in WWHM3 where City GIS conveyance system data did not exist.

The finished stormwater modeling software provided to the City of Bellingham gives the city staff the full range of tools to use the model to do basin planning now and in the future. The model can be used by city staff to evaluate proposed landuse developments and mitigation measures within the city's watersheds, determine the effectiveness of upgrading the city's stormwater conveyance system, and simulate how changes in the city's urban growth area limits will impact stormwater flows in the city's streams.

To take advantage of these modeling options the city also needs to invest appropriate resources to maintain and update the model. These resources consist of city staff training, additional calibrations, and the filling of GIS data gaps.

The city staff was trained in the use of the WWHM3 modeling software in May 2007. This model training provided the city staff with the basics for running the WWHM3 modeling software, but annual training review and updates are needed to ensure optimal use of the model by city staff.

The future availability of additional observed streamflow data in the city's creeks will provide the necessary information to calibrate the model's HSPF parameters to the individual hydrologic characteristics of the city's watersheds. Currently there are only sufficient observed streamflow data to perform calibrations for Silver Beach Creek and Whatcom Creek. Ideally, in time, two or more years of observed streamflow data will be available for use in the HSPF calibration of Silver, Squalicum, Baker, Padden, and Chuckanut Creek. This will assist in the refinement and updating of the model.

It will also be important to fill in GIS data gaps. These data gaps are mostly in the form of missing or incomplete conveyance system data. Missing data often meant that stormwater pipe network data were missing one or more invert elevation, manhole cover elevation, pipe length, or culvert material. Open channel data were rarely available from the GIS data. These conveyance system data gaps limited the availability of the model to identify stormwater conveyance capacity limitations and other related problem areas. As discussed in the following sections, the conveyance system data gaps prevented identification of stormwater problems and solutions for most of Silver, Squalicum, Baker, Padden, and Chuckanut Creek.

Recommendations

The following recommendations are based on the information provided in this plan.

1. Extend City Staff Training: Provide WWHM3 modeling software training, review, and updates to city staff on an annual basis to ensure optimal use of the model by city staff.

2. Continue City Stream Gaging: Initiate and/or continue to collect observed streamflow data from the city streams, in particular, Silver, Squalicum, Baker, Padden, and Chuckanut Creek. Collect a minimum of two years of streamflow data for each stream.

3. Complete City GIS Conveyance System Data: Fill in missing or incomplete GIS conveyance system data. This includes invert elevations, manhole cover elevations, pipe lengths, culvert material, and open channel data. Missing GIS data are a problem in all of the city's watersheds and in particular for Silver, Squalicum, Baker, Padden, and Chuckanut Creek.

4. Extend Model Calibration: Calibrate the HSPF hydrologic parameter values for Silver, Squalicum, Baker, Padden, and Chuckanut Creek. The model calibrations will provide input to the city's basin planning efforts.

5. Extend City GIS Impervious Coverage: Extend the impervious coverage to all impervious areas including driveways, sidewalks, and other miscellaneous impervious surface within the city's major watersheds.

6. Model the Entire Whatcom Lake Drainage: Extend the Whatcom Creek model to include Whatcom Lake and the entire lake drainage. This will involve collecting land use, soil, and vegetation data on the entire area that drains into the lake and adding to the model long-term precipitation records for the lake drainage. Additional information needed to model the lake and its outlet is the city's seasonal management of the flows out of the lake. This seasonally changing stage-discharge relationship will also have to added to the combined Whatcom Lake-Whatcom Creek model. It will then be possible to continuously model the lake discharge and Whatcom Creek flows for a 40 to 50-year time period. And, with a 40 to 50-year Whatcom Creek simulated streamflow record, the 2-year frequency flow can be calculated and the 50% value compared with the field erosive flow analysis.

7. Use Conveyance System Sizing Information: Use the conveyance system sizing information presented in this plan to identify specific projects for in-depth study prior to design and construction.

Acknowledgements

The Stormwater Comprehensive Plan was a team effort. Individuals who were instrumental in the development of the plan include:

William Reilly, Manager, Storm and Surface Water Utility Manager, City of Bellingham

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Shannon White, Senior Programmer, Clear Creek Solutions, Inc.

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Jeffrey Coop, P.E., Parametrix
Julie Brandt, P.E., Parametrix
Jim Glassley, Parametrix
Jenna Friebel, Parametrix

Joanne Greenberg, P.E., President, HydroLogic Services Company

STUDY AREAS

General

The City of Bellingham is located in Whatcom County. Whatcom County lies between the Georgia Strait to the west, the crest of the Cascades to the east, British Columbia to the north, and Skagit County to the south. The study areas include portions of six watersheds that flow through the City of Bellingham. These watersheds include Whatcom Creek, Silver Beach, Padden Creek, Chuckanut Creek, Squalicum Creek, and Silver Creek.

The study areas within each watershed were selected because of known and/or suspected stormwater problems. City of Bellingham GIS stormwater conveyance system data and land use data were used to model the study areas and identify stormwater problems. Data from the 1995 HDR study were used for the portions of the study areas where City GIS stormwater conveyance system data were missing.

Watershed Locations

Figure 1 shows the location of each watershed and the study area limits.

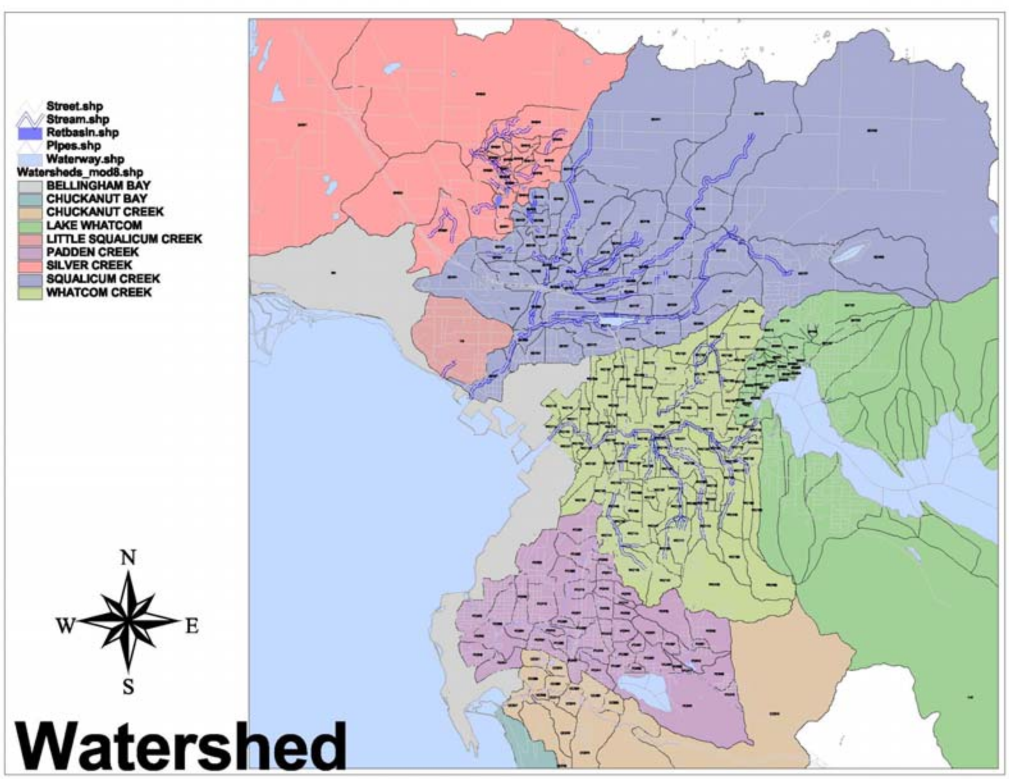


Figure 1. City of Bellingham Watersheds

From north to south the city's watersheds are Silver Creek, Squalicum Creek (including Baker Creek), Silver Beach Creek, Whatcom Creek (including Hannah, Fever, Cemetery, and Lincoln creeks), Padden Creek (including Connelly Creek), and Chuckanut Creek.

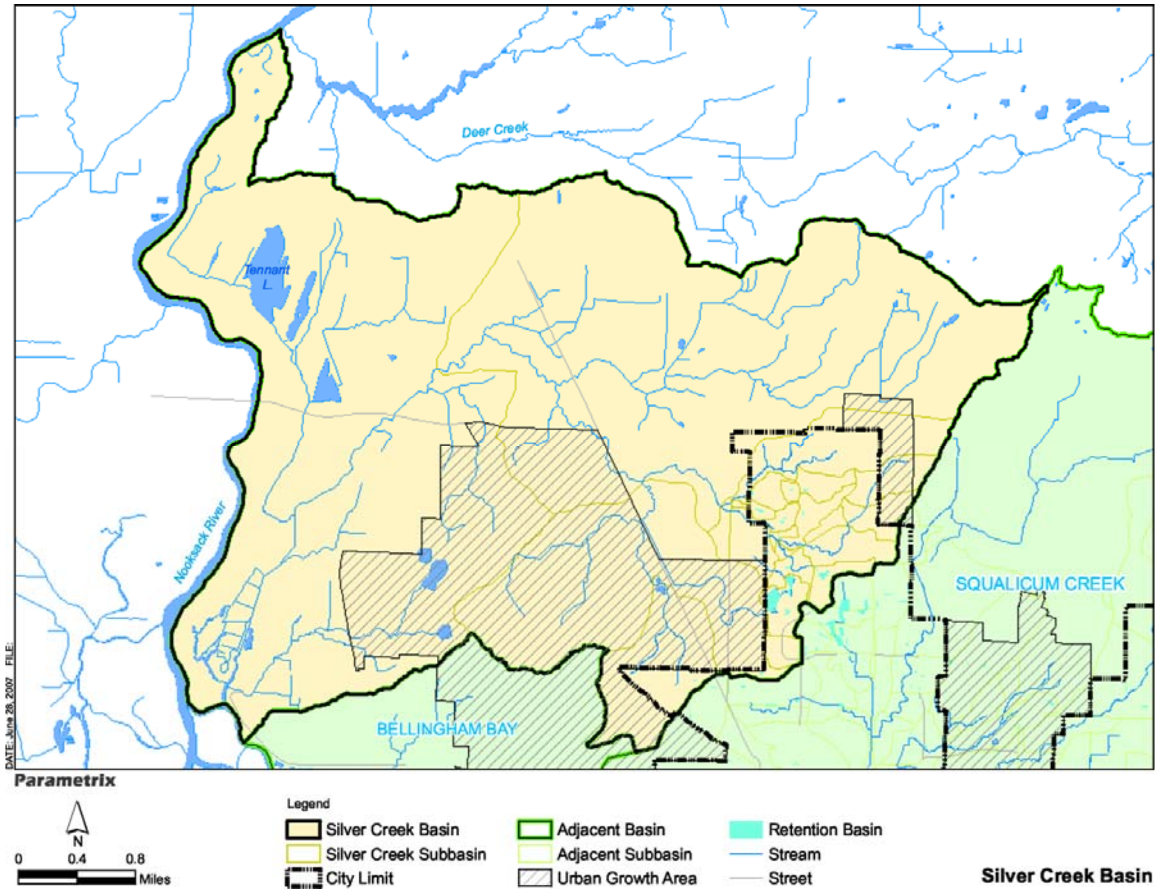


Figure 2. Silver Creek Drainages

The Silver Creek watershed is in the northwest corner of the City of Bellingham (Figure 2). It drains to unincorporated Whatcom County to the northwest. The study area is limited to the portion of Silver Creek within the city limits.

The highest and lowest elevations in the Silver Creek drainages are 370 feet and sea level, respectively. 7% of the Silver Creek watershed is inside the city limits; an additional 22% is in the UGA (Urban Growth Area).

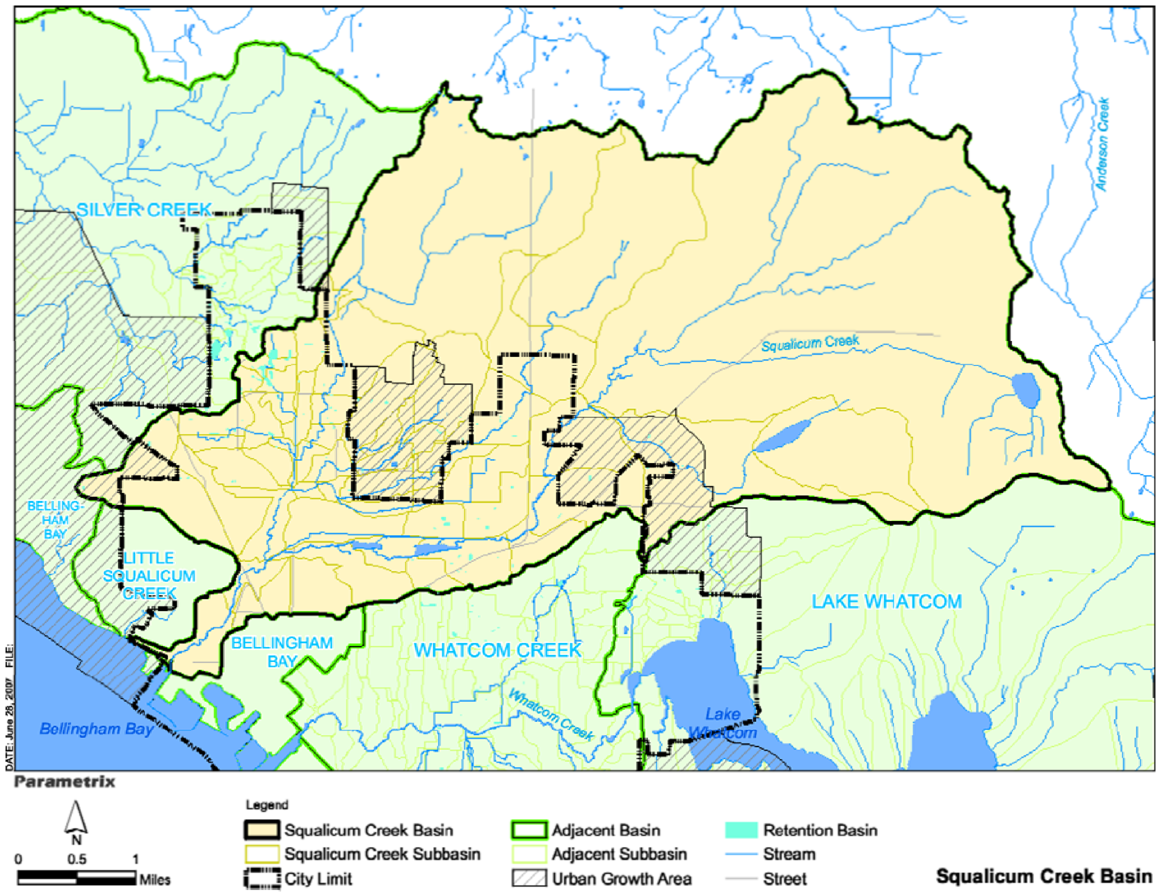


Figure 3. Squalicum and Baker Creek Drainages

The Squalicum Creek watershed is located north of downtown Bellingham and the Whatcom Creek drainage (Figure 3). The study area includes Baker Creek, Spring Creek, and the main stem of Squalicum Creek below the confluence with Baker Creek.

The highest and lowest elevations in the Squalicum and Baker Creek drainages are 1540 feet and sea level, respectively. 25% of the Squalicum Creek watershed is inside the city limits; an additional 9% is in the UGA (Urban Growth Area).

The Silver Beach Creek watershed area is located at the northern end of Lake Whatcom and drains down to the lake. The study area is just to the east of Whatcom's Fever Creek tributary area (see Figure 4).

The highest and lowest elevations in the Silver Beach Creek drainage are 1540 feet and 307 feet, respectively. 3% of the Silver Beach Creek watershed is inside the city limits; an additional 44% is in the UGA (Urban Growth Area).

The Whatcom Creek watershed extends from Lake Whatcom westward to Bellingham Bay. It includes most of downtown Bellingham and associated industrial and residential drainage basins draining to Whatcom Creek. Whatcom Creek's four major drainage basins are Fever Creek on the north side of Whatcom Creek and Hannah Creek, Cemetery Creek, and Lincoln Creek, all on the south side (see Figure 4).

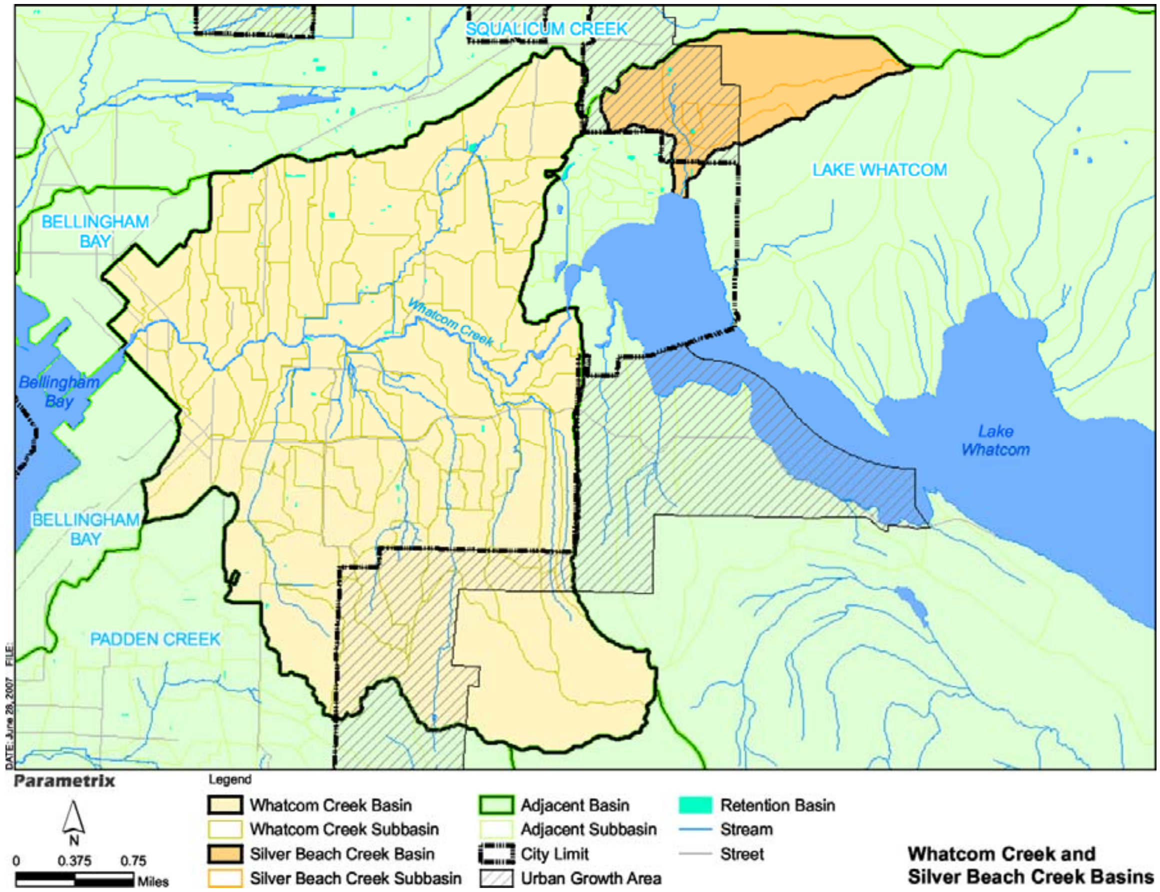


Figure 4. Whatcom and Silver Beach Creek Drainages

The highest and lowest elevations in the Whatcom Creek drainages are 1365 feet and sea level, respectively. 78% of the Whatcom Creek watershed is inside the city limits; an additional 11% is in the UGA (Urban Growth Area).

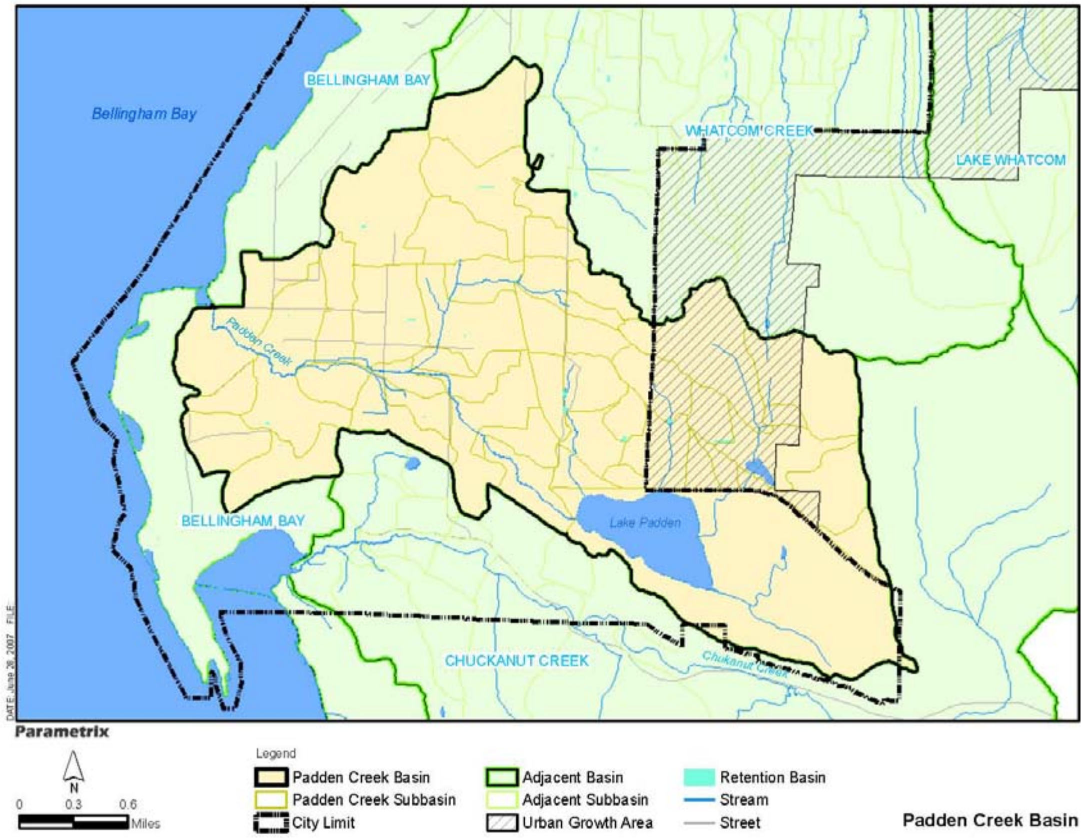


Figure 5. Padden Creek Drainages

The Padden Creek watershed includes both the Lake Padden drainage and the downstream Padden Creek and its major tributary, Connelly Creek (Figure 5). The Padden Creek watershed is immediately south of the Whatcom Creek watershed. Much of the Lake Padden drainage area is outside of the city limits. Padden Creek drains from Lake Padden to Bellingham Bay. Connelly Creek drains the area northwest of Lake Padden before joining Padden Creek.

The highest and lowest elevations in the Padden Creek drainages are 1780 feet and sea level, respectively. 81% of the Padden Creek watershed is inside the city limits; an additional 13% is in the UGA (Urban Growth Area).

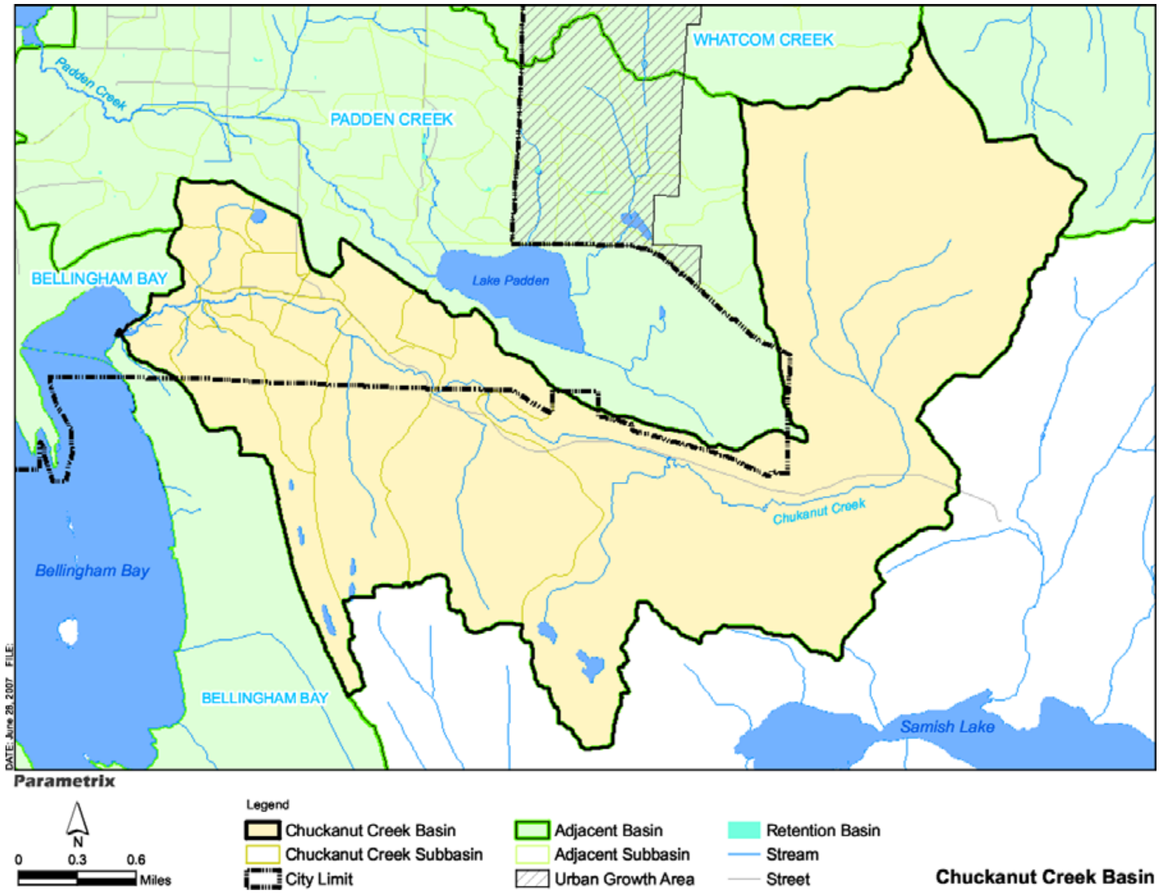


Figure 6. Chuckanut Creek Drainages

The Chuckanut Creek watershed (Figure 6) is south and east of Lake Padden and Padden Creek. The study area, within the city limits, extends westward towards Chuckanut Bay.

The highest and lowest elevations in the Chuckanut Creek drainages are 1780 feet and sea level, respectively. 18% of the Chuckanut Creek watershed is inside the city limits; there is no additional area in the UGA (Urban Growth Area).

Climate

The climate of the City of Bellingham is Marine Pacific West Coast. The air temperatures are usually mild and abundant precipitation occurs from September through May. Fall, winter, and spring are typically cool and breezy. In the winter occasional arctic air masses from Canada converge with moist maritime from the Pacific Ocean result in snowfall down to sea level. During the summer months a warm Pacific high pressure typically dominates the local weather patterns and brings clear skies and warm temperatures. Long-term average annual precipitation is 35-40 inches in the City of Bellingham.

Precipitation data are collected at 15-minute intervals at 20 stations in or near the City of Bellingham, as shown in Figure 7.

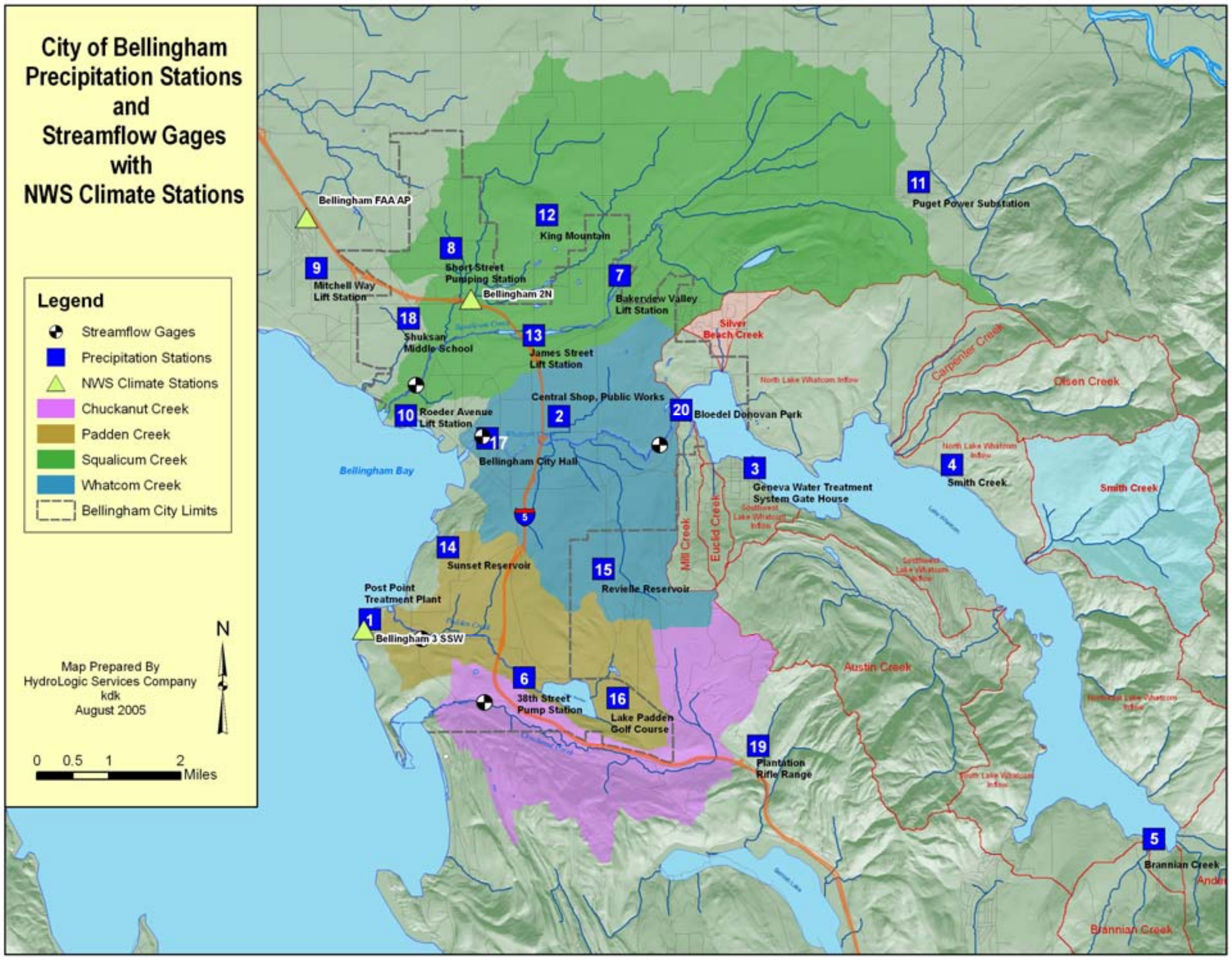


Figure 7. City of Bellingham Precipitation Stations

For comparison purposes, a review of the 20 stations found that only 8 of the 20 have a complete record for water years 2002, 2003, and 2004 (October 2001 through September 2004). The mean annual precipitation for these eight stations is shown in Table 1.

Table 1. City of Bellingham Precipitation Stations

Station	Location	Mean Annual Precipitation (in)
Post Pt	200 McKenzie Ave, adjacent to WWTP	30.21
Brannian	south end of Lake Whatcom	58.51
Central	2221 Pacific St	30.93
Smith	NE side of Lake Whatcom	42.96
Mitchell	near Bellingham Airport	29.76
38th	at Lake Padden	41.27
Roeder	near 851 Coho Way	29.96
Bakerview	4059 Bakerview Valley Rd	30.05

The five stations (Post Point, Central, Mitchell, Roeder, and Bakerview) near or within the City of Bellingham show consistent mean annual precipitation values in the range of 29-31 inches for the three-year comparison period . The stations at higher elevations (Brannian, Smith, and 38th Street Pump Station) all have higher mean annual precipitation values that show the influence of orographic features on the rainfall distribution.

Land Use

Existing land use in the City of Bellingham varies from a high density commercial downtown to undeveloped forest lands. Most of the land can be classified as residential, suburban development. City GIS data were used to convert the City's multiple land use categories into specific hydrology-based categories for use in WWHM3 to compute stormwater runoff.

The Silver Creek study area is to the northwest of the city. This is an area where forest and agricultural land is being converted into suburban neighborhoods.

The Squalicum Creek study area has become more highly developed as new residential neighborhoods are built to the north of Bellingham. Commercial development has focused along the I-5 and State Highway 539 corridors. The northern and eastern edges of the study area still contain some forested and agricultural lands.

The Silver Beach Creek study area is mostly covered with suburban residential developments.

The Whatcom Creek study area is highly developed. The western portion of the study area is the commercial center of the City of Bellingham. Light industrial development is to the east of the downtown along the Whatcom Creek corridor. Residential land use is found both north and side of Whatcom Creek. Park land along Whatcom Creek upstream of Woburn Street protects the creek from encroaching urban development. Along the south edge of the watershed are forested, hill slopes. Development is slowly replacing the forests with suburban housing.

The Padden Creek study area is a mixture of land use development patterns. Most of the drainage area into Lake Padden is forested or developed at a relatively low density for residential or recreational use (golf course). There are residential developments on the north side of the lake. Downstream of the lake the land use changes from rural to urban. The northern and western portions of the Padden Creek drainage are highly developed with a mix of commercial, industrial, and residential use. The Connelly Creek drainage includes relatively dense residential and commercial developments.

Most of the Chuckanut Creek watershed is in forest lands located south of the City of Bellingham. There are residential neighborhoods on the western and northern sides of the study area and along Chuckanut Drive.

For each study area the City of Bellingham GIS provided land use layers that included soils, land use categories, and topography. This information was used to identify and determine the drainage area (acres) for each pervious land type (PERLND) and associated impervious area for each subbasin. Within a single subbasin there can be multiple different PERLNDs plus impervious area (IMPLND). Each PERLND has its own unique combination of soil, vegetation, and land slope that defines its hydrologic response to precipitation.

The individual PERLNDs used in the stormwater modeling are shown in Table 2.

Table 2. PERLND Categories

PERLND No.	Soil	Vegetation/Surface	Slope
1	A/B	Forest	Flat
2	A/B	Forest	Moderate
3	A/B	Forest	Steep
4	A/B	Pasture	Flat
5	A/B	Pasture	Moderate
6	A/B	Pasture	Steep
7	A/B	Lawn	Flat
8	A/B	Lawn	Moderate
9	A/B	Lawn	Steep
10	C	Forest	Flat
11	C	Forest	Moderate
12	C	Forest	Steep
13	C	Pasture	Flat
14	C	Pasture	Moderate
15	C	Pasture	Steep
16	C	Lawn	Flat
17	C	Lawn	Moderate
18	C	Lawn	Steep
19	Saturated	Forest	Flat
20	Saturated	Forest	Moderate
21	Saturated	Forest	Steep
22	Saturated	Pasture	Flat
23	Saturated	Pasture	Moderate
24	Saturated	Pasture	Steep
25	Saturated	Lawn	Flat
26	Saturated	Lawn	Moderate
27	Saturated	Lawn	Steep

Land slope categories: flat (0-5%), moderate (5-15%), and steep (>15%).

Impervious areas were separated from pervious land areas based on the type of land use and its associated impervious fraction (see Table 3).

Table 3. Impervious Land Fraction

Impervious Land Use Category	Impervious Fraction
Low Density Residential	0.08
High Density Residential	0.20
Multi-Family Residential	0.40
Commercial	0.85
Industrial	0.85
Roadways	0.85
Parks	0.05
Forest Lands	0.00
Right-of-way	0.02
Farms/Agricultural Lands	0.02

The impervious area fractions were used to determine the number of acres of impervious area for each land use category instead of using the city's GIS impervious coverage. This was done for two reasons:

1. The city's GIS impervious coverage was reviewed and found to not include all impervious surfaces within the urban area. General street curb-to-curb and building roof impervious coverages were provided, but impervious surfaces such as driveways, sidewalks, and other impervious surfaces were not. Use of the GIS impervious coverage would have resulted in the under-reporting of the total impervious area in each drainage subbasin.

2. The city's GIS impervious coverage did not extend to the portions of the city's watersheds outside of the city limits. To include these areas in the hydrologic modeling it was necessary to compute their impervious area based on the impervious land fractions shown in Table 3.

The city's GIS impervious coverage can be used in the model in place of the impervious land fraction values in computing the number of impervious acres in the future when the two current GIS impervious coverage limitations are resolved. Until that time the impervious land fraction values should be used.

The modeling software options include the ability to quickly update the model with new landuse data, as it becomes available. A description of the procedures involved in updating the model with new GIS data is presented in the Hydrologic Modeling Procedures section of this plan and in the GIS Import documentation in the WWHM3 Project Book given to the city staff.

ENVIRONMENTAL

The environmental documentation of the wetlands and streams conducted for the 1995 plan still provides a good assessment of the City of Bellingham's fresh water aquatic environment. As stated in that 1995 plan, "preservation of natural water courses in the City's drainage basins was considered a high priority in the development of watershed management recommendations." No survey of the city's aquatic resources was made to update this assessment; such a survey was outside of the scope of work.

Environmental Study Description

The 1995 plan conducted detailed field studies of the drainage basin areas, based on priority subbasins, and the priority streams and wetlands within those priority subbasins. Priority subbasins were selected based on the chances of being impacted by nearby development. Priority streams within the selected subbasins were chosen based on their size, fish habitat, the potential for nearby development encroachment on the stream's riparian corridor. Priority wetlands were determined to be those wetlands that are hydrologically connected or potentially hydrologically connected to priority streams.

Priority Wetlands

Wetlands identified by the 1991 Bellingham Wetland Inventory and directly associated with priority streams, were examined for the 1995 plan field investigations. The presence of hydrophytic vegetation, wetland hydrology, and hydric soils were inspected in each wetland. The dominant species in each vegetation layer was identified and density and maturity were estimated. Hydrologic information consisted of a flow rate measurement where surface flow was present, observations of hydrologic constrictions, and an assessment of the wetland's hydroperiod. Information on other important wetland parameters including shape, size, slope, and complexity of the upland/wetland boundary were also noted along with a characterization of the wetland soil substrate.

A simplified functional values analysis was performed on the wetlands in the 1995 study. This analysis consisted of evaluations of wildlife habitat, water quality benefits, flow attenuation potential, and groundwater recharge function for a given wetland. These evaluations were subjective (non-quantitative), based upon qualitative analysis performed by field biologists.

Because wildlife species have unique requirements for food, cover, water quality, and other habitat factors, the general status of wildlife habitat was evaluated in the 1995 study by considering three factors:

- The degree of disturbance to natural vegetation, where greater disturbance is likely to be detrimental rather than beneficial to existing wildlife.

- Proximity to development, where high density development and heavily traveled roadways generally reduce habitat quality of adjacent areas.
- The complexity of the ecosystem, where the presence of multiple wetland classes is biologically more diverse and more valuable.

The water quality benefits of wetlands were evaluated for the ability of their vegetation and soils to filter pollutants entering the wetlands. Wetland geometry and vegetation density are important factors in determining the filtering efficiency.

Floodwater attenuation was evaluated by noting whether irregular wetland topography or the presence of substantial persistent hydrophytic vegetation could attenuate potentially high floodwater velocities. Reducing velocities reduces erosion and stabilizes the existing wetland system. Although wetlands are commonly areas of groundwater surface discharge they can also be an important contributor to groundwater recharge.

A wetland impacts assessment gauged the existing and potential effects of stormwater runoff on investigated wetlands. Stormwater runoff affects wetlands in three general ways:

- Modifying the frequency and duration of wetland inundation which may be a direct influence on the stability of existing vegetation and wildlife communities.
- Increasing erosion and downstream deposition during high water flows.
- Reducing water quality through increased amounts of man-made pollutants and increased suspended solids from erosion.

For each wetland studied a subjective interpretation was performed concerning impacts caused by periodic flooding, runoff water quality, and wetland groundwater exchange. Wetlands which were most or least sensitive to stormwater impacts were listed and the anticipated impacts to these wetlands described. Wetlands with currently limited value, but with potential for improved value from enhancement were noted in the 1995 study.

Priority Streams

The 1995 priority stream inventory consisted of stream characteristics including channel dimensions, riparian vegetation, and other physical characteristics of the streams. Channel dimensions such as bankfull width and depth reveal the stream's carrying capacity, regardless of the water level present at the time of the field investigation. Riparian vegetation was identified and evaluated for species diversity, habitat types, percent cover, and percent shade. Other stream characteristics considered important for a comprehensive understanding of the stream environment included the identification of the stream substrate composition and degree of compactness, an estimate of slopes on land adjacent to the streams, occurrence and extent of bank erosion, water flow rate, and water clarity.

Streams were qualitatively evaluated for wildlife habitat, aesthetics, and water clarity. Fish are an important wildlife associated with Bellingham streams. Stream obstructions that appeared likely to prevent the passage of salmonid species were noted where observed. An aesthetic evaluation gauged the nature and degree of human disturbance on the local stream environment. Water clarity was noted and considered the best indicator of general water quality in the absence of laboratory testing for contaminants. Water clarity is largely a function of suspended solid content and contamination by point and nonpoint source pollutants. For observations made during low water levels, flow velocities are relatively slow. Consequently, erosion and suspended sediment are low in the stream channel and water clarity is only impacted by nearby development-related activities. At high flows dilution diminishes the effects of development-related pollutants and clarity is affected more by suspended solids produced by stream channel erosion.

Additional development will result in increased stormwater runoff. The 1995 stream impacts assessment characterized the general effects of stormwater runoff on inventoried streams. These general effects include:

- Increased potential for stream flooding
- Increased frequency and duration of high flow events
- Increased erosion
- Increased pollutant loadings from nonpoint sources
- Displacement of the current wildlife and vegetation communities

Included in the analysis of the stormwater impacts on streams were qualitative interpretations of potential impacts to studied streams due to periodic flooding and increased pollutant loadings. In each drainage basin field inventoried streams were identified relative to their sensitivity to stormwater impacts. In addition, streams were identified which were considered to be of limited value but have potential for improved value through enhancement projects.

Fisheries

Fish habitat in the streams within the study areas was determined in the 1995 study through a review of existing literature and data bases listed in the bibliography. Because the available literature on local fish resources was limited, additional information was sought through personal communications with local fisheries experts. Fish resources documented in each basin are listed. Information is specific to a stream or stream reach or fish species, as available. Routine observations were made while walking through each stream corridor including the identification of blockages to fish passage.

The general effects of increased stormwater runoff on fisheries habitat were subjectively assessed. The effects of additional erosive flows will increase sedimentation and pollutant transport and may pose a significant threat to salmon spawning habitat as well as other fisheries resources.

Water Quality

Since the previous stormwater comprehensive plan was prepared, the City has been managing stormwater using source controls, education, and both on-site and regional treatment Best Management Practices (BMPs). In particular, water quality in Lake Whatcom has been of concern for many years. A commonly identified cause of the lake's poor water quality is stormwater runoff, which includes many of the constituents typically associated with urban stormwater, e.g., suspended solids, metals, and nutrients. Of these, phosphorus is of particular concern due to Lake Whatcom's algal productivity.

The efforts made by the City to control phosphorus in stormwater are currently being evaluated. The evaluation will include a summary of BMPs the City has implemented, BMPs the City has retrofitted, and previous studies conducted by the City and others (e.g., Western Washington University) on phosphorus in Lake Whatcom and in stormwater runoff. Part of the evaluation will also include a review of alternative approaches either presented in general literature or approaches implemented by similar jurisdictions. Lastly, the City's current stormwater management program will be reviewed to identify any additional incentives and/or enforcement actions the City could implement. This evaluation is being performed specifically for phosphorous control in the Lake Whatcom basin.

