

CRESCENT CREEK FRESHWATER INPUT ANALYSIS



By

Eric Mickelson

Skagit River System Cooperative

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and

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TABLE OF CONTENTS

Introduction	1
Methods and Data Sources	6
Study Area.....	6
Hydrograph Modeling.....	6
Current Pervious and Impervious Surfaces	7
Potential Pervious and Impervious Surface Areas	8
Time of Concentration.....	8
Runoff Curve Numbers	9
Design Storm.....	9
Results	11
Watershed and Channel Network.....	11
SBUH Model Inputs	12
Current Impervious Surface	12
Potential Future Impervious Surface	14
Time of Concentration.....	16
Runoff Curve Numbers	16
Design Storm.....	18
Current and Potential Future Hydrograph	18
Discussion	21
References	24

TABLES AND FIGURES

Tables

Table 1. Impervious surface multipliers for various parcels and Property Conditions Assessments. Data from Island County Planning (2007).....	14
Table 2. Potential changes to land use and impervious surface area within the Crescent creek watershed.	16
Table 3. Precipitation depths for 24-hour storm events at 10-, 50-, and 100-year recurrence intervals. Data from WSDOT 2009.....	18

Table 4. Comparison of current and potential Crescent Creek flow rates and timing. ...	18
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Figures

Figure 1. Crescent Creek is a ditched seasonal stream that enters the Crescent Harbor Salt Marsh restoration site (outlined in yellow) at its northwestern edge.	3
Figure 2. Battelle/PNNL FVCOM hydrodynamic model grid for the Crescent Harbor Restoration site. An accurate estimate of freshwater inputs to the system is essential for obtaining good modeling results.	4
Figure 3. Example of the differences in contrast and resolution between the 2006 NAIP and the 2009 Google Maps imagery. While digitization took place on the NAIP imagery, the Google Maps imagery was used as a reference.	7
Figure 4. Example of isopluvials map used for determining design storm precipitation depths. Map retrieved from WSDOT GIS data download website (WSDOT 2009).....	10
Figure 5. Crescent Creek watershed boundaries and drainage network.	12
Figure 6. Crescent Creek impervious surface and land use categories. Categories were digitized manually using high resolution aerial photographs.	13
Figure 7. Crescent Creek zoning and parcel boundaries. Zoning and Parcel data are from Island County Planning (2007).....	15
Figure 8. Crescent Creek soils map. Data downloaded from the USDA Natural Resources Conservation Service (NRCS) Soils Data Mart website (retrieved March 17, 2009 from http://soildatamart.nrcs.usda.gov/).	17
Figure 9. Crescent Creek existing and potential conditions hydrograph, 10 year, 24 hour design storm.....	19
Figure 10. Crescent Creek existing and potential conditions hydrograph, 50 year, 24 hour design storm.	19
Figure 11. Crescent Creek existing and potential conditions hydrograph, 100 year, 24 hour design storm.	20

INTRODUCTION

Urbanization of watersheds in the form of increasing impervious surface area has been shown to result in degradation of downstream aquatic ecosystems (Booth and Jackson 1997). Increases in impervious surface reduce the infiltration capacity of the soil, leading to overland flows more frequently and rapidly than in a system with lower amounts of impervious surface. In combination with the ditches and gutters and the straightening or deepening of natural channels that typically accompany such systems, impervious surfaces serve to increase the rate and volume of stormwater flows to downstream reaches. These changes to the hydrologic flow regime can increase erosion, sediment delivery, and overall rates of disturbance to stream habitat (Booth 2000). Additionally, stormwater flows over impervious surfaces entrain pollutants deposited on impervious surfaces and transport these pollutants to stream systems.

Analysis of existing and potential habitat conditions is an important step in planning habitat restoration projects. Changes to stream habitat and runoff conditions are an important component of this process. Therefore, this study assessed potential changes to runoff conditions resulting from urbanization of the Crescent Creek watershed. This work is intended to supplement and support work that has already taken place to develop the Crescent Harbor Salt Marsh Restoration Project. Located on NAS Whidbey Island property near Oak Harbor, the restoration project will restore tidal inundation and fish access to approximately 206 acres of salt marsh habitat on Whidbey Island. The Crescent Harbor Salt Marsh restoration project has been identified in the Skagit Chinook recovery plan, and will benefit all six stocks of wild Skagit Chinook salmon as well as other native Puget Sound salmonids, forage fish, and wildlife species.

Once Crescent Harbor Salt Marsh has been reconnected to Crescent Bay, Crescent Creek may potentially offer suitable spawning habitat for coho salmon (based on field observations of the existing stream channel; no historic data are known to exist). The freshwater wetland buffering Crescent Creek just above the connection with the Crescent Harbor Salt Marsh has been identified as a possible site for future restoration work (personal communication, John Phillips, NAS Whidbey Environmental Affairs). In addition to the potential spawning

habitat benefits, this wetland serves to modulate storm flows reaching the salt marsh and surrounding landscape. The ditching of Crescent Creek has likely reduced the ability of this wetland area to buffer flows.

For this project, Island Salmon Recovery Program Capital Project Development funds were used to conduct a GIS-based analysis of current and future impervious surface and freshwater volumes reaching the Crescent Harbor Salt Marsh via Crescent Creek, a ditched seasonal stream that enters the salt marsh at its northwest edge (Figure 1). Estimates of current and future impervious surface and freshwater inputs from 10-, 50-, and 100- year storm events will serve as an initial step in assessing the feasibility of potential future restoration projects associated with the Crescent Harbor Salt Marsh/ Crescent Creek complex. Additionally, current freshwater contribution for storm events will be used as inputs into a regional hydrodynamic model that has been developed by the Battelle Memorial Institute/ Pacific Northwest National Laboratory (PNNL). This model will be used to assess the impacts of changes to the original Crescent Harbor Salt Marsh restoration project design (PWA 2003), and results will be presented to project stakeholders.

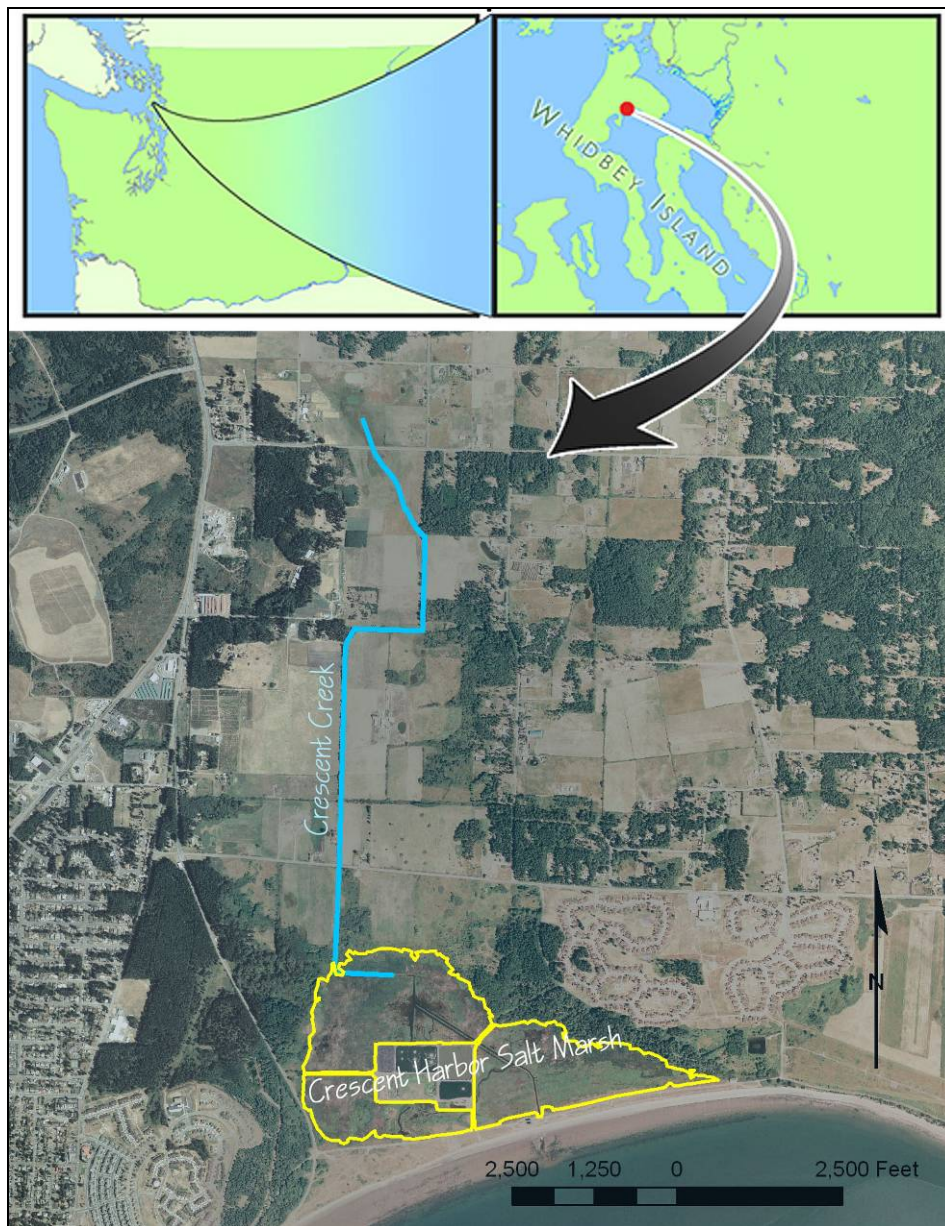


Figure 1. Crescent Creek is a ditched seasonal stream that enters the Crescent Harbor Salt Marsh restoration site (outlined in yellow) at its northwestern edge.

The Battelle/PNNL hydrodynamic model is currently being extended into the Crescent Harbor restoration site (Figure 2), and will be used to assess flood risk, sedimentation, and salinity for restoration conditions that have expanded on those proposed in feasibility assessments previously conducted at this site (PWA 2003). Accurate estimates of freshwater inputs are essential to allow this model to function properly. Up until early 2008, no gage existed for Crescent Creek, so no historical flow record is available. Therefore, a GIS-based

approach is necessary to complete this analysis. This analysis employs the Santa Barbara Urban Hydrograph Model (SBUH) (WADOE 2005), which was developed for small, urbanizing watersheds such as the Crescent Harbor watershed.



Figure 2. Battelle/PNNL FVCOM hydrodynamic model grid for the Crescent Harbor Restoration site. An accurate estimate of freshwater inputs to the system is essential for obtaining good modeling results.

The SBUH model requires several inputs, all of which can be derived from GIS data or existing maps. Watershed area and flow pathways were measured based on LiDAR- (Light Detection and Ranging) derived digital elevation models. Pervious and impervious surface area was digitized directly from high-resolution digital orthoimagery. Land use was classified into simple categories based on this imagery, and was used together with Natural Resource Conservation Service (NRCS) soils maps to select appropriate runoff curve numbers from NRCS tables (NRCS 2009). Finally, 10-, 50-, and 100-year storm events was selected based on National Oceanographic and Atmospheric Administration (NOAA) isopluvial maps for the region. Island County zoning and parcel layers was used to derive an estimate of

potential future impervious surface area, and these estimates will be used to model future stream flow in Crescent Creek.

This analysis serves as a first step in allowing SRSC staff to assess restoration feasibility for freshwater components of the Crescent Bay Salt Marsh System. Additionally, the results of the Battelle/PNNW modeling, to which this project will contribute, will be presented to project stakeholders to address concerns related to project design and onsite infrastructure. Beyond the restoration feasibility and flood assessment benefits offered by this analysis, this project assists with allowing Battelle/PNNW researchers to fine-tune and expand the geographic scope of their regional hydrodynamic model, a highly useful tool for organizations involved with habitat restoration and protection in the Puget Sound Region.

METHODS AND DATA SOURCES

Study Area

The Crescent Creek watershed was delineated using the ArcMap 9.2 hydrology toolset (ESRI 1999-2006) and 2001-2002 bare-earth lidar DEM's obtained from the Puget Sound Lidar Consortium website (PSLC 2001-2002). The elevation rasters had a cell size of 6ft and a stated vertical accuracy of ± 15 centimeters. The study area was covered by several DEM tiles, which were combined into a contiguous dataset in ArcMap before analysis of hydrology. A hillshade was also generated from these data to better allow visual inspection of analysis outputs.

After first processing the lidar data to fill in sinks that would inhibit the definition of flow pathways, the tools were used to determine flow accumulations, routing and contributing watershed area through the use of slope, aspect, and distance patterns in the elevation data. The output for this analysis consisted of a shapefile of watershed and subwatershed polygons and a shapefile of potential flow routing pathways within these basins.

Hydrograph Modeling

The Santa Barbara Urban Hydrograph Method (WADOE 2005) was selected for this analysis because it allows assessment of freshwater inputs to a location using a fairly simple methodology and data sources that can be readily obtained or derived using available GIS datasets. All hydrograph modeling was completed using the Hydraflow Hydrographs Extension for AutoCAD Civil 3D 2009 (AutoDesk, Inc. 2008).

Four main variables are required to create a model hydrograph using the SBUH method:

1. Pervious and Impervious land areas
2. Time of Concentration
3. Runoff curve numbers (CN) appropriate for soil conditions in the watershed
4. A design storm appropriate for the region under consideration.

To analyze potential changes to freshwater inputs under full buildout conditions, zoning and parcel data were also required. More detailed descriptions of the processes used to derive model inputs are described in the following sections.