The finding from this evaluation will be documented in a separate report to the City.

The following water quality discussion is from the 1995 plan's presentation of general water quality impacts from stormwater runoff.

Pollutant Loadings

Pollutant loading estimates were done in the 1995 study using a simple spreadsheet analysis. The spreadsheet included annual washoff rates for 11 constituents and five different land uses.

The constituents included:

- Biochemical Oxygen Demand (BOD)
- Chemical Oxygen Demand (COD)
- Total Suspended Solids (TSS)
- Dissolved Solids (DS)
- Total Nitrogen
- Total Ammonia
- Total Phosphorus
- Dissolved Phosphorus
- Copper
- Lead
- Zinc

Source information for annual loading estimates included information available from King County METRO, WRMS Water Quality Manual, National Urban Runoff Program (NURP), and the Municipality of Anchorage, Alaska. The loadings do not reflect potential reductions from water quality improvement policies or implemented best management practices.

The land use categories are:

- Commercial
- Industrial
- High Density Residential
- Low Density Residential
- Forest/Open Space

The purpose of developing these estimates was to look for trends in how land use development impact pollutant buildup and washoff.

GENERAL ISSUES AND RECOMMENDATIONS

One of the City of Bellingham's most valuable resources is its natural streams. As development occurs stormwater runoff increases in both frequency and duration. In some portions of the city the natural stream character has been modified or replaced by channeling, piping, or armoring (rock lining) of the natural channel. The 1995 plan recommended ways to preserve the character of the city's natural stream as a valued resource.

This section presents known drainage and water quality issues and problems, identifies alternative solutions, and provides recommended actions to enhance the general stream and stormwater system. It includes information that pertains to all six watersheds. Issues specific to individual watersheds are discussed in the following sections.

Water Quantity Issues, Problems, and Approaches

The following sections present known drainage problems that were identified through several sources: hydrologic and hydraulic computer modeling and analysis, flood problems reported by City of Bellingham Public Works staff, and field visits. The alternative solutions have been identified and recommended for actions to improve the City's stormwater management.

The capacities of open channels, culverts, and stormwater pipe systems in the study areas were determined from the WWHM3 computer modeling. Locations where floodwater surcharge was identified were identified as problem sites.

A number of different approaches can be taken to correct or mitigate stormwater problems. These approaches include local site detention, regional detention, bypass piping, upsizing stormwater culverts and pipes, and armoring channels to reduce channel erosion. These issues must be addressed on a site-by-site basis because of the unique characteristics of each subbasin. Water quantity solutions also have an impact on water quality and, as a result, water quality issues must be also included in the decision process.

Both regional and local site detention have advantages and disadvantages. Regional detention facilities need space (a dedicated land parcel), but can be used for multiple purposes, including habitat enhancement, recreation, and open space. The advantage of regional detention is that storage volume can be more efficiently used compared to multiple local site detention facilities. Reasons for the regional facility's efficiency include setback buffers, pond side slope requirements, and fewer control structures. One large pond has a more efficient surface area to volume ratio than multiple small ponds.

Regional detention facilities also have lower maintenance costs when compared to multiple local facilities that equal the same total storage volume. The regional facilities owned by the City can be serviced on a regular maintenance schedule. Local site facilities are often owned by homeowner associations who are not aware of their facilities' maintenance requirements, do not have the knowledge or equipment to maintain the facilities properly, nor have the funds to contract the maintenance work.

The disadvantages of regional systems include the difficulty of finding locations on which to build the facilities, the need to convey stormwater flows to the regional facilities without damaging the natural drainage system, and the inability to fund and construct regional facilities prior to pending upstream land development. In addition, local site facilities, such as rain gardens, are better at reducing stormwater runoff and pollutants at the source prior to their entering the public stormwater system.

Bypass piping is considered an option where high flows need to be transported around rather than through a sensitive stream reach or wetland. By redirecting the high flows the bypass reduces stream channel erosion. In comparison to channel armoring, bypass piping also reduces the need to disrupt the riparian corridor with equipment and construction activities. Easement acquisition requirements are also generally less than buying additional stream buffers. The disadvantages of bypass piping include potential conflict with other utilities in the street right-of-way, environmental damage if constructed in the riparian corridor, and high construction costs.

The use of riprap or channel armoring reduces or destroys the natural qualities of a stream and transports high flows and pollutant loads downstream without any attenuation. Maintenance is required to maintain these channel protection facilities. Changes in the flow regime can lead to other erosion and flooding problems. The selection of any instream measure or facility must also include analysis of the disruption and environmental damage that will occur due to construction and maintenance. Slope stabilization methods that include bioengineering can be less damaging to the riparian corridor than standard riprap. However, they must be carefully protected to prevent undercutting and monitored to make sure that the vegetation is healthy.

Stormwater detention based on the Washington State Department of Ecology flow control standards prevents an increase in erosion by limiting the erosive flows from new development. Stormwater detention facilities also provide an opportunity for water quality improvements. This can be in the form of sediment and pollutant settling in wet pond forebays and/or biofiltration. By comparison, increasing downstream conveyance system capacity does not reduce erosive flows nor provides water quality benefits. However, increasing capacity reduces flooding of public and private property and can be included in the road right-of-way.

Washington State Department of Ecology flow control standards require that for new development that the stormwater runoff flow duration (percent of time) not increase above the predeveloped (forested land use) erosive flows (flows between ½ of the 2-year peak flow to the 50-year peak flow, as computed by WWHM3. WWHM3 statistically computes the 2-year and 50-year peak flow using 30-50 years of HSPF-generated hourly runoff, selecting the annual peak discharges, and using a Log Pearson Type III distribution.

Environmental Issues, Problems, and Approaches

The 1995 plan included field work conducted in the inventoried drainage basins. That field work identified environmental problems and solutions. One of the general issues identified was the effect of existing and increased land development on the natural resources (streams, wetlands, fish resources, and water quality) in the individual drainage basins. The development of land impacts the natural dynamics of the predevelopment environment along the riparian corridor and in wetlands. This can result in the presence of nonpoint chemical pollutants and sediment loads in the City's freshwater aquatic environment. This development together with the construction of physical barriers such as culverts in the stream channels can severely affect the ability of native fish and wildlife to survive the changes to their natural ecosystem. Associated with issues of land development-related impacts are issues of providing opportunity for development and economic viability within the City of Bellingham while at the same time protecting the valuable, and sometimes fragile, natural ecosystem. Add to this situation the need to restore natural environments that have been impacted negatively in the past.

The environmental problems identified during the 1995 field work were directly related to the impacts of land development and land use changes. Problems include:

- Stream reaches with severely eroded channels
- Loss of fish habitat from the physical alteration of streams and adjacent woody riparian vegetation
- Wetlands that have been so disturbed that many of their ecological functions have been degraded and their vegetative composition altered
- Degraded water quality in both streams and wetlands

In general, solutions to the problems are dependent on the successful implement of this and other plans and their associated recommendations and proposed best management practices (BMPs). Streams, wetlands, and fish resources can be better protected by identifying high value resources and by proposing basin-specific guidelines successfully mitigate the impacts of future land use change. Resources that are currently highly degraded can be restored by implementing subbasin-specific development recommendations and restoration plans. These solutions protect and improve water quality and fish habitat in streams and wetlands.

Water Quality Issues and Recommendations

Water quality degradation is directly related to increased land development and intensified land use. Runoff sediment increases from both erosion and washoff from streets and parking lots. Many pollutants attach to sediment particles and are transported in the stormwater runoff. Nutrient loading increases because of land use practices such as fertilizer applications on residential properties. The plant cover cannot utilize all of the applied nutrients and soil cannot absorb them. In addition, the amount of oxygen demanding organics increases with land use intensity, as do hydrocarbons, heavy metals, and organic compounds. Heavy metals and organic compounds increase toxicity in the streams and hydrocarbons also adversely impact water quality.

The 1995 plan identified steps that need to be taken to prevent water quality degradation as land development increases. Many of these steps can be retrofitted into currently developed areas to improve surface water runoff quality.

The Washington State Department of Ecology has established in Western Washington a water quality treatment standard of 91% of the total stormwater runoff volume that must be treated. All new development should be required to implement on-site water quality measures to meet this standard.

Examples of best management practices (BMPs) to improve water quality include the use of grass filter strips, settling ponds, biofilters, constructed wetlands, oil/water separators, infiltration, and water quality cartridges. They can also include incorporating stream setbacks, removing livestock from streams and other sensitive areas, cleaning up pet wastes, revising landscaping and runoff patterns, stabilizing slopes by terracing and/or bioengineering, and improving ground cover.

Public environmental education can be an important element in improving stream water quality. Both residential contributors and commercial and industrial contributors should be targeted. Examples of public education programs include water quality programs in schools, public forums, and printed brochures describing how to dispose of or recycle yard and other household wastes including automobile motor oil, anti-freeze, car wash water, and household cleaners. Illegal sanitary sewer and industrial discharge connections to the stormwater sewer system and the streams should be eliminated.

Key public education topics include:

- The promotion of integrated pest management
- Proper application of fertilizers
- Use of native plants in landscaping
- Proper disposal or recycling of wastes, such as soapy water, oils, anti-freeze, cleaners, solvents, etc.
- Reducing impervious surfaces

The 1995 study included observations of nonpoint pollution sources made on each inventoried stream corridor. Nonpoint source pollution problems observed included manure in runoff from livestock, failed septic systems from adjacent residences, lawn and garden chemicals and fertilizers, automobile oils, anti-freeze and gasoline leakage, chemical washoff from manufacturing facilities, pollutants from roadways (zinc, lead, asbestos, anti-freeze, oils, etc.), winter road salts and traction sand, and illegal outfalls to streams and wetlands.

The Washington State Department of Ecology's *Stormwater Management Manual for Western Washington* requires implementing source control and treatment of stormwater to treat 91% of the total runoff volume for new development. The manual also requires that for new development that the stormwater runoff flow duration (percent of time) not increase above the predeveloped (forested land use) erosive flows (flows between ½ of the 2-year peak flow to the 50-year peak flow.

The National Pollutant Discharge Elimination System (NPDES) program requires a water quality monitoring program to identify pollutant discharge locations and sources. The program also requires corrective measures.

HYDROLOGY

The hydrologic and hydraulic modeling for the City of Bellingham Comprehensive Stormwater Plan was based on continuous simulation methodology. Continuous simulation modeling keeps track of the entire hydrologic cycle on an hourly or smaller time step for multiple years.

The continuous simulation modeling software used for the comprehensive stormwater plan is the Western Washington Hydrology Model version 3 (WWHM3). WWHM3 was originally developed for the Washington State Department of Ecology by Clear Creek Solutions, Inc. WWHM3 uses EPA HSPF as its computational engine to compute stormwater runoff. Stormwater runoff routing is computed using HSPF for open channel conveyance systems and PCSWMM for stormwater pipe conveyance systems. City of Bellingham GIS stormwater conveyance system data were used to model the stormwater pipe systems.

The 1995 HDR stormwater calculations were made using Waterworks software. Conveyance system data from the Waterworks models were used in WWHM3 where City GIS conveyance system data did not exist.

Model Development

Unlike the 1995 Waterworks single-event hydrology model, WWHM3 does not use design storms to generate stormwater runoff. The City of Bellingham Central Shop hourly precipitation record was used by WWHM3's HSPF computational engine to calculate stormwater runoff. Runoff was then routed using HSPF's RCHRES algorithms and/or SWMM's Transport algorithms.

Basins, subbasins, and their boundaries in each watershed study area were based originally on the 1995 plan. They were checked and revised, as needed, using the City of Bellingham's GIS data. Subbasins were delineated to reflect tributary area to modeled conveyance system facilities. Critical locations in each basin were identified by comparing existing facility capacity with generated stormwater flows.

WWHM3's HSPF hydrology parameter values are based on regional watershed calibrations performed by the U.S. Geological Survey. These are the default values used in WWHM3. Two of the City of Bellingham's watersheds, Silver Beach Creek and Whatcom Creek, were calibrated to determine appropriate HSPF parameter values that best represented the hydrology of the city's watersheds.

HSPF Calibration

HSPF model calibration is an art as much as it is a science. HSPF calibration involves 17 PERLND parameters, of which four (LZSN, UZSN, INFILT, and INTFW) are the major calibration parameters.

As described in the Land Use section, the pervious and impervious land types were identified and measured in terms of their area (acres) and where they discharge to the nearest stream channel or stormwater conveyance system. Pervious land types were divided according to soil, vegetation, and land slope. In the Bellingham area the major soil categories used are A/B (outwash), C (till) and saturated (wetland). Vegetation categories are usually forest, pasture, and lawn (turf grass). Land slopes are flat (0-5%), moderate (5-15%), and steep (>15%). Impervious land types are usually lumped together, although they can be separated according to land slope.

HSPF PERLNDs are based on the pervious land types. For example, one PERLND will represent till soil, forest vegetation, on a flat slope (0-5%). Multiple PERLNDs are usually defined for each HSPF model. For each of these PERLNDs the 17 parameters need to be assigned the appropriate values. Most of the 17 parameters are represented by physical processes.

The PERLND parameters and the processes are defined below in Table 4.

Table 4. PERLND Parameters

Parameter	Description	Value Based on
LZSN	Lower Zone Storage Nominal (inches)	Calibration
INFILT	Infiltration (inches per hour)	Calibration
LSUR	Length of Surface Overland Flow (feet)	Map Measurement
SLSUR	Slope of Overland Flow Path (feet/feet)	Map Measurement
KVARY	Variable Groundwater Recession	See Table 5
AGWRC	Active Groundwater Recession Constant (per day)	See Table 5
INFEXP	Infiltration Exponent	See Table 6
INFILD	Infiltration Ratio (mean to maximum)	See Table 6
DEEPFR	Deep Fraction of Groundwater	See Table 6
BASETP	Baseflow Evapotranspiration	See Table 6
AGWETP	Active Groundwater Evapotranspiration	See Table 6
CEPSC	Interception Storage (inches)	See Table 7
UZSN	Upper Zone Storage Nominal (inches)	Calibration
NSUR	Surface Roughness Coefficient (Manning's n)	See Table 7
INTFW	Interflow Index	Calibration
IRC	Interflow Recession Constant (per day)	See Table 7
LZETP	Lower Zone Evapotranspiration	See Table 7

As shown in Table 4, most of the values for the parameters can be determined from map measurements or have recommended values. Four parameters (LZSN, INFILT, UZSN, and INTFW) are determined through the calibration process.

LZSN (Lower Zone Storage Nominal) controls the amount of water (soil moisture) in the lower soil zone. The lower soil zone is the soil layer between the upper soil layer (typically the top 6 inches) and the groundwater table. The nominal value is not the maximum value (max LZS = 2.5*LZSN). In Western Washington typical LZSN values range from 3 to 12 inches of water.

When LZS (Lower Zone Storage) approaches its maximum value (2.5*LZSN) the amount of water entering the lower zone storage approaches zero. Water remains in the upper zone and surface storage and is available for runoff as interflow and surface runoff. A small LZSN value will result in more interflow and surface runoff than a large LZSN value.

INFILT (Infiltration) controls the rate at which water enters the lower zone storage. The actual infiltration rate is calculated each time step and changes based on the ratios of LZS/LZSN and UZS/UZSN, which change each time step. If the soil moisture is low at the start of a major storm event then the actual infiltration rate will be high. As the storm event progresses the actual infiltration rate will decrease as the soil moisture levels increase. If the storm event lasts long enough and produces enough precipitation the actual infiltration rate will approach zero as the soil becomes fully saturated.

A small INFILT value (for example, the INFILT value for till soils) limits the movement of water into the lower zone storage. Water remains in the upper zone and surface storage and is available for runoff as interflow and surface runoff. A small INFILT value will result in more interflow and surface runoff than a large INFILT value.

UZSN (Upper Zone Storage Nominal) controls the amount of water (soil moisture) in the upper soil zone. The upper soil zone is the soil layer between the surface and the lower soil zone. It is typically considered to be the top 6 inches of soil. The nominal value is not the maximum value (max UZS = 3.5*UZSN). In Western Washington typical UZSN values range from 0.25 to 1.0 inch of water.

When UZS (Upper Zone Storage) approaches its maximum value (3.5*UZSN) the amount of water entering the upper zone storage approaches zero. Water remains in the surface storage and is available for runoff as surface runoff. A small UZSN value will result in more surface runoff than a large UZSN value.

INTFW (Interflow) determines the distribution of runoff between interflow (shallow, subsurface runoff) and surface runoff. Interflow travels through the top layer of soil and takes longer to travel to a conveyance system than surface runoff. A large value for INTFW results in more interflow and less surface runoff. This will decrease the size of peak runoff events, but not change their total runoff volume.

The calibration process is an iterative process. After all of the HSPF calibration parameter values were selected the model was run and the simulated and observed streamflow data compared. For the Silver Beach Creek calibration and the Whatcom Creek calibration the calibration started with the HSPF regional parameter values included in WWHM3 (Western Washington Hydrology Model version 3). These values have been tested on multiple local watersheds and found to accurately represent the hydrology of Western Washington watersheds. The WWHM3 HSPF PERLNDs are listed in Table 2. The associated WWHM3 HSPF regional parameter values are shown in Tables 5, 6, and 7. During the calibration process the calibration parameter values were adjusted to better represent the specific calibration site conditions. This was an iterative process involving approximately 10 calibration iterations for Silver Beach Creek and two dozen iterations for Whatcom Creek.

The calibration comparison process was based on a visual comparison of the observed and simulated hydrographs.

Visual observation allows the user to identify periods when the simulated results match well with the observed data and when they do not. Problems with matching the simulated results with the observed may be because of data problems (examples of which are described below in the calibration discussions) or because inappropriate calibration parameter values were selected. Through the iterative process parameter values were changed and the model rerun to compare the new simulated results with the observed data. This iterative process continued until a good calibration result was achieved.

There is no single process or statistic that determines whether a calibration is good or not. A calibration can always be improved, but at some point in the iteration process a decision must be made that the simulated results are close enough to the observed results to proceed to the next step in the modeling work.

Based on the comparison of the simulated flows with the observed flows we are confident that we have good calibrations for both Silver Beach Creek and Whatcom Creek. A discussion of the calibration results for each of these two streams follows.

Table 5. WWHM3 HSPF Regional Pervious Parameter Values – Part I

PERLND No.	LZSN	INFILT	LSUR	SLSUR	KVARY	AGWRC
1	5.0	2.00	400	0.050	0.3	0.996
2	5.0	2.00	400	0.100	0.3	0.996
3	5.0	2.00	400	0.150	0.3	0.996
4	5.0	1.50	400	0.050	0.3	0.996
5	5.0	1.50	400	0.100	0.3	0.996
6	5.0	1.50	400	0.150	0.3	0.996
7	5.0	0.80	400	0.050	0.3	0.996
8	5.0	0.80	400	0.100	0.3	0.996
9	5.0	0.80	400	0.150	0.3	0.996
10	4.5	0.08	400	0.050	0.5	0.996
11	4.5	0.08	400	0.100	0.5	0.996
12	4.5	0.08	400	0.150	0.5	0.996
13	4.5	0.06	400	0.050	0.5	0.996
14	4.5	0.06	400	0.100	0.5	0.996
15	4.5	0.06	400	0.150	0.5	0.996
16	4.5	0.03	400	0.050	0.5	0.996
17	4.5	0.03	400	0.100	0.5	0.996
18	4.5	0.03	400	0.150	0.5	0.996

PERLND No.	LZSN	INFILT	LSUR	SLSUR	KVARY	AGWRC
19	4.0	2.00	100	0.001	0.5	0.996
20	4.0	2.00	100	0.010	0.5	0.996
21	4.0	2.00	100	0.100	0.5	0.996
22	4.0	1.80	100	0.001	0.5	0.996
23	4.0	1.80	100	0.010	0.5	0.996
24	4.0	1.80	100	0.100	0.5	0.996
25	4.0	1.00	100	0.001	0.5	0.996
26	4.0	1.00	100	0.010	0.5	0.996
27	4.0	1.00	100	0.100	0.5	0.996

LZSN: Lower Zone Storage Nominal (inches)
INFILT: Infiltration (inches per hour)
LSUR: Length of surface flow path (feet)
SLSUR: Slope of surface flow path (feet/feet)
KVARY: Variable groundwater recession
AGWRC: Active Groundwater Recession Constant (per day)

Table 6. WWHM3 HSPF Pervious Parameter Values – Part II

PERLND No.	INFEXP	INFILD	DEEPFR	BASETP	AGWETP
1	2	2	0	0	0.00
2	2	2	0	0	0.00
3	2	2	0	0	0.00
4	2	2	0	0	0.00
5	2	2	0	0	0.00
6	2	2	0	0	0.00
7	2	2	0	0	0.00
8	2	2	0	0	0.00
9	2	2	0	0	0.00
10	2	2	0	0	0.00
11	2	2	0	0	0.00
12	2	2	0	0	0.00
13	2	2	0	0	0.00
14	2	2	0	0	0.00
15	2	2	0	0	0.00
16	2	2	0	0	0.00
17	2	2	0	0	0.00
18	2	2	0	0	0.00
19	10	2	0	0	0.70
20	10	2	0	0	0.70
21	10	2	0	0	0.70
22	10	2	0	0	0.50
23	10	2	0	0	0.50
24	10	2	0	0	0.50
25	10	2	0	0	0.35
26	10	2	0	0	0.35
27	10	2	0	0	0.35

INFEXP: Infiltration Exponent
INFILD: Infiltration ratio (maximum to mean)
DEEPFR: Fraction of groundwater to deep aquifer or inactive storage
BASETP: Base flow (from groundwater) Evapotranspiration fraction
AGWETP: Active Groundwater Evapotranspiration fraction

Table 7. WWHM3 HSPF Pervious Parameter Values – Part III

PERLND No.	CEPSC	UZSN	NSUR	INTFW	IRC	LZETP
1	0.20	0.50	0.35	0	0.7	0.70
2	0.20	0.50	0.35	0	0.7	0.70
3	0.20	0.50	0.35	0	0.7	0.70
4	0.15	0.50	0.30	0	0.7	0.40
5	0.15	0.50	0.30	0	0.7	0.40
6	0.15	0.50	0.30	0	0.7	0.40
7	0.10	0.50	0.25	0	0.7	0.25
8	0.10	0.50	0.25	0	0.7	0.25
9	0.10	0.50	0.25	0	0.7	0.25
10	0.20	0.50	0.35	6	0.5	0.70
11	0.20	0.50	0.35	6	0.5	0.70
12	0.20	0.30	0.35	6	0.3	0.70
13	0.15	0.40	0.30	6	0.5	0.40
14	0.15	0.40	0.30	6	0.5	0.40
15	0.15	0.25	0.30	6	0.3	0.40
16	0.10	0.25	0.25	6	0.5	0.25
17	0.10	0.25	0.25	6	0.5	0.25
18	0.10	0.15	0.25	6	0.3	0.25
19	0.20	3.00	0.50	1	0.7	0.80
20	0.20	3.00	0.50	1	0.7	0.80
21	0.20	3.00	0.50	1	0.7	0.80
22	0.15	3.00	0.50	1	0.7	0.60
23	0.15	3.00	0.50	1	0.7	0.60
24	0.15	3.00	0.50	1	0.7	0.60
25	0.10	3.00	0.50	1	0.7	0.40
26	0.10	3.00	0.50	1	0.7	0.40
27	0.10	3.00	0.50	1	0.7	0.40

CEPSC: Interception storage (inches)
UZSN: Upper Zone Storage Nominal (inches)
NSUR: Surface roughness (Manning's n)
INTFW: Interflow index
IRC: Interflow Recession Constant (per day)
LZETP: Lower Zone Evapotranspiration fraction

Silver Beach Creek Calibration

The Silver Beach Creek HSPF calibration was summarized in a CCS memo to the City of Bellingham dated 28 February 2006. The highlights of that calibration memo are presented below.

The Silver Beach Creek watershed was calibrated with WWHM3 to provide local hydrologic parameter values for use in the City of Bellingham's edition of WWHM3. The calibration period was October 2001 through September 2004 (water years 2002-2004). WWHM3 simulated flow was compared with observed USGS streamflow data at the mouth of Silver Beach Creek. The calibration results show a good match between simulated and observed flows, except for the large flood event of February 23, 2002 (more on that below).

Silver Beach Creek is located at the northern end of Lake Whatcom (see red dot on Figure 8). The Bakerview rain gage was used for the rainfall on the Silver Beach Creek watershed. Potential evapotranspiration data were provided by HydroLogic Services Company.

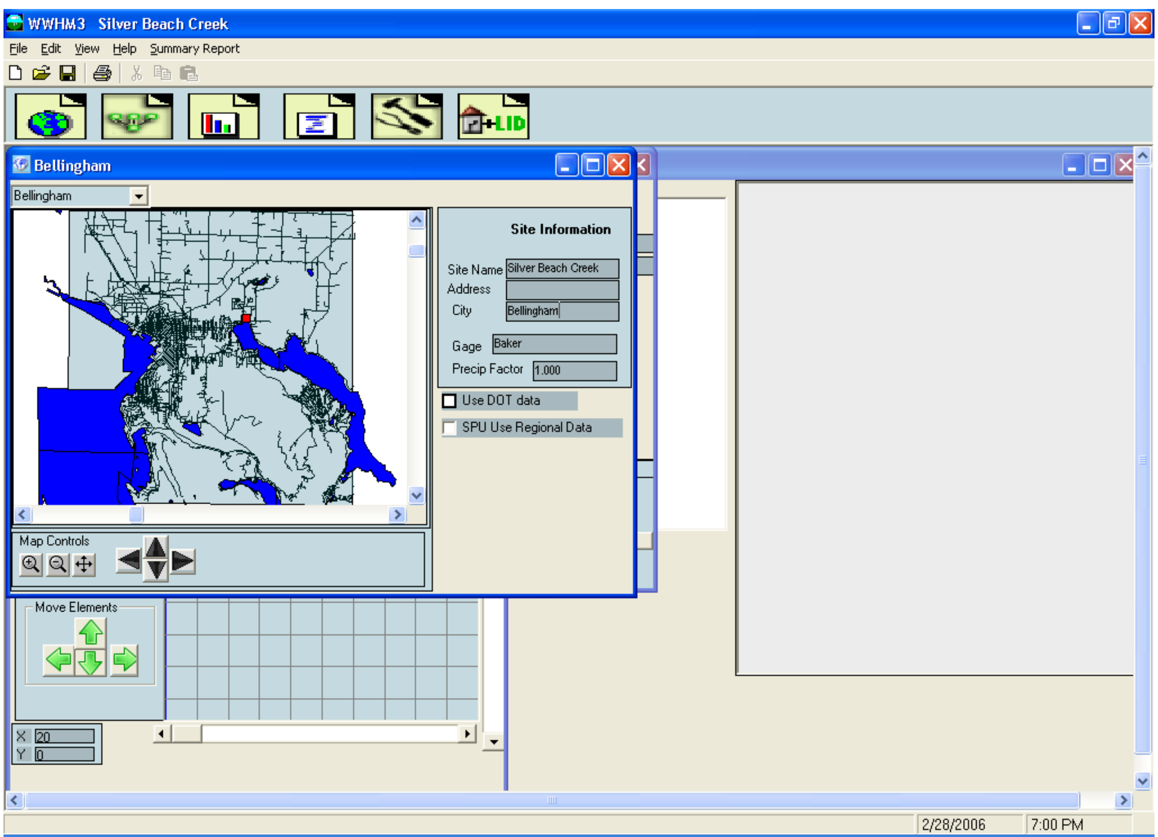


Figure 8. Silver Beach Creek Watershed

The Silver Beach Creek watershed model was created in WWHM3 using GIS land use data provided by the City of Bellingham and converted into appropriate hydrologic land categories by Parametrix. Table 8 summarizes the Silver Beach Creek watershed land use for the five subbasins delineated by Parametrix.

Table 8. Silver Beach Creek Watershed Land Use

Subbasin	Pervious Area (ac)	Impervious Area (ac)	Total Area (ac)	Flows to
SV101	350.61	58.78	409.39	3
SV102	104.18	17.82	122.00	1
SV103	53.31	18.27	71.58	1
SV104	64.53	29.37	93.90	2
SV105	8.11	4.13	12.24	Woodlake Pond
Total	580.74	128.37	709.11	

City GIS information and Woodlake Meadows Estates construction drawings were used to create the Silver Beach Creek conveyance system input to WWHM3. The Silver Beach Creek conveyance system consists of three open channel stream reaches and one stormwater detention pond (Woodlake Pond). The conveyance system linkages are shown in Table 9 and Figure 9.

Table 9. Silver Beach Creek Conveyance System

Reach	Flows to
1	Lake Whatcom
2	1
3	2
Woodlake Pond	1

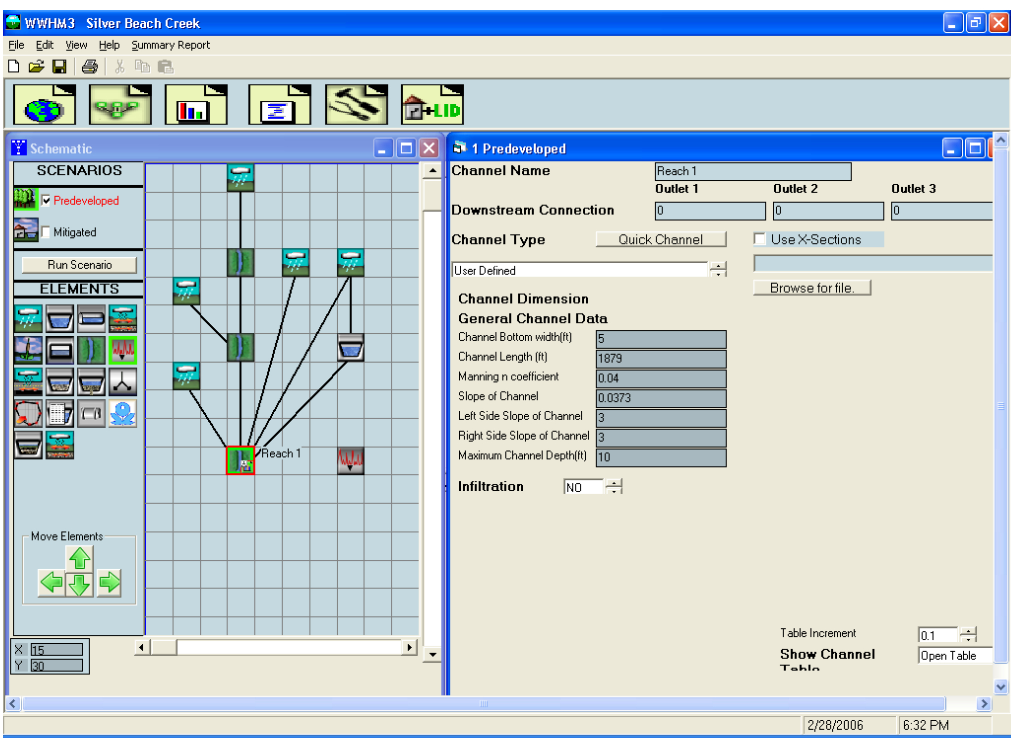


Figure 9. Silver Beach Creek Subbasin and Conveyance Linkages

Simulated and observed daily streamflow were compared at the USGS gage near the mouth of the creek.

In particular, winter flows (December through March) were compared to evaluate the ability of the model to represent this period when most major flooding occurs. Figures 10, 11, and 12 show the winter flows for water years 2002, 2003, and 2004, respectively.

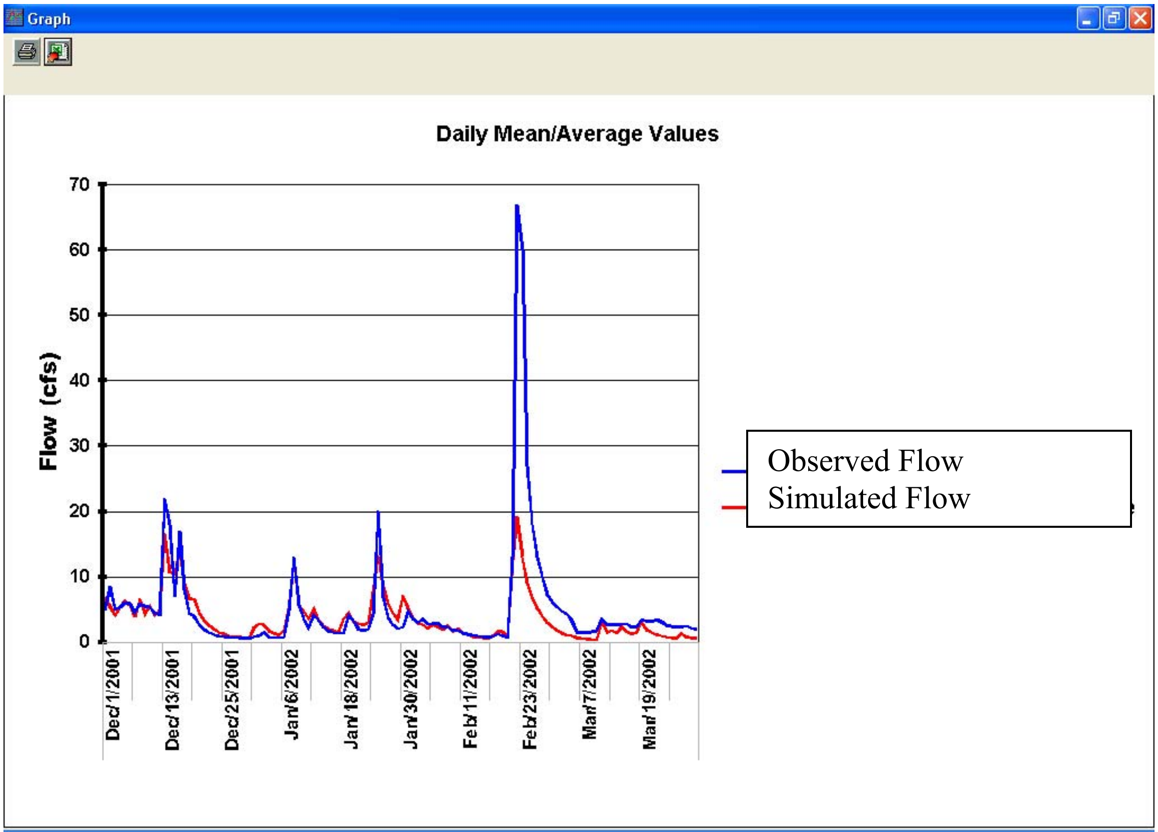


Figure 10. Winter Flows (Dec 2001 – Mar 2002)

As can be seen in Figure 9, the simulated flows match well with the observed data except for the large flood event of February 23, 2002. The inability of the model to reproduce the observed peak flow of 68 cfs is due to one of two reasons:

1. The large peak flow was caused by a particularly heavy rainfall event that partially missed the Bakerview rain gage. The Bakerview gage recorded 2.77 inches over two days, but to produce a peak of this size would require a much higher volume of rainfall (probably in the range of 5-8 inches). Geneva is the next closest gage and it recorded a similar 2.78 inches. A review of the 2-day precipitation for this storm at the other Bellingham precipitation stations found that all of the rain gages recorded total volumes in the range of 2.4-3.5 inches, as shown in Table 10. It appears highly unlikely that a higher precipitation total needed to produce such a large peak flow would not have been recorded at one of the stations.

Table 10. Two-day Precipitation for February 23, 2002, Flood Event

Station	Precipitation (in)
Bakerview	2.77
Geneva	2.78
Roeder Ave	2.40
Central Shops	2.47
Post Pt	2.61
Short St	2.68
Mitchell Way	2.70
38th St	3.18
Smith Creek	3.28
Brannian Creek	3.49

2. The observed streamflow peak value of 68 cfs is inaccurate. It is difficult to accurately measure peak flow events. The standard field survey method of measuring flow velocities is usually impossible due to the high in-bank channel velocities. Instead, rating curves are extrapolated to estimate the peak flow value based on observed high water marks. The Silver Beach Creek stream gage is just upstream of where the creek crosses under North Shore Drive. Backwater from the road culvert constriction may have caused the gage to record an inappropriately high peak stage (water depth), which, when converted into flow, produced an inappropriately high peak flow value.

It is our professional opinion that the inability of the model to match this one peak flow event while matching the remainder of the two-year simulation period is due to Reason #2 above. The observed streamflow peak value of 68 cfs is inaccurate and the correct flow for this event is probably in the range of 20-25 cfs. The model does not have sufficient precipitation to match the observed peak flow regardless of the hydrologic parameters used and yet it matches the other peaks well, as shown in figures 10, 11, and 12.

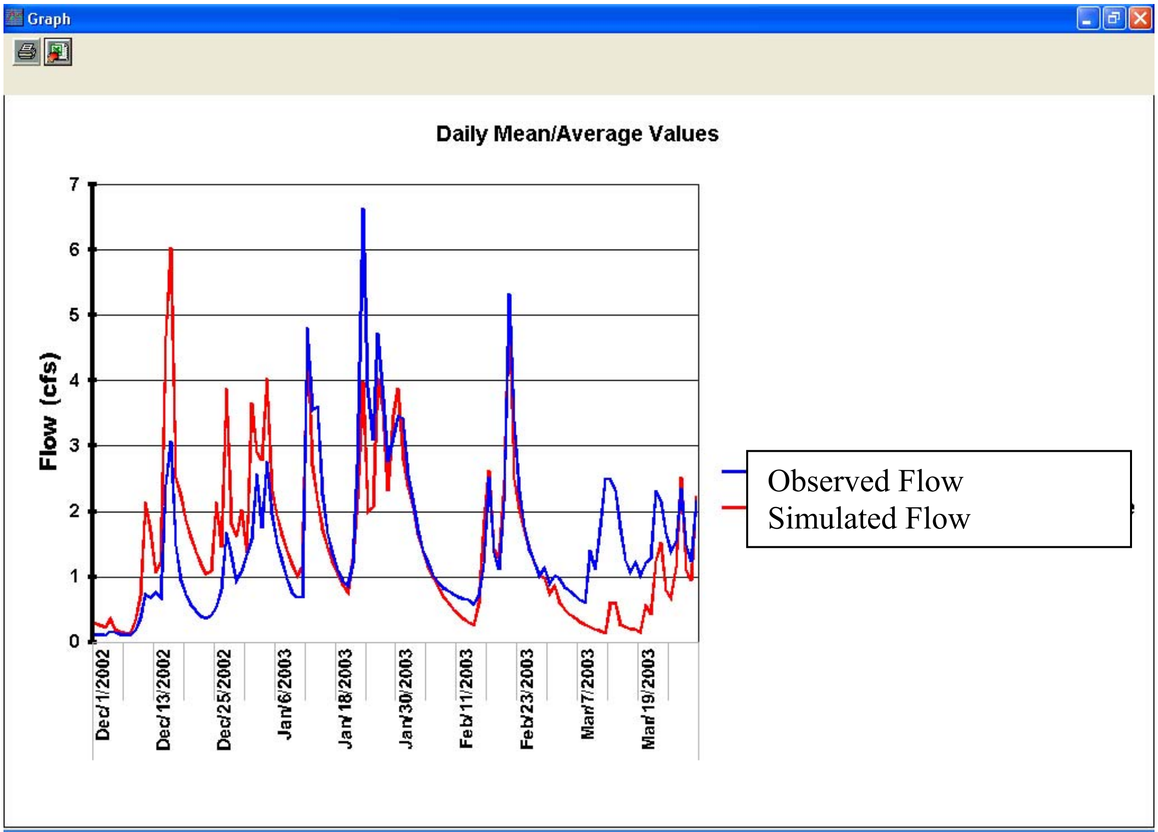


Figure 11. Winter Flows (Dec 2002 – Mar 2003)

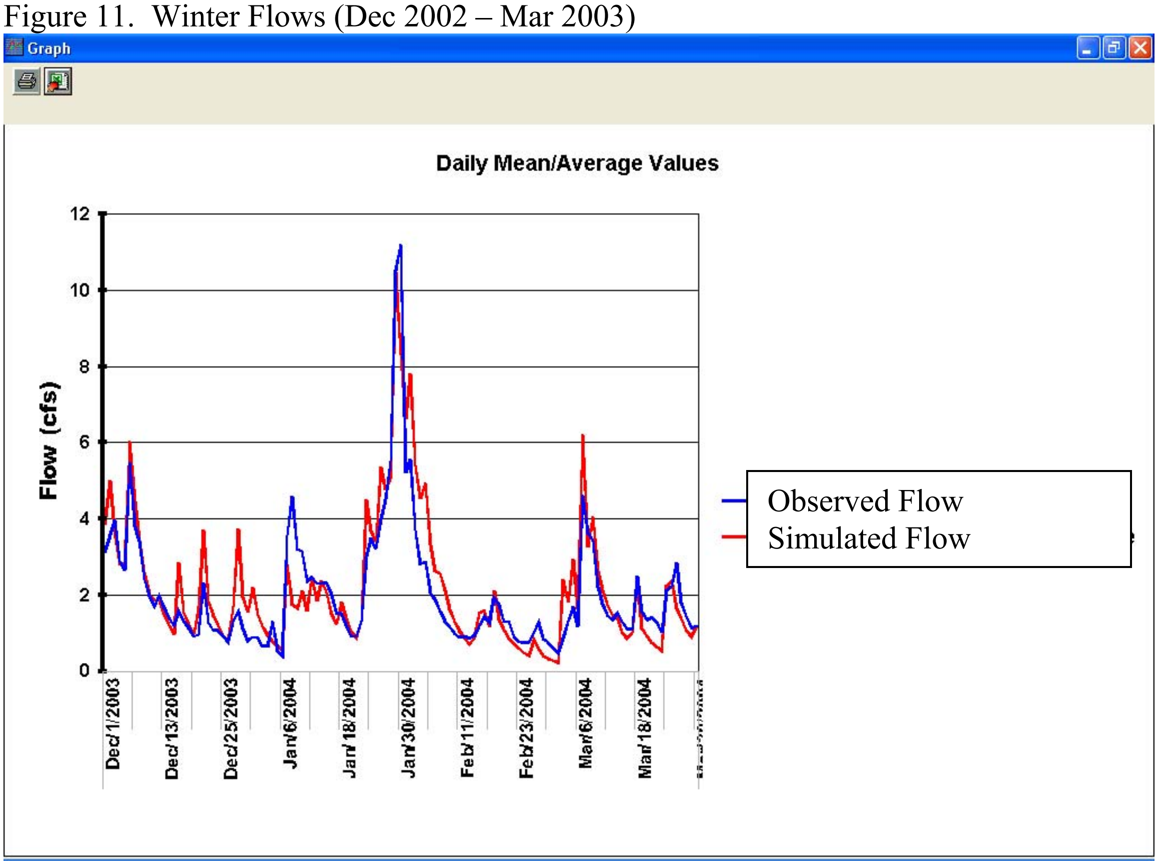


Figure 12. Winter Flows (Dec 2003 – Mar 2004)

The winter 2003 and 2004 (Figure 10 and Figure 11, respectively) flows match well. A few observed peak flows are oversimulated and a few are undersimulated, but the majority are a very close match.

Whatcom Creek Calibration

The Whatcom Creek HSPF calibration was summarized in a CCS memo to the City of Bellingham dated 30 May 2006. The highlights of that calibration memo are presented below.

The Whatcom Creek watershed was calibrated with WWHM3 to provide local hydrologic parameter values for use in the City of Bellingham's edition of WWHM3. The calibration period was April 2002 through September 2004 (water years 2002-2004). WWHM3 simulated flow was compared with observed streamflow data at the Dupont Street gage. The calibration results show a good match between simulated and observed flows.