Current Pervious and Impervious Surfaces

Existing impervious surface area was delineated directly from 2006 National Agriculture Imagery Program aerial imagery (NAIP 2006). The raster NAIP imagery had a cell size of one meter (3.28 feet). During analysis it became apparent that portions of this imagery were lacking sufficient contrast to allow digitization of impervious surface area. Therefore, higher resolution imagery available online via Google Map (Google 2009) was used as an additional reference in areas where it was difficult to determine the boundaries of impervious surface areas. Though the resolution of the Google Map imagery is not stated, it is readily apparent that the resolution is finer than that of the NAIP imagery (Figure 3). Digitization of impervious surfaces was completed using AutoCAD Civil 3D software (AutoDesk, Inc. 2008) and then exported to ArcMap 9.2 (ESRI 1999-2006) for area calculations and further GIS analysis.



Figure 3. Example of the differences in contrast and resolution between the 2006 NAIP and the 2009 Google Maps imagery. While digitization took place on the NAIP imagery, the Google Maps imagery was used as a reference.

Definitions used to determine whether a surface was classified as impervious were derived from the Island County Code (ICC)(Island County 2006). The ICC definition for impervious surface includes such nominally pervious surfaces as gravel roadways. This is a

valid inclusion, since such surfaces are highly compacted and thus very low in permeability at best (Booth and Jackson 1997). After importing the CAD file into the GIS, the polygons were coded as either impervious or open, and the area for each polygon was calculated.

Potential Pervious and Impervious Surface Areas

To obtain an estimate of potential future impervious surface area under full buildout conditions, definitions from the Housing Element of the Island County Comprehensive Plan (Island County 2008) were first used to determine the minimum number of acres per dwelling unit (DU) allowable under current zoning standards. Next, the parcel layer was merged with the zoning layer to determine which zone each parcel belonged to. Areas that were considered unbuildable (lakes and wetlands, slopes greater than 40%) or that were already built, were removed from the analysis. An additional 5% of each parcel area was also removed to account for rights-of-way and other development requirements, as recommended by the Center for Watershed Protection (Zielinski 2002). After removing unbuildable areas and parcels that have already been built, multipliers were used to estimate potential impervious surface area based on zoning and parcel size. These multipliers were derived from average existing impervious surface percentages for several size classes of developed parcels. Changes to the landcover classes were approximated by subtracting the estimated impervious surface area from the landcover class that a given parcel was located within.

Time of Concentration

Time of concentration is a measure of the time required for water to travel from the most hydrologically remote point in a basin to the point of collection. Calculation requires as inputs the slope of the longest watercourse in the study area, and the length of the flow path. The pathway was selected using the outputs from the hydrology tools described under the *Study Area* section of this report. The slope was measured by subtracting the height of this watercourse at its mouth from that at its head and dividing by the length of the pathway. Kirpich's Equation (Kirpich 1940) was selected for simplicity. This equation is given as:

$$t_c = 0.0078 \left(\frac{L^{0.77}}{S^{0.385}} \right)$$

Where t_c = time of concentration, L = flow length, and S – slope.

Runoff Curve Numbers

Runoff Curve Numbers (CN) used as inputs to the SBUH model are empirical parameters developed by the USDA Natural Resources Conservation Service (NRCS) for predicting direct runoff or infiltration from rain events (NRCS 2009). Selection of appropriate CNs requires characterization of land use, soil types, and antecedent moisture conditions in the study area.

To simplify this analysis, land use in the study area was very roughly categorized into one of two classes: agricultural/residential and forested. Though much finer distinctions might have been drawn, for the purposes of the hydrograph model it was sufficient to simplify the analysis by using only these broad categories. To delineate land use, forested and unforested areas were digitized in CAD and exported to GIS. In the GIS, the imported polygons were digitized and geocoded into their respective classes, and then merged with the impervious surface layer. Finally the area of each polygon was computed.

Soil types were characterized using NRCS soil survey maps and classified into Hydrologic Soil Groups (HSG) (NRCS 2007). The HSG that a given soil type belongs to gives an indication of the expected infiltration rate under thoroughly wetted conditions. The CN for a given land use depends on the HSG prevalent in the watershed.

Antecedent moisture conditions describe the amount of rainfall infiltrating into the soil during the five days previous to the design storm used for estimating the hydrograph. These are classified into three broad categories: AMC I (“dry”), AMC II (“normal”), and AMC III (“wet”). The CN for a given land use can vary depending on the antecedent moisture conditions.

Design Storm

Washington Department of Transportation (WSDOT) storm models for the study area were used to determine total precipitation depth for 24-hour storm events at the 10-year, 50-year, and 100-year recurrence interval over the study watershed (Figure 4). These precipitation depths were modeled by MGS Engineering Consultants and Oregon Climate Service for

WSDOT using precipitation and terrain data (WSDOT 2002), and were obtained online as GIS datasets from the WSDOT website (2009).

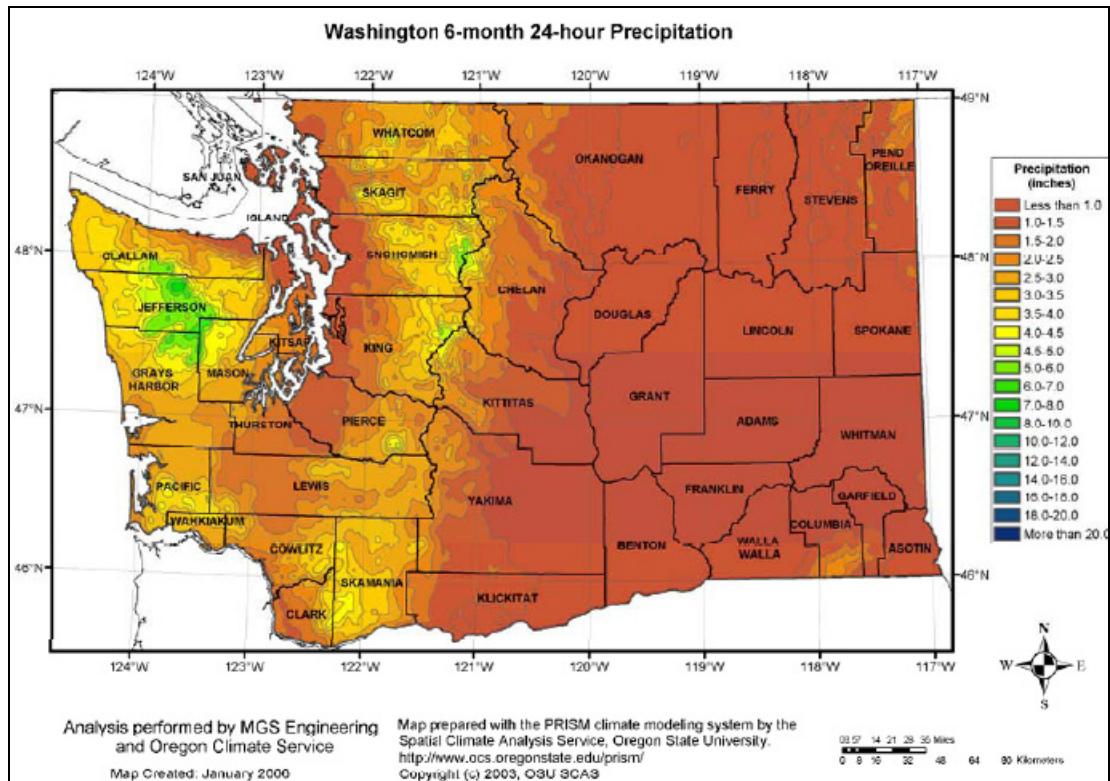


Figure 4. Example of isopluvials map used for determining design storm precipitation depths. Map retrieved from WSDOT GIS data download website (WSDOT 2009).

RESULTS

Watershed and Channel Network

Analysis of elevation data using ArcGIS hydrology tools (ESRI 1999-2006) resulted in delineation of a nearly 5,000 acre watershed draining to Crescent Harbor just east of Oak Harbor (Figure 5). This drainage is comprised of 111 sub-watersheds, which have an average area of 43.2 acres. Although the stream network that is referred to here as Crescent Creek flows into the northwestern portion of the Crescent Harbor salt marsh restoration site, subwatersheds contributing to the final outfall point at the southeastern portion of the salt marsh were also included in the analysis. This added approximately 600 acres to the overall area of the Crescent Creek watershed.

The drainage network defined using the hydrology tools resulted in delineation of 29.4 miles of drainage pathways within the Crescent Creek watershed. The channels currently empty into Crescent Harbor via a tidegate located at the southeastern portion of the salt marsh restoration site. A considerable portion of these channels follow straight lines, likely running through ditches at the edges of farm fields and roads.

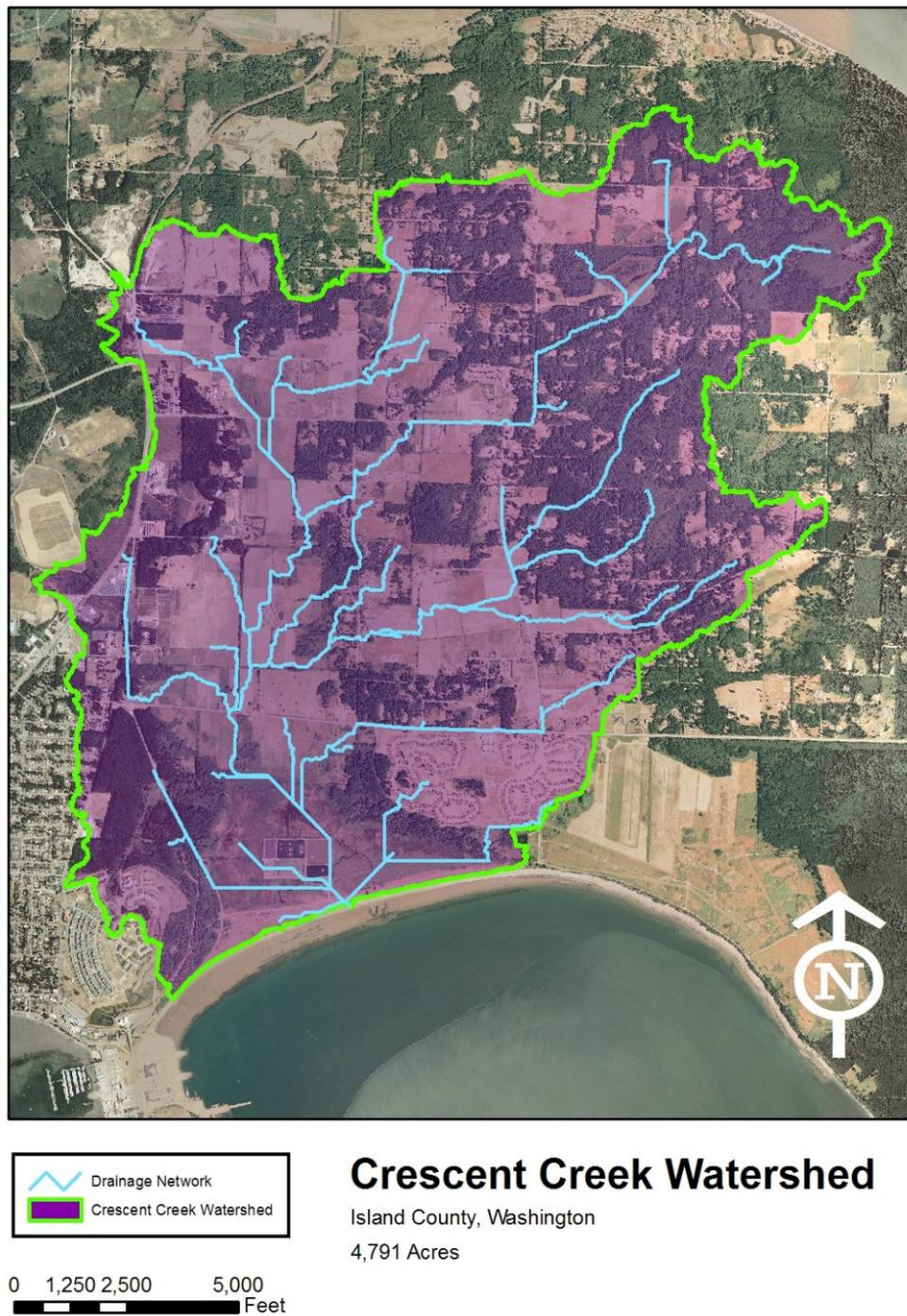


Figure 5. Crescent Creek watershed boundaries and drainage network.

SBUH Model Inputs

Current Impervious Surface

Digitization of current impervious surface area showed that 7.5% of the watershed (just less than 360 acres) is currently covered with impervious surfaces. Much of the impervious

surfaces are concentrated at the southeast and southwest edges of the watershed, where housing areas associated with NAS Whidbey Island or the City of Oak Harbor are located (Figure 6). Most of the mid and northern portions of the watershed relatively low density rural residential and agricultural development, with lower impervious surface area.