Whatcom Creek is the outlet of Lake Whatcom. Whatcom Creek starts near the northwestern corner of Lake Whatcom (see Figure 13) and flows westward through the city to Bellingham Bay. The Central Shop rain gage was used for the rainfall on the Whatcom Creek watershed. Potential evapotranspiration data were provided by HydroLogic Services Company.

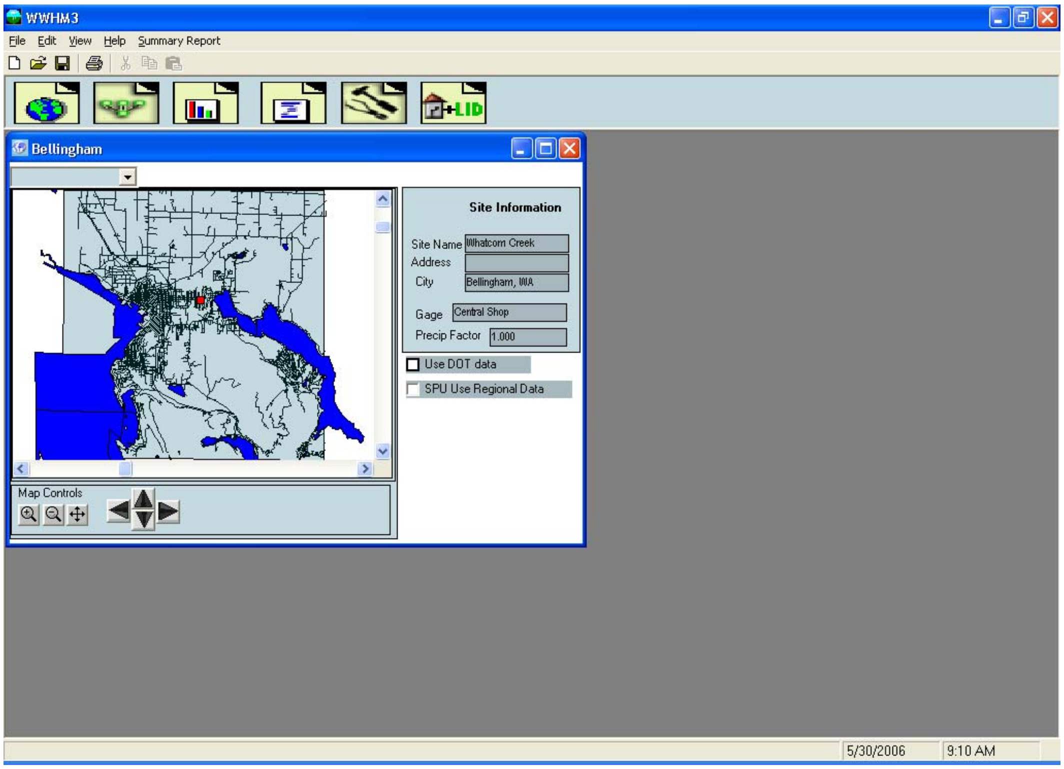


Figure 13. Whatcom Creek Watershed

Between Lake Whatcom and Bellingham Bay are four major tributaries that drain into Whatcom Creek: Hannah, Cemetery, Lincoln, and Fever. Hannah, Cemetery, and Lincoln all drain the tributary area south of Whatcom Creek; Fever Creek drains the area on the north side of Whatcom Creek drainage.

The Whatcom Creek calibration focused on calibrating the HSPF PERLND (pervious area) parameters of the drainage area of these four tributaries plus the subbasins that drain directly into Whatcom Creek. These parameters are used to compute runoff in WWHM3.

No long-term observed streamflow data were available for any of the four Whatcom tributaries. As a result, the calibration focused on the gain of flow between the upper Whatcom Creek stream gage (Derby Pond) near the outlet of Lake Whatcom and the lower Whatcom Creek gage (at Dupont Street).

The Whatcom Creek watershed model was created in WWHM3 using GIS land use data provided by the City of Bellingham and converted into appropriate hydrologic land categories by Parametrix. Table 11 summarizes the Whatcom Creek watershed land use for the subbasins delineated by Parametrix. Figure 14 shows the locations of the subbasins.

Table 11. Whatcom Creek Watershed Land Use

Subbasin	Pervious Acres	Impervious Acres	Total Acres	Drains to:
101	31.12	57.75	88.88	Fever
102	75.90	27.78	103.68	Fever
103	20.44	21.59	42.03	Fever
104	65.15	37.04	102.20	Fever
105	11.89	27.39	39.28	Whatcom 4
106	17.77	18.50	36.27	Whatcom 3
107	26.20	26.72	52.93	Whatcom 3
108	20.21	14.81	35.02	Whatcom 2
109	17.45	28.83	46.28	Whatcom 1
110	36.04	34.82	70.86	Whatcom 1
111	10.93	20.24	31.17	Whatcom 1
112	7.52	32.17	39.69	Whatcom 2
113	36.86	12.89	49.74	Whatcom 9
114	5.39	14.27	19.66	Whatcom ds
115	60.97	13.01	73.98	Whatcom 7
116	2.76	8.13	10.89	Whatcom 3
118	22.05	2.37	24.42	Whatcom 9
120	86.65	3.70	90.35	Whatcom 7
121	43.62	15.91	59.53	Whatcom 6
122	4.48	17.81	22.29	Whatcom ds
123	4.68	25.03	29.71	Whatcom 1
124	9.87	29.80	39.67	Whatcom 3
125	126.34	44.83	171.17	Lincoln
126	20.32	17.19	37.51	Whatcom 3
127	7.93	32.89	40.82	Whatcom ds

Subbasin	Pervious Acres	Impervious Acres	Total Acres	Drains to:
128	461.82	85.52	547.35	E Cemetery
129	106.40	21.06	127.45	Hannah
130	3.84	20.70	24.54	Whatcom 2
131	49.43	58.82	108.25	Whatcom 2
132	1.52	5.79	7.31	Cemetery
133	23.14	7.48	30.62	W Cemetery
134	21.27	34.60	55.87	W Cemetery
135	57.23	15.50	72.73	E Cemetery
136	12.74	7.34	20.08	E Cemetery
137	20.17	10.45	30.62	Lincoln
138	55.14	16.21	71.34	W Cemetery
139	15.61	7.74	23.35	E Cemetery
140	112.46	20.07	132.52	E Cemetery
141	68.93	35.69	104.62	W Cemetery
142	107.11	38.75	145.86	Lincoln
143	56.06	36.08	92.14	Lincoln
144	25.36	50.70	76.06	Lincoln
145	22.92	39.97	62.90	Lincoln
146	19.89	35.41	55.29	Lincoln
147	40.91	24.19	65.10	Lincoln
148	13.06	15.39	28.45	Lincoln
149	9.63	44.12	53.75	Lincoln
150	5.08	28.57	33.65	Lincoln
151	34.90	67.02	101.93	Fever
153	58.08	19.26	77.34	Fever
154	26.31	13.24	39.55	Fever
155	21.33	9.08	30.41	Fever
156	26.72	13.27	39.99	Fever
157	22.89	11.44	34.33	Fever
159	24.16	16.97	41.12	Fever
160	6.35	14.94	21.29	Fever
161	22.53	0.92	23.45	Hannah
162	5.28	2.36	7.64	Hannah
163	24.84	10.80	35.63	Hannah
164	30.75	11.00	41.75	Hannah
165	55.08	14.38	69.46	Hannah
166	73.22	17.06	90.28	Hannah
168	117.10	5.58	122.67	Hannah
169	198.08	2.10	200.18	Hannah
170	20.55	8.79	29.34	Hannah
171	29.72	18.48	48.20	W Cemetery
172	23.66	20.13	43.79	Fever
173	54.07	52.68	106.75	Fever
174	37.45	29.86	67.31	Fever
175	41.83	18.55	60.38	W Cemetery
176	23.61	11.66	35.27	Fever
177	45.16	27.48	72.65	Fever
178	10.88	14.78	25.66	Whatcom 1

Subbasin	Pervious Acres	Impervious Acres	Total Acres	Drains to:
179	13.11	28.22	41.34	Whatcom 2
180	36.93	34.84	71.78	Whatcom 3
181	6.36	21.73	28.09	Whatcom 3
182	6.72	9.55	16.28	Whatcom 3
183	26.15	92.97	119.12	Fever
184	12.07	22.39	34.47	Whatcom 4
185	20.52	16.85	37.37	Fever
188	61.49	19.48	80.97	Fever
189	32.58	15.69	48.28	Fever
190	11.65	6.77	18.42	Fever
191	43.61	29.32	72.94	Fever
192	44.53	39.41	83.94	Whatcom 2
193	22.07	24.05	46.12	Whatcom 3
194	7.17	4.14	11.31	Lincoln
195	36.36	24.08	60.44	Lincoln
196	16.39	10.17	26.56	Lincoln
197	38.82	23.58	62.39	W Cemetery
198	49.16	21.45	70.61	W Cemetery
199	28.22	14.15	42.37	W Cemetery
200	49.76	28.47	78.23	E Cemetery
201	13.45	5.37	18.82	E Cemetery
203	18.98	10.11	29.10	Hannah
Total	3,712.88	2,180.24	5,893.12	Whatcom

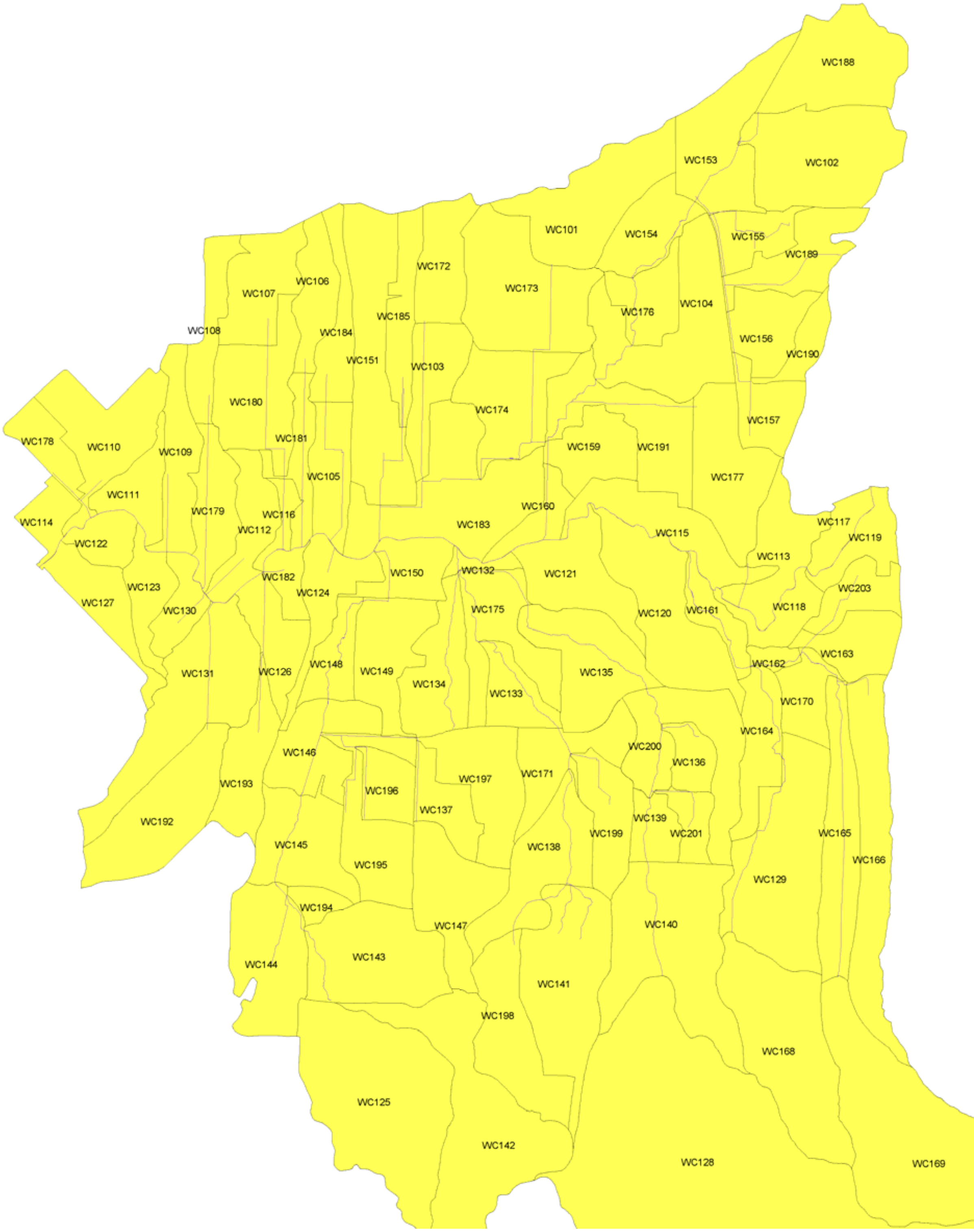


Figure 14. Whatcom Creek Subbasins

The City GIS did not contain any open channel information for Whatcom Creek or its tributaries. The City provided cross section data for the lower reaches of Whatcom Creek from previous studies. These cross sections were used to define the lower seven reaches of Whatcom Creek. Data for the upper two reaches of Whatcom Creek and the stream cross sections for Hannah, Cemetery, Lincoln, and Fever creeks were gathered in a field survey of the streams by CCS staff in May 2006. This information was then used in the WWHM3 Whatcom Creek model.

As previously mentioned, the purpose of the calibration was to determine appropriate HSPF PERLND parameter values to accurately represent the Whatcom Creek drainage area hydrology in WWHM3. As a result, the complex hydraulic conveyance systems represented in the WWHM3 SWMM element were not included in the calibration process. They were later used to identify stormwater problems in the city and they are included in the completed WWHM3 package provided to the City of Bellingham.

Table 12 shows the simplified conveyance system used in the Whatcom Creek calibration and Figure 15 shows their representation in WWHM3.

Table 12. Whatcom Creek Conveyance System

Stream	Reach	Upstream End	Flows to
Whatcom	9	Derby Pond	8
Whatcom	8	9	7
Whatcom	7	8	6
Whatcom	6	7	5
Whatcom	5	6	4
Whatcom	4	5	3
Whatcom	3	4	2
Whatcom	2	3	1
Whatcom	1	2	Dupont Gage
Hannah			Whatcom 7
East Cemetery			Cemetery
West Cemetery			Cemetery
Cemetery		East Cemetery, West Cemetery	Whatcom 5
Lincoln			Whatcom 4
Fever			Whatcom 4

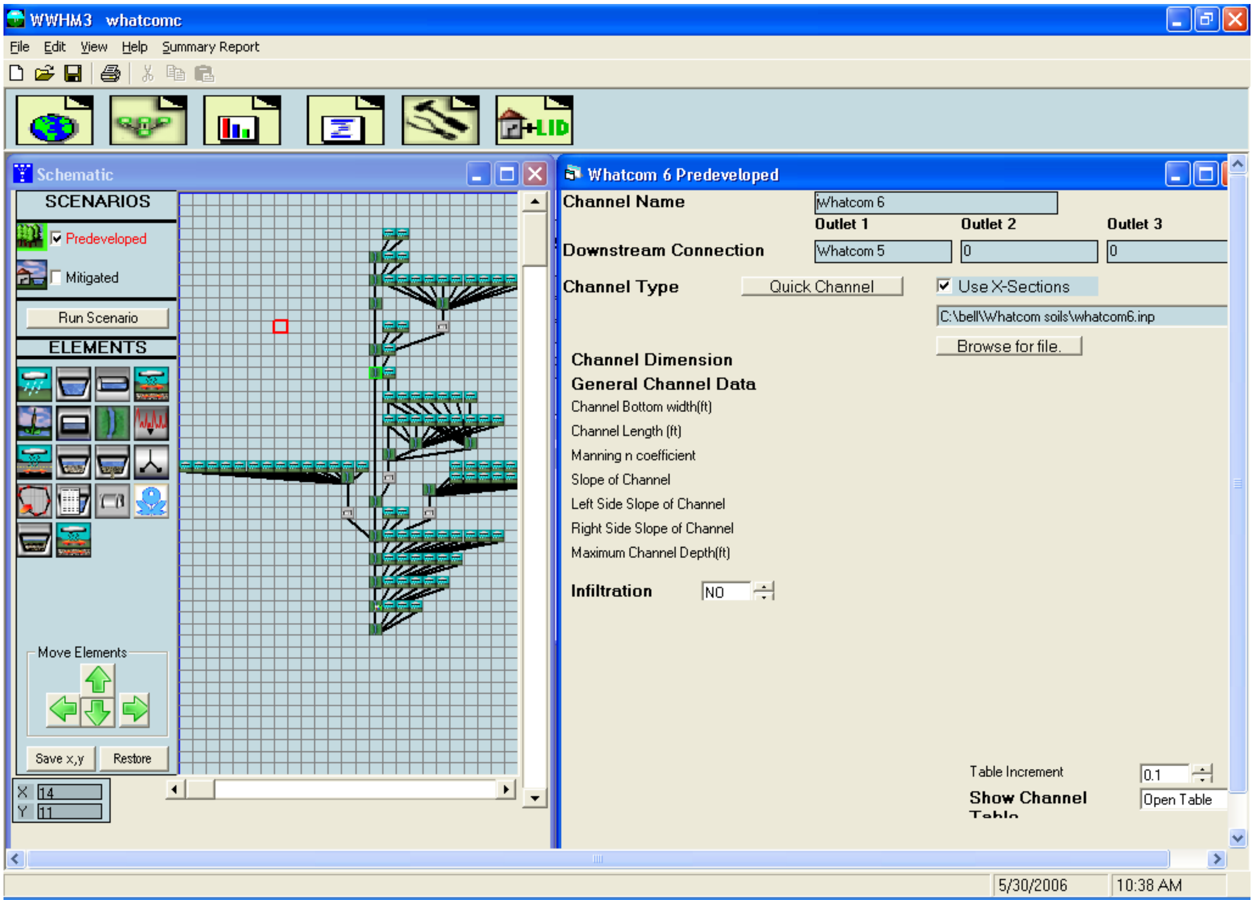


Figure 15. Whatcom Creek Subbasin and Conveyance Linkages

Simulated and observed hourly streamflow were compared at the Dupont Street gage near the mouth of Whatcom Creek.

Because the Whatcom Creek simulated flows include the upstream Whatcom Creek inflow from Lake Whatcom, measured at Derby Pond, a comparison of the upstream Derby Pond inflow and the downstream observed flow at Dupont Street is important. Figure 16 shows the two streamflow time series.

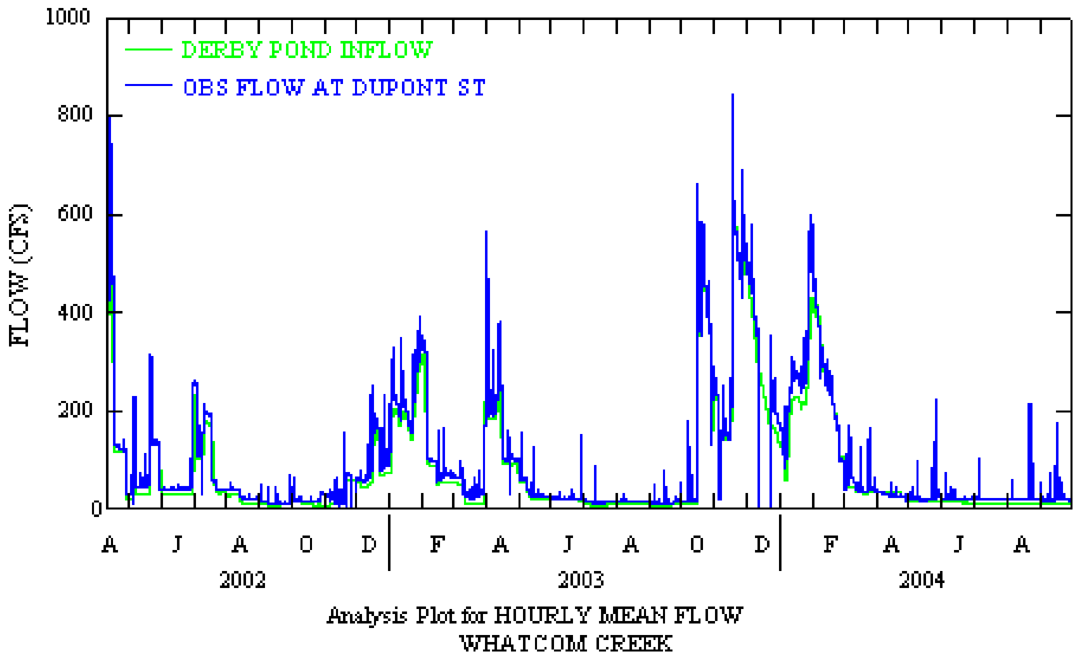


Figure 16. Comparison of Whatcom Creek Observed Inflow and Outflow

As can be seen from Figure 16, the two observed streamflow time series match fairly closely, especially in the winter months. This means that Lake Whatcom is providing most of the flow in Whatcom Creek most of the time. The exceptions are the small peak events that are caused by the flow into Whatcom Creek from the four tributaries (Hannah, Cemetery, Lincoln, and Fever) between the two Whatcom gages. The Whatcom Creek calibration focused on matching these small peak events.

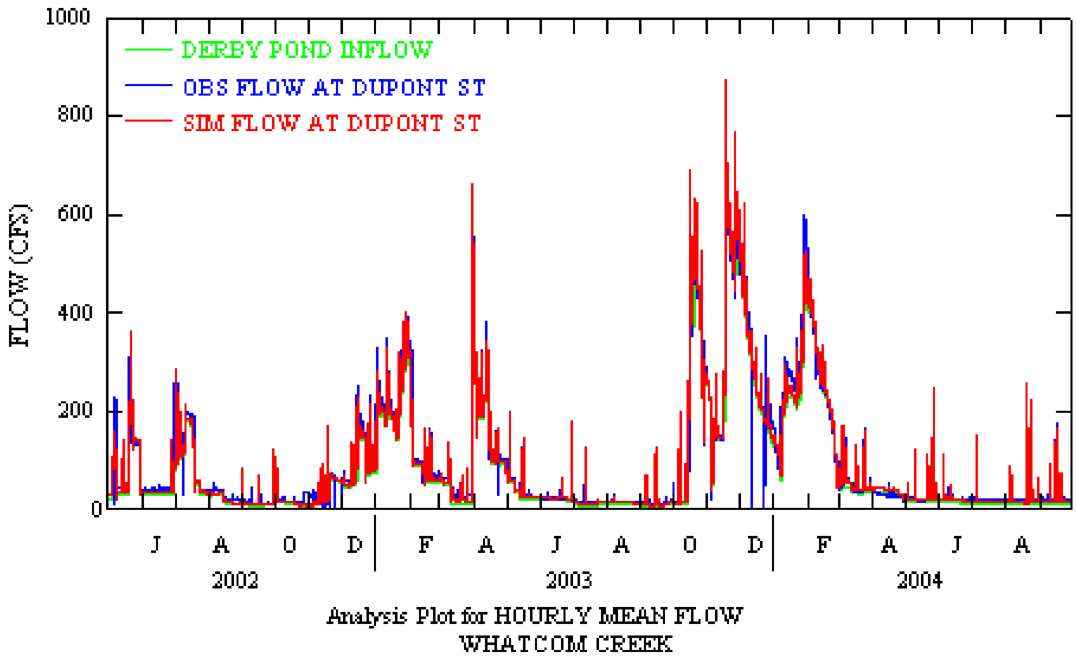


Figure 17. Comparison of Whatcom Creek Observed and Simulated Flow at Dupont Street

Figure 17 shows the same time period as Figure 16, but with the WWHM3 simulated streamflow added. The red (simulated flow) line matches well with the blue (observed flow) line. But, as discussed above, it is important to look at individual small peak events.

Figures 18 through 22 compare the simulated and observed hydrographs at Dupont Street for these small peak events.

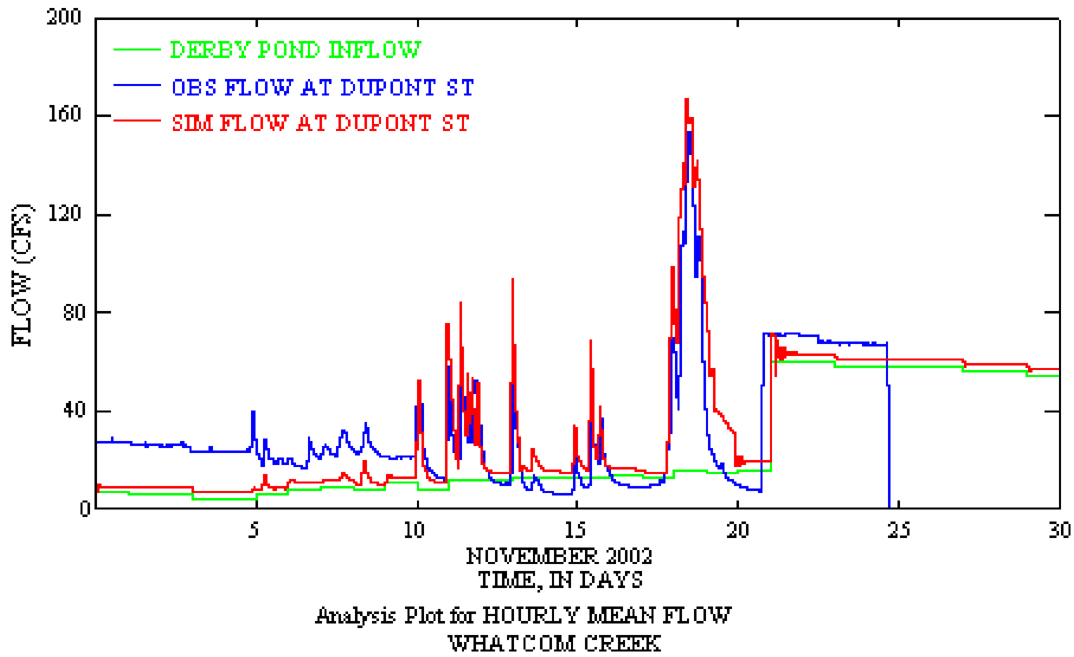


Figure 18. Whatcom Creek (November 2002)

In Figure 18 the observed base flow at the start of November is much higher than the simulated flow (and the Derby Pond inflow). There is an inconsistency between the observed Derby Pond inflow (shown in green) from Lake Whatcom to Whatcom Creek and the observed Whatcom Creek streamflow at Dupont Street. During dry periods when there is little or no inflow from the Whatcom Creek tributaries (Hannah, Cemetery, Fever, and Lincoln) the downstream flow at Dupont Street should be very close to the upstream inflow at Derby Pond. That should have been true for early November. However, as shown in Figure 18, that is not the case and one or the other of the two gage records must be in error. The error may be in either the observed flow at Derby Pond or the observed flow at Dupont Street. Without looking at the original records and knowing the details of how the lake outlet was managed in October and November 2002 it is impossible to identify which of the two observed flow records contains the error. In terms of the calibration of the Whatcom Creek model it is not important to determine the source of the error. What is important is that once the autumn rains start the simulated peaks match well the observed peaks. This is especially true for the 19 November 2002 peak event. The 19 November 2002 peak flow is produced from the runoff from the tributaries (Hannah, Cemetery, Fever, and Lincoln) and it is for the hydrology of their drainage areas that we are calibrating the model.

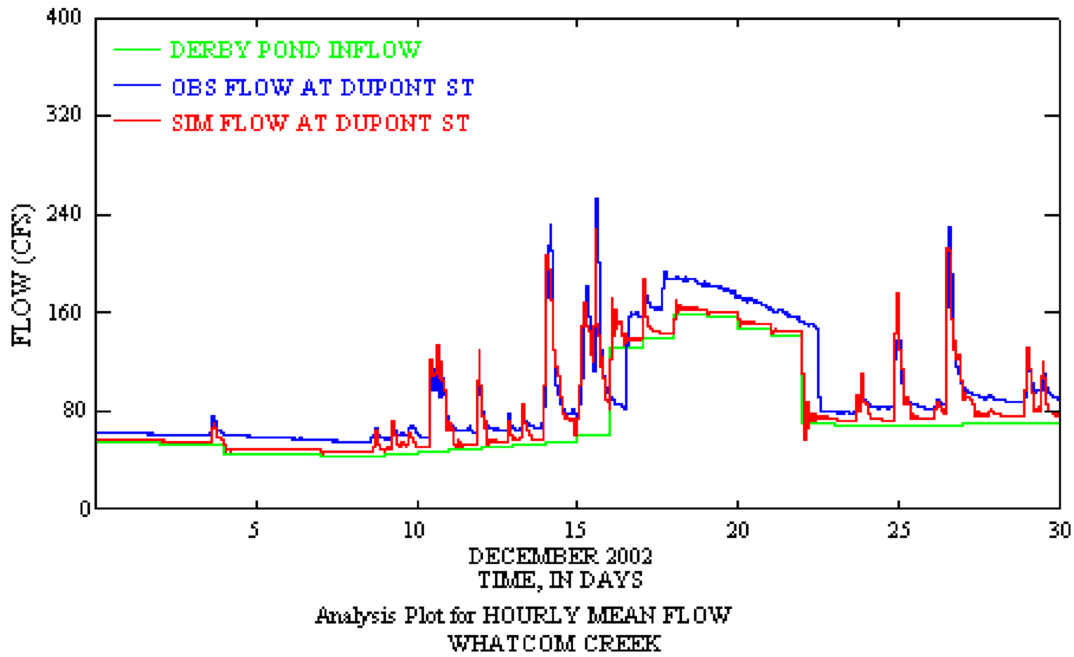


Figure 19. Whatcom Creek (December 2002)

December 2002 (Figure 19) shows a relatively constant flow from Lake Whatcom and a good match of the simulated and observed flows for seven small peak events during the month.

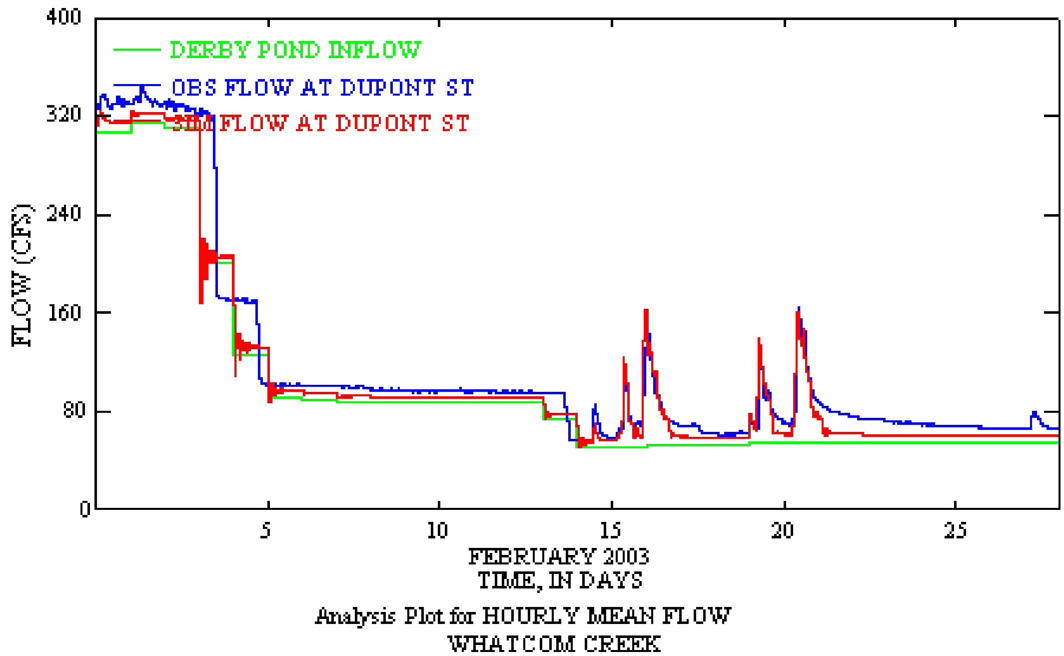


Figure 20. Whatcom Creek (February 2003)

Following high flows from Lake Whatcom in January 2003 there is a good match of the small peaks on 16 February and 20 February 2003 (Figure 20).

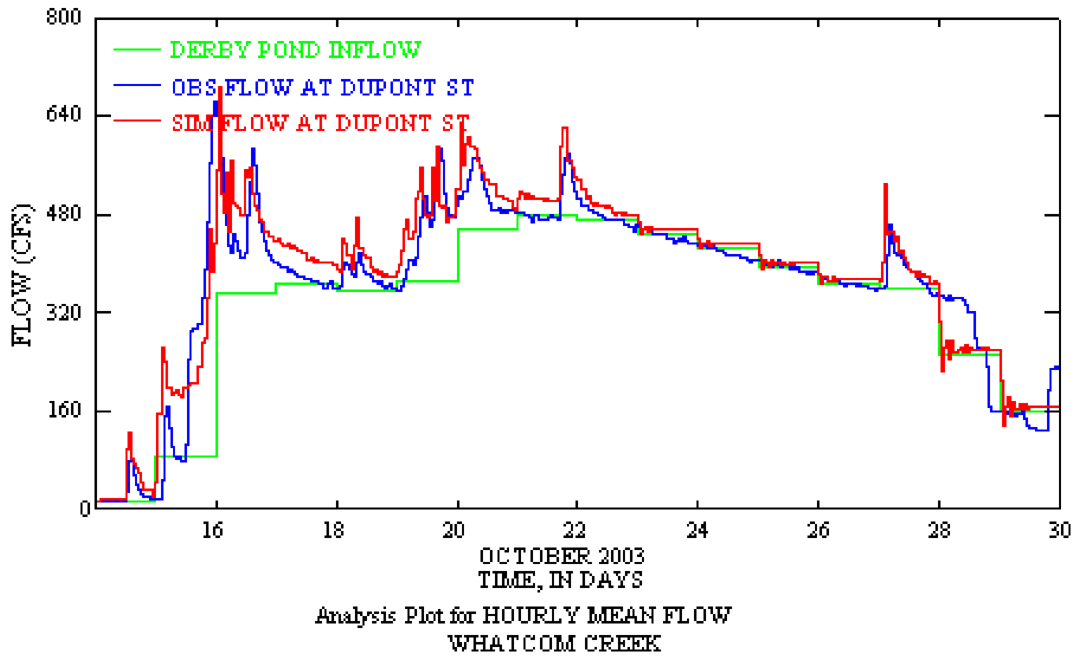


Figure 21. Whatcom Creek (October 2003)

October 2003 (Figure 21) is a good example of a month in which there is a large increase in the discharge from Lake Whatcom (from almost zero to 480 cfs) and yet the small peak events created by the flows from Hannah, Cemetery, Lincoln, and Fever can still be identified. The simulated and observed small peaks match well.

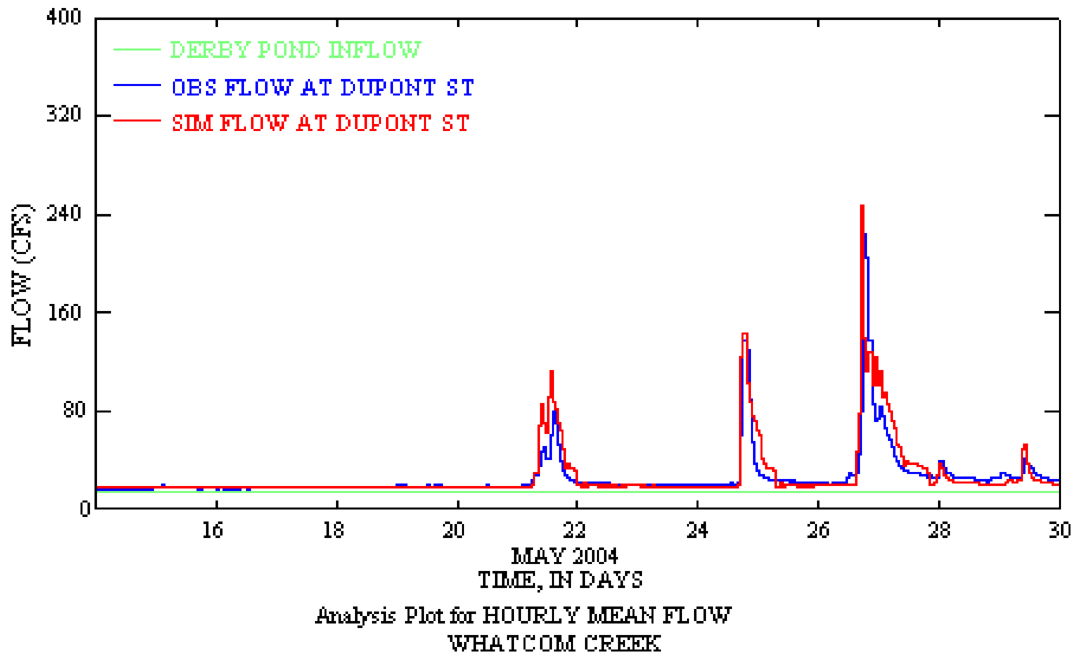


Figure 22. Whatcom Creek (May 2004)

The small peaks of May 2004 (Figure 22) show another period where there is a good calibration match. The flow from Lake Whatcom is constant. The peaks are produced by the runoff from the Whatcom Creek tributary area (Hannah, Cemetery, Lincoln, and Fever drainages) between the two gage sites and match well.

The Whatcom Creek calibrated hydrologic parameter values differ from the Silver Beach Creek calibrated values. The calibration was initiated using the Silver Beach Creek values. These values were found to produce too large peak events when compared to the observed Whatcom Creek flows at Dupont Street. The WWHM3 regional values were used in the calibration and they produced the best simulated peak flows.

The Whatcom Creek HSPF calibration parameter values were then used for the entire City of Bellingham because they are more representative of the entire city's drainage area than those of the much smaller Silver Beach Creek drainage area.

Erosive Flow Analysis

The Department of Ecology bases its NPDES permit flow control standard (Minimum Requirement #7) on the range of erosive flows in Western Washington streams. Based on work done at the University of Washington by Booth and Jackson (1997), it was found that the typical range of erosive flows in Western Washington streams is from half of the

2-year peak flow to the full 50-year peak flow. This standard erosive flow range is the basis for Ecology's Minimum Requirement #7.

Local municipalities have the option of conducting watershed-specific erosive flow analysis to replace Ecology's standard erosive flow range. As part of this plan, this erosive flow analysis was done for Whatcom Creek by Parametrix in October 2007. The analysis focused on determining the flow at which erosion/scour of the stream channel bedload begins.

The Wolman pebble count field survey procedure was used at three locations in Whatcom Creek to provide the data needed to compute minimum scour flow. The median diameter of at least 100 pebbles was measured and recorded in the field at each site. All streams were sampled in riffles. Field samples from Whatcom Creek were by collected by Parametrix and City of Bellingham staff. Channel slope and cross section information were not surveyed at the time of the pebble count. Channel width and slope were estimated in the field based on visual observations.
Pebble counts were performed at the following locations:

Falls Park Reach – Site 1
Redtail Reach – Sites 1 through 4
Salmon Park Reach – Site 1

The pebble count data was analyzed using the Bathurst Equation to estimate the stream discharge that would trigger bedload movement (Bathurst et al 1987).

$D_{84} = 3.45 * S^{0.747} * (SF * q_c)^{2/3} / g^{1/3}$

where:

D_{84} = median particle diameter (ft) of the 84th percentile sediment particle
S = channel slope
SF = safety factor = 1.25
q_c = critical discharge rate (cfs/ft), and
g = gravity (ft/s)

This equation was selected because it is appropriate to predict the critical unit discharge for the threshold of sediment in coarse, heterogeneous channels. Field data was also analyzed to estimate critical shear stress, which is the point at which sediment begins to move, using the equation (WDFW 2003):

$\tau_{cr} = 4 \text{ x } D_{50}$

where:

D_{50} = median particle diameter (ft) of the 50th percentile sediment particle
4 = constant based on a critical dimensionless shear stress of approximately 0.039 (WDFW 2003).

Table 13 summarizes the results of the analysis and the predicted flow for the threshold of bedload movement and the critical shear stress. As noted above, because such a large percentage of the particles sampled at the Falls Park reach were bedrock, the actual critical discharge rate may be underestimated. In addition, because the cross sectional geometry and slope were not surveyed in the field, the results are provided for a range of conditions estimated based on field observations. The results are provided for a slope ranging from 0.01 to 0.03 (Table 13).

Table 13. Whatcom Creek Minimum Erosive Flow (Bathurst Equation)

	Estimated Discharge at incipient point of sediment motion (cfs)		
Site	Slope = 0.03	Slope = 0.01	τ_{cr}
Falls Park Reach Site 1	29.5	101.1	0.83
Redtail Reach Site 1	2.4	8.2	0.45
Redtail Reach Site 2	3.9	13.3	0.60
Redtail Reach Site 3	3.6	12.4	0.52
Redtail Reach Site 4	6.3	21.5	0.88
Salmon Park Reach Site 1	4.1	14.2	0.59

These results can be refined if cross sectional geometry and slope are surveyed. In general, the flows in Table 13 should roughly correspond to the bankfull discharge rate. Based on numerous geomorphic studies performed on a variety of streams, bankfull discharge generally corresponds to a flow rate with a return frequency of slightly less than the 2-year return frequency flow.

In addition, if the channel cross sectional geometry and slope are surveyed the hydraulic radius can be determined and the maximum shear stress in the channel can be calculated. This can be compared to the critical shear stress (Table 13) and the stability of the stream can be estimated. In addition, if the channel geometry is know then depth and corresponding flow for the point when the critical shear stress equals the maximum shear stress, which is the point at which bedload becomes mobile.

The pebble count analysis shows that erosive flows in Whatcom Creek general start in the flow range of 10-30 cfs. The general assumption is that these flows should roughly correspond to bankfull flow which generally corresponds to a flow rate with a return frequency of slightly less than the 2-year return frequency flow.

The question is then: How do these flows compare with 50% of the 2-year Whatcom Creek peak flow computed by WWHM3? There is no easy answer to this question.

Flood frequency is computed in WWHM3 using a Log Pearson Type III statistical distribution of annual peak flow values. Typically, 40-50 years of simulated streamflow is needed to produce a statistically-valid flood frequency distribution and compute the 2-year peak flow value. To compute the 2-year Whatcom Creek peak flow at any location from the lake outlet to the bay requires that we model a 40- to 50-year time period. Currently we do not have the Whatcom Lake outlet flow data to model this long of a time period.

The appropriate way to model Whatcom Creek for a 40 to 50-year time period is to not only model Whatcom Creek but to also model the entire Whatcom Lake drainage.

However, due to budget considerations, modeling the entire Whatcom Lake drainage was outside of the scope of this project.

Modeling the entire Whatcom Lake drainage area would involve collecting land use, soil, and vegetation data on the entire area that drains into the lake and adding to the model long-term precipitation records for the lake drainage. Additional information needed to model the lake and its outlet is the city's management of the flows out of the lake. The lake stage-discharge relationship is changed seasonally by changing the weir at the outlet of the lake. This seasonally changing relationship would also have to added to the Whatcom Lake-Whatcom Creek model. With all of the above information in the model it would then be possible to continuously model the lake discharge and Whatcom Creek flows for a 40 to 50-year time period. With the 40 to 50-year Whatcom Creek simulated streamflow record the 2-year frequency flow can be calculated and the 50% value compared with the field erosive flow analysis.

Parametrix also conducted an erosive flow analysis of Whatcom Creek tributaries (Hannah, Lincoln. Fever, and Cemetery) in March 2006. The selected pebble count field sites were:

- Site 1. Hannah Creek – samples collected approximately ten yards upstream of culvert under the trail from the water plant.
- Site 2. Hannah Creek – samples collected approximately sixty yards downstream of culvert under trail from water plant.
- Site 3. Lincoln Creek – samples collected at the edge of youth baseball field located east of I-5 and east of intersection of Frazer Street and Monroe Street.
- Site 4. Fever Creek – samples collected in Roosevelt Park, approximately forty yards upstream of the park footbridge.
- Site 5. Cemetery Creek – samples collected downstream of the power line right-of-way at the south end of Kenover Street; approximately sixty yards downstream of power line culvert.