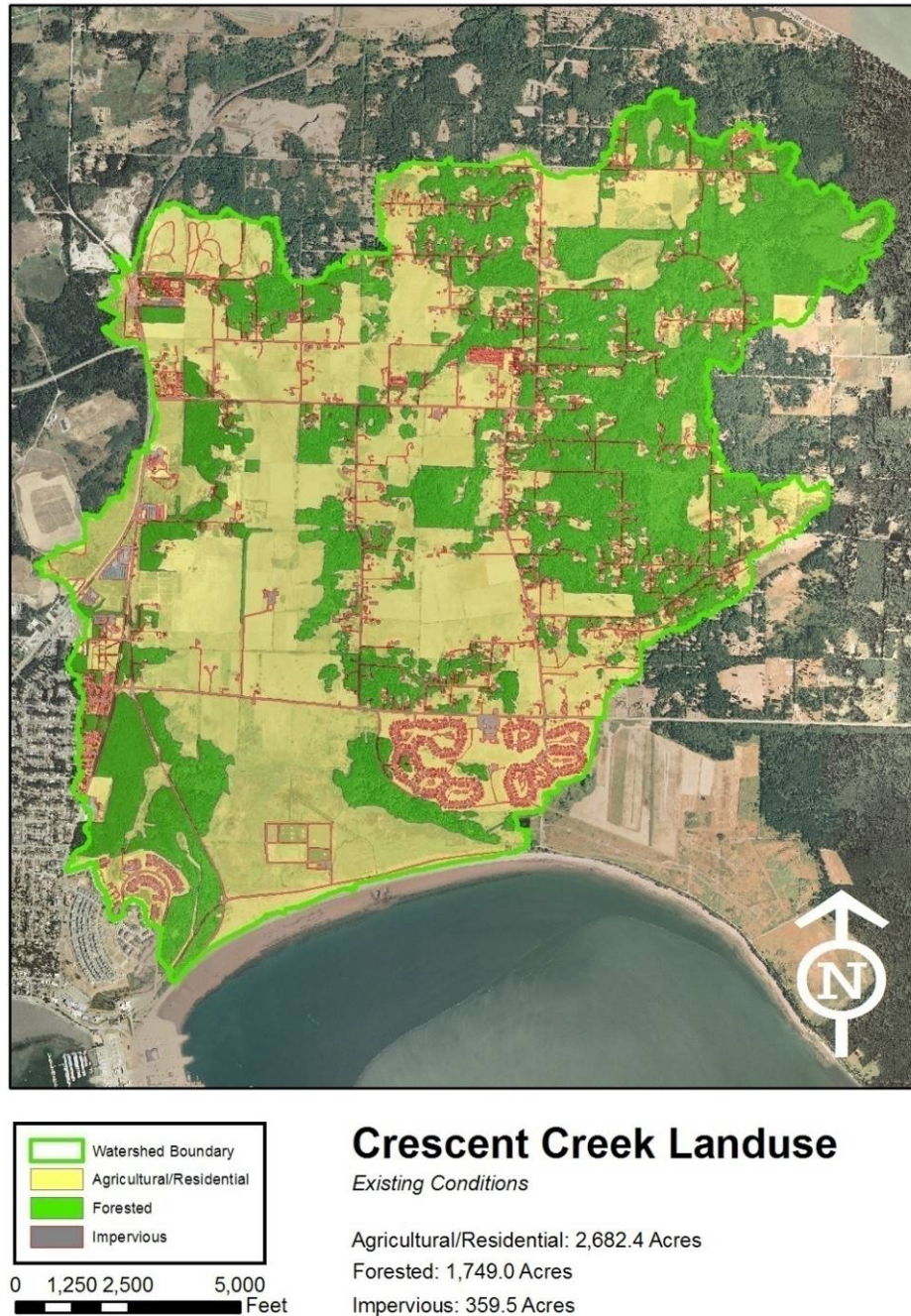


Figure 6. Crescent Creek impervious surface and land use categories. Categories were digitized manually using high resolution aerial photographs.

Potential Future Impervious Surface

After first subtracting unbuildable areas, multipliers estimated from existing developed parcels (Table 1, Figure 7) were used to approximate future impervious surface area under full buildout conditions. Potential impervious surface was estimated at 11.25%, an increase of 3.75% from current conditions. Forested area would potentially decrease by 1.41%, and Agricultural/Residential area would potentially decrease by 2.34% (Table 2).

Table 1. Impervious surface multipliers for various parcels and Property Conditions Assessments. Data from Island County Planning (2007).

Parcel PCA Code	Description	Impervious Surface Area Coefficient (% of Total Area)
0,53,77	Vacant	0.0%
87,88,94	Conservation Land	0.0%
51-52, 831,95	Agriculture	1.9%
77	Open Urban Land	8.6%
171	2 Acre Lot Residential	10.6%
161	1 Acre Lot Residential	14.3%
131-151	0.5 Acre Lot Residential	21.2%
	0.125 Acre Lot	
21-61,81-91,121	Residential	32.6%
611-621	Multifamily Residential	44.4%
N/A- See Zoning	Institutional	34.4%
711-741	Industrial	53.4%
631-681	Commercial	72.2%
N/A- See Zoning	Road	100.0%
N/A- See Zoning	Water	0.0%
181	3 Acre Lot Residential	9.0%
32,35,37	3+ Acre Lot Residential	5.5%