The erosive flow results are shown in Table 14.

Table 14. Whatcom Creek Tributaries Minimum Erosive Flow (Bathurst Equation)

		Estimated Discharge at incipient point of sediment motion (cfs)		$\square_{cr}$	
Site	**Stream Width (ft)**	**Slope = 0.01 Low D_{84}**	**Slope = 0.02 High D_{84}**	**Low D_{50}**	**High D_{50}**
Site 1: Hannah Creek	10	6.8	24.9	0.10	0.15
Site 2: Hannah Creek	10	6.8	24.9	0.10	0.15
Site 3: Lincoln Creek	6	1.4	5.3	0.05	0.07
Site 4: Fever Creek	12	4.9	17.8	0.07	0.10
Site 5: Cemetery Creek	15	48.3	182.3	0.30	0.42

There is a large range of minimum erosive flows for each tributary stream. No attempt was made to try to correlate these flow values to Ecology's 50% of the 2-year flow at these sites. Additional field and modeling work is required to accurately relate these flow values to the model results.

STORMWATER MODELING

With WWHM3's HSPF parameter values based on the calibration efforts described above, the stormwater modeling of the six watersheds progressed. The stormwater modeling of each watershed included the computation of runoff based on each subbasin's hydrology and conveyance systems.

Subbasin pervious land areas (PERLNDs) and impervious areas (IMPLNDs) were based on the land use categories described in the Land Use section. Each individual PERLND and IMPLND produced runoff based on its unique hydrologic characteristics. This runoff was summed for each subbasin and routed through the subbasin's conveyance system (the drainage system of pipes, culverts, and open channels).

City of Bellingham GIS conveyance system data were used where possible. Missing or incomplete GIS conveyance system data were filled based on adjacent data. GIS conveyance system data were available for the most or parts of the Whatcom Creek watershed, Squalicum Creek watershed, and Silver Creek watershed. No GIS conveyance system data were available for the Padden Creek watershed, Chuckanut Creek watershed, or the Silver Beach Creek watershed. For these watersheds conveyance system data were based on previous Waterworks models and/or other data provided by city staff.

Stormwater runoff routing through the conveyance systems was computed using HSPF RCHRES for open channel and culvert conveyance systems and PCSWMM Transport for stormwater pipe conveyance systems. Both routing options are available in WWHM3 PRO SWMM edition.

The WWHM3 model was used for the following purposes:

- To provide data to analyze stormwater problems
- To evaluate the effectiveness of alternative solutions to reduce stormwater flooding

Modeled stormwater runoff data were used to identify locations where the stormwater conveyance system is undersized and at risk of failure.

STORMWATER DRAINAGE ANALYSIS

The stormwater drainage analysis was conducted using the Stormwater Management Model (SWMM) module of the WWHM3 software. The hydrology for each basin was established as described earlier in the computer model methodology section. After the basin hydrology was analyzed, a conveyance system was developed for the SWMM module. Conveyance system data were drawn from various sources and are described in more detail in the following basin-specific sections.

Generally, after the conveyance network was developed and model calibration parameter values were established, an initial model analysis was performed to identify surcharging pipes and culverts throughout the network. SWMM's automatic pipe resizing routine was then used to increase the pipe diameter in the vicinity of the surcharging pipes identified during the initial model analysis. This routine provides required conveyance capacity through the system by increasing the capacity of all pipes that would be affected by an increase in downstream flow resulting from improved upstream conveyance capacity. The resizing routine uses an iterative process, incrementally increasing conveyance sizes, until flow is conveyed without surcharging. This routine solves the problem of resizing a single pipe only to shift a flooding problem downstream. The model-identified problems (i.e., surcharging pipes) and potential solutions (increased pipe diameters) are summarized for each basin in the following sections. Detailed problem identification and solution information is presented in Appendix A.

The automatic pipe resizing routine also includes conveyance capacities of open channels. To use this routine for an open channel, the SWMM module first converts the open channel to an equivalent capacity pipe diameter. Locations of open channels are shown on the basin maps and can be found in Appendix A where the model indicates the pipe diameter was increased to a large diameter, such as 8.5 or 11.0 feet.

Cost opinions for capital improvement projects have been prepared for the Whatcom Creek Study Area, only (Appendix B). As discussed in the computer model methodology section, GIS data were most readily available for the Whatcom Creek Study Area, but not available for much of the drainage area outside of that area. Therefore, model results identifying system deficiencies are more reliable for the Whatcom Creek Study Area than for the other study areas. However, even within the Whatcom Creek Study Area, GIS data were not available for portions of the existing conveyance system and had to be interpolated as discussed earlier in this report. With the available conveyance system data, model results in other study areas are considered conceptual and intended for planning-level decisions only.

These results for the other study areas are not considered detailed enough to generate reliable cost opinions at this time. Cost opinions for capital improvement projects in these other study areas can be prepared in the future as additional system data are acquired and the model is updated.

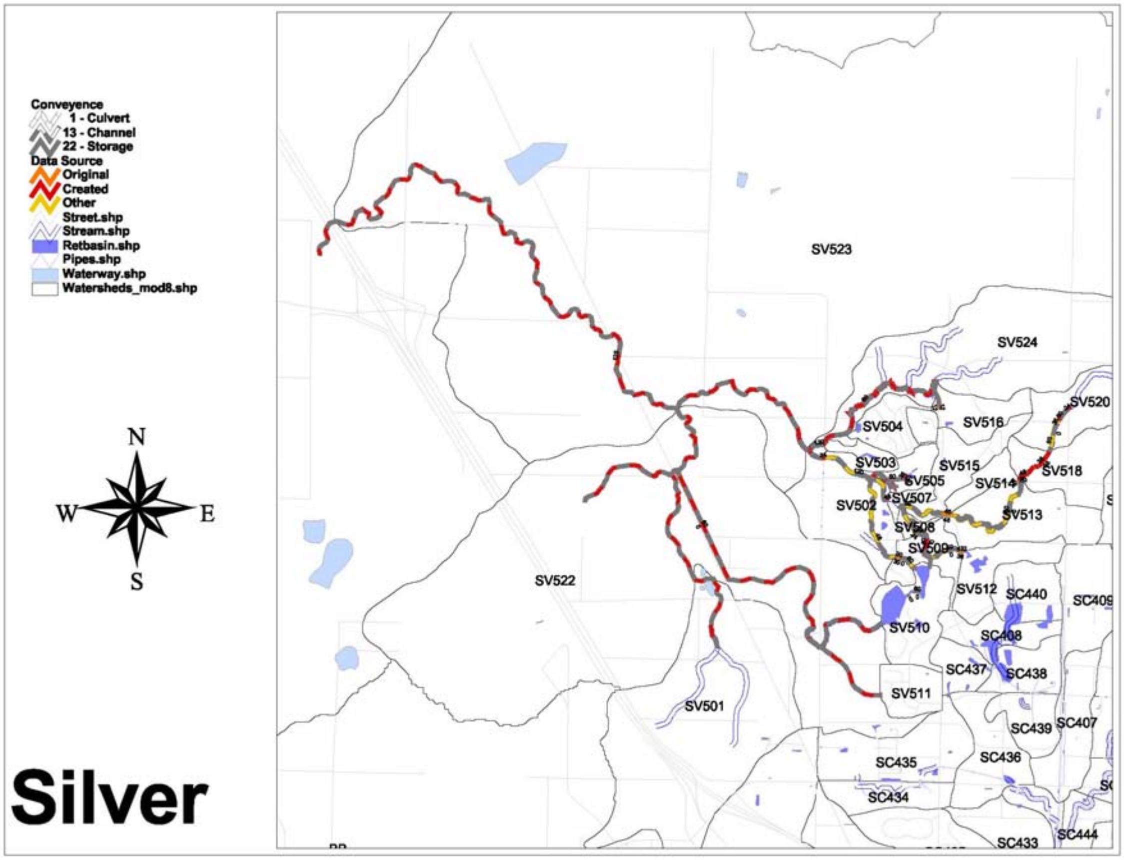
The City of Bellingham will be using the conveyance system sizing information presented in this plan to identify specific projects for in-depth study prior to design and construction.

No attempt was made to try to compare the WWHM3 HSPF and SWMM-produced flow results with the 1995 Waterworks-produce flow values. This is because the two studies use completely different meteorological input to compute runoff. Waterworks, a single-event model, uses hypothetical storm events to compute runoff. For example, a 2-year storm with a total 24-hour rainfall volume of 1.8 inches was used to compute the 2-year peak flow at numerous locations along the Bellingham streams. WWHM3, an HSPF-based continuous simulation model, used the historic City of Bellingham precipitation to compute runoff. The historic precipitation record does not contain a hypothetical 2-year storm event (or any hypothetical storm event). It contains only actual measured rainfall. And, so, rather than try to match or compare the results of two different methodologies our modeling focused on identifying locations in the stormwater conveyance systems where the historic precipitation produced simulated historic runoff that exceeded the capacity of the conveyance facility (pipe, culvert, etc.). This information was reported in the stormwater drainage analysis problem identification discussions presented below.

As per city staff instructions, the following stormwater drainage analysis results are presented from north to south (Silver, Squalicum, Silver Beach Creek, Whatcom, Padden, and Chuckanut).

SILVER CREEK STUDY AREA

The Silver Creek study area is approximately 10,419 acres (see Table 15), and averages 28% impervious area. The Silver Creek watershed is located north and west of the Squalicum Creek watershed and drains outside of the City of Bellingham to the Nooksack River.



Conveyance in the model for the Silver Creek Study Area consisted primarily of the existing stream network. The previous WaterWorks modeling analysis did not include Silver Creek. GIS conveyance data also were not available for this study area. The stream network was established in the WWHM3/SWMM model using stream alignment data from the City's GIS. Slopes for these stream reaches were estimated from area topography, and generalized assumptions were input for stream cross-sectional geometry.

Table 15. Silver Creek Study Area

Subbasin	Pervious (ac)	Impervious (ac)	Total (ac)
SV501	222.41	141.82	364.23
SV502	51.48	17.84	69.32
SV503	4.76	8.27	13.02
SV504	27.07	3.75	30.82
SV505	19.07	9.44	28.50

Subbasin	Pervious (ac)	Impervious (ac)	Total (ac)
SV507	5.25	3.06	8.31
SV508	4.97	1.40	6.36
SV509	12.95	20.02	32.97
SV510	34.88	25.84	60.73
SV511	17.64	14.62	32.26
SV512	15.02	28.92	43.95
SV513	36.92	42.95	79.86
SV514	5.10	12.33	17.43
SV515	25.73	20.00	45.73
SV516	26.97	10.17	37.13
SV518	31.42	34.82	66.25
SV520	60.87	20.02	80.89
SV521	3337.02	1196.13	4533.15
SV522	580.59	479.89	1060.48
SV523	2848.12	640.44	3488.56
SV524	174.74	143.86	318.61
TOTAL	7542.99	2875.58	10418.58

See separate Sheet 1 for location of subbasins.

The Silver Creek watershed was not included in the 1995 study and, therefore, less is known about its stream corridor, wetlands, fisheries, and water quality. That said, it is expected that the Silver Creek drainage is similar in nature to the other Bellingham watersheds, especially nearby Baker Creek and Squalicum Creek.

All three of the above-named streams originate in the rural outskirts of the City of Bellingham. In all three drainages there has been and continues to be a transformation of the land surface from forestry and agriculture to residential and commercial. With these land transformations come associated stormwater runoff problems and solutions.

These stormwater runoff problems affect the Silver Creek wetlands, fisheries, and water quality. As most of the land development has been relatively recent, damage to Silver Creek and its stream corridor is relatively minor. However, future development pressures can and will change this situation and will lead to additional stream degradation unless proper mitigation measures are required.

Silver Creek, being relative rural in character, has water quality problems associated with rural areas. Manure runoff from agricultural operations is a significant source of nonpoint pollution entering Silver Creek and its tributaries. Automobile-related pollutants from roads together with fertilizers and herbicides from lawns are the most likely nonpoint source pollutants entering the suburban portions of Silver Creek.

Most of the growth anticipated for the Silver Creek study area is expected to be a mixture of commercial, industrial, and residential. Nonpoint source pollution will increase. Water quality mitigation must provide biofiltration and stormwater detention from these developments to provide opportunities for sediment capture, suspended soils filtration, and biological uptake of fertilizers, herbicides, and organic pollutants.

Public environmental education is another way to reduce the impacts of new (and existing) development on water quality. Key needs include proper application of yard and garden fertilizers, fencing livestock out of stream corridors, use of native plants in landscaping, and proper disposal and recycling of household wastes (including soapy water, oils, anti-freeze, cleaners, etc.).

Problem Identification

As previously discussed, after the conveyance network was developed within the model, an initial model analysis was performed to identify any surcharging within the network. Locations of model-identified problems are summarized in Table 16. Detailed problem identification is presented in Appendix A.

Solutions

Following initial problem identification, SWMM's automatic pipe resizing routine was used to increase pipe diameters in the vicinity of the surcharging pipes identified during the initial model analysis. Quantities of potential pipe diameters to be increased are summarized in Table 16. Detailed solution information is presented in Appendix A.

Table 16. Silver Creek Model Results

Basin	**Improvement Project Group**	**Pipe Upgrade Quantity (linear feet)**
Silver	Culverts, storm drains	1,300
Total		**1,300**

Cost Estimate

As previously discussed, GIS data for the existing system were not available for this basin. Therefore, model results provide valid stream flow values for planning purposes, but are not considered detailed enough to generate reliable cost opinions for this basin. A cost opinion for capital improvement projects in this basin will be prepared in the future by others as additional system data are acquired and the model is updated.

SQUALICUM CREEK STUDY AREA

The Squalicum Creek study area is approximately 15,120 acres (see Table 17), and averages 20% impervious area. The Squalicum Creek watershed is located north of the Whatcom Creek watershed and drains to Bellingham Bay.

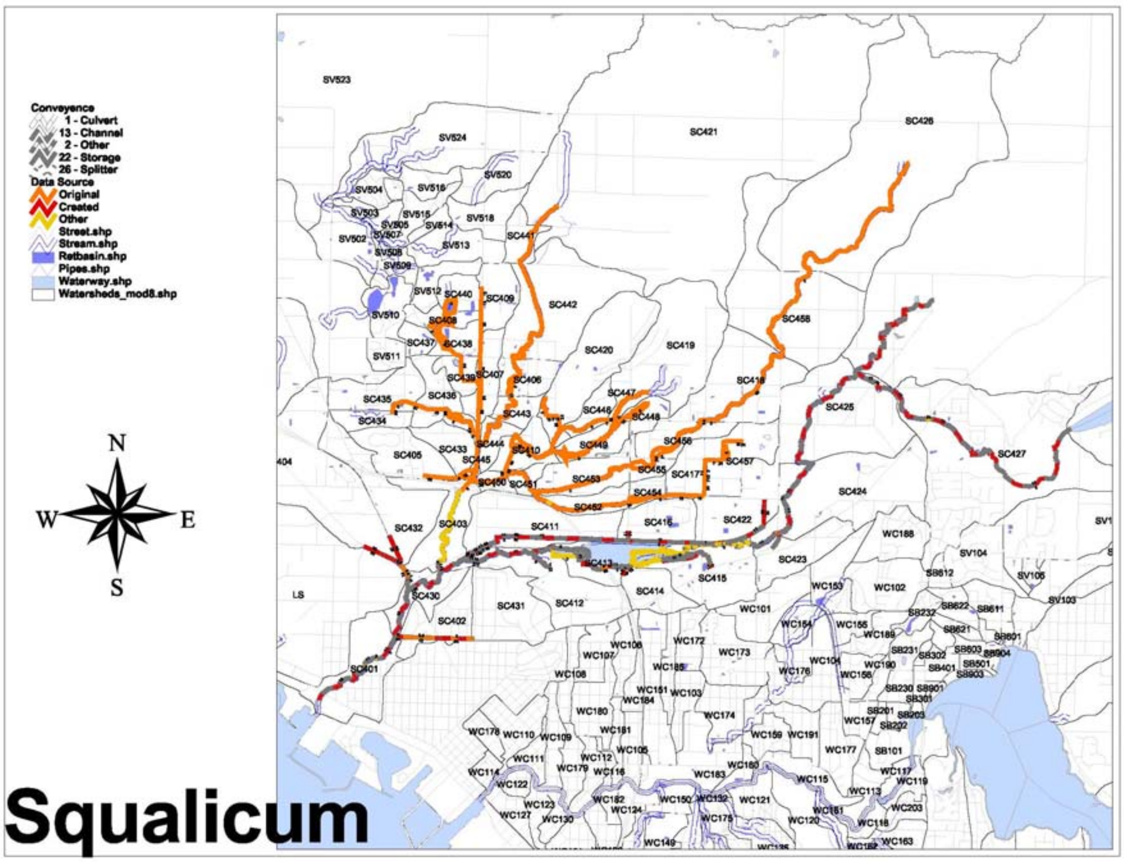


Table 17. Squalicum Creek Study Area

Subbasin	Pervious (ac)	Impervious (ac)	Total (ac)
SC401	91.25	77.67	168.92
SC402	75.25	16.87	92.12
SC403	90.09	19.79	109.88
SC404	244.77	132.50	377.27
SC405	51.71	49.97	101.68
SC406	32.80	25.06	57.86
SC407	16.80	41.07	57.87
SC408	11.76	24.94	36.70
SC409	31.02	38.92	69.94
SC410	28.29	31.48	59.77
SC411	96.72	86.15	182.87
SC412	100.28	71.61	171.89
SC413	25.77	55.73	81.50
SC414	13.92	51.54	65.45

Subbasin	Pervious (ac)	Impervious (ac)	Total (ac)
SC415	71.56	96.58	168.14
SC416	62.14	21.89	84.03
SC417	12.48	39.45	51.93
SC418	122.02	84.37	206.39
SC419	213.21	31.62	244.83
SC420	158.14	52.81	210.95
SC421	1626.91	241.92	1868.83
SC422	42.34	88.62	130.96
SC423	66.49	28.82	95.31
SC424	209.90	82.92	292.82
SC425	203.70	75.01	278.71
SC426	820.44	91.28	911.72
SC427	589.17	128.49	717.66
SC428	505.68	56.78	562.46
SC429	5041.76	563.14	5604.90
SC430	43.57	24.86	68.43
SC431	118.24	20.96	139.20
SC432	119.37	35.69	155.06
SC433	9.28	44.55	53.83
SC434	23.78	14.42	38.19
SC435	50.63	38.46	89.09
SC436	16.35	45.92	62.27
SC437	13.49	11.70	25.19
SC438	9.07	28.19	37.26
SC439	6.63	28.86	35.49
SC440	12.35	29.24	41.59
SC441	36.02	6.43	42.45
SC442	226.70	41.11	267.81
SC443	17.17	16.38	33.55
SC444	6.49	25.94	32.43
SC445	6.58	15.30	21.89
SC446	34.72	4.62	39.34
SC447	20.00	5.52	25.52
SC448	21.31	12.30	33.61
SC449	44.75	8.56	53.31
SC450	5.62	12.97	18.59
SC451	9.22	12.09	21.31
SC452	37.59	9.33	46.91
SC453	73.45	16.16	89.61
SC454	17.51	7.21	24.72
SC455	10.00	16.24	26.25
SC456	47.25	18.59	65.83
SC457	20.48	82.80	103.28
SC458	308.48	56.15	364.63
TOTAL	12022.47	3097.53	15120.00

See separate Sheet 2 for location of subbasins.

Most of the Squalicum watershed is located outside of the city limits and is forested or developed in low density residential or agricultural land use. Within the City of Bellingham there is high density development west of I-5 and along Guide Meridian. Established residential neighborhoods are found in the downstream subbasins near the bay.

The watershed is drained primarily by the main stem of Squalicum Creek and two major tributaries: Baker Creek and Spring Creek. Most drainage features consist of streams and culverts, with pipes and ditches in the more heavily developed southwest/downstream subbasins.

The 1995 study did not investigate any inventoried wetlands along the main stem of Squalicum Creek. However, a 1992 report by R.W. Beck noted that,

> The portion of Squalicum Creek drainage basin between Guide Meridian Street and Hannegan Street to the east is dominated by a complex system of wetlands. Wetland habitats presently range from open water (Bug Lake and Sunset Pond) to mature forested wetlands. Emergent wetlands primarily exist in the eastern portion of this area. Due to their size, frequency, and hydrologic association with (and proximity to) Squalicum Creek and the two ponds, the numerous individual areas of wetland in the study area could be considered all parts of a single, large wetland system. Potential impacts to wetlands in this portion of the Squalicum Creek basin could result in future adjacent land development which could affect wetland hydrologic regimes. Regulatory mechanisms currently exist to protect these wetlands from filling, and then exists good opportunity for restoration and enhancement of previously impacted, or currently grazed, wetland areas.

The lower portion of Squalicum Creek has been impacted by adjacent development of moderate density. The stream has riprapped banks and substantial industrial and commercial development nearby.

Farther upstream Squalicum Creek is less heavily impacted by adjacent development. The riparian corridor consists of immature forest vegetation and some development encroachment.

Between Guide Meridian and Hannegan Street Squalicum Creek lies in a relatively flat-bottomed valley. The creek flows through a single contained channel. However, there are several locations where the stream becomes heavily braided and may flow underground. Along this stretch two major tributaries enter Squalicum Creek: North Fork Squalicum Creek and Tributary W.

Squalicum Creek is barrier-free to salmon passage for most of its distance within the city limits. Coho and chum salmon utilize Squalicum Creek from Bellingham Bay to Hannegan Road. Problem passage sites identified in the 1992 Beck study consist of (1) a footpath in Cornwall Park upstream of Guide Meridian, (2) underground channel upstream of Bug Lake, (3) entering the I-5 culverts, and (4) heavily braided channel between I-5 and Bug Lake and upstream of Sunset Pond.

The lower reaches of Squalicum Creek suffer from nonpoint source pollution due to the proximity of residential and commercial development and runoff from the I-5 corridor. Automobile-related pollutants from roads and parking areas together with fertilizers and herbicides from lawns are the most likely nonpoint source pollutants entering Squalicum Creek.

The 1995 study reported that most of the growth anticipated for the Squalicum Creek study area is expected to be a mixture of commercial, industrial, and residential. Nonpoint source pollution will increase. Water quality mitigation must provide biofiltration and stormwater detention from these developments to provide opportunities for sediment capture, suspended soils filtration, and biological uptake of fertilizers and herbicides.

Public environmental education is another way to reduce the impacts of new (and existing) development on water quality. Key needs include proper application of yard and garden fertilizers, use of native plants in landscaping, and proper disposal and recycling of household wastes (including soapy water, oils, anti-freeze, cleaners, etc.).

Problem Identification

As previously discussed, after the conveyance network was developed within the model, an initial model analysis was performed to identify any surcharging pipes within the network. Locations of model-identified problems (surcharging pipes) are summarized in Table 18. Detailed problem identification is presented in Appendix A.

Solutions

Following initial problem identification, SWMM's automatic pipe resizing routine was used to increase pipe diameters in the vicinity of the surcharging pipes identified during the initial model analysis. Quantities of potential pipes to be replaced with larger diameter pipes are summarized in Table 18. Detailed solution information is presented in Appendix A.

Table 18. Squalicum Creek Model Results

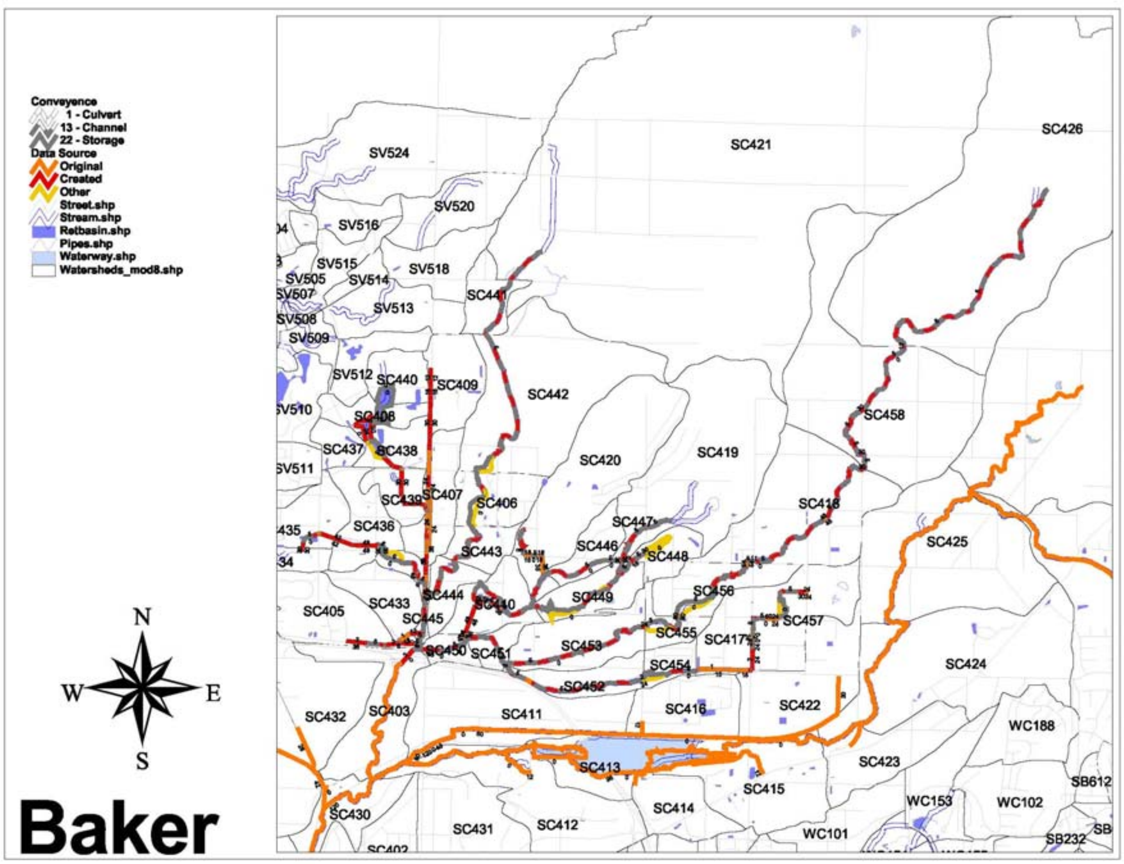
Subbasin	Improvement Project Group	Pipe Upgrade Quantity (linear feet)
Squalicum	Culverts, storm drains	2,000
Baker and Spring	Culverts, storm drains	3,650
Total		**5,650**

Cost Estimate

As previously discussed, GIS data for the existing system were not available for this basin. Therefore, model results identifying system deficiencies are conceptual and intended for planning-level decision-making only. With the available conveyance system data, model results are not considered detailed enough to generate reliable cost opinions for this basin. A cost opinion for capital improvement projects in this basin will be prepared in the future by others as additional system data are acquired and the model is updated.

Baker Creek Study Area

Within the Squalicum Creek watershed the Baker Creek study area is a major tributary, draining the northern portion of the watershed. The Baker Creek basin is adjacent to and primarily north of Interstate 5. The southern and western portions of the basin along I-5 and Guide Meridian are generally covered by commercial land uses, except for the drainage area immediately downstream of I-5 that is within the Bellingham Golf and Country Club property. The eastern and northern portions are primarily residential. The headwaters have minimal development.



The drainage system is a mixture of natural stream channels, ditches, and pipes.

The 1995 study identified nine major wetlands in the Baker Creek drainage. In general, these wetlands were situated in low, seasonally saturated bottomlands and were hydrologically connected to Baker Creek or its tributaries. Most of the wetlands were characterized by mixtures of forest and scrub-scrub vegetation. Other areas had wet meadow/pasture grass vegetation.

The 1995 study found a low to moderate degree of disturbance resulting from adjacent agricultural and residential. In places, culverts and channelization have modified the natural water course. Minimal development has occurred in the riparian corridor and the potential for nonpoint source pollution problems appears to be low.

Baker Creek has a barrier to fish passage a short distance upstream of its confluence with Squalicum Creek. The culvert under Birchwood Avenue blocks upstream salmon migration.

The lower reaches of Baker Creek suffer from nonpoint source pollution due to the proximity of commercial development and runoff from the I-5 and Guide Meridian corridors. Automobile-related pollutants from roads and parking areas together with fertilizers and herbicides from lawns are the most likely nonpoint source pollutants entering lower Baker Creek. Upstream, manure runoff from agricultural operations is a significant source of nonpoint pollution entering Baker and its tributaries.

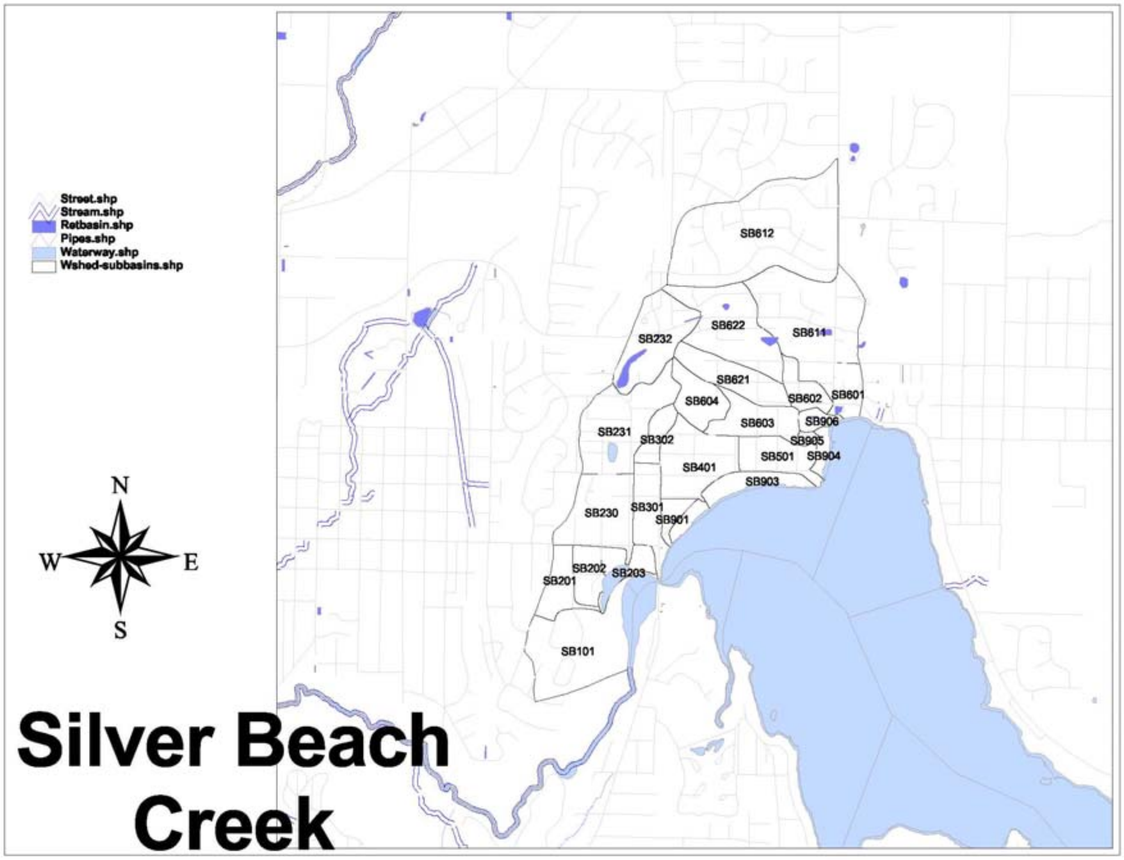
The 1995 study reported that most of the growth anticipated for the Baker Creek study area is expected to be a mixture of commercial, industrial, and residential. Nonpoint source pollution will increase. Water quality mitigation must provide biofiltration and stormwater detention from these developments to provide opportunities for sediment capture, suspended soils filtration, and biological uptake of fertilizers and herbicides.

Public environmental education is another way to reduce the impacts of new (and existing) development on water quality. Key needs include proper application of yard and garden fertilizers, use of native plants in landscaping, and proper disposal and recycling of household wastes (including soapy water, oils, anti-freeze, cleaners, etc.).

Baker Creek problem identification is included in the Squalicum Study Area presentation above.

SILVER BEACH CREEK STUDY AREA

The Silver Beach Creek watershed is approximately 714 acres (see Table 19), and averages 19% impervious area. Silver Beach Creek is located at the north end of Lake Whatcom and drains into the lake.



A number of the Silver Beach subbasins drain directly into Lake Whatcom and do not contribute to the Silver Beach Creek streamflow. For convenience and completion of the City of Bellingham drainages, they are included in the Silver Beach study area discussion and modeling.

The subbasins listed below in Table 19 contribute directly to the Silver Beach Creek streamflow.

Table 19. Silver Beach Creek Study Area

Subbasin	Pervious (ac)	Impervious (ac)	Total (ac)
SV101	350.62	62.27	412.88
SV103	53.31	18.27	71.58
SV102	104.17	19.10	123.28
SV104	64.54	29.37	93.90
SV105	8.11	4.13	12.24
TOTAL	580.74	133.14	713.88

See separate Sheet 3 for location of subbasins.

Problem Identification

For the Silver Beach Creek Study Area, after the conveyance network was developed within the model, an initial model analysis was performed to identify any surcharging pipes within the network. However, given the limited conveyance system information available, model results were not considered conclusive. Future model analysis is recommended when more detailed conveyance system data become available.

Solutions

Since problem identification model results for the Silver Beach Creek Study Area were not considered conclusive, potential solutions have been deferred to future model analysis when more detailed conveyance system data become available.

Cost Estimate

Model results identifying system deficiencies are conceptual and intended for planning-level decisions only. With the available conveyance system data, model results are not considered detailed enough to generate reliable cost opinions for this study area. A cost opinion for capital improvement projects in this basin will be prepared in the future by others as additional system data are acquired and the model is updated.

WHATCOM CREEK WATERSHED

The Whatcom Creek watershed extends from Lake Whatcom westward to Bellingham Bay. It includes most of downtown Bellingham and associated industrial and residential drainage basins draining to Whatcom Creek. Whatcom Creek's four major drainage basins are Fever Creek on the north side of Whatcom Creek and Hannah Creek, Cemetery Creek, and Lincoln Creek, all on the south side. Direct drainage to Whatcom Creek is also included.

The entire Whatcom Creek study area is approximately 5922 acres (see Table 20) and averages 30% impervious area. The northern portion is zoned primarily for industrial uses. Much of the remainder is high density residential.

Table 20. Whatcom Creek Study Area

Subbasin	Pervious (ac)	Impervious (ac)	Total (ac)
WC101	33.66	55.22	88.88
WC102	85.65	18.03	103.68
WC103	25.83	16.20	42.03
WC104	78.71	23.49	102.20
WC105	15.22	24.05	39.28
WC106	22.02	14.25	36.27
WC107	32.15	20.78	52.93
WC108	25.60	9.42	35.02
WC109	21.11	25.17	46.28
WC110	45.25	25.61	70.86
WC111	13.18	17.99	31.17
WC112	8.15	31.54	39.69
WC113	40.54	9.20	49.74
WC114	6.36	13.30	19.66
WC115	50.57	5.71	56.28
WC116	3.19	7.70	10.89
WC117	13.41	4.48	17.89
WC118	23.05	1.36	24.42
WC119	21.10	5.14	26.24
WC120	88.20	2.15	90.35
WC121	45.90	13.63	59.53
WC122	4.80	17.50	22.29
WC123	4.80	24.91	29.71
WC124	11.84	27.82	39.67
WC125	142.85	28.32	171.17
WC126	26.09	11.42	37.51
WC127	8.64	32.18	40.82
WC128	487.34	60.01	547.35
WC129	109.06	18.40	127.45
WC130	3.93	20.61	24.54
WC131	61.95	46.30	108.25

Subbasin	Pervious (ac)	Impervious (ac)	Total (ac)
WC132	1.60	5.71	7.31
WC133	25.73	4.89	30.62
WC134	22.39	33.48	55.87
WC135	62.65	10.08	72.73
WC136	15.14	4.94	20.08
WC137	23.87	6.76	30.62
WC138	57.32	14.02	71.34
WC139	18.21	5.14	23.35
WC140	118.96	13.57	132.52
WC141	80.63	23.99	104.62
WC142	119.26	26.59	145.86
WC143	69.31	22.83	92.14
WC144	30.57	45.50	76.06
WC145	25.24	37.65	62.90
WC146	22.53	32.76	55.29
WC147	48.91	16.19	65.10
WC148	16.52	11.93	28.45
WC149	9.77	43.98	53.75
WC150	5.08	28.57	33.65
WC151	41.70	60.22	101.93
WC153	62.62	14.72	77.34
WC154	30.66	11.21	41.86
WC155	24.24	6.17	30.41
WC156	31.30	8.69	39.99
WC157	27.17	7.16	34.33
WC159	28.36	12.76	41.12
WC160	6.84	14.45	21.29
WC161	22.82	0.63	23.45
WC162	6.16	1.48	7.64
WC163	28.08	7.55	35.63
WC164	34.03	7.71	41.75
WC165	55.72	13.74	69.46
WC166	74.20	16.08	90.28
WC168	117.10	5.58	122.67
WC169	198.58	1.61	200.18
WC170	23.55	5.79	29.34
WC171	36.65	11.55	48.20
WC172	27.91	15.88	43.79
WC173	62.76	43.99	106.75
WC174	44.03	23.28	67.31
WC175	46.63	13.75	60.38
WC176	27.52	7.74	35.27
WC177	54.11	18.53	72.65
WC178	13.42	12.23	25.66
WC179	15.64	25.69	41.34
WC180	47.58	24.20	71.78
WC181	7.35	20.74	28.09
WC182	8.24	8.04	16.28

Subbasin	Pervious (ac)	Impervious (ac)	Total (ac)
WC183	27.89	91.23	119.12
WC184	16.44	18.03	34.47
WC185	25.49	11.89	37.37
WC188	68.82	12.15	80.97
WC189	37.87	10.41	48.28
WC190	14.25	4.17	18.42
WC191	52.31	20.63	72.94
WC192	55.13	28.81	83.94
WC193	29.22	16.90	46.12
WC194	7.46	3.86	11.31
WC195	42.43	18.01	60.44
WC196	18.32	8.24	26.56
WC197	47.48	14.91	62.39
WC198	57.16	13.45	70.61
WC199	32.56	9.81	42.37
WC200	55.77	22.46	78.23
WC201	14.88	3.94	18.82
WC203	21.88	7.22	29.10
TOTAL	4164.12	1757.75	5921.87

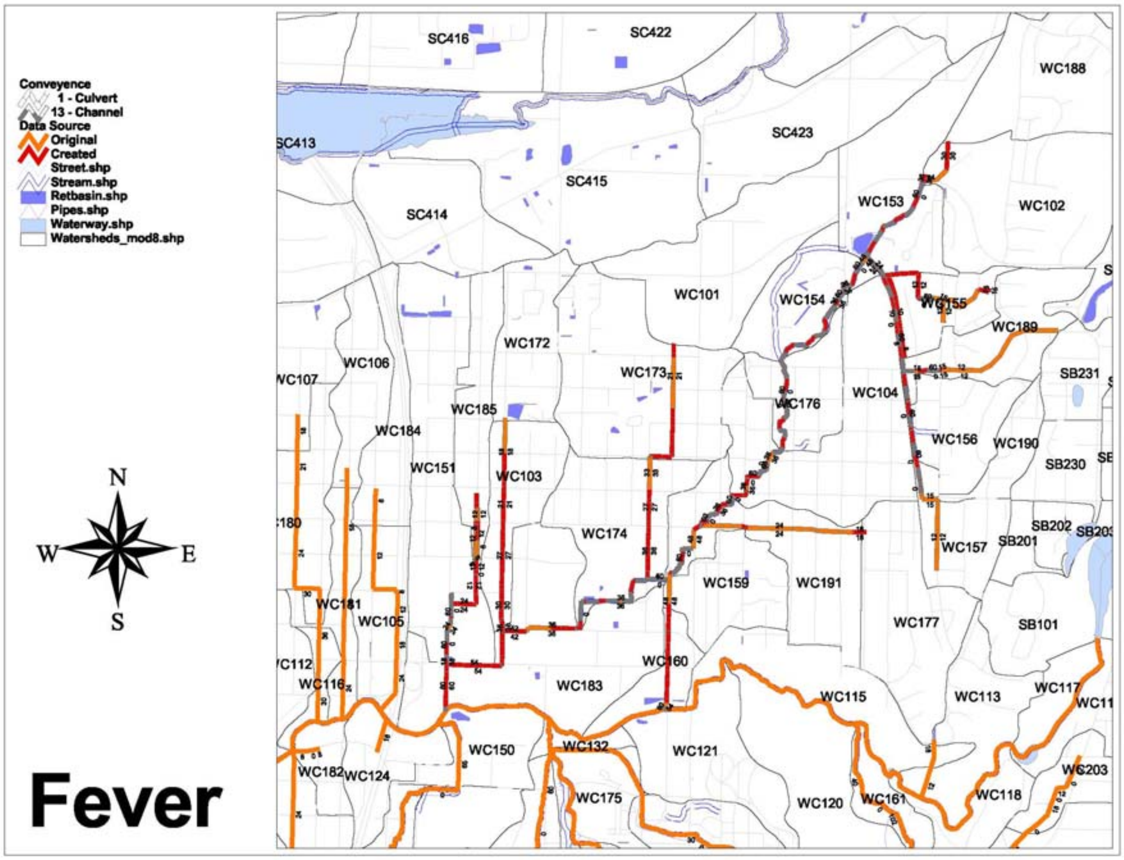
See separate Sheet 3 for location of subbasins.

The Whatcom Creek study area is highly developed. The western portion of the study area is the commercial center of the City of Bellingham. Light industrial development is to the east of the downtown along the Whatcom Creek corridor. Residential land use is found both north and south side of Whatcom Creek. Park land along Whatcom Creek upstream of Woburn Street protects the creek from encroaching urban development. Along the south edge of the watershed are forested, hill slopes. Development is slowly replacing the forests with suburban housing.

The 1995 plan's environmental assessment included East Cemetery, West Cemetery, and Lincoln Creek wetlands. Additionally, selected wetlands in the Fever Creek drainage basin and direct drainage to Lake Whatcom between the Whatcom Creek inlet and Silver Beach Creek were included in the field inventory of aquatic resources. A modified wetland functions and values assessment was performed in the 1995 study on selected wetlands which were originally identified in the 1991 Bellingham Wetland Inventory and are associated with East Cemetery Creek, West Cemetery Creek, Lincoln Creek, Fever Creek, the direct drainage to Lake Whatcom between the Whatcom Creek inlet and Silver Beach Creek. East Cemetery Creek, West Cemetery Creek, and Lincoln Creek were inventoried in the 1995 field study.

Fever Creek Study Area

Within the Whatcom Creek watershed the Fever Creek study area is approximately 1426 acres and averages 44% impervious area. The northern portion is zoned primarily for industrial uses. Much of the remainder is high density residential.



Fever Creek has been mostly confined within a channelized ditch. There is little or no undeveloped floodplain along the creek. Most of the subbasin drainage facilities are stormwater piping systems and open channel ditches.

One Fever Creek wetland (WH-33a) was studied during the field investigation conducted for the 1995 study. This wetland consisted of forested and scrub-shrub wetland classes and was associated with an existing stormwater detention facility. A complex combination of wetland types provided excellent wildlife habitat. The combination of thick herbaceous and persistent vegetation provides moderate biofiltration and floodwater attenuation.