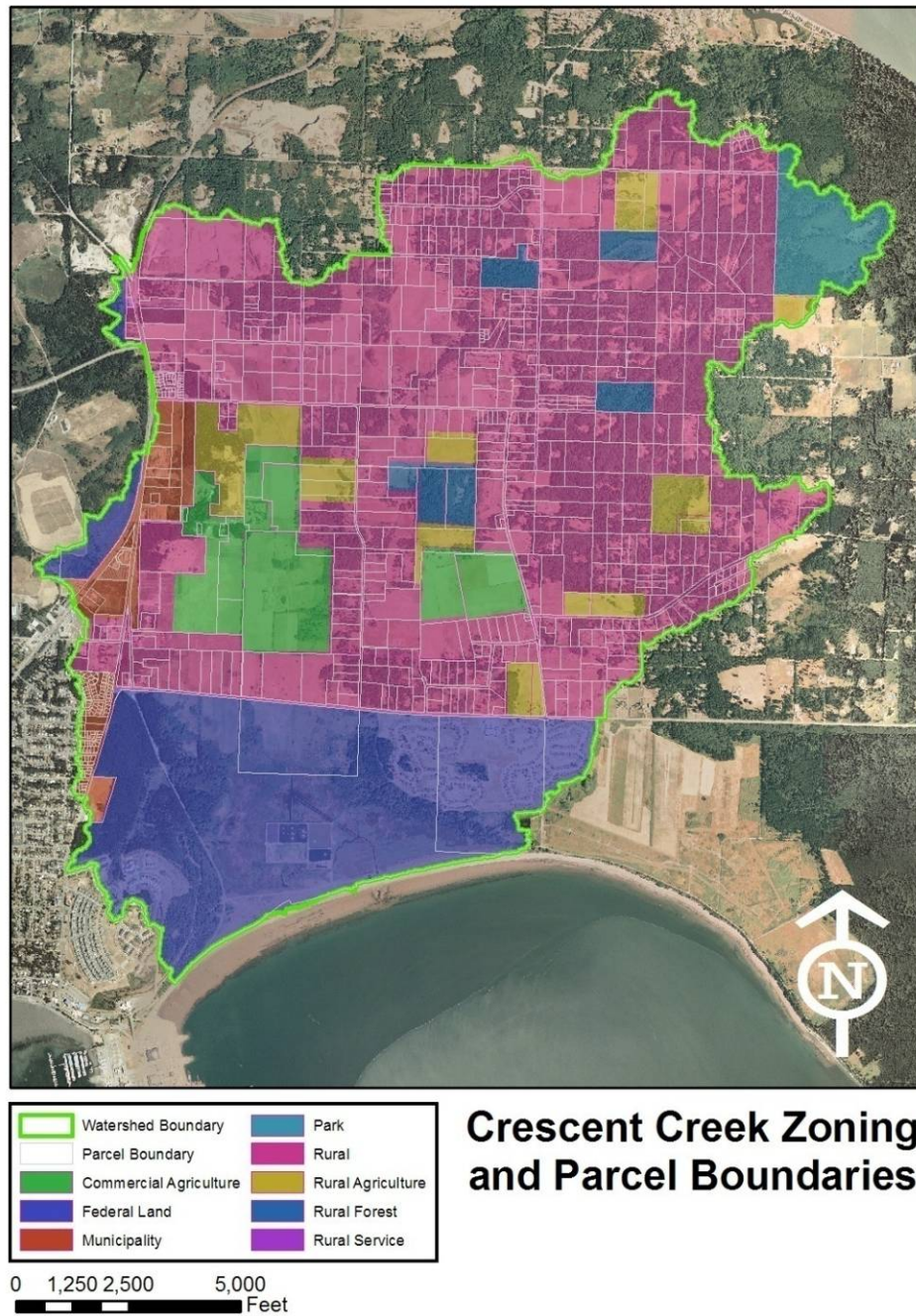


Figure 7. Crescent Creek zoning and parcel boundaries. Zoning and Parcel data are from Island County Planning (2007).

Table 2. Potential changes to land use and impervious surface area within the Crescent creek watershed.

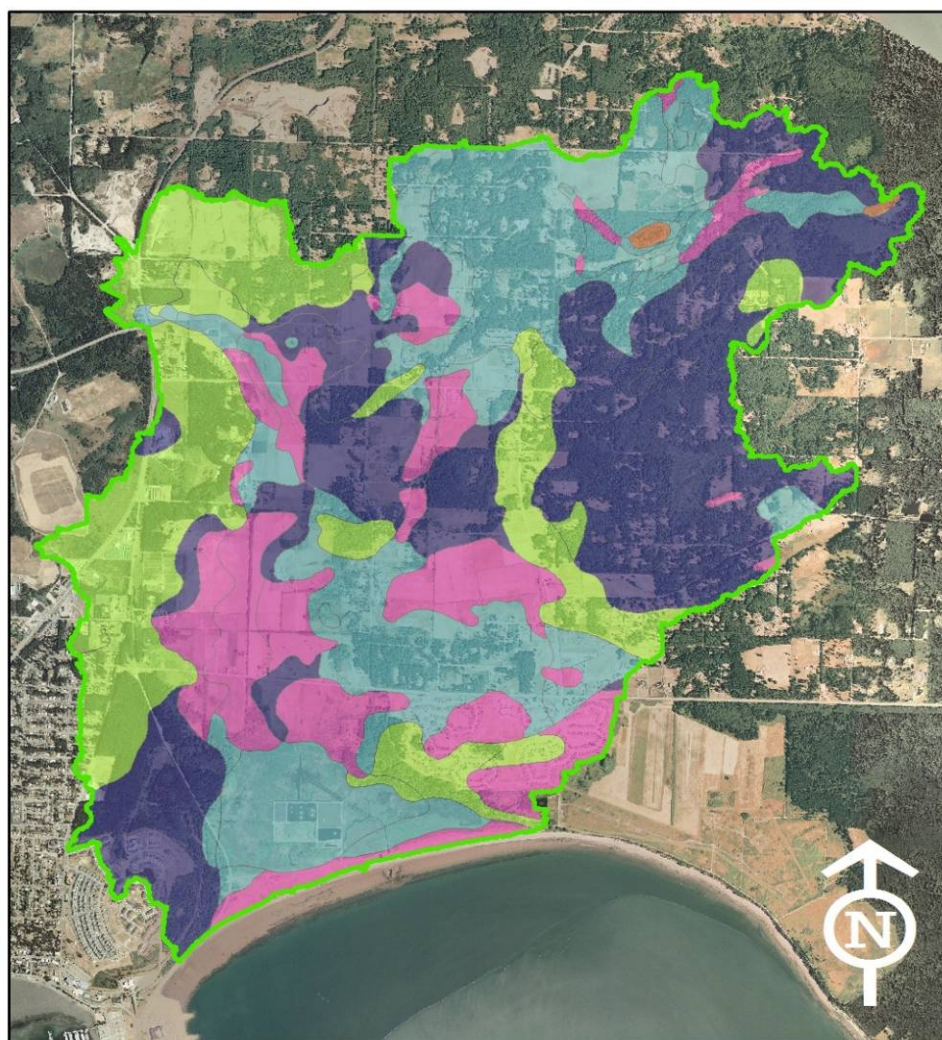
Land Use Category	Current Cover (acres)	Current Percentage of Total Area	Potential Cover (acres)	Potential Percentage of Total Area
Forested	1,749.03	36.51%	1,681.36	35.09%
Agriculture/Residential	2,682.41	55.99%	2,570.41	53.65%
Impervious	359.52	7.50%	539.19	11.25%

Time of Concentration

Time of concentration was measured from the endpoint of the furthest flow pathway from the outfall point at Crescent Bay. This point, located near the northeastern edge of the watershed, was 33,750 linear feet from the outfall point. The elevation at the point, taken from lidar data) was 376.8 ft (NAVD88). The elevation of the outfall point was 12.7 ft. This results in an elevation change of 364.1 ft and a slope of .0108 ft/ft (1.08 percent). Using Kirpich's Equation (Kirpich 1940), Time of Concentration was estimated at 118.9 minutes.

Runoff Curve Numbers

Review of NRCS soils maps showed that the majority of the soils in the study area are classified in Hydrologic Soils Group (HSG) "C" (Figure 8). These soils are generally sandy clay loam, and are considered to have low infiltration rates when thoroughly wetted (NRCS 2007). Antecedent Moisture Condition II (Average Wetness) was selected as appropriate for the study area. Under these conditions, a Curve Number (CN) of 98 was used for impervious surfaces, a CN of 70 was selected for forested areas, and a CN of 71 was chosen for agricultural/residential areas.



0 1,250 2,500 5,000
Feet

Crescent Creek Soils Map

by NRCS Hydrologic Soils Groups

Figure 8. Crescent Creek soils map. Data downloaded from the USDA Natural Resources Conservation Service (NRCS) Soils Data Mart website (retrieved March 17, 2009 from <http://soildatamart.nrcs.usda.gov/>).

Design Storm

Precipitation depths chosen for the study area ranged from less than two inches (10 year event) to nearly three inches (100 year event) (Table 3). Shorter recurrence intervals or storm durations were not used in this analysis.

Table 3. Precipitation depths for 24-hour storm events at 10-, 50-, and 100-year recurrence intervals. Data from WSDOT 2009.

24-Hour Storm Event	Precipitation Depth
10 Year Storm	1.8"
50 Year Storm	2.44"
100 Year Storm	2.74"

Current and Potential Future Hydrograph

A nearly four percent increase in impervious surface area for potential future conditions relative to existing resulted in an average of a ten percent increase in flow for the modeled hydrographs. Generally, peak flows occurred sooner in the potential hydrographs, and maximum flow rate was higher. For the 100 year storm events, there was no difference in the time to peak flow, but the flow rate did recede more quickly in the potential hydrograph than in the existing hydrograph (Table 4 and Figures 9-11).

Table 4. Comparison of current and potential Crescent Creek flow rates and timing.

Event	<i>Current Landcover (7.5% Impervious)</i>		<i>Potential Landcover (11.3% Impervious)</i>		<i>Difference</i>	
	Peak Flow (cfs)	Time to Peak (hours)	Peak Flow (cfs)	Time to Peak (hours)	Peak Flow (cfs)	Time to Peak (hours)
10 Year, 24-hour Storm	86.75	14	96.35	13.5	+9.60	-0.5
50 Year, 24-hour Storm	221.93	12.5	243.89	12	+21.96	-0.5
100 Year, 24-hour Storm	308.22	12	336.23	12	+28.01	0

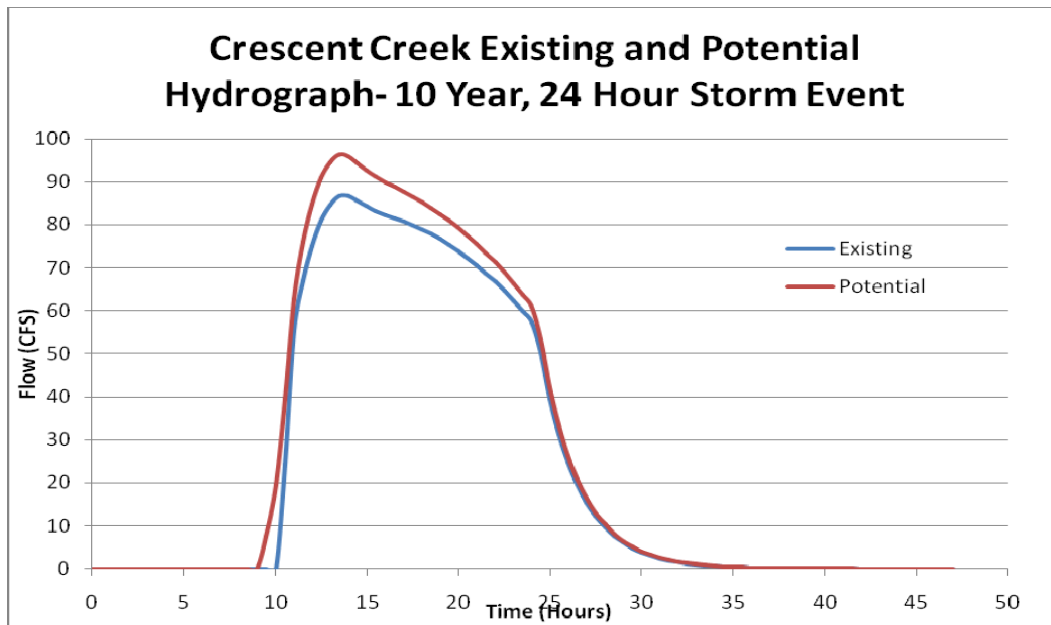


Figure 9. Crescent Creek existing and potential conditions hydrograph, 10 year, 24 hour design storm.

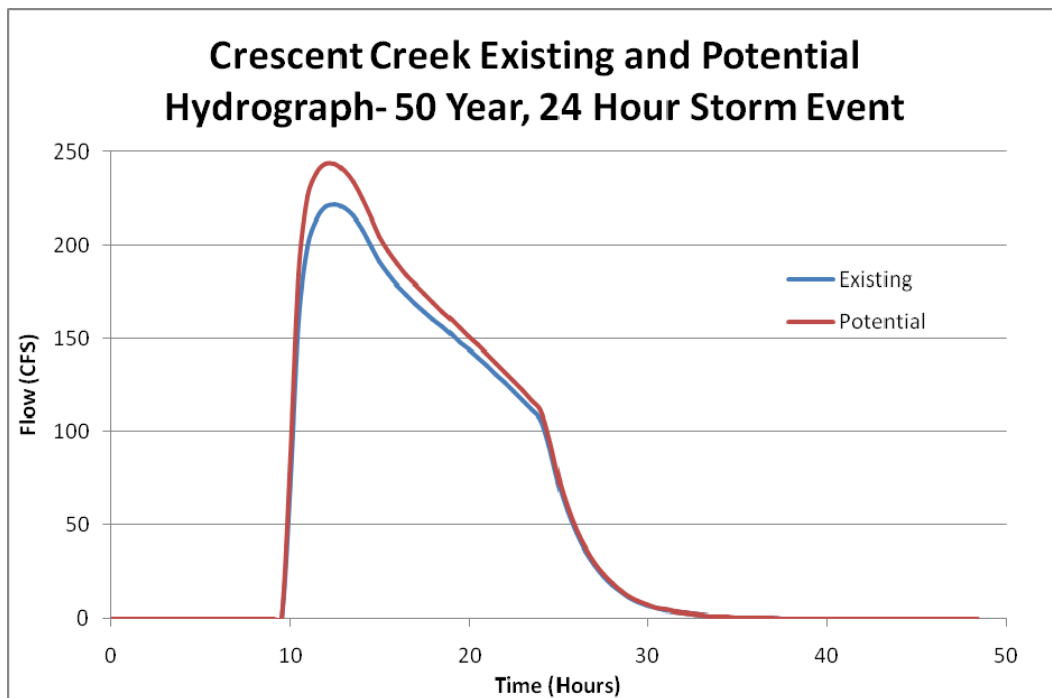


Figure 10. Crescent Creek existing and potential conditions hydrograph, 50 year, 24 hour design storm.