There are no known fish resources in Fever Creek.

The potential for nonpoint source pollution problems is high due to the high density residential and commercial development found in the Fever Creek study area. Pollutants will be typical of those produced by roadways and residential and commercial development, as described in the previous general discussion of pollutant loadings.

The 1995 study reported that most of the growth anticipated for the Fever Creek study area is expected to be industrial. As a result, there will be increased impervious area and automobile traffic. Associated industrial and roadway-related pollutants will increase. Many of these pollutants attached to and are transported by suspended solids. By removing solids from the stormwater runoff, these pollutants are also removed. As clearing and grading occur in anticipation or as part of these development activities, water quality facilities must be incorporated in the individual sites' temporary erosion and sedimentation control plans and stormwater management plans. Sediment traps should be included in the plans. Grassed swales should be installed as part of the site grading plans and for parking lot runoff to remove pollutants before they enter the stormwater conveyance system.

For Fever Creek residential areas public environmental education is key to getting the public to support lifestyle modifications to improve water quality. Key needs include promoting integrated management and proper application of yard and garden fertilizers, use of native plants in landscaping, proper disposal and recycling of household wastes (including soapy water, oils, anti-freeze, cleaners, etc.), and reducing impervious surfaces in residential site design.

Fever Creek Stormwater Problems (see separate Sheet 3 for location of elements)

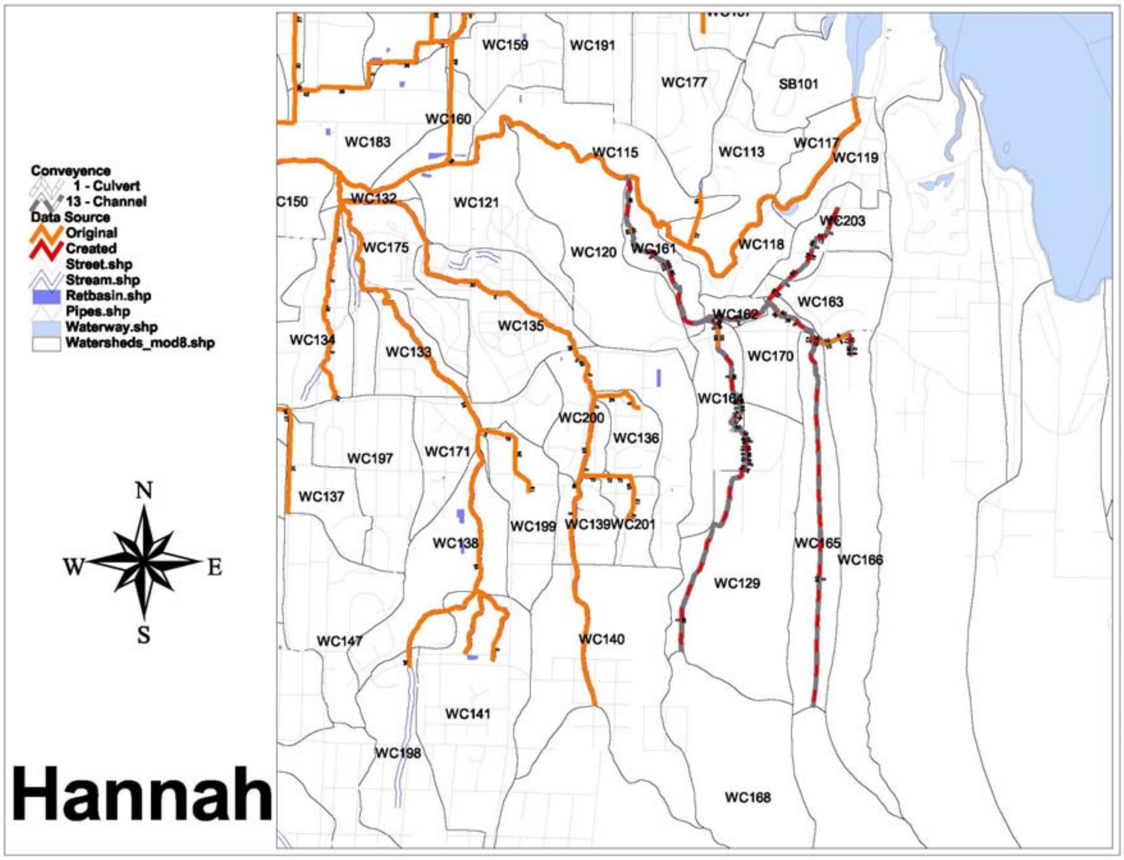
Element ID	Original Size (ft)	Size Increase (ft)	New Size (ft)
1031	4.00	1.50	5.50
1034	1.75	0.75	2.50
1055	0.67	0.33	1.00
1060	0.67	0.33	1.00
1074	1.75	1.00	2.75
1075	1.75	0.75	2.50
1102	2.75	0.25	3.00
1108	1.50	1.25	2.75
1129	1.75	1.25	3.00
1130	1.75	1.25	3.00
1133	3.00	0.50	3.50
1134	4.00	1.50	5.50
1136	3.00	0.50	3.50
1150	3.00	1.00	4.00
1151	3.50	0.50	4.00
1152	3.00	1.50	4.50
1154	3.00	1.00	4.00
1165	1.00	0.25	1.25
1182	1.00	0.25	1.25
1243	0.67	0.33	1.00
1245	1.00	0.50	1.50
1250	1.00	1.00	2.00
1251	2.00	1.00	3.00
1252	2.00	0.25	2.25

Element ID	Original Size (ft)	Size Increase (ft)	New Size (ft)
1257	1.75	1.00	2.75
1277	2.25	1.25	3.50
1278	3.00	0.50	3.50
1279	3.00	0.50	3.50
1284	4.00	1.00	5.00
1338	2.00	0.50	2.50
1339	3.00	0.50	3.50
1341	3.00	0.50	3.50
1365	3.00	1.00	4.00
1373	1.00	0.25	1.25
1378	2.50	0.50	3.00
1436	1.50	1.25	2.75
1451	2.75	0.75	3.50
1453	1.75	0.25	2.00
1456	3.00	0.50	3.50
1457	3.00	0.50	3.50
1467	3.50	0.50	4.00
1468	3.00	1.00	4.00
1517	0.67	0.33	1.00
1518	1.00	0.75	1.75
1523	2.25	1.25	3.50
1525	3.00	0.50	3.50

Hannah Creek Study Area

Within the Whatcom Creek watershed the Hannah Creek study area is approximately 777 acres and averages 13% impervious area. The northern portion is primarily residential. Much of the southern portion of the area is undeveloped forest land.

Hannah Creek flows in a natural channel, mostly through backyards. There are some tributary stormwater piping systems and open channel ditches.



Wetlands were originally identified in the 1991 wetland inventory. They are primarily located away from the main conveyance course of Hannah Creek. As a result, the 1995 study did not investigate any of the Hannah basin wetlands.

There are no known fish resources in Hannah Creek.

The potential for nonpoint source pollution problems is high due to the residential development found in the Hannah Creek study area. Pollutants will be typical of those produced by roadways and residential development, as described in the previous general discussion of pollutant loadings.

The 1995 study reported that most of the growth anticipated for the Hannah Creek study area is expected to be residential. Nonpoint source pollution will increase due to the construction of additional homes and roads. Water quality mitigation must provide biofiltration from these developments.

Public environmental education is another way to reduce the impacts of new (and existing) development on water quality. Key needs include proper application of yard and garden fertilizers, use of native plants in landscaping, and proper disposal and recycling of household wastes (including soapy water, oils, anti-freeze, cleaners, etc.). The control and elimination of illegal refuse dumping in the basin will also help improve water quality.

Hannah Creek Stormwater Problems (see separate Sheet 3 for location of elements)

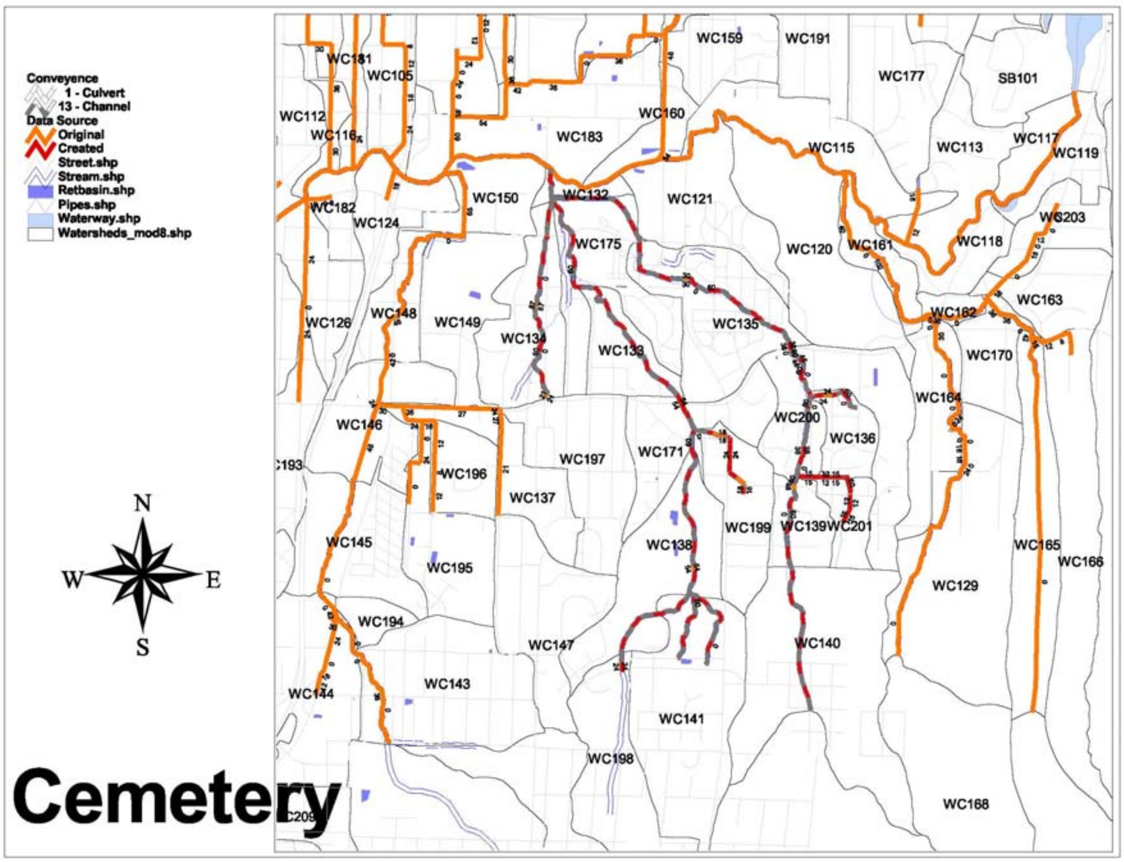
Element ID	Original Size (ft)	Size Increase (ft)	New Size (ft)
1010	1.25	0.25	1.50
1011	1.25	0.25	1.50
1048	1.50	0.25	1.75
1050	0.67	0.33	1.00
1052	1.00	0.50	1.50
1053	1.00	0.50	1.50
1084	1.50	0.50	2.00
1094	2.00	0.75	2.75
1096	1.50	0.25	1.75
1099	2.25	0.25	2.50
1104	2.00	0.25	2.25
1105	2.00	0.25	2.25
1111	3.50	0.50	4.00
1116	1.00	0.25	1.25
1137	1.25	0.50	1.75
1138	0.67	1.33	2.00
1139	1.00	0.50	1.50
1140	0.67	0.83	1.50
1141	1.00	1.00	2.00
1159	1.50	0.50	2.00
1160	1.50	0.50	2.00
1161	1.83	0.75	2.58
1175	1.50	0.25	1.75
1177	2.50	0.25	2.75
1178	2.00	0.75	2.75
1179	2.50	0.50	3.00
1183	1.50	0.50	2.00
1184	1.25	0.50	1.75
1208	1.75	0.25	2.00
1223	2.25	0.25	2.50
1224	2.25	0.25	2.50
1239	0.67	0.58	1.25
1256	2.00	0.25	2.25
1280	1.00	1.00	2.00
1281	1.00	0.75	1.75
1282	0.67	0.83	1.50
1283	0.67	1.08	1.75

Element ID	Original Size (ft)	Size Increase (ft)	New Size (ft)
1285	2.50	2.00	4.50
1290	1.25	0.75	2.00
1291	1.25	1.25	2.50
1294	1.75	0.75	2.50
1295	1.75	0.50	2.25
1296	1.75	0.25	2.00
1297	1.75	0.25	2.00
1302	1.75	0.50	2.25
1306	1.00	0.75	1.75
1310	1.50	0.50	2.00
1313	0.67	0.83	1.50
1349	3.33	0.50	3.83
1387	1.00	0.75	1.75
1401	0.67	0.33	1.00
1402	1.50	0.25	1.75
1420	2.50	1.50	4.00
1438	1.50	0.75	2.25
1447	2.25	0.25	2.50
1449	2.25	0.25	2.50
1454	0.67	0.33	1.00
1460	1.50	0.25	1.75
1474	1.83	1.00	2.83
1475	1.67	0.50	2.17
1476	1.67	0.25	1.92
1477	1.50	0.50	2.00
1478	2.00	0.50	2.50
1479	2.00	0.25	2.25
1480	2.00	0.25	2.25
1481	2.00	0.25	2.25
1482	1.25	0.50	1.75
1496	1.00	0.25	1.25
1502	1.75	0.25	2.00
1505	1.50	1.50	3.00
1506	1.50	1.50	3.00
1520	1.75	1.00	2.75
1526	1.00	1.00	2.00
1527	1.00	0.75	1.75
1528	0.67	1.33	2.00
1530	1.75	1.00	2.75
1534	1.75	0.75	2.50
1535	1.50	0.75	2.25
1536	1.75	0.75	2.50
1537	1.75	0.75	2.50
1538	1.50	0.75	2.25
1539	1.50	0.50	2.00
1542	0.67	1.08	1.75
1544	2.00	2.00	4.00
1776	1.50	0.50	2.00

Element ID	Original Size (ft)	Size Increase (ft)	New Size (ft)
1778	1.50	0.25	1.75

Cemetery Creek Study Area

Within the Whatcom Creek watershed the Cemetery Creek study area consists of the drainages of East Cemetery Creek, West Cemetery Creek, and the main stem of Cemetery Creek. The total drainage area is approximately 1447 acres and averages 25% impervious area. The downstream (northern) portion of the basin is a combination of commercial, undeveloped wetlands, and a large cemetery. The central portion is primarily residential. Much of the southern portion of the area is undeveloped forest land.



The upper portions of the Cemetery Creek tributaries flow in natural channels. There are some tributary stormwater piping systems and open channel ditches. The lower reaches of East Cemetery Creek and West Cemetery Creek flow through a large, high quality, forested wetland.

East Cemetery Creek is moderately disturbed in its lower portion, downstream of Woburn Road. The stream flows through a mature forest and wetland WH-42, a large, relatively undisturbed, palustrine forested wetland associated with the confluence of East and West Cemetery Creek. The stream channel has been partial channelized in sections, near residential and commercial development. Between Woburn and Lakeway Drive the creek flows through Bayview Cemetery. The stream gradient is relatively steep and the channel is strongly incised into the bedrock. Upstream of Lakeway Drive there is greater disturbance due to adjacent residential development. Vegetation in the riparian corridor has been highly altered. Water quality appears to be poor due to nonpoint source pollution entering the stream. In contrast, the headwaters are still relatively undisturbed and are characterized by mature forest vegetation and little or no adjacent development.

West Cemetery Creek flows through a similar range of riparian conditions. The lower portion of West Cemetery Creek is in a relatively, undeveloped riparian corridor with mature forest vegetation. The creek flows through a broad, low gradient palustrine forested wetland that contains a series of braided overflow channels. Upstream of Lakeway Drive West Cemetery Creek is confined within a high gradient, highly incised channel with a highly disturbed riparian corridor. There is serious stream bank cutting. The surrounding residential development suggests the presence of potential washoff of lawn fertilizers and herbicides into the creek. The headwaters are located in low density residential neighborhoods that contain a combination of mature forest, lawn, and horse pasture vegetation. The lawns and horse pastures contribute fertilizer, herbicide, and livestock manure to the stream.

Coho and Chinook salmon have been observed in East Cemetery Creek below Woburn Street and West Cemetery Creek below Lakeway Drive. Salmon apparently do not utilize habitat upstream of these locations due to culvert passage problems. The upper reaches of both creeks have good habitat for sea-run cutthroat spawning and juvenile rearing, once fish passage blockages are removed.

Water quality is adversely impacted by fertilizer and herbicide runoff from Bayview Cemetery and the nearby Eaglewood residential neighborhood. Automobile-related pollutants associated with roads and parking areas are also being washed off into Cemetery Creek. The upper reaches of West Cemetery Creek also receive fertilizer, herbicide, and livestock manure washoff, as previously noted.

The 1995 study reported that most of the growth anticipated for the Cemetery Creek study area is expected to be residential. Nonpoint source pollution will increase due to the construction of additional homes and roads. Water quality mitigation must provide biofiltration from these developments.

Public environmental education is another way to reduce the impacts of new (and existing) development on water quality. Key needs include proper application of yard and garden fertilizers, use of native plants in landscaping, and proper disposal and recycling of household wastes (including soapy water, oils, anti-freeze, cleaners, etc.). The control and elimination of illegal refuse dumping in the wetlands at the mouth of Cemetery Creek will also help improve water quality.

Lincoln Creek Study Area

Within the Whatcom Creek watershed the Lincoln Creek study area is approximately 913 acres and averages 45% impervious area. The basin is adjacent to and primarily east of Interstate 5. The southern and western portions of the basin along I-5 are generally covered by commercial land uses. The eastern and northern portions are primarily residential. The headwaters have minimal development.

The drainage system is a mixture of natural stream channels, ditches, and pipes. Lincoln Creek discharges to Whatcom Creek through a 43-inch by 63-inch arch pipe under Fraser Street.

The 1995 study found that the wetlands located in the lower reaches of Lincoln Creek were characterized by moderate to high degrees of disturbance resulting from adjacent and relatively extensive residential and commercial development. The wetland plant communities have low species diversity. Culverts and channelization have modified the natural water course. Development has occurred in the riparian corridor and the potential for nonpoint source pollution problems appears to be high.

In contrast, development in the vicinity of the upper reach wetlands is relatively low density and adverse wetland impacts were found to be minor. The inventoried upper wetlands have a combination of emergent, shrub-dominated, and forested vegetation types.

The Lincoln Creek stream channel downstream of Lakeway Drive has been highly disturbed by extensive channelization and nearby residential and commercial development. The upstream, middle section of Lincoln Creek has been altered by road construction, residential development, and commercial activities. The upstream headwaters suffer some, but less, damage from residential development.

The lower reaches of Lincoln Creek are considered important habitat for cutthroat trout, coho, and chinook salmon in spite of the degradated stream channel. Salmon cannot journey upstream of Lincoln Street because of an impassable culvert at that location. However, the upstream reaches could provide good sea-run cutthroat spawning and juvenile rearing areas.

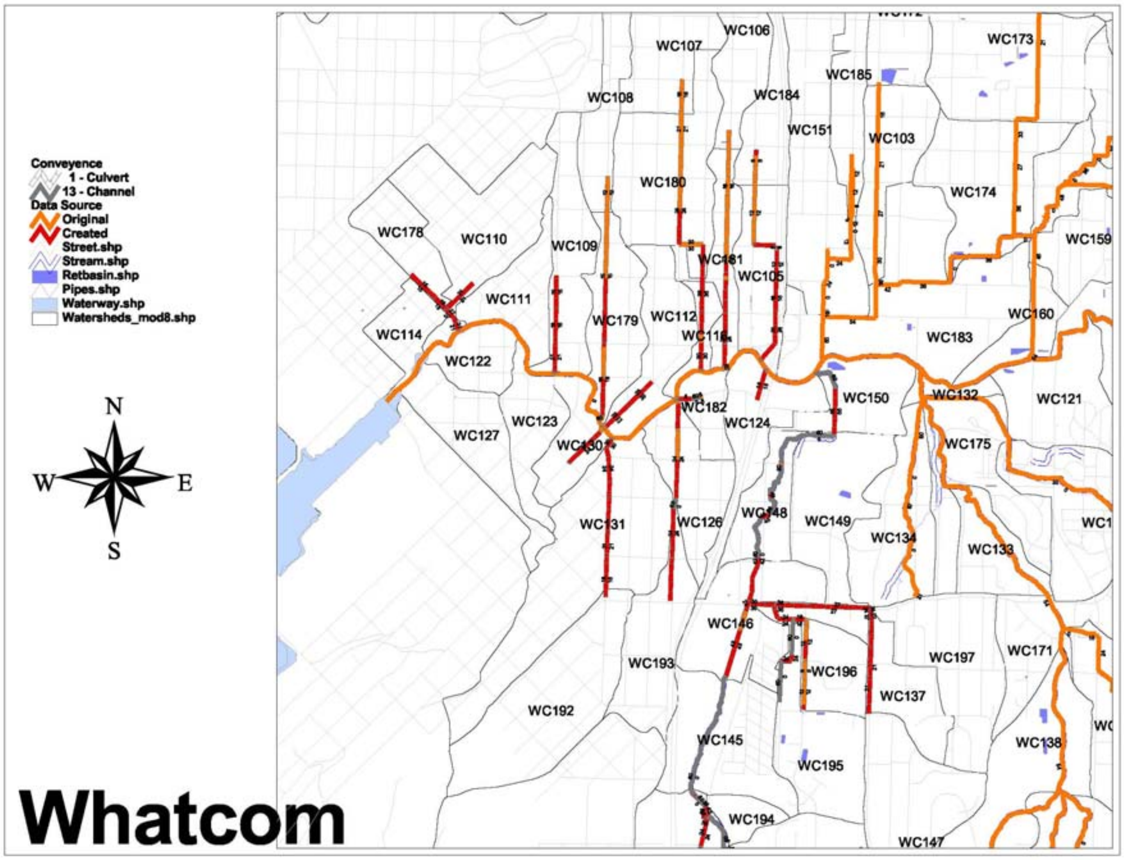
The lower reaches of Lincoln Creek suffer from nonpoint source pollution due to the proximity of residential and commercial development and runoff from the I-5 corridor. Automobile-related pollutants from roads and parking areas together with fertilizers and herbicides from lawns are the most likely nonpoint source pollutants entering Lincoln Creek.

The 1995 study reported that most of the growth anticipated for the Lincoln Creek study area is expected to be a mixture of commercial, industrial, and residential. Nonpoint source pollution will increase. Water quality mitigation must provide biofiltration and stormwater detention from these developments to provide opportunities for sediment capture, suspended soils filtration, and biological uptake of fertilizers and herbicides.

Public environmental education is another way to reduce the impacts of new (and existing) development on water quality. Key needs include proper application of yard and garden fertilizers, use of native plants in landscaping, and proper disposal and recycling of household wastes (including soapy water, oils, anti-freeze, cleaners, etc.).

Direct Whatcom Creek Study Area

Within the Whatcom Creek watershed the direct Whatcom Creek study area is approximately 1330 acres and averages 50% impervious area. This study area consists of subbasins that flow directly into Whatcom Creek. Most of these subbasins are located in the main east-west commercial/industrial corridor along Iowa Street between Woburn Street and the bay. Correspondingly, they are heavily covered by impervious surfaces.



The drainage system is a mixture of ditches and pipes. There are multiple direct discharges to Whatcom Creek all along its length from Lake Whatcom to Bellingham Bay.

No wetlands of any size remain in or along the main Whatcom Creek corridor between Whatcom Falls Park and the bay. The entire riparian corridor has been modified due to high degrees of disturbance resulting from adjacent and relatively extensive industrial and commercial development. The potential for nonpoint source pollution problems appears to be high. The City of Bellingham is working to restore a natural stream channel and vegetation along portions of the riparian corridor.

Upstream of the commercial corridor, Whatcom Falls Park provides a beautiful natural setting for the stream to flow through. In the park mature forest vegetation remains, providing shade and cool temperatures for Whatcom Creek. The park provides a reminder of what this stream corridor used to look like all the way down to Bellingham Bay.

The lower reaches of Whatcom Creek are considered important habitat for cutthroat trout, coho, and chinook salmon in spite of the degradated stream channel. Salmon cannot journey upstream of Whatcom Falls in Whatcom Falls Park. However, they have good access to Fever, Cemetery, and Lincoln creeks (Hannah Creek enters Whatcom Creek through a man-made chute upstream of the falls.

The lower reaches of Whatcom Creek suffer from nonpoint source pollution due to the proximity of commercial, industrial, and residential development and runoff from the Iowa Street corridor. Automobile-related pollutants from roads and parking areas together with fertilizers and herbicides from lawns are the most likely nonpoint source pollutants entering Whatcom Creek.

The 1995 study did not include the direct Whatcom Creek study area. The subbasins that make up this study area are, for the most part, fully built out. For any redevelopment activities water quality mitigation should be included. Such mitigation must provide biofiltration and stormwater detention from these developments to provide opportunities for sediment capture, heavy metals and automobile-related pollutant filtration, and biological uptake of fertilizers and herbicides.

Public environmental education is another way to reduce the impacts of development on water quality. Key needs include proper disposal and recycling of industrial wastes (including soapy water, oils and solvents, anti-freeze, cleaners, etc.), elimination of illegal connections and discharges to Whatcom Creek, and street sweeping to collect and remove automobile-related pollutants.

Direct Whatcom Creek Stormwater Problems (see separate Sheet 3 for location of elements)

Element ID	Original Size (ft)	Size Increase (ft)	New Size (ft)
1010	1.25	0.25	1.50
1011	1.25	0.25	1.50
1048	1.50	0.25	1.75
1050	0.67	0.33	1.00
1052	1.25	0.25	1.50
1053	1.25	0.25	1.50
1084	1.75	0.25	2.00
1094	2.50	0.25	2.75
1096	1.50	0.25	1.75
1099	2.25	0.25	2.50
1104	2.00	0.25	2.25
1105	2.00	0.25	2.25
1111	3.50	0.50	4.00
1116	1.00	0.25	1.25
1159	1.75	0.25	2.00
1160	1.75	0.25	2.00

Element ID	Original Size (ft)	Size Increase (ft)	New Size (ft)
1161	2.33	0.25	2.58
1175	1.50	0.25	1.75
1177	2.50	0.25	2.75
1178	2.50	0.25	2.75
1179	2.75	0.25	3.00
1183	1.75	0.25	2.00
1184	1.50	0.25	1.75
1208	1.75	0.25	2.00
1223	2.25	0.25	2.50
1224	2.25	0.25	2.50
1233	1.75	0.25	2.00
1239	1.00	0.25	1.25
1256	2.00	0.25	2.25
1280	1.75	0.25	2.00
1281	1.50	0.25	1.75
1282	1.25	0.25	1.50
1283	1.50	0.25	1.75
1285	4.00	0.50	4.50
1294	2.25	0.25	2.50
1295	2.00	0.25	2.25
1296	1.75	0.25	2.00
1297	1.75	0.25	2.00
1302	2.00	0.25	2.25
1306	1.50	0.25	1.75
1332	3.50	0.50	4.00
1401	0.67	0.33	1.00
1420	3.50	0.50	4.00
1438	2.00	0.25	2.25
1447	2.25	0.25	2.50
1449	2.25	0.25	2.50
1454	0.67	0.33	1.00
1460	1.50	0.25	1.75
1474	2.58	0.25	2.83
1475	1.92	0.25	2.17
1476	1.67	0.25	1.92
1477	1.75	0.25	2.00
1478	2.25	0.25	2.50
1479	2.00	0.25	2.25
1480	2.00	0.25	2.25
1481	2.50	0.25	2.75
1482	1.50	0.25	1.75
1496	1.00	0.25	1.25
1502	1.75	0.25	2.00
1505	2.75	0.25	3.00
1506	2.75	0.25	3.00
1520	2.50	0.25	2.75
1526	1.75	0.25	2.00
1527	1.50	0.25	1.75

Element ID	Original Size (ft)	Size Increase (ft)	New Size (ft)
1528	1.75	0.25	2.00
1530	2.50	0.25	2.75
1534	2.25	0.25	2.50
1535	2.00	0.25	2.25
1536	2.25	0.25	2.50
1537	2.25	0.25	2.50
1538	2.00	0.25	2.25
1539	1.75	0.25	2.00
1542	1.00	0.25	1.25
1544	3.50	0.50	4.00

Problem Identification

As previously discussed, after the conveyance network was developed within the model, an initial model analysis was performed to identify any surcharging pipes throughout the network. Locations of problems (surcharging pipes) are summarized in Table 21. Detailed problem identification is presented in Appendix A.

For the Cemetery Creek study area, insufficient data were available to determine if there are conveyance deficiencies in the network. Data missing from City-supplied GIS files were filled in as discussed above, and no deficiencies were found during the model analysis (e.g., there were no indications of surcharging). However, if deficiencies had been identified, the limited data available would have been insufficient to determine the pipe sizes needed to address the deficiencies. Also, if there are differences between model results and actual data, there may be deficiencies within the existing system that the model would not be able to identify. Future analysis is recommended as field data are obtained and incorporated into the model, to determine whether actual deficiencies exist.

Solutions

Following initial problem identification, SWMM's automatic pipe resizing routine was used to increase the pipe network in the vicinity of the surcharging pipes identified during the initial model analysis. As previously discussed, the SWMM automatic pipe resizing routine increases capacity throughout the system by increasing the diameters of all pipes that would be affected by an increase in downstream flow resulting from upstream improved capacity. This routine avoids the problem of resizing a single pipe only to shift a flooding problem downstream. Quantities of potential pipes to be replaced with larger diameter pipes are summarized in Table 21. Detailed solution information is presented in Appendix A.

Cost Opinion

As previously discussed, the GIS data were most readily available and most nearly complete for the Whatcom Creek Study Area; therefore, the model results were considered detailed enough for generation of a reliable cost opinion. The cost opinion for the Whatcom Creek Study Area is summarized in Table 21. Detailed cost opinion information for the Whatcom Creek Study Area is presented in Appendix B.

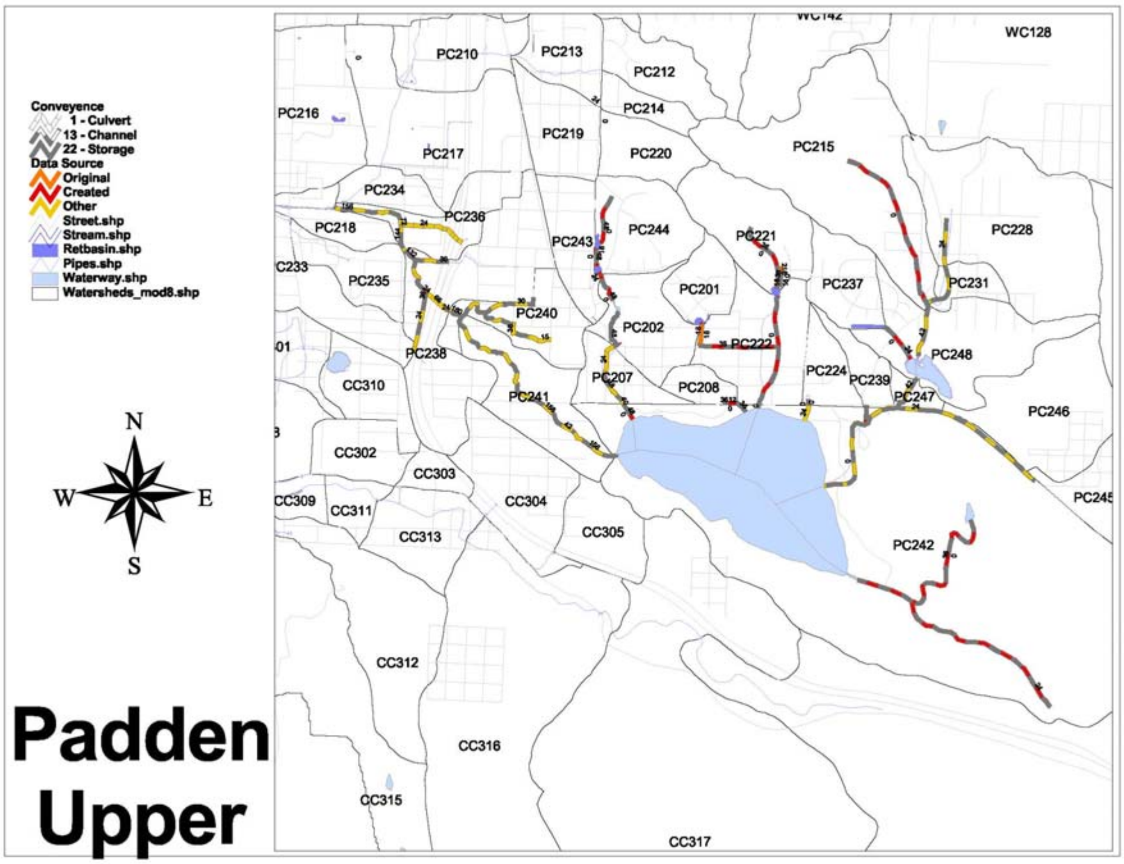
The projects listed in Table 21 were arranged based on geographical proximity of the improvements. For example, Ellis Street #1 and Ellis Street #2 represent increasing the pipe diameters identified in the model within Ellis Street on the south and north sides, respectively, of North State Street. The projects listed in Table 21 may be combined or otherwise compiled differently as needed by the City.

Table 21. Whatcom Creek Model Results and Cost Opinion

Subbasin	Improvement Project Group	Pipe Upgrade Quantity (linear feet)	Cost Opinion
Whatcom Creek	Ellis Street #1	2,250	$1,858,000
	Ellis Street #2	2,050	$1,176,000
	King/Virginia/Lincoln	3,400	$2,032,000
	Meador Avenue	200	$129,000
	State Street	900	$398,000
	Misc. Whatcom Outfalls	250	$176,000
Fever Creek	Kentucky Street	1,050	$1,373,000
	Orleans/Nevada	1,600	$925,000
	Valencia/North/Verona	3,500	$3,330,000
	Misc. Improvements	700	$480,000
Cemetery Creek	(Insufficient conveyance system data)		
Hannah Creek	Lakeway Drive	800	$486,000
	Raymond Street	200	$185,000
Lincoln Creek	Lincoln Creek	1,050	$813,000
Total		**17,950**	**$13,361,000**

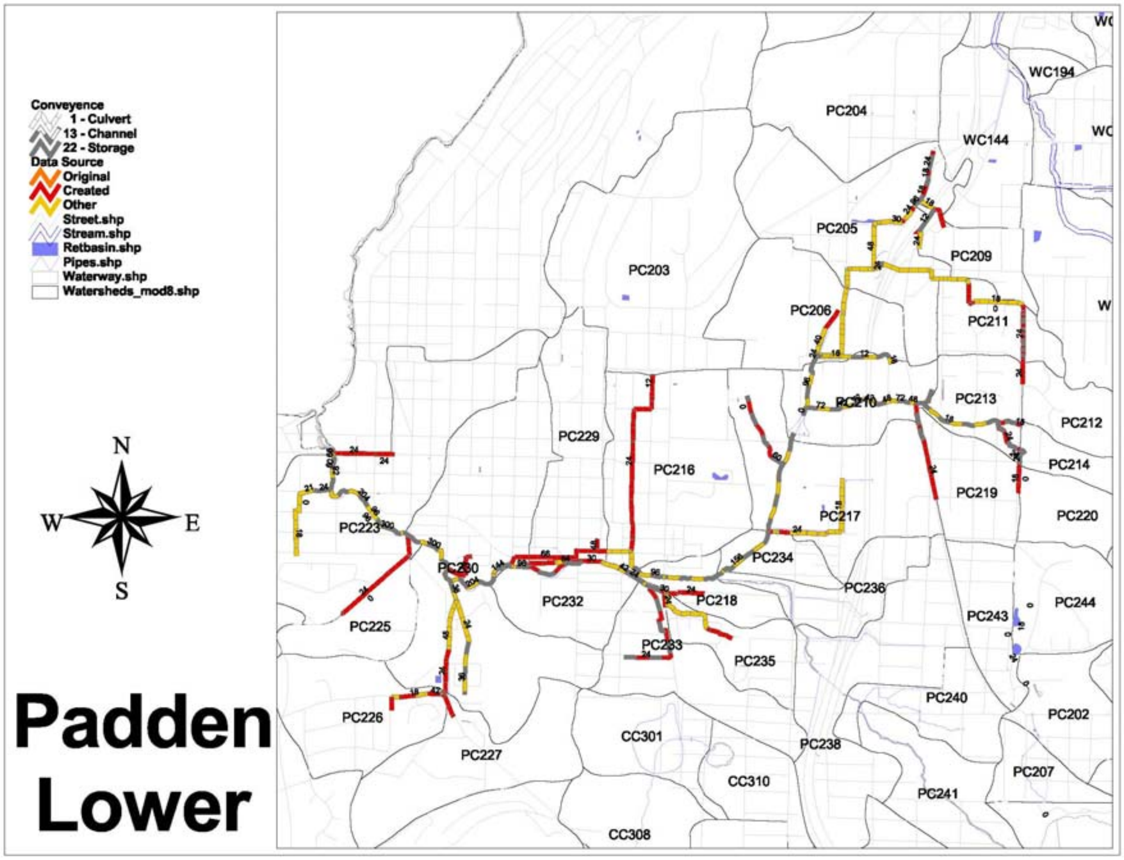
PADDEN CREEK STUDY AREA

The Padden Creek study area is approximately 4125 acres, including the Lake Padden drainages (see Table 22), and averages 19% impervious area. This study area consists of subbasins that flow directly into Lake Padden in addition to the downstream Padden Creek drainages plus the Connelly Creek tributary area. The Padden Creek watershed is located south of the Whatcom Creek watershed.



The streams draining directly to Lake Padden are generally intermittent in nature and flow out of heavily forested areas. The 150-acre Lake Padden outlets to a perennial stream, Padden Creek, that flows westward under I-5 to Bellingham Bay.

The upper section of Padden Creek is in a highly disturbed stream channel that has been adversely impacted by a mixture of residential and commercial development.



Downstream Padden Creek flows through an approximately 2100-foot long conveyance pipe (known as the "Brick Tunnel") beneath Old Fairhaven Parkway. The stream then enters Fairhaven Park, just south of the Fairhaven commercial district, before finally flowing through substantial commercial and industrial development near the bay.

Connelly Creek drains the tributary area north of Old Fairhaven Parkway east of 21st Street, including a portion of I-5 and Samish Way. The lower portion of Connelly Creek is a shrub and grass-dominated riparian corridor surrounded by residential development. The upstream channel is located in a mature forest vegetation setting.

Table 22. Padden Creek Study Area

Subbasin	Pervious (ac)	Impervious (ac)	Total (ac)
PC201	24.30	5.65	29.95
PC202	43.08	9.26	52.34
PC203	138.88	57.82	196.70
PC204	111.53	26.49	138.02
PC205	86.90	49.17	136.07
PC206	53.93	33.50	87.44
PC207	23.91	4.61	28.52
PC208	12.14	2.83	14.97
PC209	26.30	5.01	31.31

Subbasin	Pervious (ac)	Impervious (ac)	Total (ac)
PC210	49.36	8.26	57.62
PC211	32.43	7.66	40.09
PC212	37.75	6.11	43.86
PC213	31.69	7.85	39.55
PC214	15.66	3.77	19.43
PC215	155.46	32.75	188.22
PC216	95.71	35.54	131.25
PC217	96.71	26.20	122.92
PC218	18.46	10.26	28.72
PC219	38.29	8.41	46.69
PC220	27.24	10.23	37.47
PC221	56.44	13.94	70.38
PC222	46.94	27.68	74.62
PC223	115.08	59.86	174.94
PC224	19.83	4.77	24.60
PC225	28.79	9.75	38.54
PC226	63.80	15.59	79.39
PC227	75.90	15.88	91.78
PC228	153.74	12.26	166.00
PC229	49.17	27.70	76.87
PC230	147.69	47.50	195.19
PC231	13.49	2.12	15.61
PC232	34.61	14.35	48.96
PC233	51.56	18.37	69.93
PC234	17.21	6.67	23.88
PC235	24.85	12.85	37.70
PC236	28.79	14.33	43.12
PC237	33.11	7.36	40.46
PC238	105.47	23.01	128.49
PC239	14.84	4.42	19.27
PC240	39.85	8.71	48.56
PC241	59.31	12.27	71.57
PC242	735.25	31.48	766.73
PC243	34.37	6.98	41.35
PC244	48.93	11.00	59.93
PC245	32.16	6.08	38.24
PC246	90.20	9.75	99.95
PC247	5.97	3.56	9.53
PC248	83.29	14.77	98.07
TOTAL	3330.41	794.39	4124.80

See separate Sheet 4 for location of subbasins.

The 1995 study identified three wetland areas tributary to Lake Padden and outside of the city limits. They were not included in the 1991 Bellingham wetland inventory. The three wetlands consist of the Our Lake wetland 1 (OL-1), Our Lake wetland 2 (OL-2), and

Governor Road wetland. OL-1 and Governor Road wetlands are open water ponds and OL-2 is a palustrine forested wetland.

Our Lake wetland 1 (OL-1) has received a high level of disturbance from substantial adjacent residential development. It has low vegetation species diversity and nonpoint source pollution problems. Our Lake wetland 2 (OL-2) and Governor Road wetland are characterized by lower levels of disturbance. They have high vegetation species diversity and fewer nonpoint source pollution problems.

Downstream of Lake Padden are four major wetland areas. These four wetland areas include estuarine intertidal wetlands, palustrine forest, scrub-shrub, and emergent wetlands. The intertidal wetlands (PA-1) provide unique wildlife habitat and important tidal flood control storage. Upstream, PA-2 and PA-4 are relatively undisturbed palustrine scrub/shrub and forested wetlands. PA-2 has moderate to good wildlife habitat; PA-4 consists of small areas along Padden Creek that are supplied by local seeps. PA-26 along Old Fairhaven Parkway has been adversely affected by a high level of human disturbance and has only minor wildlife habitat. The wetland does provide biofiltration and flood flow attenuation.

Wetlands in the Connelly Creek subbasins include wetlands PA-27 and PA-28 in the lower reaches of Connelly Creek. These disturbed wetlands consist of predominantly emergent and scrub-shrub vegetation. In contrast, wetlands PA-29 and PA-33 in the upper reaches of Connelly Creek consist of mature forest vegetation and provide excellent wildlife habitat and water quality benefits. PA-33 is part of an existing stormwater detention facility.

Cutthroat, rainbow trout, and landlocked sockeye salmon (also known as kokanee) are found in Lake Padden. Cutthroat and kokanee spawning habitat is provided by two unnamed tributaries to Lake Padden: a stream at the southeast end of the lake and the stream that flows from Our Lake through the Lake Padden Golf Course to Lake Padden.

Downstream of the lake coho and chum salmon have been observed in the lower reaches of Padden Creek. Fish ladders beneath the Chuckanut Drive bridge and at the east end of Fairhaven Park allow anadromous fish to travel upstream as far as the Brick Tunnel; however, the tunnel is reported to be impassable to upstream fish migration.

The Brick Tunnel also prevents salmon from reaching Connelly Creek. Coho are planted in Connelly Creek and cutthroat and steelhead have been observed in the creek, according to the 1995 study.

Nonpoint source pollutants in the form of chemicals used in lawn and garden maintenance and automobile-related oils and heavy metals enter Lake Padden. Downstream, residential and commercial development produces pollutants that are washed off into Padden Creek. Marine service companies adjacent to wetland PA-1 contribute pollutants to the intertidal habitat.