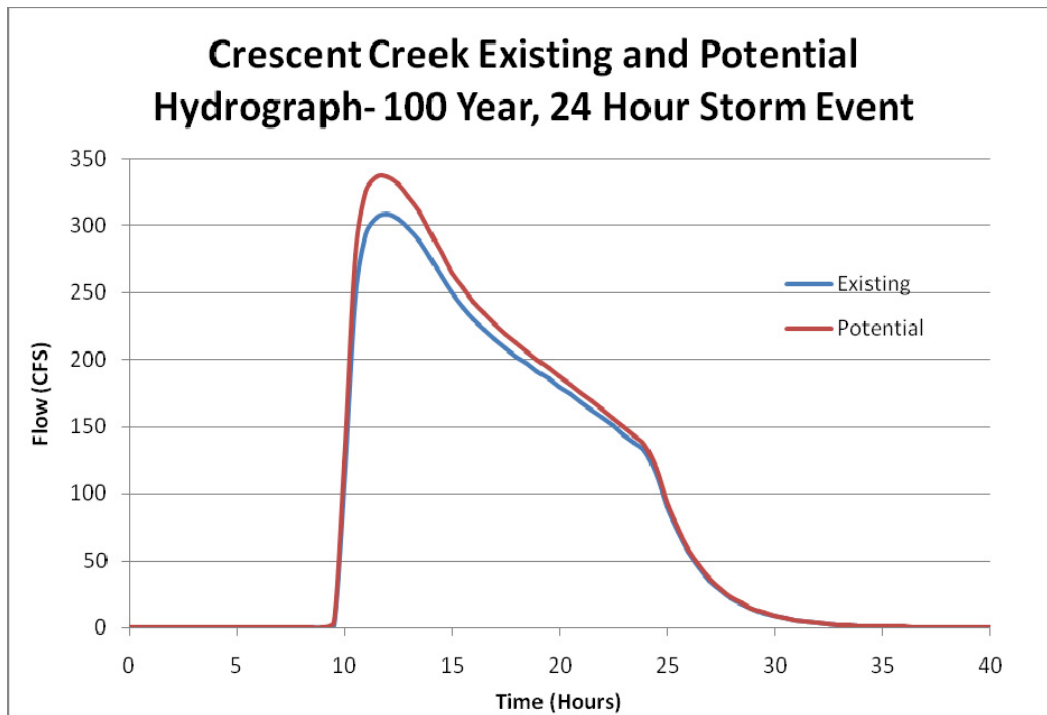


Figure 11. Crescent Creek existing and potential conditions hydrograph, 100 year, 24 hour design storm.

DISCUSSION

While the Crescent Creek drainage is relatively small in size, the changes to peak flow rates and timing under potential conditions are larger than they might first appear. Although impervious surface area was estimated to increase from 7.5 percent to 11.25 percent (a change of less than four percent), peak flow rates increased by an average of ten percent across the three storm scenarios. Such changes can have large impacts on the stability of channels and instream habitat. Booth and Jackson (1997) found that stream channel stability, characterized by little or no erosion along stream beds and banks, decreased markedly above ten percent impervious surface in several King County, WA study watersheds.

Similarly, Booth and Jackson noted a strong relationship between fish habitat degradation and watershed impervious surface area (1997). These authors found that increased stream flows can reduce channel roughness and diversity, alter pool to riffle ratios, and reduce overall fish usage. Similar relationships between habitat quality and percent impervious surface have been noted in wetland systems (Adamus 2007).

Beyond the physical effects of increased erosion and other processes that can degrade downstream habitat conditions, the effects of chemical changes to water quality through the introduction of pollutants entrained during stormwater flows across impervious surfaces can be quite substantial. Such pollutants are deposited on impervious surfaces from a variety of sources, including: wet and dry atmospheric deposition, street refuse deposition, traffic emissions, and urban erosion (Novotny et al. 1985). Some authors have noted that increased concentrations of pollutants can occur with even low levels of watershed urbanization (Hatt et al. 2004). These pollutants can reduce primary productivity within streams (Grimm et al 2005), and streams in urbanized catchments typically have reduced species richness and abundance for benthic macroinvertebrates and fish species (Walsh et al 2005).

In the Crescent Creek watershed, our analysis indicates that, based on current zoning regulations, impervious surface area can be expected to increase to above the ten percent threshold noted above. While this indicates that some degradation to the stream system in

the watershed will likely occur as the watershed approaches full buildout conditions, the percentage alone does not indicate the spatial arrangement of impervious surfaces within the watershed. In the study area, most of the impervious surfaces and areas that will potentially show the greatest future gains in impervious surface area are concentrated at its southeast and southwest edges (Figure 6). Furthermore, a large proportion of the impervious surface areas that are present are not directly hydraulically connected to the stream network, which somewhat reduces their impact by allowing some infiltration to occur prior to reaching the drainage network (Wang et al. 2001).

The portions of the watershed that are directly connected to the majority of the stream network are largely made up of much lower-density-impervious-surface agricultural lands (Table 1). As such, these areas may hold potential for restoration of features that can improve in-stream habitat conditions and/or buffer the potential impacts of upstream development. Currently, much of the stream channel, particularly in the lower portions of the watershed just above Crescent Harbor Salt Marsh, has been ditched and straightened. There is a general lack of shade and vegetative filtration along many of these reaches.

This study would only be one component of a full feasibility study. However, it is probable that the reintroduction of meanders and floodplain benches to currently ditched stream reaches and the reintroduction of native vegetation along the stream corridor would improve habitat conditions at the freshwater marsh where Crescent Creek drains into the Crescent Harbor Salt Marsh. Such actions would help to remove suspended sediments and pollutants, reduce flow velocities, and would provide increased habitat area for fish, benthic macroinvertebrates, and other stream and wetland organisms.

Much of the land at the lowest end of the drainage is located on NAS Whidbey property, and surrounds the Navy-sponsored Crescent Harbor Salt Marsh restoration project, so there is great potential for building on and complementing that work. Restoration of these features would be of particular importance if there is potential for coho salmon spawning within the drainage. Further research should be done to determine the timing and volume of actual stream flows, the composition of substrates, and other factors that can influence the likelihood of occupation by spawning coho once fish access is restored to stream channels.

It should be noted that the methods employed here are simplistic and intended for a rapid assessment of changes to the hydrograph in this system. The Santa Barbara Urban Hydrograph Method is a single-event type model, and as such is unable to take into account storm events that may occur just prior to or just following the design storm used for analysis (WADOE 2005). Such single-event models also assume that the entire basin functions in the same way, hydrologically speaking, and likely do not adequately account for subsurface flows (Booth 1991). Additionally, selecting CN's based on a more diverse array of land cover types would likely improve the hydrograph estimates presented here. Such an in-depth assessment was not deemed feasible or necessary given the scope of this analysis. Similarly, because of the methods used for estimating future impervious surface, the watershed was treated as a single unit for hydrograph, so the hydrograph was not modeled separately for each sub-basin.

Despite the coarse scale, this analysis provides information that will be useful to further restoration planning efforts. Battelle/PNNL will use the flow information generated as part of this assessment to evaluate potential flood effects of restoration activities at the Crescent Harbor Salt Marsh site. These results may also be used to inform focus areas for future restoration efforts that can be used to synergistically maximize the benefits of the current Crescent Harbor restoration project.

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