The 1995 study reported that most of the growth anticipated for the Padden Creek study area is expected to be a mixture of commercial and residential. Nonpoint source pollution will increase. Water quality mitigation must provide biofiltration and stormwater detention from these developments to provide opportunities for sediment capture, suspended soils filtration, and biological uptake of fertilizers and herbicides.

Public environmental education is another way to reduce the impacts of new (and existing) development on water quality. Key needs include proper application of yard and garden fertilizers, use of native plants in landscaping, and proper disposal and recycling of household wastes (including soapy water, oils, anti-freeze, cleaners, etc.).

Problem Identification

As previously discussed, after the conveyance network was developed within the model, an initial model analysis was performed to identify any surcharging pipes within the network. Locations of model-identified problems (surcharging pipes) are summarized in Table 10. Detailed problem identification is presented in Appendix A.

Solutions

Following initial problem identification, SWMM's automatic pipe resizing routine was used to increase the pipe diameter in the vicinity of the surcharging pipes identified during the initial model analysis. Quantities of potential pipes to be upsized are summarized in Table 23. Detailed solution information is presented in Appendix A.

Table 23. Padden Creek Model Results

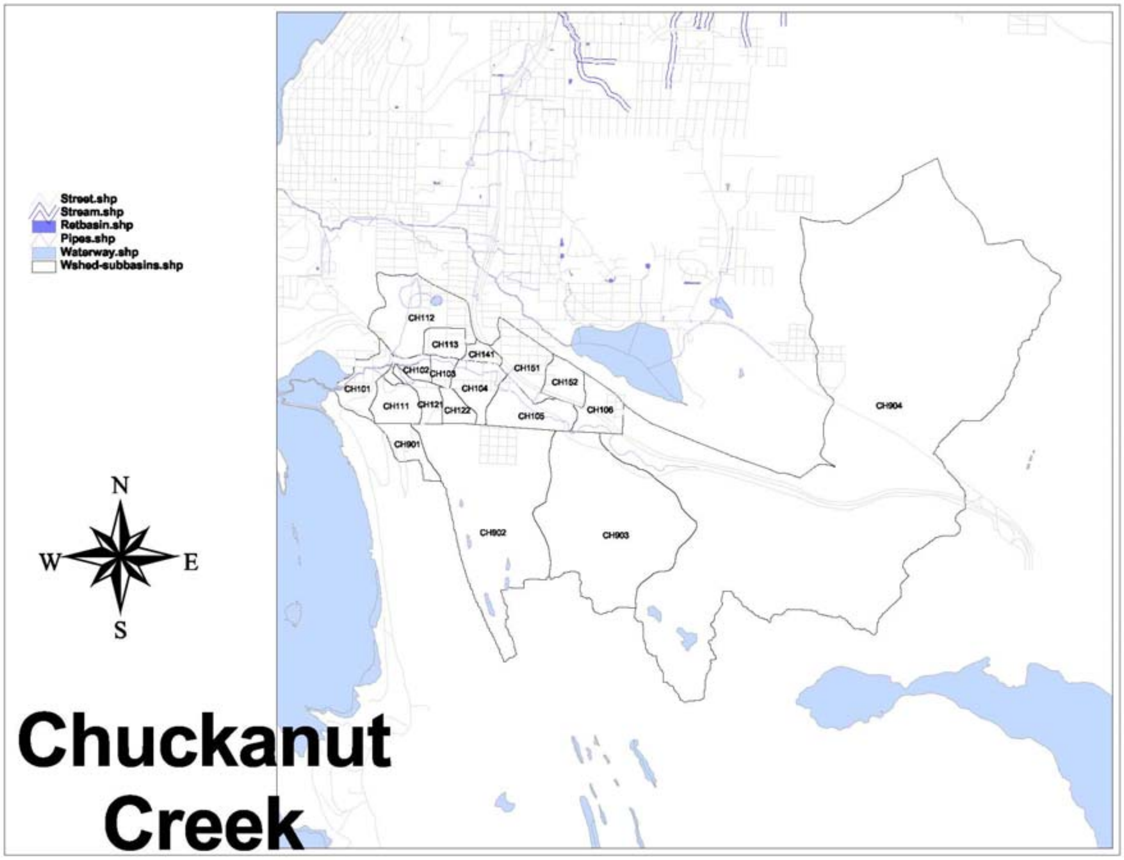
Basin	Improvement Project Group	Pipe Upgrade Quantity (linear feet)
Padden	Culverts, storm drains	6,500
Total		**6,500**

Cost Estimate

As previously discussed, GIS data for the existing system were not available for this basin. Therefore, model results identifying system deficiencies are conceptual and intended for planning-level decision-making only. With the available conveyance system data, model results are not considered detailed enough to generate reliable cost opinions for this basin. A cost opinion for capital improvement projects in this basin will be prepared in the future by others as additional system data are acquired and the model is updated.

CHUCKANUT CREEK STUDY AREA

The Chuckanut Creek study area is approximately 4724 acres (see Table 24), and averages 5% impervious area. The Chuckanut Creek watershed is located west and south of the Padden Creek watershed and drains to Chuckanut Bay.



Most of the Chuckanut watershed is still undeveloped forest lands, located outside of the city limits. Rural density single-family residential development has occurred along the major roads crossing the watershed. More established residential neighborhoods are found in the downstream subbasins near the bay.

The watershed is drained primarily by the main stem of Chuckanut Creek, which is fed by small perennial and intermittent tributaries. Hoag Pond and a large wetland located along the Interurban Trail provide stormwater storage and attenuation in the northwestern portion of the study area. Most drainage features consist of streams and culverts, with a few pipes and ditches in the more heavily developed northwest/downstream subbasins.

Table 24. Chuckanut Creek Study Area

Subbasin	Pervious (ac)	Impervious (ac)	Total (ac)
CC301	46.55	10.88	57.43
CC302	32.54	4.06	36.60
CC303	12.34	3.08	15.42
CC304	66.30	14.74	81.04
CC305	40.76	3.08	43.84
CC307	51.45	14.58	66.03
CC308	54.91	10.39	65.30
CC309	20.95	4.81	25.75
CC310	38.93	4.02	42.95
CC311	18.28	1.00	19.28
CC312	112.94	2.65	115.59
CC313	50.73	4.19	54.92
CC315	255.10	18.38	273.48
CC316	365.90	5.64	371.54
CC317	621.68	20.94	642.62
CC318	2688.65	123.24	2811.89
TOTAL	4478.00	245.68	4723.68

See separate Sheet 5 for location of subbasins.

The 1995 study studied six Chuckanut wetlands (CH-1, CH-10, CH-26, CH-27, CH-31, and CH-47). All of these wetlands have suffered only relatively low levels of human disturbance. They still have the native forest vegetation intact and provide moderate to excellent wildlife habitat.

Within the city limits Chuckanut Creek is barrier-free to salmon passage. Coho and chum salmon utilize Chuckanut Creek from Chuckanut Bay to a short distance upstream of the city limits, where the creek flows over steep rock outcrops that form an impassable barrier to farther passage. Cutthroat trout and steelhead trout make use of most of Chuckanut Creek and may be able to surmount the steep rock outcrops just upstream of the city limits.

Chuckanut Creek suffers few of the nonpoint source pollution problems found in the more highly urbanized Bellingham watersheds. However, failure of private older septic systems located in the creek's floodplain near the mouth of the stream pose a potential pollution problem. The 1995 study discovered another problem where I-5 drainage discharges into wetland CH-31. The wetland is filtering roadway pollutants, but is becoming adversely impacted. There are also locations where small creekside animal pastures contribute manure-laden runoff to Chuckanut Creek.

The 1995 study reported that most of the growth anticipated for the Chuckanut Creek study area is expected to be residential. Nonpoint source pollution will increase. Water quality mitigation must provide biofiltration and stormwater detention from these developments to provide opportunities for sediment capture, suspended soils filtration, and biological uptake of fertilizers and herbicides.

Public environmental education is another way to reduce the impacts of new development on water quality. Key needs include proper application of yard and garden fertilizers, use of native plants in landscaping, and proper disposal and recycling of household wastes (including soapy water, oils, anti-freeze, cleaners, etc.).

Problem Identification

For the Chuckanut Creek Basin, after the conveyance network was developed within the model, an initial model analysis was performed to identify any surcharging pipes within the network. However, given the limited conveyance system information available, model results were not considered conclusive. Future model analysis is recommended when more detailed conveyance system data become available.

Solutions

Since problem identification model results for the Chuckanut Creek Basin were not considered conclusive, potential solutions have been deferred to future model analysis, when more detailed conveyance system data become available.

Cost Estimate

As previously discussed, GIS data for the existing system were not available for this basin. Therefore, model results identifying system deficiencies are conceptual and intended for planning-level decision-making only. With the available conveyance system data, model results are not considered detailed enough to generate reliable cost opinions for this basin. A cost opinion for capital improvement projects in this basin will be prepared in the future by others as additional system data are acquired and the model is updated.

OPERATIONS AND MAINTENANCE

The City of Bellingham has approximately 120 public stormwater facilities and 800 private facilities connected to its stormwater system. The operations and maintenance of these facilities is governed by the City's NPDES Phase II permit and the Department of Ecology's 2005 *Stormwater Management Manual for Western Washington*.

The City's NPDES Phase II Municipal Stormwater Permit includes General Conditions G2, Proper Operation and Maintenance, which states

> Permittees shall at all times properly operate and maintain all facilities and systems of collection, treatment, and control (and related appurtenances) which are installed or used by the Permittee for pollution control to achieve compliance with the terms and conditions of this Permit.

The City's NPDES Phase II Municipal Stormwater Permit also includes Section 4.9 Minimum Requirement #9: Operation and Maintenance, which states

> Permittees must require an operation and maintenance manual that is consistent with the provisions of Volume V of the *Stormwater Management Manual for Western Washington* (2005) for all proposed stormwater facilities and BMPs. The party (or parties) responsible for maintenance and operation shall be identified in the operation and maintenance manual. For private facilities approved by the Permittee, a copy of the manual 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 manual 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 government.

The objective of this minimum requirement is to ensure that stormwater control facilities are adequately maintained and operated properly.

Volume V of the *Stormwater Management Manual for Western Washington* (2005) includes Section 4.6, Maintenance Standards for Drainage Facilities. This section provides facility-specific maintenance standards. For each type of facility the maintenance standards provide a table of information including the maintenance component, defect, conditions when maintenance is needed, and results expected when maintenance is performed.

Maintenance standards are provided for detention ponds, infiltration, closed detention systems (tanks/vaults), control structures/flow restrictors, catch basins, debris barriers (trash racks, etc.), energy dissipaters, typical biofiltration swales, wet biofiltration swales, filter strips, wetponds, wetvaults, sand filters (above ground/open), sand filters (below ground/closed), Stormfilter (leaf compost filter), baffle oil/water separators (API type), coalescing plate oil/water separators, and catchbasin inserts.

The City of Bellingham requires an operations and maintenance manual for all public and private stormwater facilities and inspects all facilities a minimum of once a year.

Maintenance, inspection, and repair of stormwater facilities is part of the City of Bellingham Department of Public Works Street Division's responsibilities. The Street Division is responsible for maintenance of storm drains and grates, catch basins, retention ponds, and street sweeping.

Appendix 6 of the City's NPDES Phase II Municipal Stormwater Permit describes procedures for street waste disposal. The general procedures state that street waste collection should emphasize retention of solids in preference to liquids. Street waste solids are the principle objective of street waste collection and are easier to store and treat than liquids. Street waste liquids usually contain high amounts of suspended and total solids and adsorbed metals and require treatment before discharge. Specific rules are presented in the appendix on the disposal of liquid street waste.

HYDROLOGIC MODELING PROCEDURES

The identification of stormwater facility deficiencies was accomplished using WWHM3 with its combination of HSPF hydrology and SWMM hydraulics. City of Bellingham GIS conveyance system data were used where possible. Missing or incomplete GIS conveyance system data were filled by CCS based on adjacent data. GIS conveyance system data were available for the most or parts of the Whatcom Creek watershed, Squalicum Creek watershed, and Silver Creek watershed. No GIS conveyance system data were available for the Padden Creek watershed, Chuckanut Creek watershed, or the Silver Beach Creek watershed. For these watersheds conveyance system data were based on previous Waterworks models and/or other data provided by city staff.

Stormwater runoff routing through the conveyance systems was computed using HSPF RCHRES for open channel and culvert conveyance systems and PCSWMM Transport for stormwater pipe conveyance systems. Both routing options are available in WWHM3 PRO COMPLETE edition.

The WWHM3 model was used for the following purposes:

To provide data to analyze stormwater problems
To evaluate the effectiveness of alternative solutions to reduce stormwater flooding

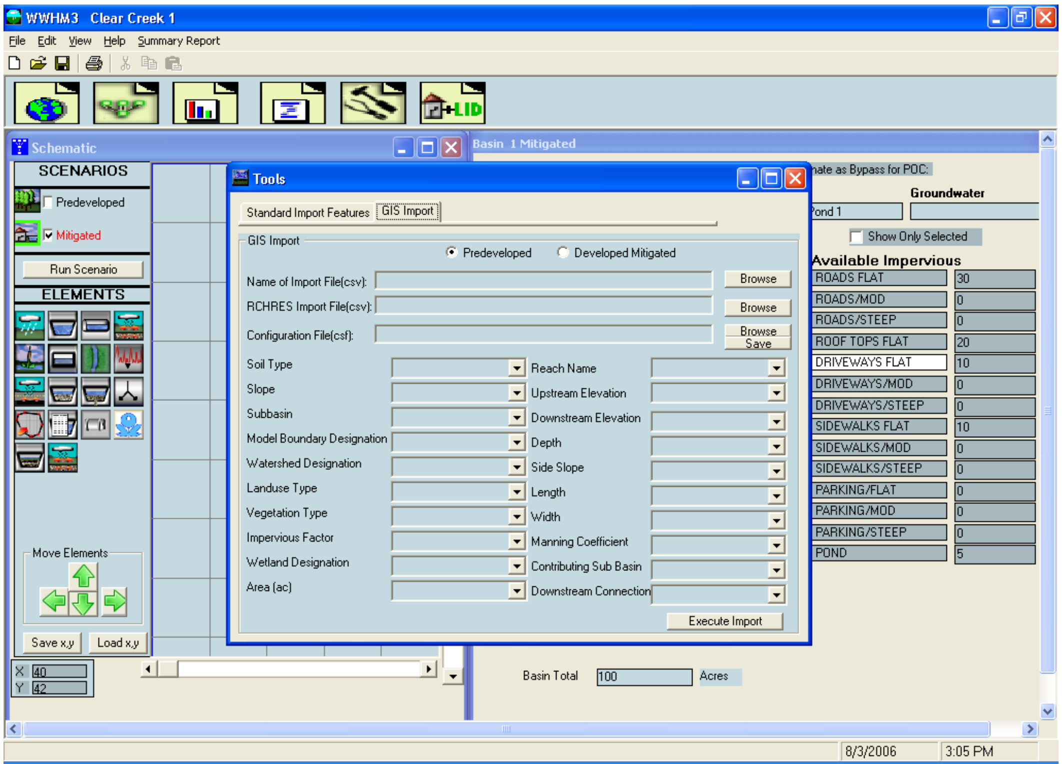
Modeled stormwater runoff data were used to identify locations where the stormwater conveyance system is undersized and at risk of failure.

CCS gave a two-day workshop to City of Bellingham staff on May 7 and 8, 2007, in which the WWHM3 modeling procedures were explained. The following information is a summary of the WWHM3 SWMM presentation given at that workshop.

The procedures for modeling the stormwater system are described below.

WWHM3 GIS IMPORT Feature

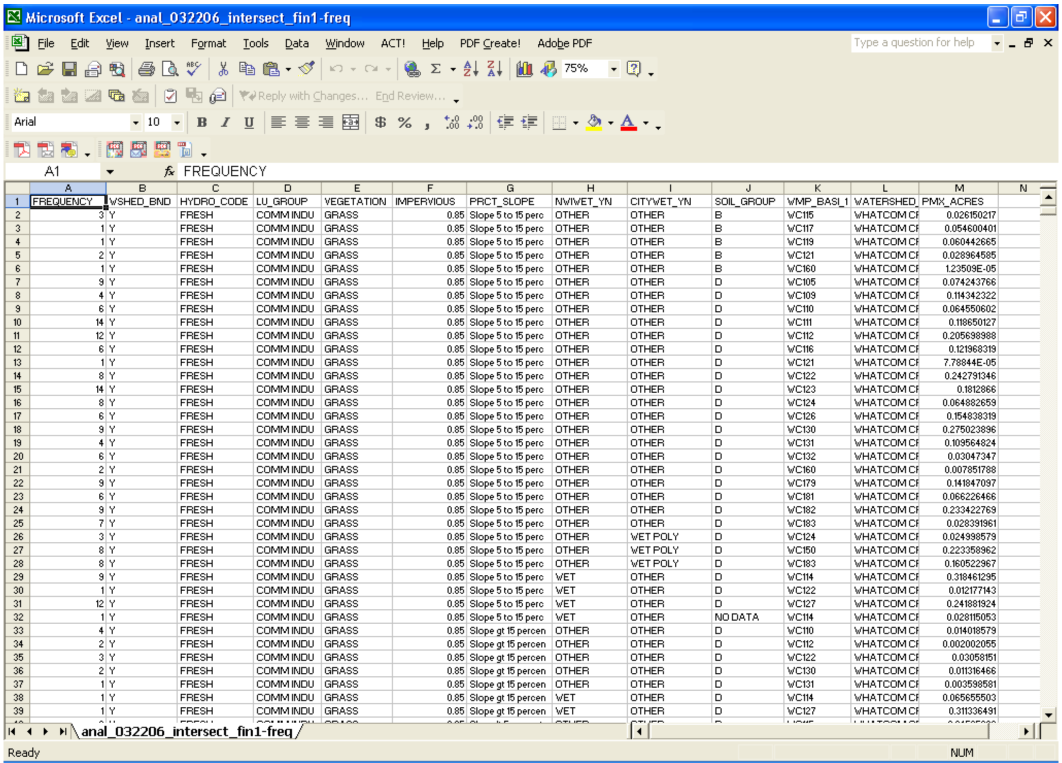
The WWHM3 GIS Import feature makes possible the direct input of GIS land use and open channel reach information to the WWHM3 model using the following procedures.



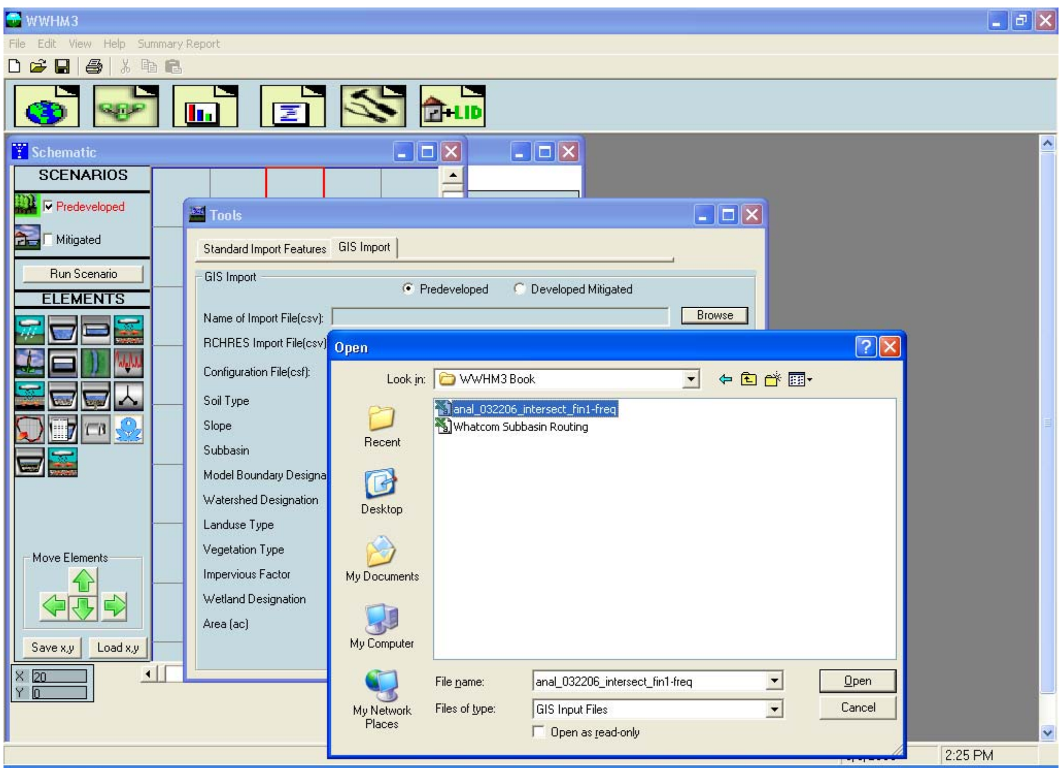
GIS Import allows the user to import basin and open channel data from a comma delimited tables created from ARC shape (.SHP) files to make a WWHM3 model.

There are three GIS Import-related files:

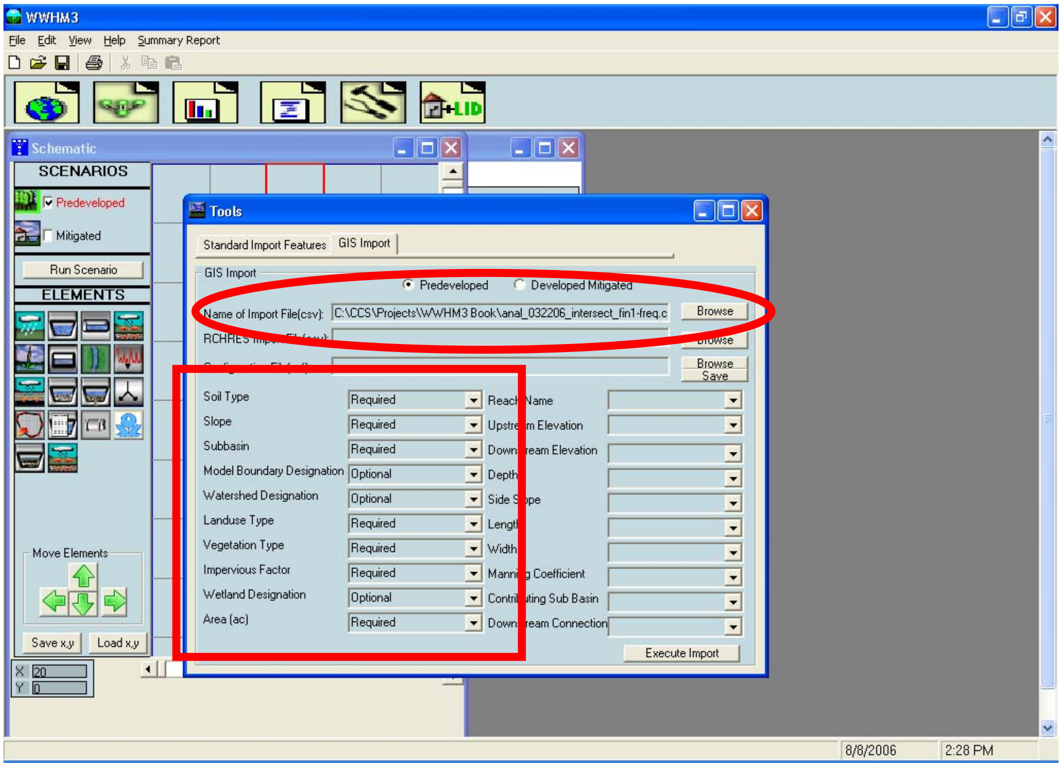
1. Import File (csv): basin land use data
2. RCHRES Import File (csv): open channel data and connections
3. Configuration File (csf): column connections file created in WWHM3 that can be later read by WWHM3 to assist in the input of basin and open channel data.



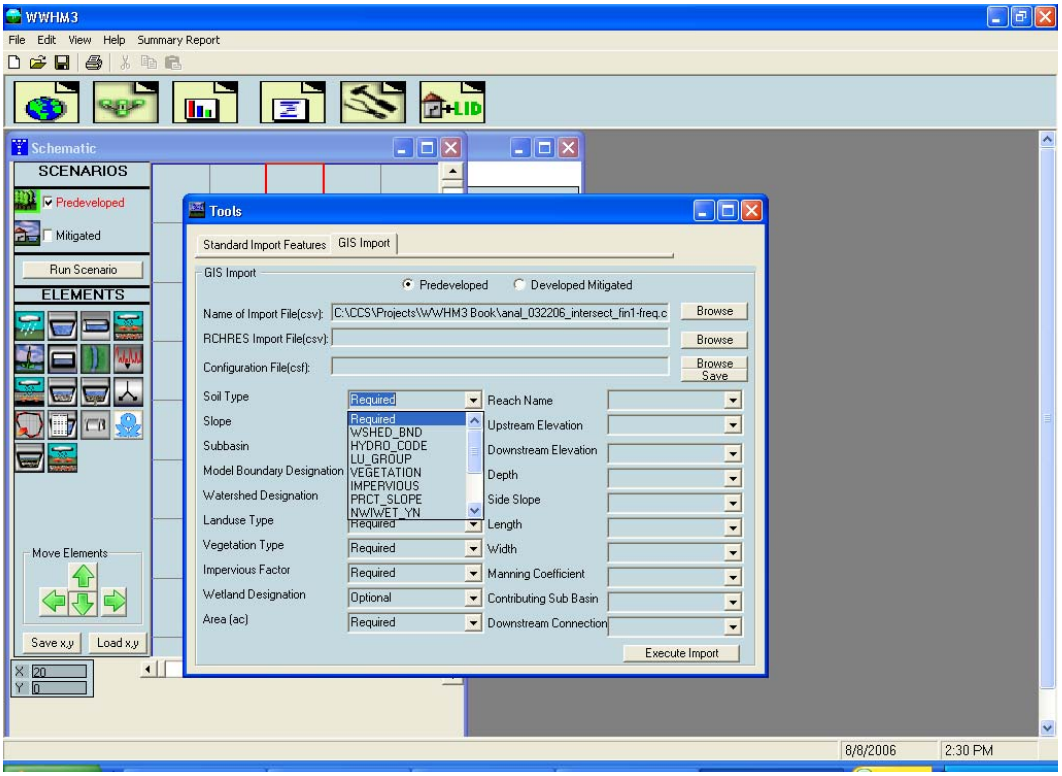
This is what an Import File looks like. It is a comma delimited file.



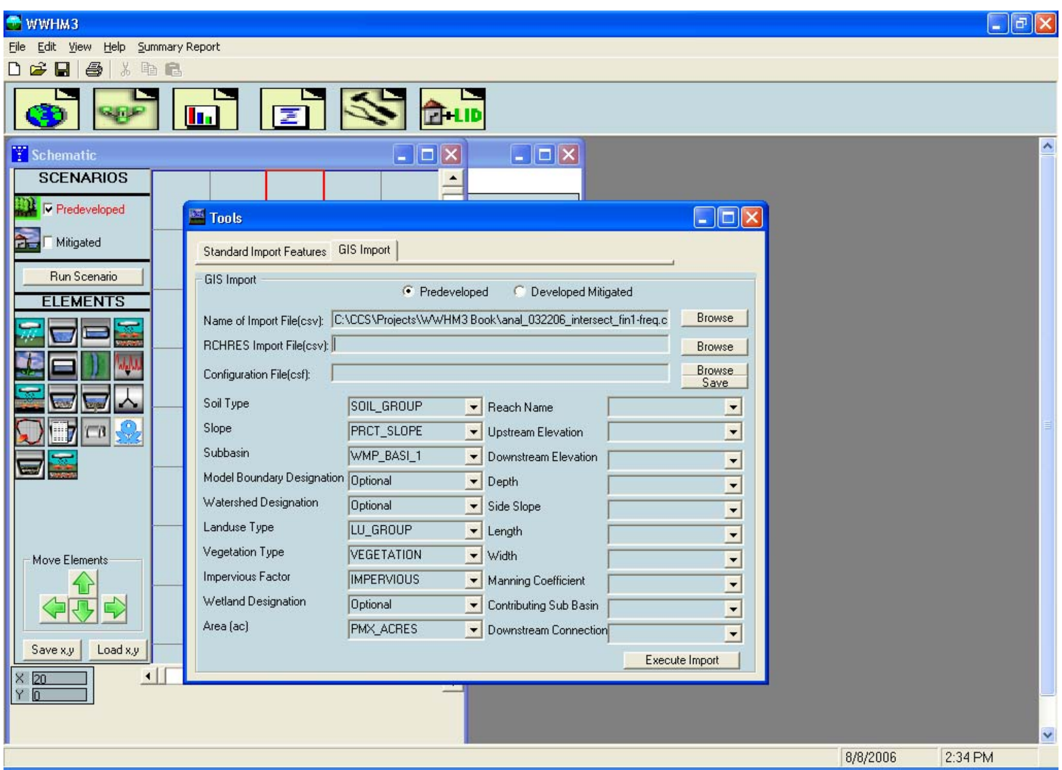
We browse to find the location of the Import File and then select and open the file.



We can see that some GIS information is required and some is optional.

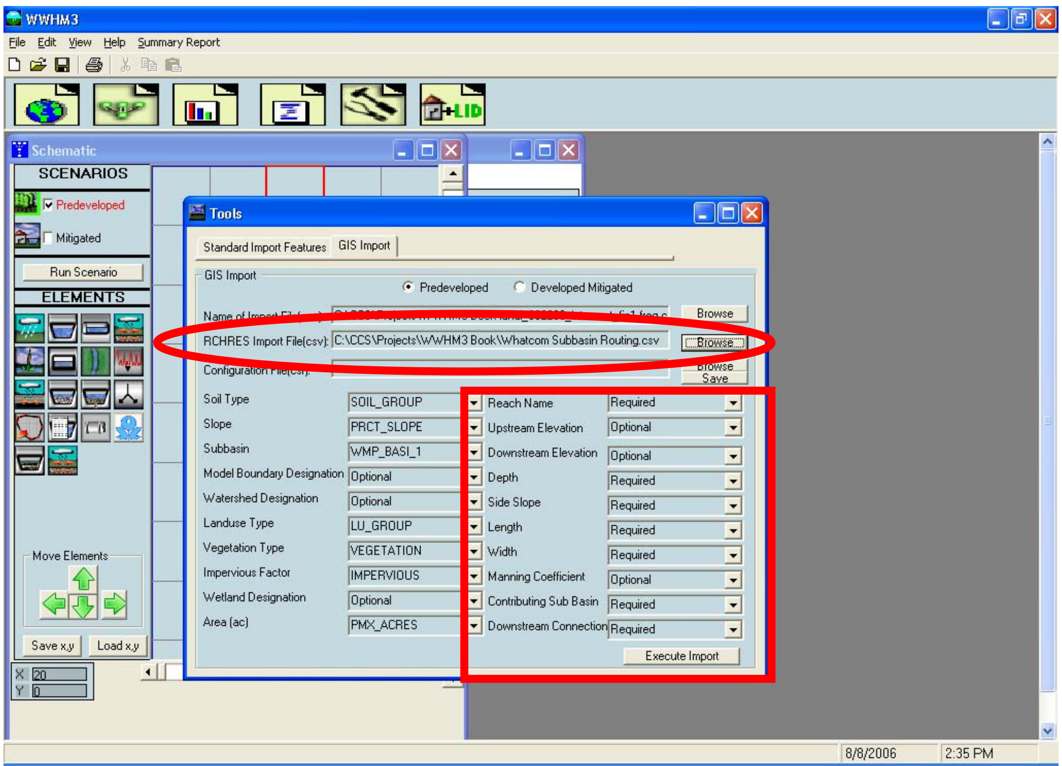


By clicking on the down arrow next to each category we can specify the appropriate header in the Import File.

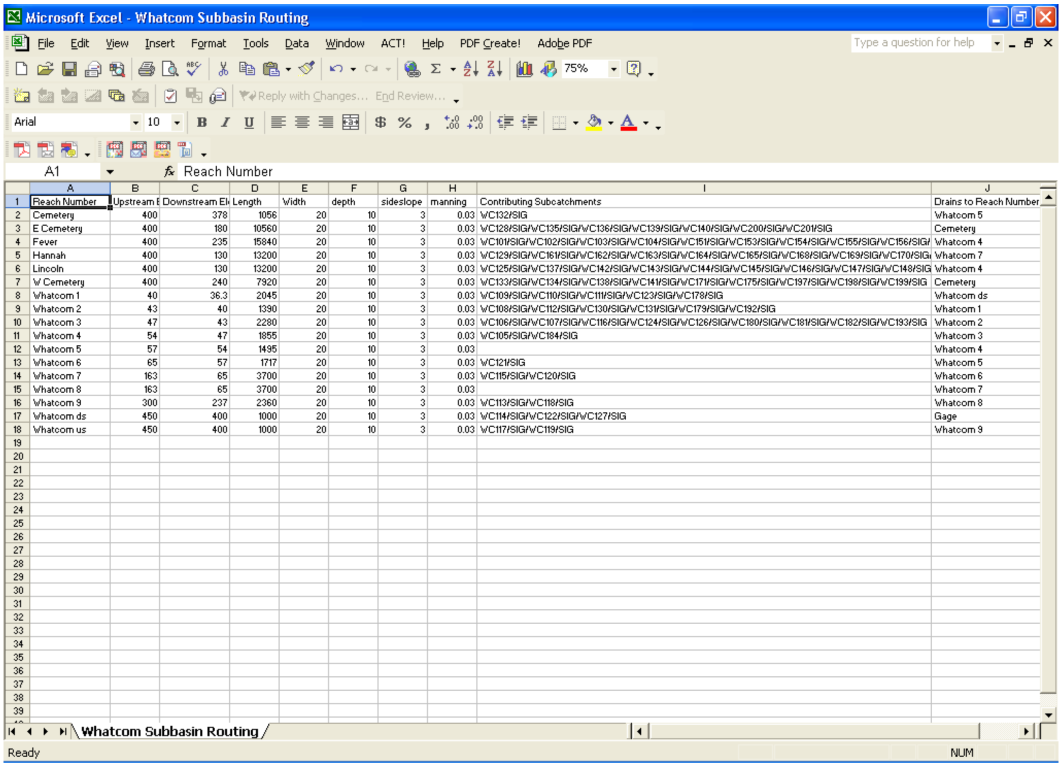


All of the required categories are now assigned the appropriate column of data from the Import File. Before clicking on Execute Import to transfer the data to WWHM3 basin elements we want to also set up the RCHRES Import File.

It is always best to set up and assign the column categories to both the Import File and the RCHRES Import File before importing data.

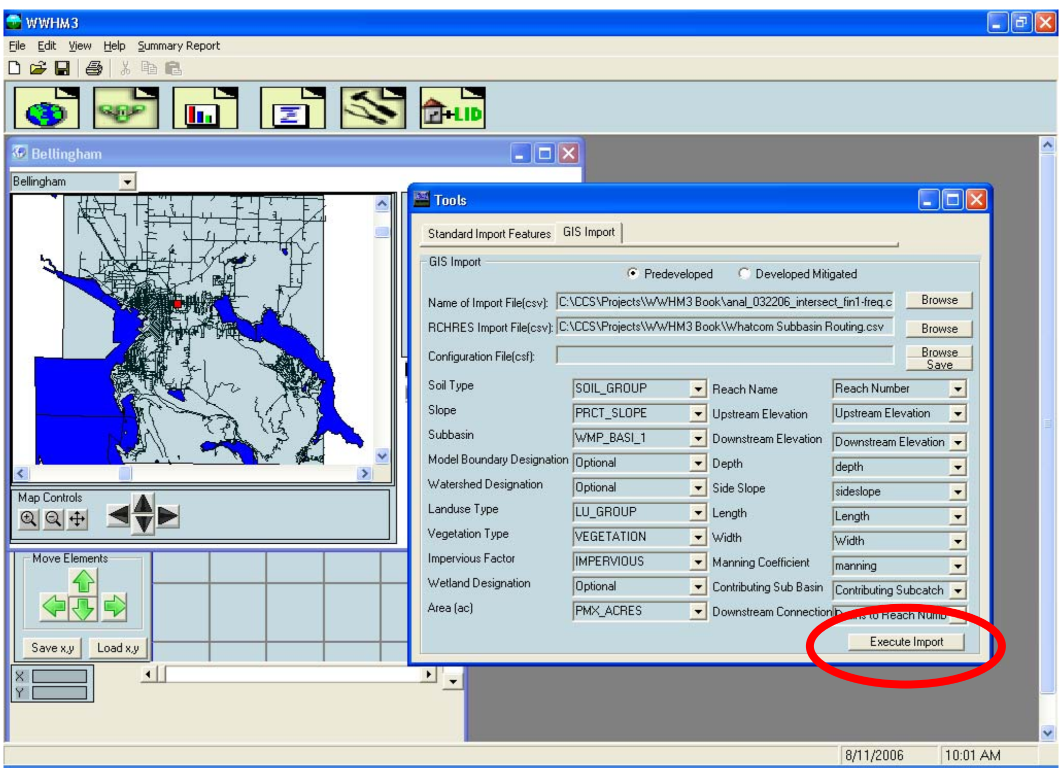


We repeat the process for the RCHRES Import File.

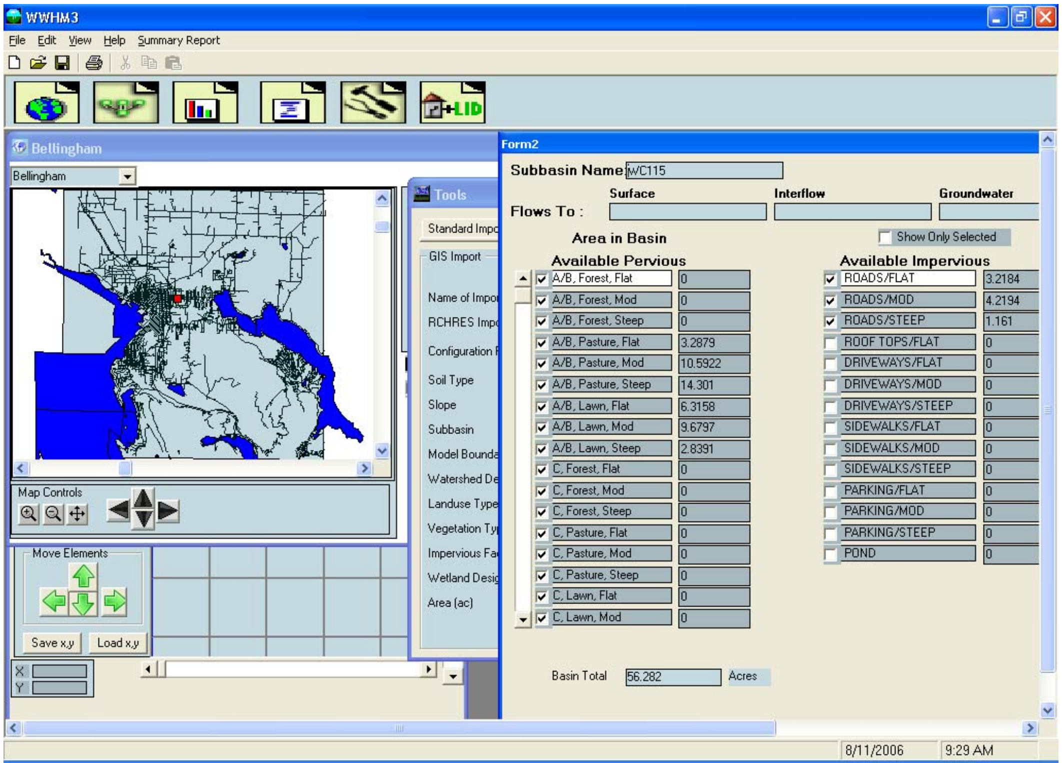


Reach Number	Upstream E	Downstream El	Length	Width	depth	sideslope	manning	Contributing Subcatchments	Drains to Reach Number
Cemetery	400	378	1056	20	10	3	0.03	WC132/SIG	Whatcom 5
E Cemetery	400	180	10560	20	10	3	0.03	WC128/SIG/WC135/SIG/WC136/SIG/WC139/SIG/WC140/SIG/WC200/SIG/WC201/SIG	Cemetery
Fever	400	235	15840	20	10	3	0.03	WC101/SIG/WC102/SIG/WC103/SIG/WC104/SIG/WC151/SIG/WC153/SIG/WC154/SIG/WC155/SIG/WC156/SIG/	Whatcom 4
Hannah	400	130	13200	20	10	3	0.03	WC129/SIG/WC161/SIG/WC162/SIG/WC163/SIG/WC164/SIG/WC165/SIG/WC168/SIG/WC169/SIG/WC170/SIG	Whatcom 7
Lincoln	400	130	13200	20	10	3	0.03	WC125/SIG/WC137/SIG/WC142/SIG/WC143/SIG/WC144/SIG/WC145/SIG/WC146/SIG/WC147/SIG/WC148/SIG	Whatcom 4
W Cemetery	400	240	7920	20	10	3	0.03	WC133/SIG/WC134/SIG/WC138/SIG/WC141/SIG/WC171/SIG/WC175/SIG/WC197/SIG/WC198/SIG/WC199/SIG	Cemetery
Whatcom 1	40	36.3	2045	20	10	3	0.03	WC109/SIG/WC110/SIG/WC111/SIG/WC123/SIG/WC178/SIG	Whatcom ds
Whatcom 2	43	40	1390	20	10	3	0.03	WC108/SIG/WC112/SIG/WC130/SIG/WC131/SIG/WC179/SIG/WC192/SIG	Whatcom 1
Whatcom 3	47	43	2280	20	10	3	0.03	WC106/SIG/WC107/SIG/WC116/SIG/WC124/SIG/WC126/SIG/WC180/SIG/WC181/SIG/WC182/SIG/WC193/SIG	Whatcom 2
Whatcom 4	54	47	1855	20	10	3	0.03	WC105/SIG/WC184/SIG	Whatcom 3
Whatcom 5	57	54	1495	20	10	3	0.03		Whatcom 4
Whatcom 6	65	57	1717	20	10	3	0.03	WC121/SIG	Whatcom 5
Whatcom 7	163	65	3700	20	10	3	0.03	WC115/SIG/WC120/SIG	Whatcom 6
Whatcom 8	163	65	3700	20	10	3	0.03		Whatcom 7
Whatcom 9	300	237	2360	20	10	3	0.03	WC113/SIG/WC118/SIG	Whatcom 8
Whatcom ds	450	400	1000	20	10	3	0.03	WC114/SIG/WC122/SIG/WC127/SIG	Gage
Whatcom us	450	400	1000	20	10	3	0.03	WC117/SIG/WC119/SIG	Whatcom 9

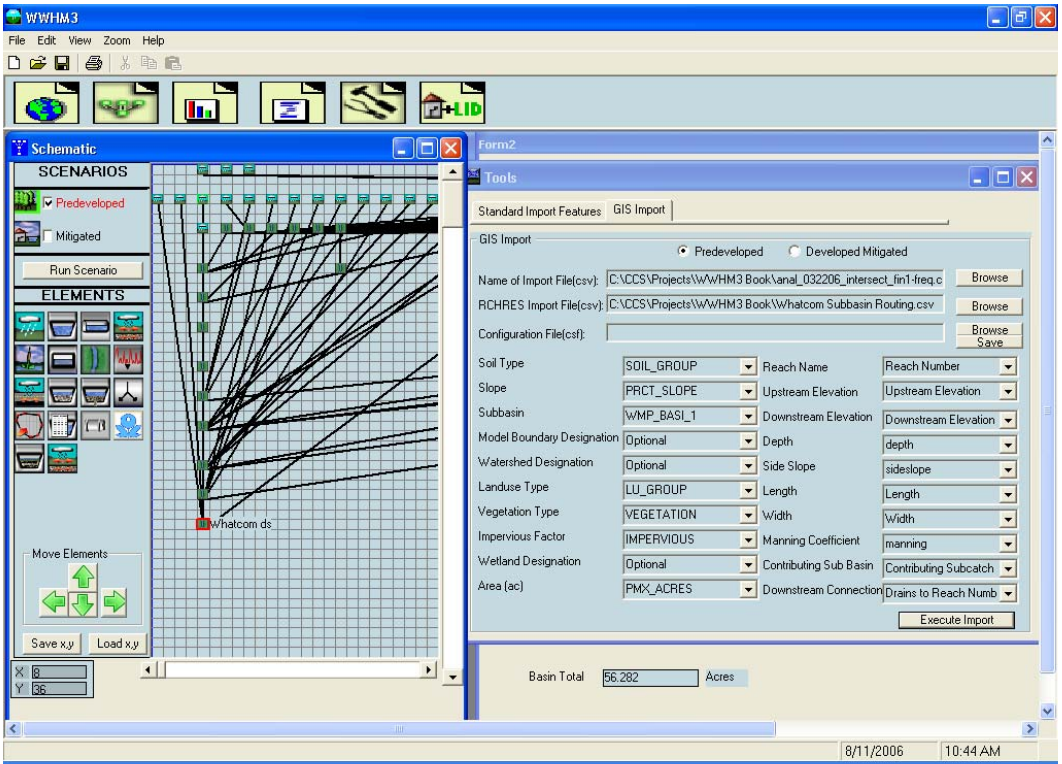
This is the form that the RCHRES Import File data is in.



All of the routing categories are assigned appropriate columns from the RCHRES Import File. After both import files are set up we click the Execute Import button to transfer the information to the WWHM3 model.

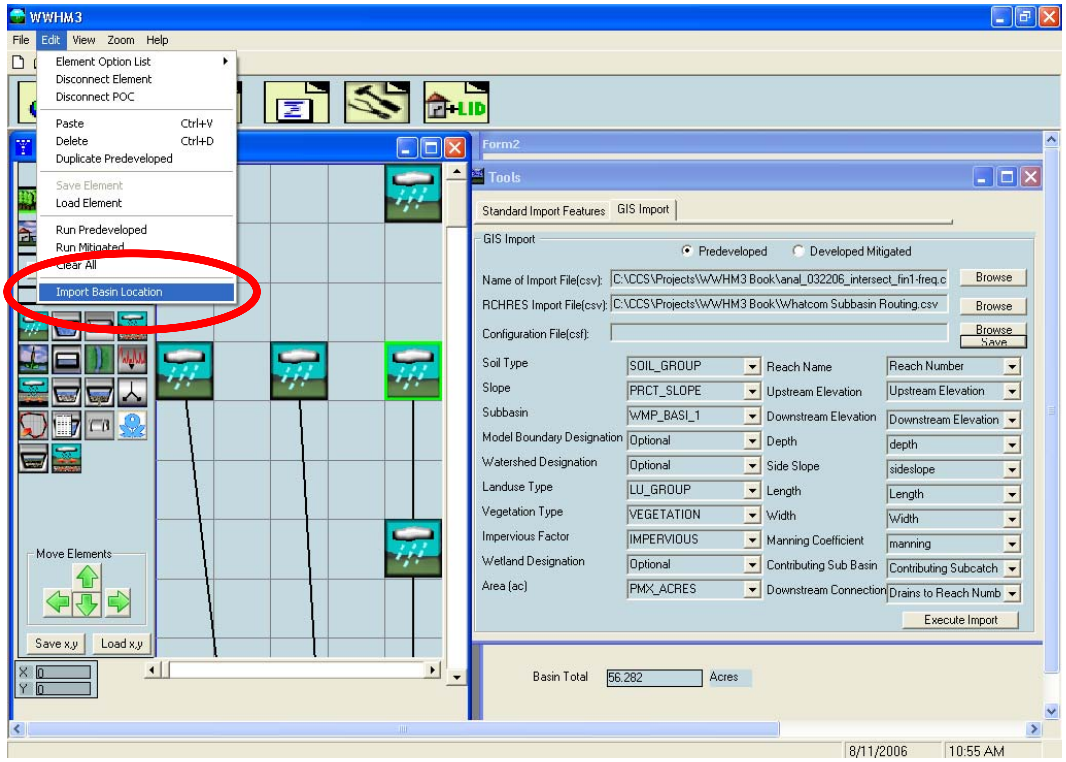


The land use information is translated by WWHM3 into the appropriate pervious and impervious land categories for each basin element.



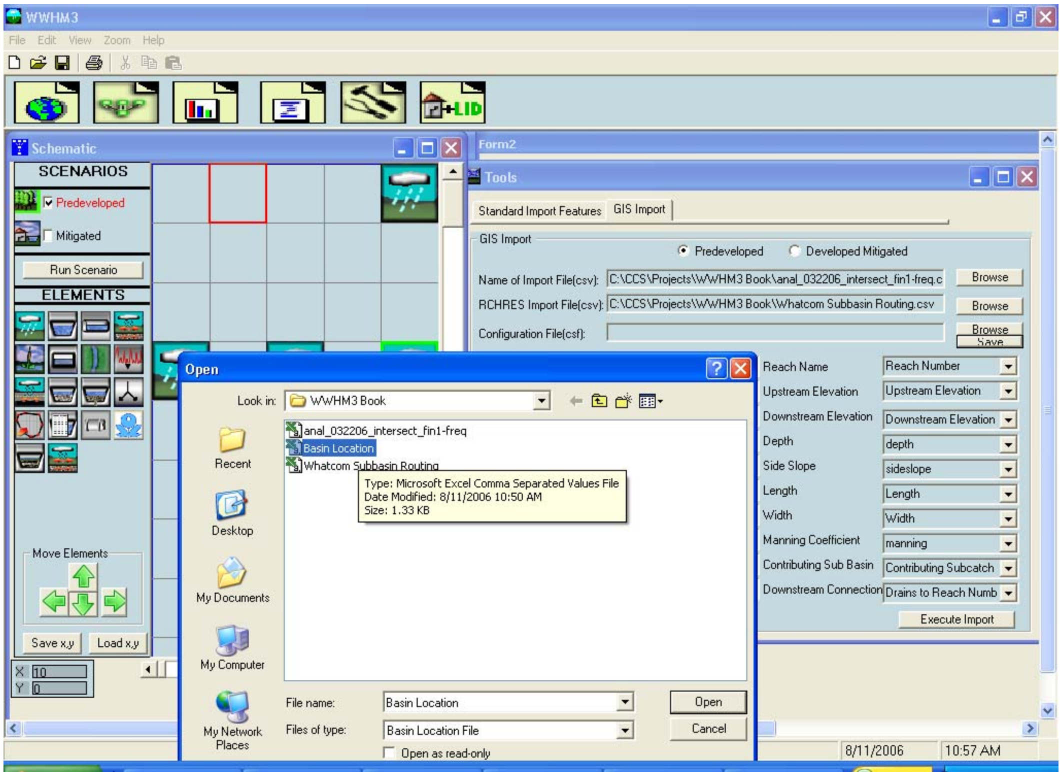
Clicking on the Schematic grid shows the combined basin and channel scenario.

If there are a large number of basins and channels the layoff of the individual elements can be confusing. Elements can be manually moved on the Schematic grid, but in the example above it would be a long and painful process.

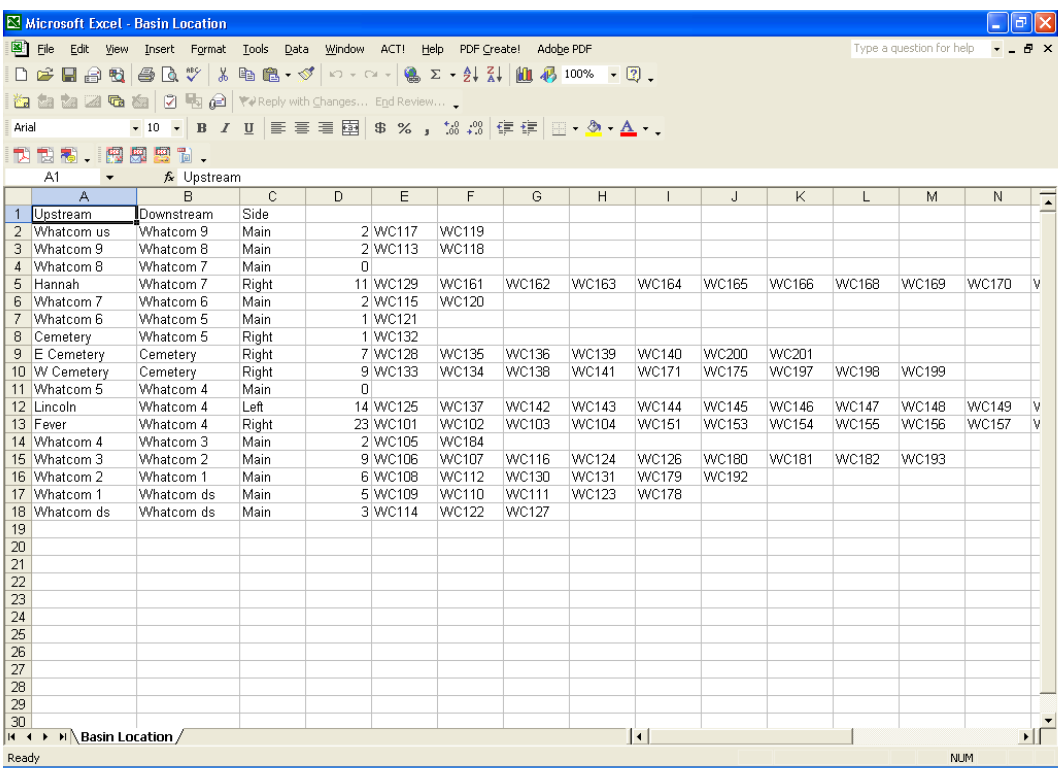


A better alternative is to import a basin location file to reorganize the basin and channel elements on the Schematic grid. Make sure that the Schematic window is lit, click on Edit, and scroll down to and click on Import Basin Location.

Before using Import Basin Location make sure that the Zoom factor for the Schematic grid is set to 1X. A Zoom factor of 2X or 5X will not work.



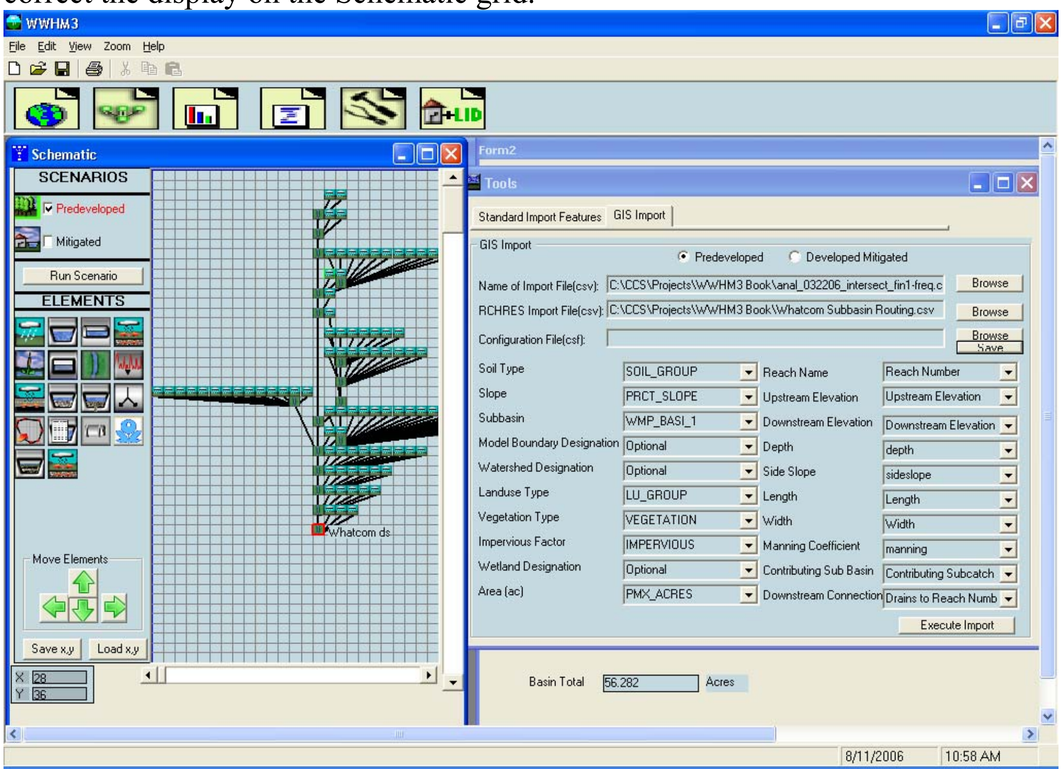
The basin location file is a user-created comma delimited spreadsheet file that specifies how the basin and channel elements are linked and displayed on the Schematic grid.



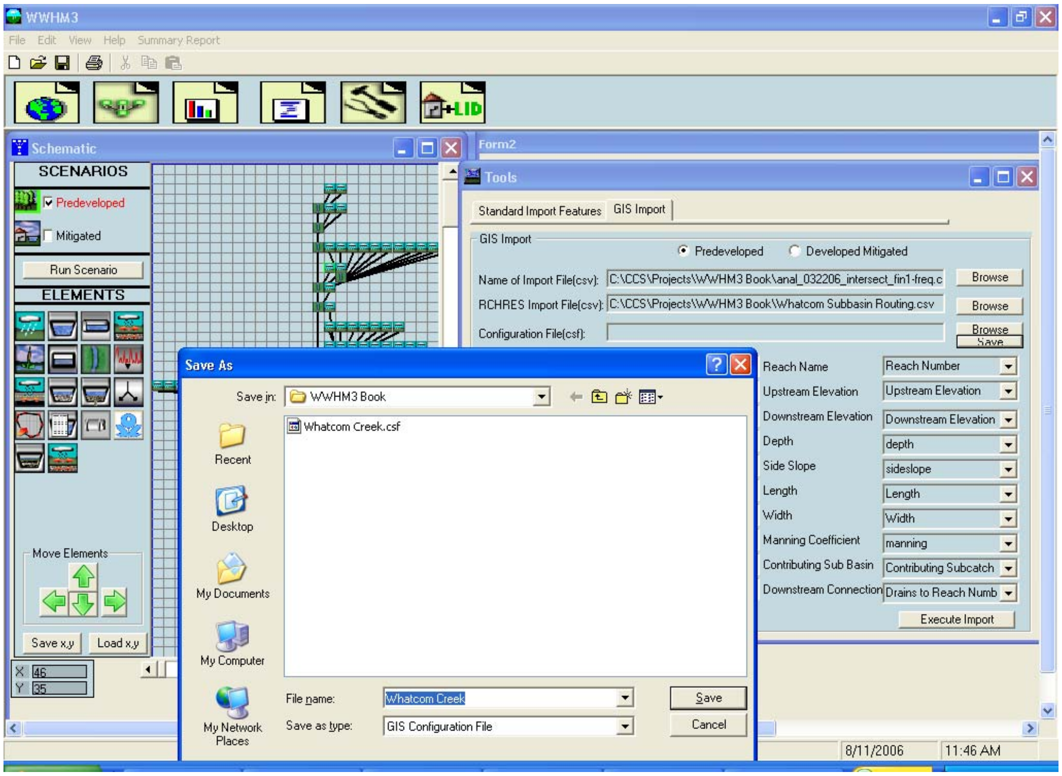
	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Upstream	Downstream	Side											
2	Whatcom us	Whatcom 9	Main	2	WC117	WC119								
3	Whatcom 9	Whatcom 8	Main	2	WC113	WC118								
4	Whatcom 8	Whatcom 7	Main	0										
5	Hannah	Whatcom 7	Right	11	WC129	WC161	WC162	WC163	WC164	WC165	WC166	WC168	WC169	WC170
6	Whatcom 7	Whatcom 6	Main	2	WC115	WC120								
7	Whatcom 6	Whatcom 5	Main	1	WC121									
8	Cemetery	Whatcom 5	Right	1	WC132									
9	E Cemetery	Cemetery	Right	7	WC128	WC135	WC136	WC139	WC140	WC200	WC201			
10	W Cemetery	Cemetery	Right	9	WC133	WC134	WC138	WC141	WC171	WC175	WC197	WC198	WC199	
11	Whatcom 5	Whatcom 4	Main	0										
12	Lincoln	Whatcom 4	Left	14	WC125	WC137	WC142	WC143	WC144	WC145	WC146	WC147	WC148	WC149
13	Fever	Whatcom 4	Right	23	WC101	WC102	WC103	WC104	WC151	WC153	WC154	WC155	WC156	WC157
14	Whatcom 4	Whatcom 3	Main	2	WC105	WC184								
15	Whatcom 3	Whatcom 2	Main	9	WC106	WC107	WC116	WC124	WC126	WC180	WC181	WC182	WC193	
16	Whatcom 2	Whatcom 1	Main	6	WC108	WC112	WC130	WC131	WC179	WC192				
17	Whatcom 1	Whatcom ds	Main	5	WC109	WC110	WC111	WC123	WC178					
18	Whatcom ds	Whatcom ds	Main	3	WC114	WC122	WC127							

The format of the basin location file is as follows:
Column A: the upstream channel reach name
Column B: the corresponding downstream channel reach name
Column C: whether the connection is Main, Right, or Left; Main means main channel (in the middle of the schematic); Right means place the elements to the right of the main channel on the schematic; Left means place the elements on the left side. The locations (Main, Right, or Left) are based on the user's sense of style and convention.
Column D: number of basins connecting to the channel reach
Columns E-Z and beyond: the names of the basins connecting to the channel reach

The basin location file can be changed or updated and reused as needed to improve or correct the display on the Schematic grid.



The basin location file is found and by clicking Open WWHM3 is given the information needed to reorganize the display of the basins and channels on the Schematic grid.



The final step in the GIS Import process is to create a Configuration File. The Configuration File records the Import File and the RCHRES Import File and their column linkages to the appropriate categories for each file.

Creation of a Configuration File is optional, but allows the user to update the information in either the Import File (for basin information) or the RCHRES Import File (for channel information) and then re-input all of the data in the WWHM3 model. This is done by selecting the previously created Configuration File and then clicking on the Execute Import button. By selecting the Configuration File the user then bypasses manually making all of the connections for the Import File and the RCHRES Import File.

The next step is the input of the GIS data into the SWMM routing option.

WWHM3 Procedure for Updating GIS Conveyance Data

Because of data gaps in the city's GIS conveyance data we needed to add conveyance system data for use in the SWMM modeling, described below. This new or modified conveyance system data needs to be documented in the city's stormwater conveyance system GIS database so that future model users know what data are based on field measurements and what data are estimated and added for modeling purposes. The estimated conveyance system data eventually should be field checked and replaced with accurate field measurements.

The information below is provided so that GIS users can identify the estimated data and understand how it has been added to the GIS database.

Clear Creek Solutions used the following steps to modify the GIS database:

1. added additional fields that include all required data
2. updated existing data, in cc_ fields only, with missing data
3. provided a file that includes 80 elements to be added to the GIS data
4. verified that the original SWMM files can be reconstructed from the updated GIS database

GIS Update:

1. File cvy_bham_cc_pmx_append1.dbf must be updated to match APPEND1.DBF
    - add 4 new required fields: cc_Geom1, cc_Geom2, cc_Geom3, cc_Barrels
    - create additional elements from APP_ADD.DBF

Files included:

append1_new.dbf (APPEND1.DBF)

- include all updated data to replace original file
- the index files *.sbn and *.sbx must to be updated or recreated by Parametrix
- includes 4 new required fields: cc_Geom1, cc_Geom2, cc_Geom3, cc_Barrels

append1_add.dbf (APP_ADD.DBF)

- includes 80 additional elements to add to the GIS model
- includes extra fields: From_Easting, From_Northing, To_Easting, To_Northing to
  assist in locating the elements
- the extra field are not required in the final product and may be dropped

Bell.mdb is the project database including all data tables, queries, and macros to update GIS database file.

Procedure to export to SWWM model database files:

The SWWM model requires two tables Conduits and Nodes. (See SWWM table layouts below for Conduits and Nodes table layouts.)

The Conduits table can be reconstructed with a single, simple query that

1) assigns ID: CStr([cc_ID]) where <> 0
2) cc_New_Tab = <see list of values>
3) assign default values to all fields with no corresponding columns
4) assign values to all fields with corresponding columns

cc_New_Tab
baker-culverts-import
cemetary-whatcom
fever-whatcom
hannah-whatcom
lower-paddenpipes-converted
silverconvey
squal-rest-culverts-import
upper-paddenpipes-converted
whatcom-whatcom

The Nodes table can be reconstructed with two queries.

First query – returns all From Nodes

1) assigns ID: CStr([cc_Node1]) where <> 0
2) cc_New_Tab = <see list of values>
3) assign default values to all fields with no corresponding columns
4) assign values to all fields with corresponding columns

Second query – returns all unmatched To Nodes

5) assigns ID: CStr([cc_Node2]) where <> any CStr([cc_Node1])
6) cc_New_Tab = <see list of values>
7) assign default values to all fields with no corresponding columns
8) assign values to all fields with corresponding columns

Bell.mdb

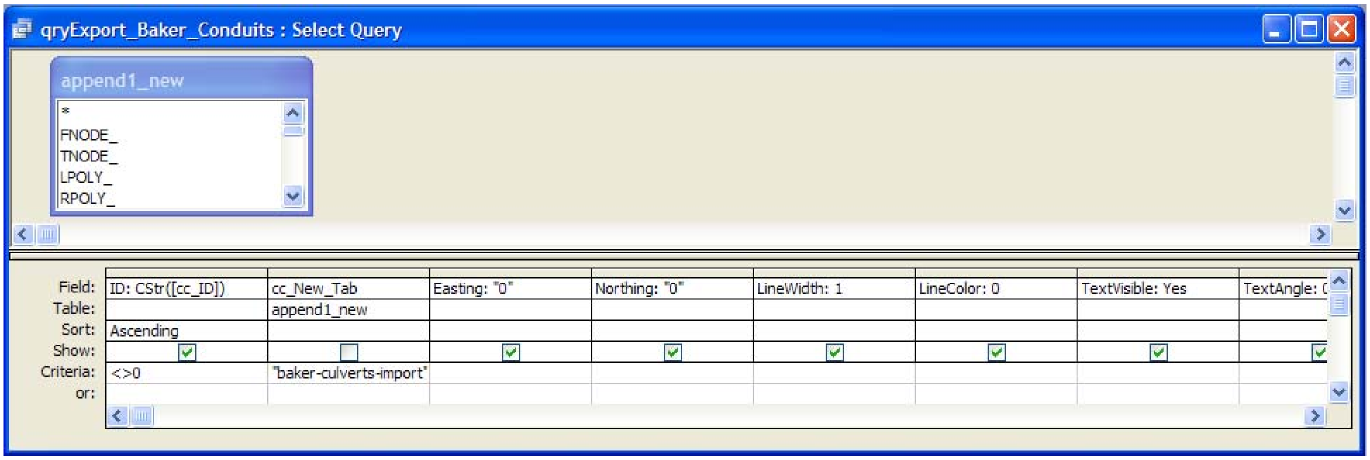
Steps to reproduce results:
Tables
1) drop tables append1_new, append1_add
2) copy layout and data from append1_new0 to append1_new
3) copy layout and data from append1_add0 to append1_add
Macros
4) run mcr_1_append1_new to
    - Add cross node records
    - Add data to new fields cc_Geom1 - cc_Barrels
    - Add cross node records
5) run mcr_2_Tables_new to
    - Drop resultant tables
    - Create resultant table structures
    - Add data from append1_new table
6) run mcr_3_Additional_add to add 95 records
    - compare original conduits and new conduits tables
    - add missing records to append1_add with Easting and Northing data
7) copy and append append1_add to append1_new
8) run mcr_2_Tables_new to
    - Drop resultant tables
    - Create resultant table structures
    - Add data from append1_new table
9) run diff* queries to note any differences between
    original conduits and new conduits tables
10) run mcr_4_Recreate to
    - recreate original database files from append1_new

Export new APPEND1.DBF and APP_ADD.DBF file to update
cvy_bham_cc_pmx_append1.dbf

1) _qryExport_append1_dbf
    - export to dBase IV format

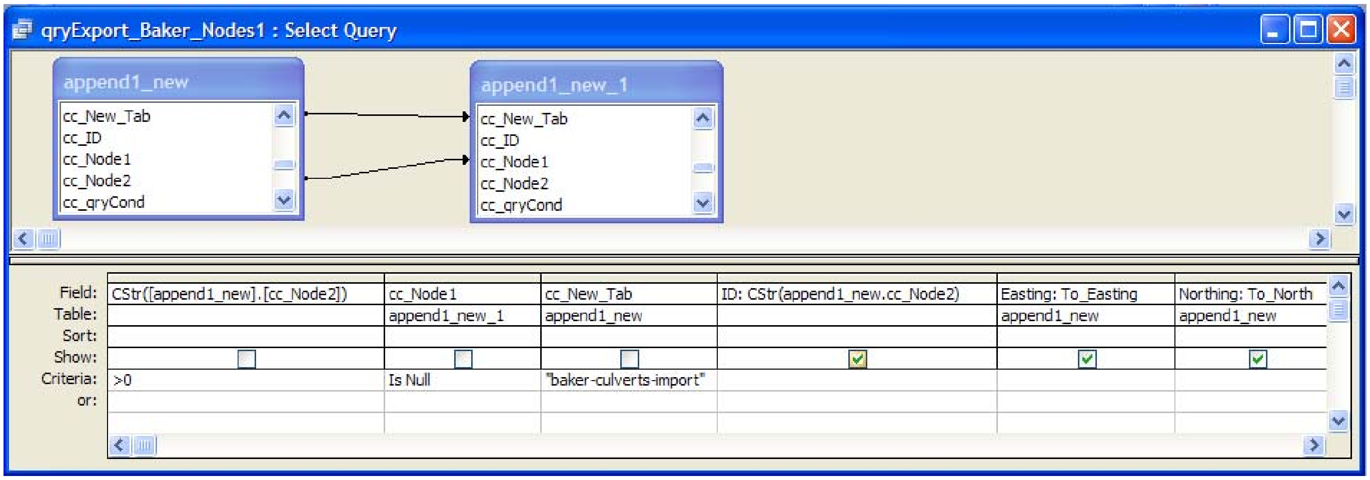
2) _qryExport_append1_add_dbf
    - export to dBase IV format

Recreate “Conduits” table (qryExport_<basin>_Conduits)



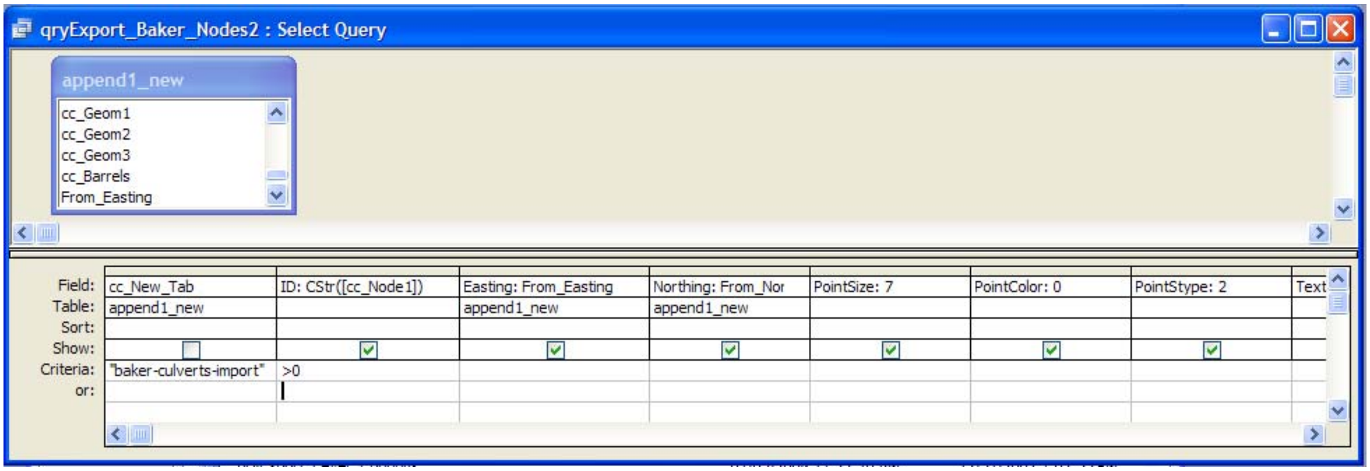

```
SELECT CStr([cc_ID]) AS ID,
        "0" AS Easting,
        "0" AS Northing,
        1 AS LineWidth,
        0 AS LineColor,
        Yes AS TextVisible,
        0 AS TextAngle,
        8 AS TextSize,
        0 AS TextColor,
        Str([cc_Node1]) AS [Node 1],
        Str([cc_Node2]) AS [Node 2],
        append1_new.cc_qryCond AS Type,
        append1_new.cc_Length AS Length,
        append1_new.cc_Slope AS Slope,
        append1_new.cc_Roughne AS Roughness,
        append1_new.cc_Geom1 AS Geom1,
        append1_new.cc_Geom2 AS Geom2,
        append1_new.cc_Geom3 AS Geom3,
        append1_new.cc_Barrels AS Barrels,
        append1_new.cc_Comment AS Comments,
        0 AS ComputedFlow,
        0 AS ObservedFlow,
        0 AS ComputedVelocity,
        0 AS ObservedVelocity,
        "" AS Field1,
        "" AS Field2,
        No AS Selected,
        -1 AS Handle1,
        -1 AS Handle2,
        -1 AS Handle3,
        -1 AS Handle4
FROM append1_new
WHERE (((CStr([cc_ID]))<>0) AND ((append1_new.cc_New_Tab)="baker-culverts-import"))
ORDER BY CStr([cc_ID]);
```

Recreate “Nodes” table query 1 of 2 (qryExport_<Basin>_Nodes1)



SELECT CStr(append1_new.cc_Node2) AS ID,
append1_new.To_Easting AS Easting,
append1_new.To_Northing AS Northing,
7 AS PointSize,
0 AS PointColor,
2 AS PointStype,
Yes AS TextVisible,
0 AS TextAngle,
8 AS TextSize,
0 AS TextColor,
0 AS Inflow,
0 AS Conc1,
0 AS Conc2,
0 AS Conc3,
0 AS Conc4,
"" AS Comments,
0 AS InlutFlow,
0 AS ComputedDepth,
0 AS ObservedDepth,
"" AS Field1,
"" AS Field2,
No AS Selected,
-1 AS Handle1,
-1 AS Handle2,
-1 AS Handle3,
-1 AS Handle4
FROM append1_new LEFT JOIN append1_new AS append1_new_1 ON (append1_new.cc_New_Tab = append1_new_1.cc_New_Tab) AND (append1_new.cc_Node2 = append1_new_1.cc_Node1)
WHERE (((CStr([append1_new].[cc_Node2]))>0) AND ((append1_new_1.cc_Node1) Is Null) AND ((append1_new.cc_New_Tab)="baker-culverts-import"));

Recreate "Nodes" table, query 2 of 2 (qryExport_<Basin>_Nodes2)




```
SELECT CStr([cc_Node1]) AS ID,
        append1_new.From_Easting AS Easting,
        append1_new.From_Northing AS Northing,
        7 AS PointSize,
        0 AS PointColor,
        2 AS PointStype,
        Yes AS TextVisible,
        0 AS TextAngle,
        8 AS TextSize,
        0 AS TextColor,
        0 AS Inflow,
        0 AS Conc1,
        0 AS Conc2,
        0 AS Conc3,
        0 AS Conc4,
        "" AS Comments,
        0 AS InlutFlow,
        0 AS ComputedDepth,
        0 AS ObservedDepth,
        "" AS Field1,
        "" AS Field2,
        No AS Selected,
        -1 AS Handle1,
        -1 AS Handle2,
        -1 AS Handle3,
        -1 AS Handle4
FROM append1_new
WHERE (((CStr([cc_Node1]))>0) AND ((append1_new.cc_New_Tab)="baker-culverts-import"));
```

SWWM table layouts:

Conduits Table

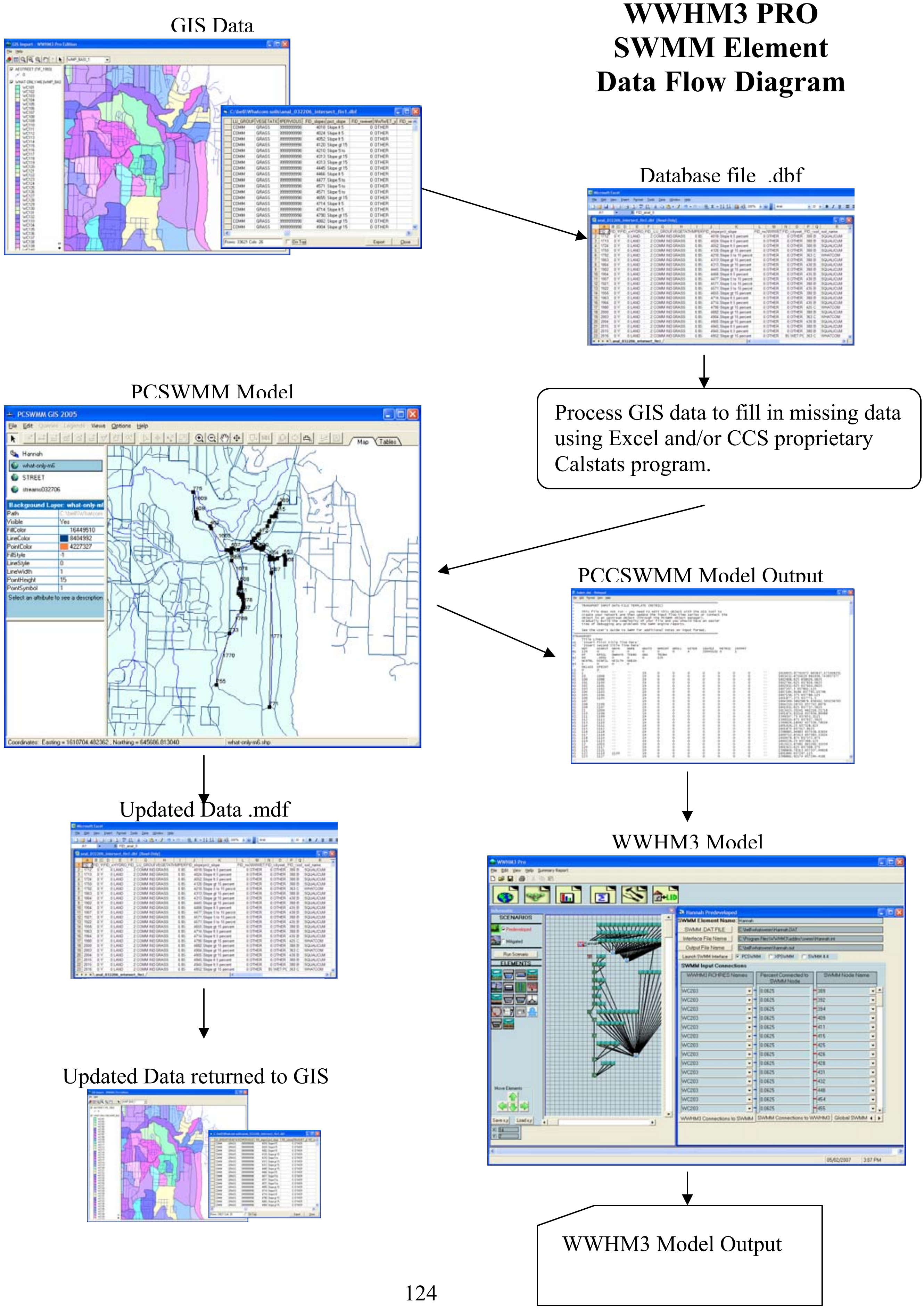
Name	Type	Size
ID	Text	50
Eastings	Memo	-
Northings	Memo	-
LineWidth	Long Integer	4
LineColor	Long Integer	4
TextVisible	Yes/No	1
TextAngle	Long Integer	4
TextSize	Long Integer	4
TextColor	Long Integer	4
Node1	Text	50
Node2	Text	50
Type	Integer	2
Length	Single	4
Slope	Single	4
Roughness	Single	4
Geom1	Single	4
Geom2	Single	4
Geom3	Single	4
Barrels	Single	4
Comments	Memo	-
ComputedFlow	Single	4
ObservedFlow	Single	4
ComputedVelocity	Single	4
ObservedVelocity	Single	4
Field1	Text	25
Field2	Text	25
Selected	Yes/No	1
Handle1	Long Integer	4
Handle2	Long Integer	4
Handle3	Long Integer	4
Handle4	Long Integer	4

Nodes Table

Name	Type	Size
ID	Text	50
Easting	Double	8
Northing	Double	8
PointSize	Long Integer	4
PointColor	Long Integer	4
PointStyle	Long Integer	4
TextVisible	Yes/No	1
TextAngle	Long Integer	4
TextSize	Long Integer	4
TextColor	Long Integer	4
Inflow	Single	4
Conc1	Single	4
Conc2	Single	4
Conc3	Single	4
Conc4	Single	4
Comments	Memo	-
InputFlow	Single	4
ComputedDepth	Single	4
ObservedDepth	Single	4
Field1	Text	25
Field2	Text	25
Selected	Yes/No	1
Handle1	Long Integer	4
Handle2	Long Integer	4
Handle3	Long Integer	4
Handle4	Long Integer	4

WWHM3 SWMM Modeling Features

WWHM3 PRO SWMM Element Data Flow Diagram



As shown in the above diagram, the data flow for use in WWHM3 is as follows:

1. GIS conveyance system data is processed from GIS files to produce a database file.

2. The database file is connected to the SWMM file to link the GIS data to the SWMM model.

3. The SWMM model output is accessed by WWHM3.

4. WWHM3 model output provides flow data statistics for identifying stormwater problems.

5. The SWMM model can also update the GIS database file.

6. The GIS database file can be read back into the GIS to update GIS files.

The SWMM conveyance element uses the EPA SWMM routing algorithms in place of HSPF's RCHRES routing. The advantage of using SWMM routing in place of the standard HSPF routing is the ability of SWMM routing to explicitly model complex hydraulic conditions. These conditions occur when there is backwater or other special situations where HSPF's assumptions of linear reservoir routing cannot accurately compute the movement of water from one conveyance element to another.

The SWMM input files were created in their native SWMM programs (WWHM3 does not create SWMM input files). WWHM3 read the previously created PCSWMM[1] input files.

WWHM3 produced a seamless (invisible to the user) linkage between the HSPF-generated runoff and the SWMM routing. The SWMM routing was computed continuously at the user-specified time step inside WWHM3. WWHM3 transferred the SWMM-generated routing output to WWHM3 downstream elements (if any) and/or the WWHM3 WDM database. Everything was done inside WWHM3. WWHM3 PRO COMPLETE and PCSWMM 2005 were used.

WWHM3 SWMM elements were used to represent the City of Bellingham stormwater pipe and/or culvert conveyance systems. When the SWMM element was placed on the WWHM3 Schematic screen then the user had access to the SWMM element window that linked WWHM3 to the SWMM environment.

Input in the SWMM element window consists of:

SWMM Element Name: Name of the SWMM element selected by the user.

SWMM .DAT file: This is the SWMM input file used when running a SWMM model. This is a complicated text-based file. This is the SWMM file that was created using

[1] PCSWMM is a registered trademark of Computational Hydraulics Int. (CHI).

either a text editor or PCSWMM. When connected to the SWMM.DAT file WWHM3 scanned the file and determined all of the possible connections between the WWHM3 and the SWMM nodes.

Interface File Name: The interface file is a binary file that contains all necessary streamflow time series data for a connection between WWHM3 and the SWMM model. This file is different for each SWMM .DAT file. This file is automatically created by the WWHM3 and connected to the SWMM file. The user only needs to put the path and name of this file in this box so that the WWHM3 knows what file to create. Multiple interface files can be created to work with one SWMM .DAT file.

Output File Name: The output file contains the output data from a SWMM run. If there is a connection from SWMM back into the WWHM3 then the streamflow time series containing this data will be in this file. The WWHM3 uses the path and filename listed in this box to find this file, extract the time series data, and automatically link it back into the WWHM3 model.

Launch SWMM Interface: This button launches the selected SWMM program. Use of this option allows the user to modify the SWMM model in any way they choose before running their WWHM3 model. The use of this interface is not required to run a SWMM model in WWHM3; all that is required to run a SWMM model is the SWMM.DAT file.

WWHM3 Connections to SWMM tab: This environment allows the user to define all of the connections from WWHM3 elements to nodes within the SWMM model. There are three columns that make up the interface between WWHM3 and SWMM. The first column contains the names of the WWHM3 elements (for example, a basin, open channel, culvert, pond, etc.). The second column contains the percent of the total runoff from the WWHM3 element that connects to the SWMM node. This is a number between 0.0000 and 1.0000. The third column contains the name of the SWMM node to which the WWHM3 element is connected.

WWHM3 Element Name: This is the name of the WWHM3 element that contributes to this SWMM node. Select an element from the list of basins or conveyance elements that are connected to the SWMM Element in the Schematic.

Fraction Connected to SWMM Node: This number defines the fraction of runoff that this element contributes to the SWMM node. The fraction must be between zero and one. If this value is 1.00 for all connections for this element then the fraction will be automatically distributed evenly between all connections. If this value is 0.00 then this connection will not contribute to the SWMM Node.

SWMM Node Name: Name of the node within the SWMM .DAT file. The SWMM node name is usually created within the software that originally created the SWMM file.

SWMM Connections to WWHM3 tab: This environment allows the user to define all of the connections from SWMM nodes back to elements within the WWHM3. There are two columns that make up the interface between SWMM and WWHM3. The first column contains the names of the SWMM elements. The second column contains the name of the WWHM3 element to which the SWMM node is connected.

SWMM Node Name: The name of the SWMM node that produces output that is then input back into the WWHM3 model.

WWHM3 Element Name: Name of the WWHM3 element that receives inflow from SWMM.

Global SWMM Preferences tab: This environment allows the user to define all of the global controls for WWHM3 interactions with SWMM. These global controls consist of runoff type connections, time control, and SWMM run control. Each global control is explained below.

Runoff Type Connections from WWHM3 to SWMM for import of SWMM file: This feature only used if there is basin land use data to import from the SWMM model. There are three runoff components that can be connected from a basin within the WWHM3 to a SWMM node. These components are:

1) Surface Runoff – generally produced only by impervious surfaces; also known as overland flow
2) Interflow – shallow, subsurface runoff produced by pervious surfaces
3) Groundwater – produced by pervious surfaces; provides base flow in streams

Stormwater runoff is defined as combined surface runoff and interflow; groundwater/base flow is excluded. Select the checkbox for each runoff component that connects to the SWMM node. In most situations only the surface runoff and interflow boxes are checked. The groundwater box is checked when the runoff goes directly to a stream, lake, or wetland.

EIA% is the percent of the impervious area that is considered hydrologically effective and produces surface runoff to a conveyance system. Some impervious area drains onto adjacent pervious surfaces, allowing some of the impervious area runoff (surface runoff) to infiltrate into the adjacent pervious soils before reaching a conveyance system. SWMM models typically assume that all of the land use coverage impervious area (total impervious area) is effective (EIA% = 100). This EIA% option allows the user to apply a percentage to impervious areas to reduce the total impervious area to represent the effective impervious area.

Time Control: The Time Control feature allows the user to control the start and end dates for the creation of interface files and set the computational time step for the SWMM model runs.

<u>Start Date:</u> Beginning date entered in the following format: yyyy mm dd
<u>End Date</u>: Ending date entered in the following format: yyyy mm dd

<u>Time Step(sec):</u> Computational time step from 1 second to 86400 seconds (1440 minutes or 24 hours). This value should be set to correspond to the needs of the SWMM model. The selection of a time step option that is larger than the time step that the WWHM3 is using will produce a WWHM3 error. (WWHM3 time step options are: 5 minutes, 15 minutes, 30 minutes, 1 hour, 1 day.) Large time steps can cause instability in the SWMM model run output; small time steps require more computation time.

SWMM Run Control: The SWWM Run Control features present the user with a number of options when running SWWM within WWHM3. These features include using an existing interface file already created by WWHM3 for input to the SWMM routing, running WWHM3 separately from SWMM, running SWMM Transport design option to resize culverts, run just a single SWMM element rather than all of the ones in the model.

<u>Use Interface file created from WWHM3 Runoff:</u> This option is for the use of an interface file that has already been created by a previous run of the WWHM3. Interface files can take a significant amount of time to generate. As a result it is best to use this option unless something has been changed in the WWHM3 model and there is the need to update/recreate the interface file.

NOTE: Interface file creation is critical to the proper use of the SWMM element. SWMM models use the inflow from interface files for all model runs.

<u>Run WWHM3 file only:</u> This option should be used if the WWHM3 model needs to be run for the purpose of creating a new interface file, but there is no need to run the SWMM model at the same time.

<u>SWMM Transport design option on:</u> This option turns on the SWMM option in the SWMM Transport module that produces automatic upsizing of existing culverts to avoid surcharging culverts.

<u>Run SWMM file only command:</u> This command option will shortcut all of the normal WWHM3 pathways for model runs and simply run the SWMM .DAT file using the most recent interface file. This is most useful when there are multiple SWMM elements in one model, but there is only the need to run one SWMM model, and not all of them.

<u>SWMM Connection File:</u> This option allows the user to save/edit/load connection files. The connection file contains all of the information shown in the WWHM3 Connections to SWMM tab window.

Save SWMM Connection File: Saves all of the information from the WWHM3 Connections to SWMM tab window to a text file than can be edited manually and re-imported using the Load SWMM Connection file option shown below.

Load SWMM Connection File: Loads the SWMM Connection text file that contains all of the connections from the WWHM3 to SWMM. This file will replace all of the existing data in the WWHM3 Connections to SWMM tab window. This allows the user to easily change WWHM3 to SWMM connections for large projects that can contain hundreds of individual connections.

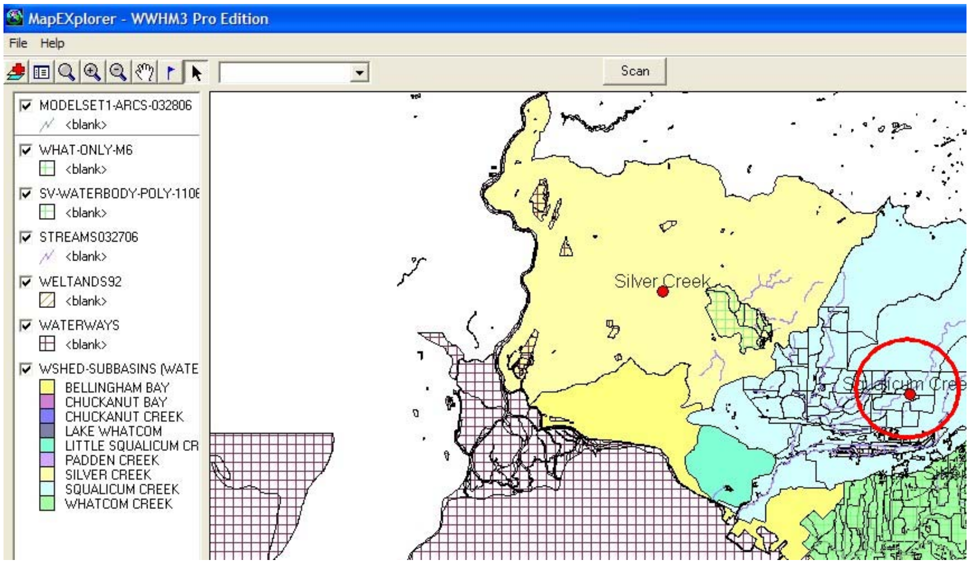
In summary, below are the typical steps for working with WWHM3 and SWMM models

1) **Obtain data from GIS**
   The GIS data should be in ESRI compatible Shape files.
   a. The Shape files can be viewed with Clear Creek's MapExplorer program
   b. MapExplorer allows the user to view GIS Data and export data by selecting a basin.
2) **Prepare GIS Data**
   The original GIS data may have missing data that will need to be corrected before it will work in SWMM and WWHM3.
   a. Open the GIS map in MapExplorer and review the database table in the data view window. This will allow you to quickly find the missing data elements and gaps in data that will need to be corrected.
   b. The data that is exported from MapExplorer can be viewed and edited with MS Excel spreadsheet or MS Access and CCS proprietary Calstats program.

   Note: Using MapExplorer is not required. It is provided as an easy to use tool for viewing and exporting GIS Data.
3) **Process data using PCSWMM program**
   See section *Prepare a PCSWMM file for connection to WWHM3*
   Recommendation: locate all GIS, SWMM, and WWHM3 file on your local C: disk to avoid potential problems.
   a. Create a PCSWMM Model Output file for each SWMM element in your project
4) **Update GIS (Optional)**
   a. The updated data file can be returned to GIS. This will reduce the time required for future iteration.
5) **Create your project in WWHM3, or use an existing project**
6) **Using SWMM data in WWHM3**
   a. Add the SWMM element to your WWHM3 project in the Schematic grid
   b. WWHM3 is capable of directly using the data from the PCSWMM Model Output file. When using a SWMM element in WWHM3, simple let WWHM3 know which SWMM output file to use for this element.
7) **Establish the SWMM to WWHM3 Connections**
   a. The SWMM element in WWHM3 provides a screen for quickly and easily creating and maintaining connections. The connections and be saved and loaded in MS Excel files for easy maintenance.
8) **Run the WWHM3 model**

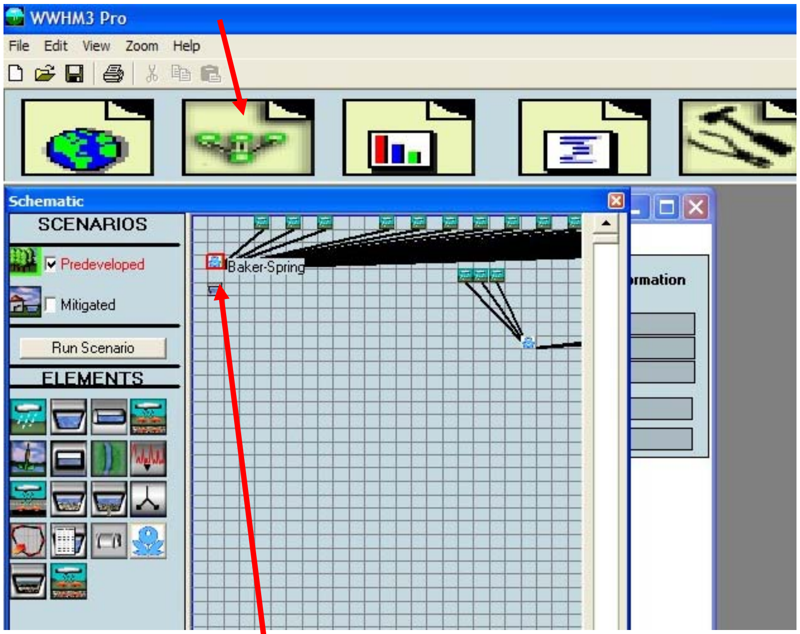
Example Project

From WWHM3 Map Explorer select the basin for the project you are working on.



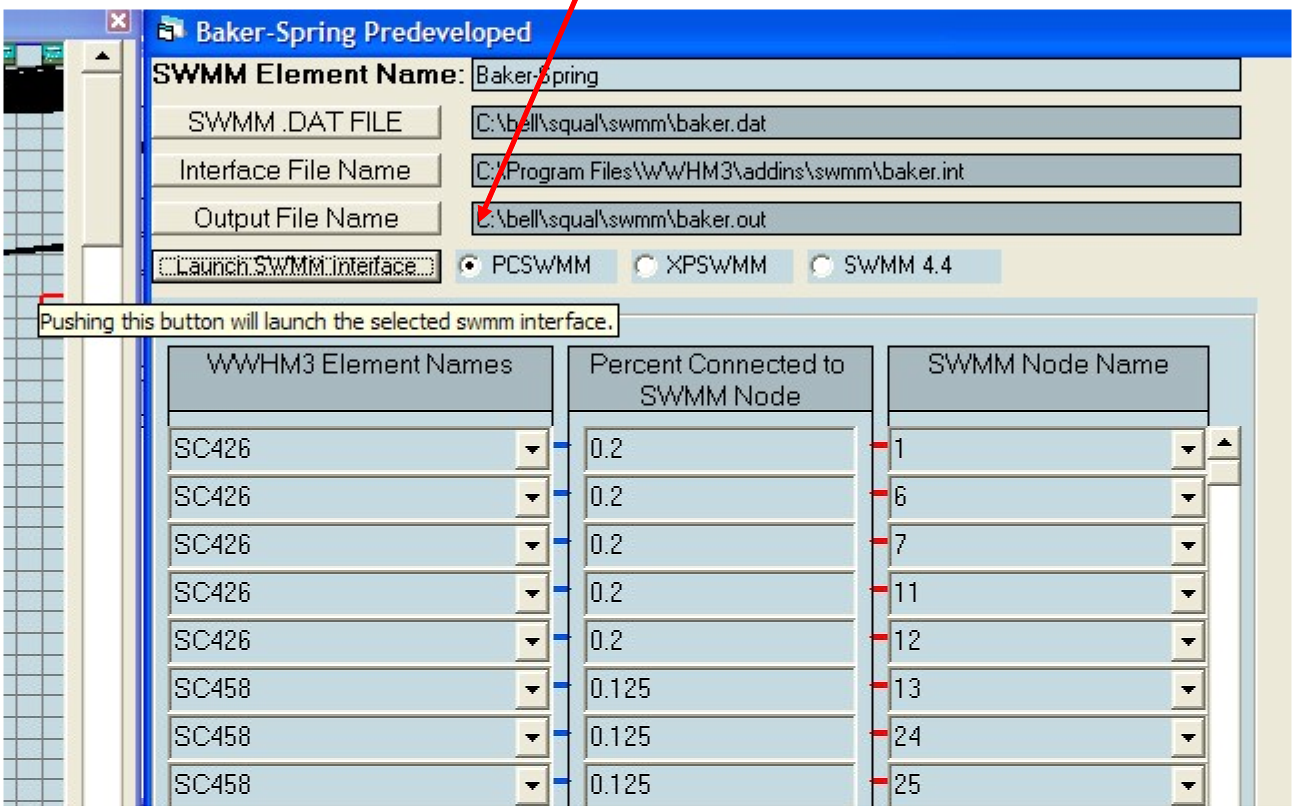
The basin project file is loaded into WWHM3.

Select the Schematic icon in WWHM3 to see all of the elements in your project.



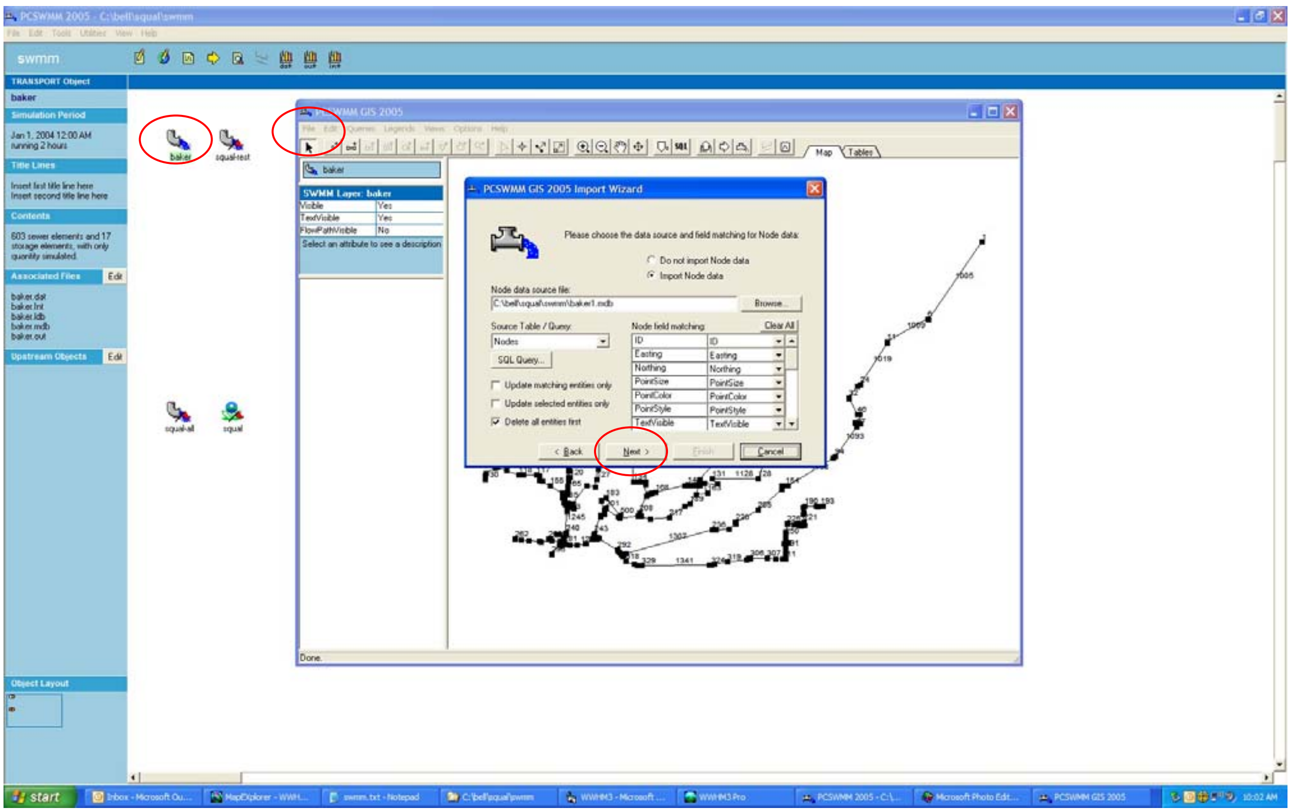
Select the “Baker Spring” SWMM Element. (SWMM Window opens)

In the SWMM window, select the "Launch SWMM Interface" button. (PCSWMM opens).

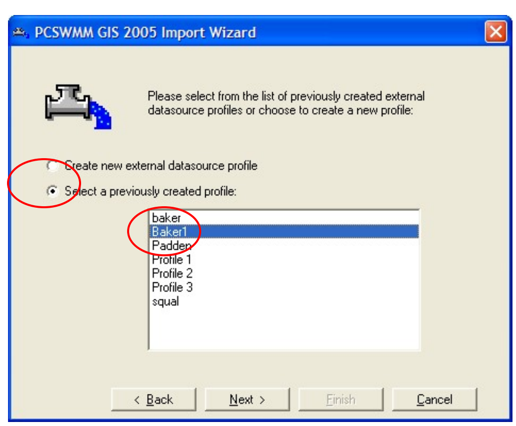


PREPARE A PCSWMM FILE FOR CONNECTION TO WWHM3

Open PCSWMM
File / Open folder
Click the 'Browse Tab'
Browse to "C:\bell\squal\swmm"
Double click the "baker" model
Select Edit GIS option
File / Import Data – this will re-import data from GIS



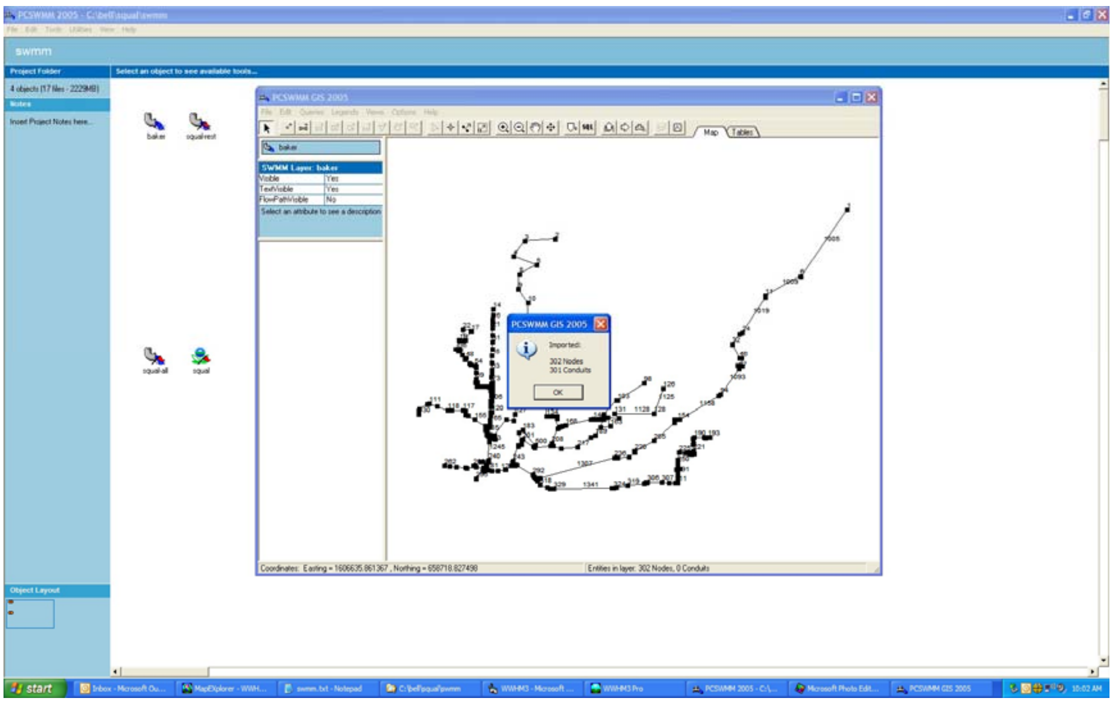
Select Database option (only reads .mdb database file)



Load 'Profile file'(the profile contains all necessary info for Nodes and Conduits)

The profile contains:

[Nodes]
Node Data Source File: C:\bell\squal\data\squal-all-import.mdb
Source Table / Query: Nodes
"Delete all entries first" is selected
Node field matching: <correct field assigned>
Click Next
[Conduit]
Node Data Source File: C:\bell\squal\data\squal-all-import.mdb
Source Table / Query: Nodes
"Delete all entries first" is selected
Node field matching: <correct field assigned>
Click Next until completed



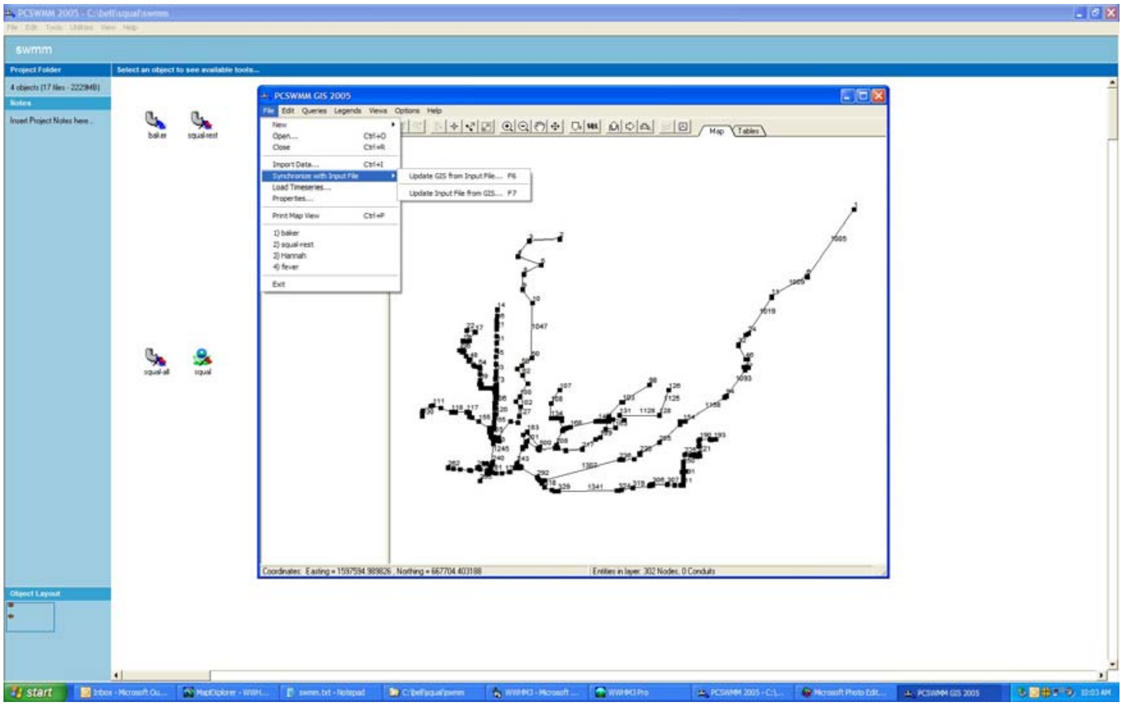
Update the input file from the GIS data files

Select File / Syncronize with input file

Update Input file from GIS 'F7'

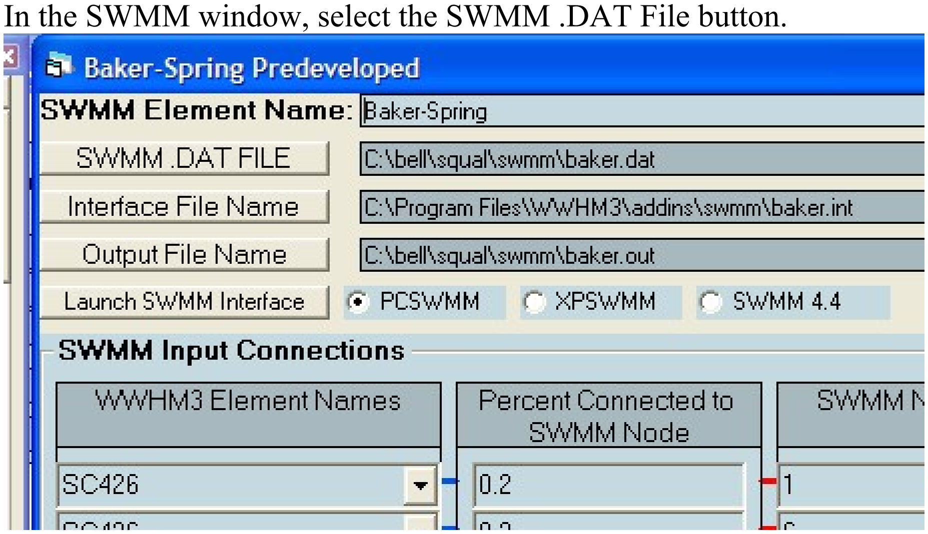
Use defaults for Update input file

Click Update

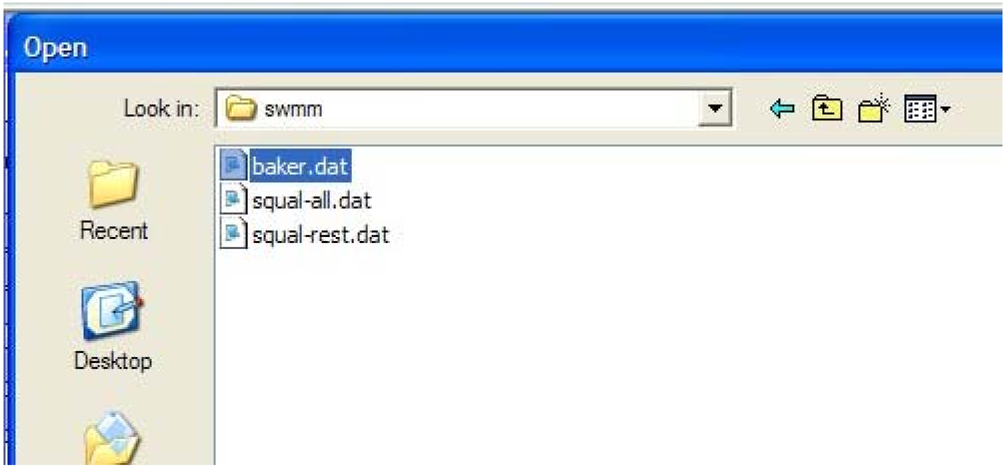


Close PCSWWM. The .DAT file is now ready for WWHM3 SWMM.

In the SWMM window, select the SWMM .DAT File button.



Select the "Baker.dat" file from the "bell/squal/swmm" directory.



The Baker input file has now been re-imported into the WWHM3.

Import Landuse Data: see also GIS Import manual.

Landuse is a combination of land cover (vegetation), land slope, and pervious or impervious.

Prepare SWMM Connection Files:

swmmnode - WWHM3 connection
subbasin - subbasin connected to SWMM Element
fraction - fraction of flow (0.0000 to 1.0000)
flows - Surface (S), Interflow (I), and/or Groundwater (G)

swmmnode	subbasin	fraction	flows
376	WC135	1	SIG
378	WC134	0.0909	SIG
413	WC134	0.0909	SIG
434	WC134	0.0909	SIG
440	WC134	0.0909	SIG
451	WC134	0.0909	SIG
470	WC134	0.0909	SIG
471	WC134	0.0909	SIG
504	WC134	0.0909	SIG
508	WC134	0.0909	SIG
509	WC134	0.0909	SIG

Running SWMM

The following text describes the steps required to:

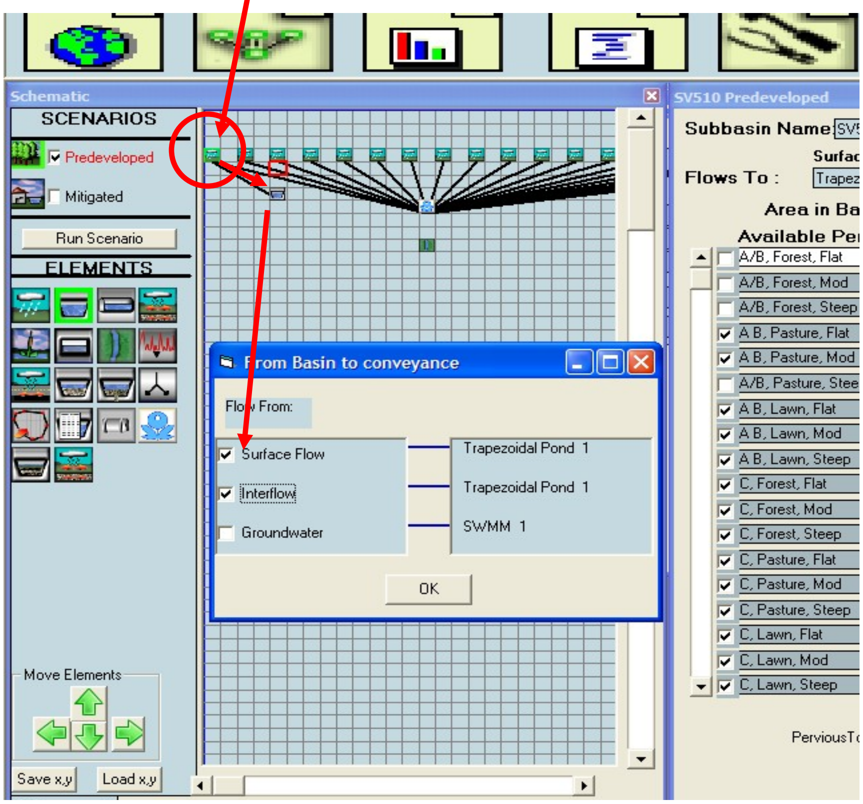
1. run an entire project with new WWHM3 elements.
2. run an entire project without generating new interface files
3. run a single SWMM element only with an existing interface file

1. Run an entire project with new WWHM3 elements.

First, manually connect new WWHM3 elements to SWMM.

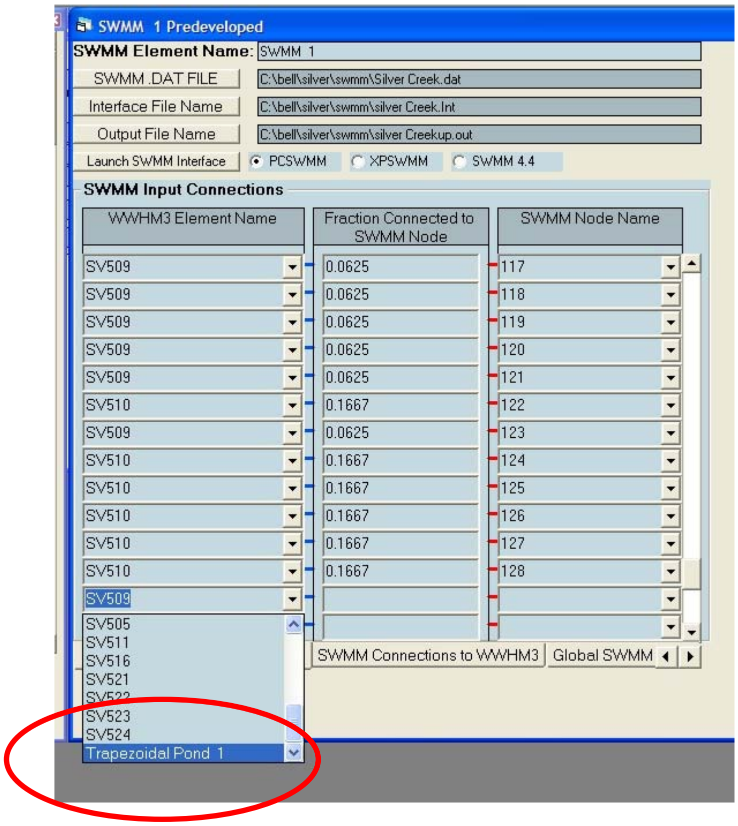
As an example, we will put a trapezoidal pond on the Schematic grid just below the basin element that will be flowing to it.

Right-click on the basin and select Connect to Element. Now select the new trapezoidal pond. Make sure only Surface Flow and Interflow are checked and select OK. This will ensure that groundwater is still connected directly to the SWMM Element.

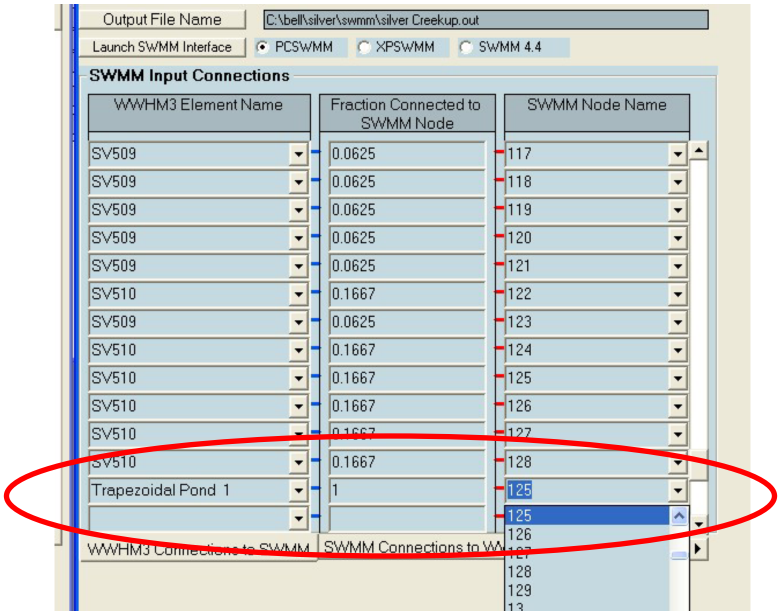


Right-click on the pond and select Connect to Element. Now select the SWMM element.

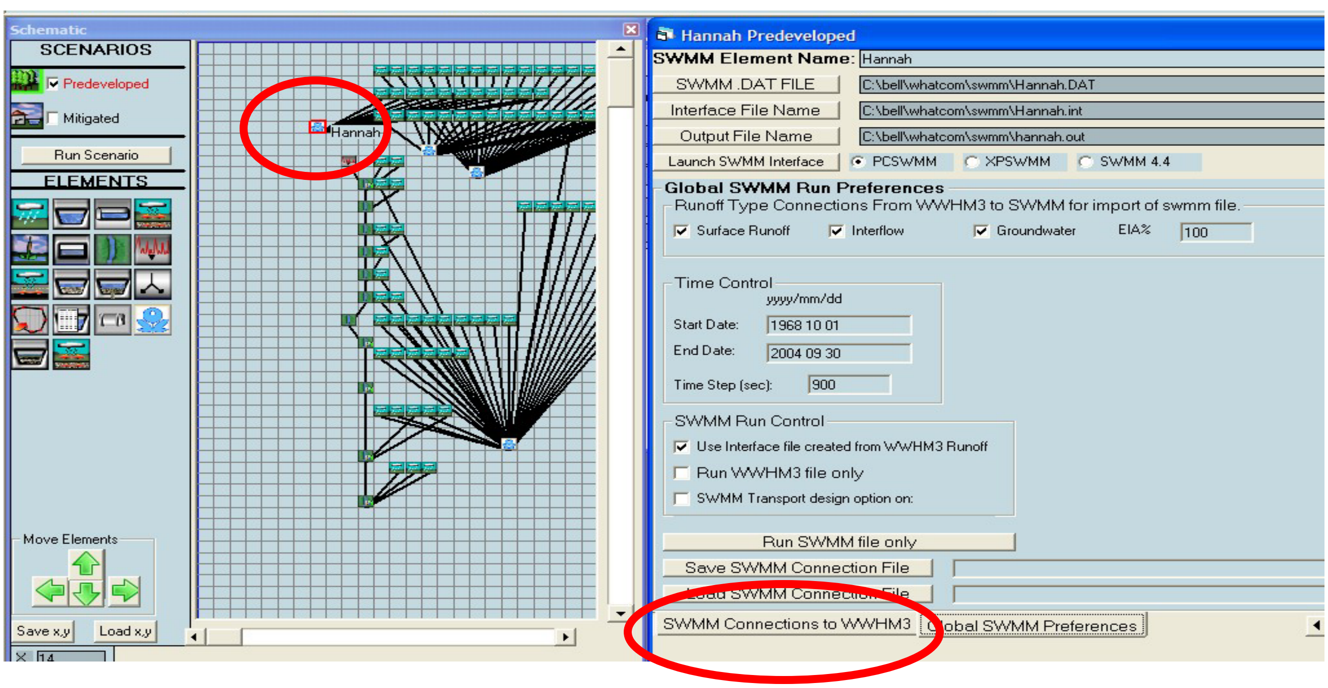
Select the SWMM element and click on the WWHM3 Connections to SWMM tab. This is where you add a connection from the pond to the SWMM element.

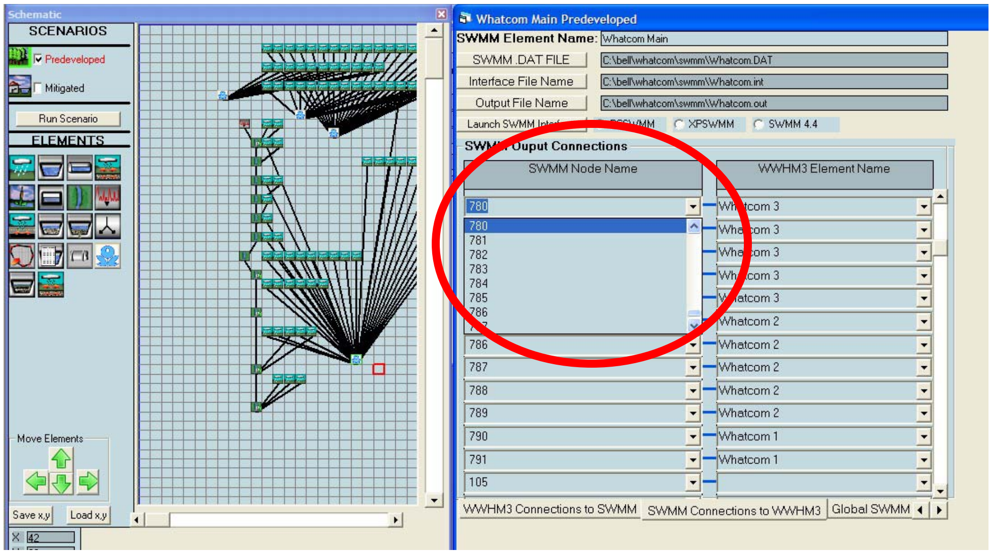


Scroll to the bottom of the connections list and click the down arrow to add a new connection. Select the down arrow on the next available drop-down box to reveal the list of elements you can connect. Select 'Trapezoidal Pond 1' from that list. In the middle column, type "1." In the third column, select the SWMM node that the pond connects to.



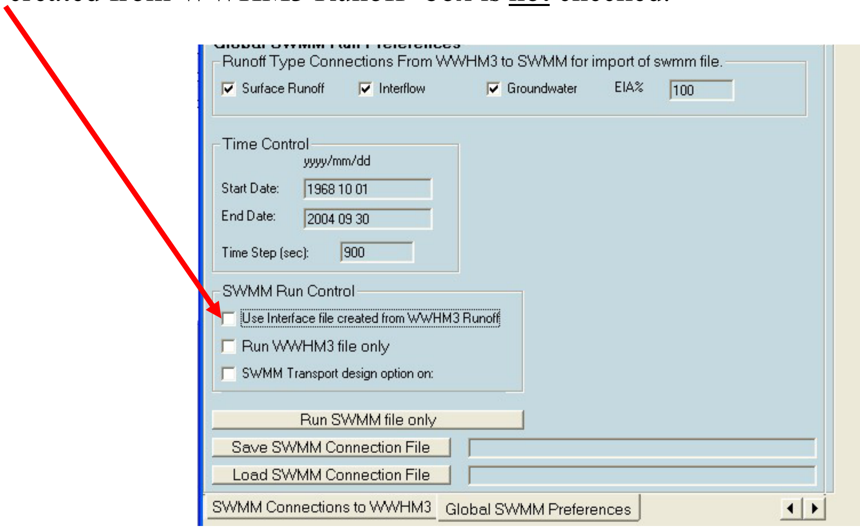
To Connect output from SWMM nodes back to WWHM3 elements select the SWMM element you wish to connect to the WWHM3 element and click on the 'SWMM Connections to WWHM3' tab.





Select a node from the SWMM Node Name column. This may be a new or existing node. Click on the drop down arrow to list the nodes and choose which node you wish to connect from the WWHM3 Element Name list. Select the element you wish to connect.

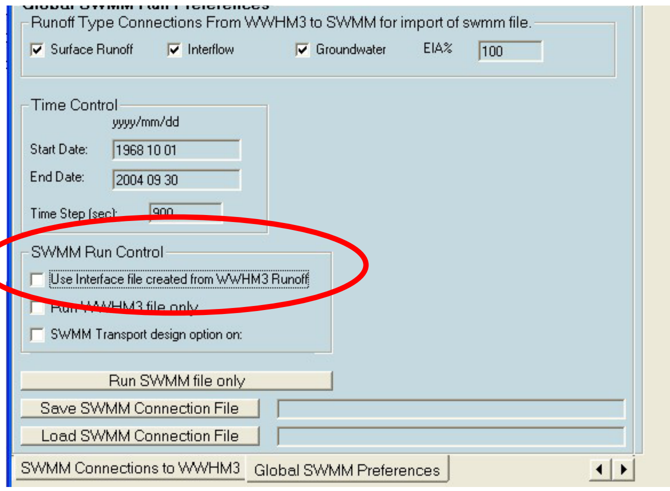
Select the GLOBAL SWMM PREFERENCES tab and make sure that the 'Use Interface file created from WWHM3 Runoff' box is <u>not</u> checked.



In the Schematic form, select RUN SCENARIO in order to create a new SWMM interface file that reflects these changes.

2. Run an entire project without generating new interface files.

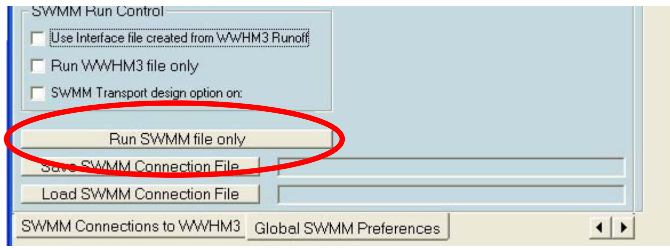
If a previously created SWMM Interface file is available and no changes are needed, you can run the model with the 'Use interface file created from WWHM3 Runoff' box checked in the GLOBAL SWMM PREFERENCES tab of the SWMM element.



3. Run a single SWMM element only with an existing interface file.

You can run a single SWMM element even if you have multiple SWMM elements shown on the Schematic grid. You may want to do this when you have made a change to that single SWMM element and have not changed anything else in the project.

Press the 'Run SWMM file only' button in the Global SWMM Preferences tab to run only that SWMM element and not any others.



Data Translation

Contents:

- BellinghamDataReport.xls - Report of added and modified data for model color.
- BellinghamDataReport_BW.xls - Report of added and modified data for model mono.
- BellinghamDataReview.xls - Detail data with changes highlighted and stats.

Data\ - Database information
Baker-Squal\ - example subbasin data directory
Baker.mdb.Conduits - Additional data fields Type, Length, Slope, Roughness, etc
Squal-all-import.mdb - MS-Access database containing all data used in this report
Tables

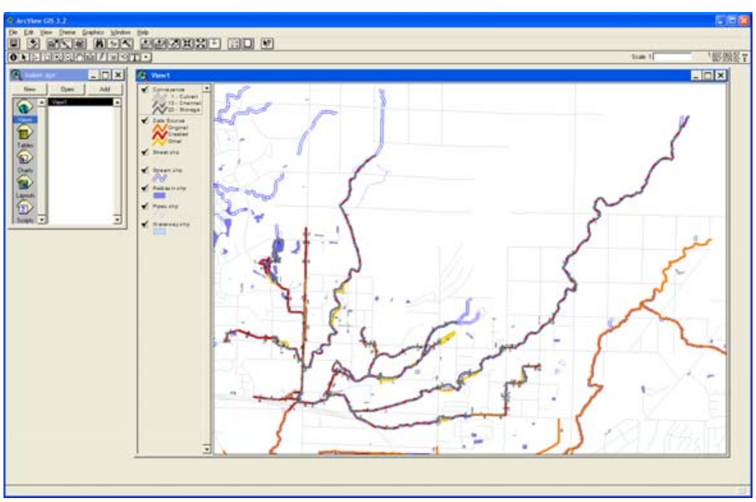
- sc-convey-arcs-110106 - Original data from GIS
- baker-culverts-import - Intermediate data required by model
- Conduits-baker - Resultant additional data fields

Queries

- qryModifiedData_baker - Return only modified records for ~DataReview.xls
- qryMap-bakerExport - Export to Baker.dbf file for use with ArcView for maps.

GIS\ - ArcView Maps

Copy GIS directory to C:\GIS
Open <subbasin>.apr using Arcview 3.2



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Wolman, M.G. 1954. A method of sampling coarse river-bed material. Transactions of the American Geophysical Union, Vol. 35 No. 6. December 1954. pp. 951 – 956.

APPENDIX A: Detailed Problem Identification and Solutions

Whatcom Creek Basin Deficiencies (PDF)
Other Creek Drainage Deficiencies (PDF)

APPENDIX B: Cost Opinions

Cost for Stormwater Improvements to the Whatcom Creek Basin (PDF)

APPENDIX C: 1995 HDR Watershed Master Plan

1995 Watershed Master Plan (9,000K PDF)

APPENDIX LW: Lake Whatcom Stormwater Management Program

An Evaluation of Stormwater Phosphorus and Recommended Management Options by Parametrix in October 2007 (9,000K PDF)